
ECO-DEGRADATION OR REGENERATION?

THE CRUCIAL CLIMATE ROLES OF WATER, SEWAGE,
AND REGENERATIVE AGRICULTURE IN THREE VOLUMES

VOL. 2 – “ECO-DEGRADATION OR REGENERATION? THE CRUCIAL CLIMATE ROLE OF REGENERATIVE AGRICULTURE”

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This is the 2025 revised version of the 2023 original, with a more central focus on the widespread and fundamental climate impacts of **FATBAS** Fertiliser, **Agrochemical**, **Tillage**, **Bare-soil Agricultural Systems**, as a primary causative agent of 'global drying', increased drought, flooding, fire, heat domes, and as having a role in increasing the occurrence and severity of extreme climate events. The book brings together a huge range of topics. It has been endlessly updated, but reached a stage that it is hopefully helpful to share. Please forgive the imperfections.

The book uses a lot of short attributed referenced and italicised quotes from a wide variety of often technical publications for accuracy, to recognise their contribution to the vast diversity of interlinked technical subjects on which this book of necessity draws, and because educational material is generally dense and carefully crafted, thus it is difficult as a generalist to rewrite concise points in a way that equally succinctly optimally and accurately conveys often complex relevant specialist information. The author hopes readers will feel inspired by the quotes, and invites them to visit at least some of the publications cited for a broader perspective. The book in the later stages have been sharpened and informed by conversations with, and data requests to, DeepSeek. All DeepSeek data is italicised and attributed.

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The author expresses gratitude and thanks to all those who have contributed to the works on which the book draws, and who helped with earlier versions.

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A confessed 'nerd',

with endless curiosity, a fascination with the emergence of humans out of the laws of the universe, a fear we will extinguish ourselves as a species, an understanding that we, the expression of our brains, thus our destiny as a species, are deeply influenced by what we eat, impacted by the quality of our food water and air, which ultimately determine our intellect, abstract thought capacity, empathy, and collectively the expression of our humanity.

Written in the hope that we achieve wisdom and a worthy vision for a future place in the universe before we wittingly or unwittingly give the power to decide our destiny to A1.

DEDICATION

I dedicate this book to all those involved in dietary, regenerative, sewage, water, and environmental research. Your persistence, dedication, and humanity have provided the knowledge needed to make an argument for change, and I am deeply grateful and indebted for your contributions. I reiterate I quote briefly from others to fully recognise their contributions and as pointless to try and to better paraphrase concise, detailed technical explanations by experts in their field.

SYNOPSIS

Implementing regenerative agriculture, and a new paradigm for urine and faeces collection and processing is more urgent than ever. Humans have taken over and imposed **FATBAS** (**F**ertiliser **A**grochemical, **T**illage, **B**are-soil **A**gricultural **S**ystems) on 39% of the Earth's ice-free surface, 5 billion hectares. Current agricultural **FATBAS** practices and **FaF** (**F**lush and **F**orget) sewage systems have significant negative health, environmental, and climate change implications.

Whilst there is no question carbon-dioxide heats the atmosphere and is slowly warming the planet, the book sets out arguments as to why it is clear **FATBAS** is the primary direct here-and-now, immediate, on the ground causal factor in increased 'global drying', floods, fire, land heating, and heat domes, and increasing the risk of extreme climate events, as well as contributing to the pollution and degradation of soils, oceans, water, air, and food.

By contributing to dietary degradation and pollution of foods and water **FATBAS** has the potential to facilitate the devolution of the human species, and certainly plays a part in falling IQ, and through dietary degradation may reduce human capacity for abstract thought, empathy, and higher human function, and is unquestionably contributing to rising levels of mental health including developmental issues.

The replacement of **FATBAS** with **regenerative agriculture** will mitigate many of the immediate climate issues we are facing, reduce pollution, and in addition increase profitability and sustainability for farmers, while maintaining yields and increasing nutrient and antioxidant density, as recognised in reports by Boston Consulting and McKinsey, as cited within the book. Curtailment of fossil fuel usage is essential but alone will not stop climate change.

Change from **FATBAS** to **regenerative agriculture** will require understanding and action at a government level, provision of education for farmers, changes in subsidies, encouragement of development of affordable equipment, including for small farmers, and possibly transition insurance. Absent government action, change requires a rich, public-spirited disruptor who sees the positive economic, environmental, social, and climate opportunities in the change.

A LITTLE BACKGROUND

The authors' musings on whether we could recycle sewage through compost, including as a source of soil carbon, ended up, after many years of long, winding journeys of self-education and lightbulb moments, as a trilogy of books on climate, regenerative agriculture, an examination of current often unappreciated fundamental flaws in the current sewage treatment protocols with a proposal for a better alternative, a new start, and an examination of our degradation of fresh water supplies.

The subjects are interlinked, so there is cross-over between the books, with particular topics dealt with in more detail in a specific volume. For example, compost is dealt with in more detail in Volume 1, which considers alternative ways to manage and recycle sewage. Do not worry, however; composting toilets, expressing your inner bear in the woods, or using sewage sludge on farmland are not suggested solutions.

The trilogy is not a story of a journey but a series of topic introductions and overviews that will hopefully lead readers down pathways of interest and help foster an understanding of the absolute need for change. The first 150 pages, attempt to provide an overview, with greater detail on specific topics included in the remaining 250 pages. Thus, there is a degree of repetition regarding the importance of the soil biome across the various topic sections, which is difficult to avoid. It is probably best to read a few sections at a time rather than trying to plough through the whole volume. Several pages of video links are included as an addendum in the first version. I sincerely hope the book is informative, thought-provoking, and brings new and interesting perspectives.

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2 AN OVERVIEW OF THE THREE VOLUMES

This set of books is, by its nature, an overview. It will comprise three Volumes, two of which are complete and one on water, in progress, respectively, covering regenerative agriculture, sewage, and water. The topics are inextricably interleaved, and all factor in climate change and environmental degradation. The books have taken several years of intermittent research and input, as well as considerable time to write.

- **REGENERATIVE AGRICULTURE Volume 2**—It is not widely appreciated that the current dominant ‘Fertiliser-Agrochemical-Tillage-Bare-soil-Agricultural-System’ (FATBAS) is both unsustainable and a substantial causative component of climate change events. In addition, FATBAS diminishes plant nutrient density, thus reducing human, pet, and livestock health. Adopting sustainable, regenerative farming practices is crucial for effective climate change management. We cannot hope to mitigate climate change unless we also address FATBAS. These are bold claims. These Volumes do their best to explain the compelling rationale and evidence in support of them.
 - **FATBAS**, ‘Fertiliser-Agrochemical-Tillage-Bare-soil-Agricultural-System’ by failing to recognise the role of soils and plants as essential elements of our planetary and climate regulatory ecosystem, is unthinkingly inevitably damaging soil biology and health, leading to, soil degradation and diminished land fertility, reduced; soil carbon, water infiltration-penetration and storage, and increased; flooding and erosion, drying crusting and heating of bare soils thus atmospheric heating, adverse weather events and drought; as well as; killing biology; adding energy to atmospheric heat domes, raising atmospheric temperatures, increasing atmospheric carbon dioxide, degrading regional hydrology, as well as contributing to and accelerating ocean acidification and deoxygenation, and more widely being a primary factor in the planetary ecosystem service degradation we call ‘climate change’.
 - Further, FATBAS fertiliser-and-agrochemical-based farming contributes to pollution, including eutrophication, thus causing river and ocean deoxygenation. This adds to the risk of ocean sulphidation, hydrogen sulphide emission into the atmosphere, and damage to the ozone layer, ultimately leading to a significant Anthropocene/Plasticene extinction event.
 - FATBAS also reduces the nutritional density of crops, thus the nutritive value of food, contributing to human and livestock ill-health, also contributing to mental ill health, including developmental issues, including the risk of reducing

human intellect, empathy, cooperation and behaviour, which, if unaddressed, will ultimately lead to species devolution, further increasing the risk of Anthropocene self-extinction.

- Carbon and water are the enablers of life. Soil carbon and water storage, through the synergistic interaction between plants and the soil biome, are part of the evolved planetary regulatory ecosystem for the land water cycle, and the partitioning oxygen and carbon/carbon dioxide between the atmosphere, oceans, soil, and living organisms. Carbon enables, and is proportional to soil water storage, which in turn enables plant life, sunlight-energy converting, surface cooling evapotranspiration, land based moisture cycles and rain.
- James Lovelock christened the product of competitive evolution, arising out of laws of matter, the interdependent self-regulating ecosphere system that is the basis of sophisticated terrestrial life; a 'Gaian' system, after a key Greek 'Earth Goddess', the mother of all creation, one of the "*primordial elemental deities (protogenoi) born at the dawn of creation*", (Theoi Greek Mythology, n.d.). Lovelock alluded to the system having the characteristics of a 'complex living organism'.
- We humans often fail to respect the fact that terrestrial soil-based and oceanic photosynthetic organisms, along with their wider bacterial and fungal symbionts, are central, obligate, and enabling pillars of more complex forms of life, and thus essential parts of the Gaian system. Plant-captured sunlight energy powers the oxygen-carbon-dioxide-cycle and the production of the complex carbon-dioxide-derived, carbon-based organic molecules that underlie the very existence of complex 'LIFE', including humans.
- FATBAS does not consider the obligate need for maintaining planetary ecosystem health, including the central necessity to optimise the photosynthetic light energy capture potential of plants, thus maximising soil carbon and life in the soil biome. This is essential to plant health and productivity, and hence life itself. Terrestrial surface incident diurnal sunlight energy, which powers the planetary ecosystem through photosynthetic organisms, including plants, and provides energy for near land surface evaporative latent heat cooling and evapotranspiration (plant sweating), is ultimately a finite resource that can build life and cool the planet, or destroy life by heating bare soils and warming the planetary surface.
- Bare soil grows no plants provide no soil carbon or metabolic water, crust, resist infiltration by rain, and store little water. Heat drives down soil carbon. Dry bare soils absorb sunlight energy heating the near land atmosphere by a mix of convection and conduction, and infrared emission, causing drying, increasing the risk, fire, flooding, increase atmospheric pressure, heat domes, and inhibition of inland movement of ocean water, adding to risk of extreme climate events.

- We humans, by taking agricultural control of 39% of the Earth's ice-free land surface billions of hectares of formerly natural green growing ecosystems and related eco-services, have substituted ourselves for crucial aspects of that evolved Gaian system without understanding the implications and consequent responsibilities this places upon us.
- Adopting regenerative agriculture, assisted by more sustainable sewage management, will help make farming more sustainable and profitable. At the same time, ceasing FATBAS and adopting regenerative agriculture is central—the adoption of regenerative agriculture is equally as necessary to solving the land-based here-and-now climate change effects we are suffering, as reducing fossil fuel combustion, and addressing the environmental climate-change-related and human health risks, outlined above. Climate change cannot be solved without addressing how we manage incident sunlight energy, and whether we allocate space to - heat absorbing bare soils, or - growing plants, soil biome carbon, related water content, and cooling plant evapotranspiration - on 39% of the Earth's ice-free land surface, which is equivalent to 5 billion hectares of agricultural land.
- **SEWAGE** Volume 1 – current Victorian WC water-based “flush and forget” ‘FaF’ technologies for collection and remediation of human and animal sewage are polluting and wasteful of carbon, minerals and nutrients, including nitrates and phosphates; environmentally degrade both the terrestrial and oceanic environment; introduce toxins into soils and thus foods, pollute water supplies; damage human and livestock health; hence are unsustainable at many levels. Untreated discharge causes even more significant environmental and health damage.
 - Yet we continue to strive to install ever larger numbers of water-demanding, intensive, wasteful and polluting, “Flush and Forget” ‘FaF’ WC sewage systems, with inadequate, and often no, water treatment, frequently primarily for the convenience of the better. In doing so, we are introducing significant quantities of contaminants, including pharmaceuticals and antibiotics, personal care products, forever chemicals, endocrine disruptors, and other pollutants, including microplastics, onto soils, into oceans and rivers, with known and as yet unforeseeable negative consequences; on life forms, including on human development in utero, intellect, and wider lifetime individual health.
 - By mixing faeces and urine into the broader waste stream, we make the adequate, environmentally sustainable treatment and recycling of sewage sludge almost impossible. Current treatment technologies cannot remediate the vast range of toxic pollutants in sewage sludge, and there is no solution. Incineration is the least bad option, but it does not close the environmental cycle.
 - Agricultural slurry is also massively wasteful and polluting, causing pollution, eutrophication, and deoxygenation of waterways and oceans and damaging soils and the wider environment.

- There are potential alternative solutions to the current Victorian FaF water-based sewage treatment system, which is fundamentally flawed and a dinosaur technology. An alternative, viable, and proven technology, albeit still in its early stages, is Vacuum WC collection, combined with hyperthermophilic anaerobic digestion, followed by hyperthermophilic composting, utilising washing machine microplastic filters as well as the separation and treatment of grey water. These technologies would enable the better integration of sewage management for urine and faeces into a circular, sustainable economy.
- WATER AND HEALTH Volume 3 (In progress) '*Water is life*', as the Bedouin aptly observe, yet we are polluting rivers, aquifers, and oceans globally at a rapid pace.
 - We facilitate large-scale FaF sewage pollution of rivers, water bodies, aquifers, and oceans. Reduced groundwater means that to grow crops, we are forced to draw down natural 'fossil water', depleting aquifers, and using polluted urban and sewage water for irrigation.
 - Through FATBAS, we are changing our climate and destroying our soils. We compact and crust our soils, leave them bare of vegetation, heating the air and causing heat domes, plough and turn and destroy them, including by exposing soil life bacteria and fungi to UV, by using a variety of chemicals that kill soil life, we use artificial fertiliser that disincentives the supply of photosynthetic carbon sugar root exudates to the soil biome, discouraging and destroying soil life that otherwise ceaselessly mines minerals and creates nitrates, and creates metabolic water, delivering them to plant roots; soil life that burrows through, mixes and aerates vast volumes of soil, their destruction combined with ploughing, collectively massively reducing rain infiltration rates, from eleven and more inches an hour, to, often less than one inch an hour; thus rain is not recharging water tables, increasing the risk of water shortages and drought. The unwarranted run-off causes flooding, erosion, related downstream damage, and ocean eutrophication.
 - Through FATBAS, we are drying our climate, reducing evapotranspiration capacity of plants land based moisture and rainfall, increasing the risk of heat domes and fires, and reducing inland ocean airflow-derived rainfall. At the same time, as temperature increases and marine air's moisture-holding capacity consequently increases, the magnitude and irregularity of rainfall events increase.
 - Regenerative agriculture, by focusing on maintaining soil health and soil biome life, conversely significantly improves water infiltration rates and regional hydrology, reduces the need for pharmaceuticals for livestock, and allows natural distributions and dispersion of livestock urine and faeces.
 - Steps such as vacuum WC systems, improved remediation, regenerative agriculture, and sponge cities are both doable and essential but require a step change in our global mindset to one committed to recognising the importance of water to life and the need to use it wisely.

The above issues, including the need for better collection, treatment, and recycling of urine and faeces; regenerative improvement of soils, including carbon sequestration; reduction in broader environmental, including marine pollution; mitigation of global warming and related issues; as well as production of higher quality foods; improving, nutrition, related societal health, including mental wellbeing: are wide-reaching, interlinked, and complex, but achievable.

Climate, regenerative agriculture, sewage, and water interlink. The need to optimise plant photosynthesis, soil biology, and soil carbon storage to improve the environment, human health, development, and well-being is a core key common factor throughout the book.

These issues at their heart have relatively simple realistic solutions, namely regenerative agriculture and a move to vacuum WC sewage collection and treatment systems; but, due to their broader economic impact on existing industries and the adaptation required, will require widespread public education and understanding; as well as government and corporate acceptance of the urgent need for change, and consequent significant adjustments, including; in farming practices, degraded land recovery and regeneration, collection and treatment of faeces and urine, pollutants including plastic reduction, and water conservation and management.

3 FATBAS AND CLIMATE CHANGE

The environmental damage due to anthropogenic activities, including **Fertiliser, Agrochemical, Bare-Soils, Agricultural Systems (FATBAS)** farming, and **Flush and Forget (FaF)** sewage and slurry treatment protocols, is interconnected. Crucially, both are global in scale and sufficiently environmentally damaging to impact planetary ecological Gaian regulatory systems at multiple levels, manifesting in climate change.

In addition, they cause significant environmental pollution. They impact human health both by degrading the nutrient value of food, and polluting the food chain. The lack of sustainability of FATBAS is, over time, compromising the world's capacity to feed itself.

Ultimately, both FATBAS and FaF are both environmentally unsustainable. Volume 1 considers the sewage slurry issue and proposes alternatives. This volume explains why FATBAS is a significant causative factor in climate change, and conversely, why regenerative agriculture will mitigate many FATBAS-related climate change effects. Further, FATBAS is more sustainable, profitable, and produces sufficient yields to feed the world.

FATBAS is arguably the primary causative agent for, and a significant contributor to, many of the climate change events which are currently impacting our day to day lives, including changes in land-based rainfall resulting in global drying, increased risk of flooding lives, including fire, drought, and increased risk of extreme climate events. More broadly, FATBAS degrades and inhibits Gaian ecosystem function, disturbing the planetary carbon-oxygen water cycle and weather regulatory systems.



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These effects are in addition to the impact of carbon dioxide emissions from fossil fuels. There is no question that carbon dioxide is a central driver of atmospheric warming. It absorbs specific infrared wavelengths that would otherwise escape to space, and the carbon dioxides effect self-magnifies, because carbon dioxide also acquires energy through impact with nitrogen and oxygen warmed by, sunlit dry bare and degraded surfaces, water vapour from evapotranspiration, and in addition carbon dioxide also reemits absorbed energy as infrared in the same critical wavelengths, warming the atmosphere.

Yes, the climate planetary regulation system is very complex. Yet, our lived experience in cities reminds that we are primarily interested in, and more immediately impacted by temperatures, land weather, drying, floods, fires and living conditions at the earth's surface, rather than the upper atmosphere.

Yes, the warming of the atmosphere has increased oceanic rainfall, weather uncertainty, and the scale of weather events, which can cause significant devastation inland. However, inland drying, warming, flooding, increased risk of fires and heat domes, are mainly due to FATBAS.

Further disturbance and inhibition of inland flows of oceanic moisture by FATBAS, by inhibiting normal flows, may exacerbate the scope and risk of, and contribute to the build-up of, extreme weather events.

Thus, climate change events and warming are not just about carbon dioxide; FATBAS also impacts them because **the fate of sunlight incident on the Earth's surface impacts climate change risk**. In terms of scale, the amount of sunlight energy incident on the Earth dwarfs human-produced energy from fossil fuels and other sources, and a significant portion of that light falls on plants.

Sunlight incident on verdant green plants, energises them, facilitates production of carbon and oxygen from carbon dioxide, cools the immediate land-surface atmosphere through evaporation and transpiration (latent heat), increases air moisture over land, seeds rain through release of bacteria, and generally mitigates many of the immediate adverse climate effects we associate with global warming.

In contrast, sunlight incident on bare soil, degraded land, and deserts heats the atmosphere through a combination of convection and conduction, as well as the emission of infrared radiation, some of which falls within the wavelength bands absorbed by carbon dioxide. (The primary gases in the atmosphere, nitrogen and oxygen, are not significantly warmed by infrared, but are heated by a mix of conduction and convection by the planetary surface, and by water vapour.)

FATBAS, through multiple mechanisms including fertilisers, agrochemicals, tillage, and bare soils, degrades and ultimately destroys the soil biome, including resident bacteria and mycorrhizae. This results in the loss of both soil carbon and retained water, reducing plant evapotranspiration both by quantity and time-span, leading to loss of inland rainfall, loss of plant life, heating of bare soils, and loss of atmospheric moisture, which are significant

contributory factors in determining whether the atmosphere and planetary land surface environments cool or heat.

FATBAS, 'Fertiliser-Agrochemical-Tillage-Bare-Agricultural-System' kills biology by a variety of mechanisms, reduces; soil biome health, and supply of photosynthetic plant carbon sugar exudate to soils, at the same time accelerating soil carbon loss, with a host of wider negative environmental consequences, including degradation of less resilient soils at greater risk of erosion, reduction of water tables, increased flood, drought, heat dome and fire risk. Fertiliser and agrochemical runoff also cause water pollution, with broader negative ecological impacts for humans, livestock, and wider ecosystems, including the oceans.



Fig 1. Lecture slide AGVISE Seminars and Don Reicosky 'Tillage and Carbon Management: Nutrient Re-Cycling Synergies' North Central Soil Conservation Research, with very many thanks to the authors. (Reicosky, 2014)

Due to the implementation of FATBAS globally, vast amounts of soil biome-life and related carbon, thus soil carbon-related plant growth and health, symbiotic assistive soil biology, related water retention and metabolic water production capacity, and evapotranspiration potential, have been lost. Lost soil carbon is converted to atmospheric carbon dioxide. Bare soils warm the atmosphere. These effects manifest as climate change impacts, including global drying, and increased occurrence of drought, floods, fires, heat events, including heat domes, and extreme weather events.

4 REGENERATIVE AGRICULTURE

Quality composts with diverse biology unquestionably facilitate seed germination and plant growth. The primary mechanism by which composts assist and promote plant growth is not the provision of organic matter but the diverse fungal and bacterial biology they supply to soils with essential accessible minerals, which are in concert crucial to germinating seeds during root growth and the related formation of symbiotic associations with the soil biome.



Fig. 2. *Mycorrhizal sheath on wheat seedlings*. Image from ‘*Quorum Sensing In The Soil Microbiome (Understanding The Role Of Soil Microbial Interactions For Soil Health)*’, presented at the 2019 Conservation Tillage and Technology Conference, March 5 - 6, 2019, Ada, Ohio, US, with many thanks to the author. (Jones, 2019b)

What is not to like? We have considerable control over whether we live among cool green, verdant landscapes, or hot, plant-devoid degraded, bare landscapes. Our lived experience reminds us that growing plants cool and shade. Green, verdant landscapes are, in turn, dependent on healthy, diverse, vibrant soil biomes. This book explores the connections between healthy soil biomes and productive ecosystems, as well as the reasons for their decline due to FATBAS. It also explains why FATBAS drives climate change, including global drying.

5 SOIL BIOME COMPOSITION AND DIVERSITY

Soil biome composition is complex and diverse, much more so than generally realised. Bacteria and fungi, and their association with plants, probably receive the most focus. They are central to the regulation of the Gaian planetary regulatory systems and to the successful evolution by farmers from FATBAS to regenerative agriculture.

Viruses and algae are also crucial parts of the soil web, but their roles are less researched, mapped, and understood. However, they have integral, essential, and fundamental roles; most of which have yet to be elucidated.

Bacteria, fungi, viruses, and algae, as well as soil fauna, microfauna, mesofauna, macrofauna, megafauna, and their roles in, and services to the soil-biome are discussed in detail in the FAO document '*The state of knowledge of soil biodiversity*'. (FAO 2020), which explores the topic of soil diversity in great detail and at length (600 pages), with multiple expert authors. Readers might like to familiarise themselves with its existence as a resource. (FAO 2020)

Life forms in the soil, mine, aerate, assist rain infiltration-penetration, tunnel, mix, move, digest, break down, incorporate soil organic debris, transport, and excrete substances beneficial to plants. In death, soil life forms break down into readily bioavailable nutrients. Thus, through cycles of life and death, denizens of the lightless soil biome cycle photosynthetic plant carbon root exudates and constantly recycle carbon compounds, oxygen, and metabolic water, renewing carbon dioxide and or, at the same time, sequestering atmospheric carbon dioxide into underground storage.



Fig 3. From the UTube lecture '*Insects a little known force of nature shaping your farmland*' Mike Bredeson, PhD with very many thanks to the authors. (Bredeson, 2021)

Bacteria and fungi, in so far as relating to the implementation of regenerative agriculture, and related climate issues, are discussed in more detail within the context of relevant sections of this book.

6 RHIZOSPHERE SYMBIOTIC MECHANISMS – WATER NUTRIENT AND OTHER PLANT ESSENTIAL SERVICES

The paper *‘Rhizosphere bacterial communities of Namib Desert plant species: Evidence of specialised plant-microbe associations,’* summarises the fundamental importance of plant soil biome interactions, including in the rhizosphere, in the following terms, “*The plant rhizosphere is a soil zone where root structures, soil particles and microbial communities form intimate associations, with the microbial populations significantly influencing the functional characteristics of the plant host. The rhizosphere is a dynamic ecological environment where the specialised microbial diversity affects a range of local processes, including carbon turnover, phytohormone levels, nutrient availability (particularly phosphate solubilisation), plant disease susceptibility and water retention. These interactions are critical for sustaining natural ecosystems.*” (Maphosa 2025)

The soil biome interacts with plants, including by enhancing plant drought resilience through both direct (epigenetic priming via DNA methylation/histone modification) upregulation of drought-response genes in the host plant genome, referred to as *‘Induced Systemic Tolerance’* (Maphosa 2025), and indirect water provision via Exo-polymeric Substances (EPS), such as Exo-Polysaccharides (Gall 2021), endophytes (Mikiciuk, 2024) biofilms, and hyphal water transport (Bitterlich 2018) mechanisms. Signalling crosstalk involving microbial VOCs, ROS, and miRNAs further fine-tunes plant stress responses. (Paragraph drafted with the assistance of DeepSeek).

The review *‘Harnessing Beneficial Microbes for Drought Tolerance: A Review of Ecological and Agricultural Innovations’* (Mikiciuk, 2024) discusses some of these pathways and the opportunities they present.

6.1 HYPHAL WATER TRANSPORT

It is fairly widely accepted that plant-soil biome associations can assist in drought resilience. The mechanisms are less clear, and it has only recently been demonstrated, using dyes and radiolabelling, that fungi can transport significant amounts of water to plants, approaching up to 50% of plant uptake. This extends the effective reach of the roots beyond their physical limits, to otherwise inaccessible, more distant and or deeper stored water, helping explain the importance of diverse healthy soil biome diversity to plant health, including during dry spells.

The 2020 paper *‘Routes to roots: direct evidence of water transport by arbuscular mycorrhizal fungi to host plants’* observes, “*Plants with AMF symbionts can have different rates of water movement into and out of roots, which affect tissue hydration and leaf physiology, and often lead to higher drought tolerance. Indeed, mycorrhizal plants typically have higher water contents than non-mycorrhizal plants in the same environment and have been shown to access soil water below the permanent wilting point of non-mycorrhizal plants*” (Kakourdis, 2020)

The study using radiolabelling and dyes, concludes “*Our study provides direct evidence that AMF can act as extensions of the root system along the soil–plant–air continuum of water*

movement, with plant transpiration driving water flow along hyphae outside of the hyphal cell membrane.” (Kakourdis, 2020) This is an essential finding with significant implications for crop health and soil moisture. Mycorrhizal transport of water, by extending access to more distant soil water stores and increasing available supplies, impacts the time frames over which evapotranspiration takes place, affecting the broader regulation of inland moisture, rainfall, and the wider weather.

6.2 SEED BIOMES – SYMBIONT INTERNAL AND EXTERNAL BACTERIA AND FUNGAL SPORES ASSIST GERMINATION AND GROWTH.

Widespread understanding of the fungal and bacterial internal and external seed biome, its relationship to the wider soil biome, and fundamental importance to optimal germination, early growth and development of the root rhizosphere, water and nutrient transport roles, are of fundamental importance to the transition from FATBAS to regenerative agriculture in as little as a year.

Evolutionary natural selection has ensured that seeds, at the point of germination, have access to an assistive bacterial and fungal, from both an internal endogenous endosphere biome, and an external exogenous exosphere seed shell biome, and in addition a diverse fungal and bacterial soil biome. Consequently, they can rapidly produce effective root systems that support healthy and resilient plant growth.

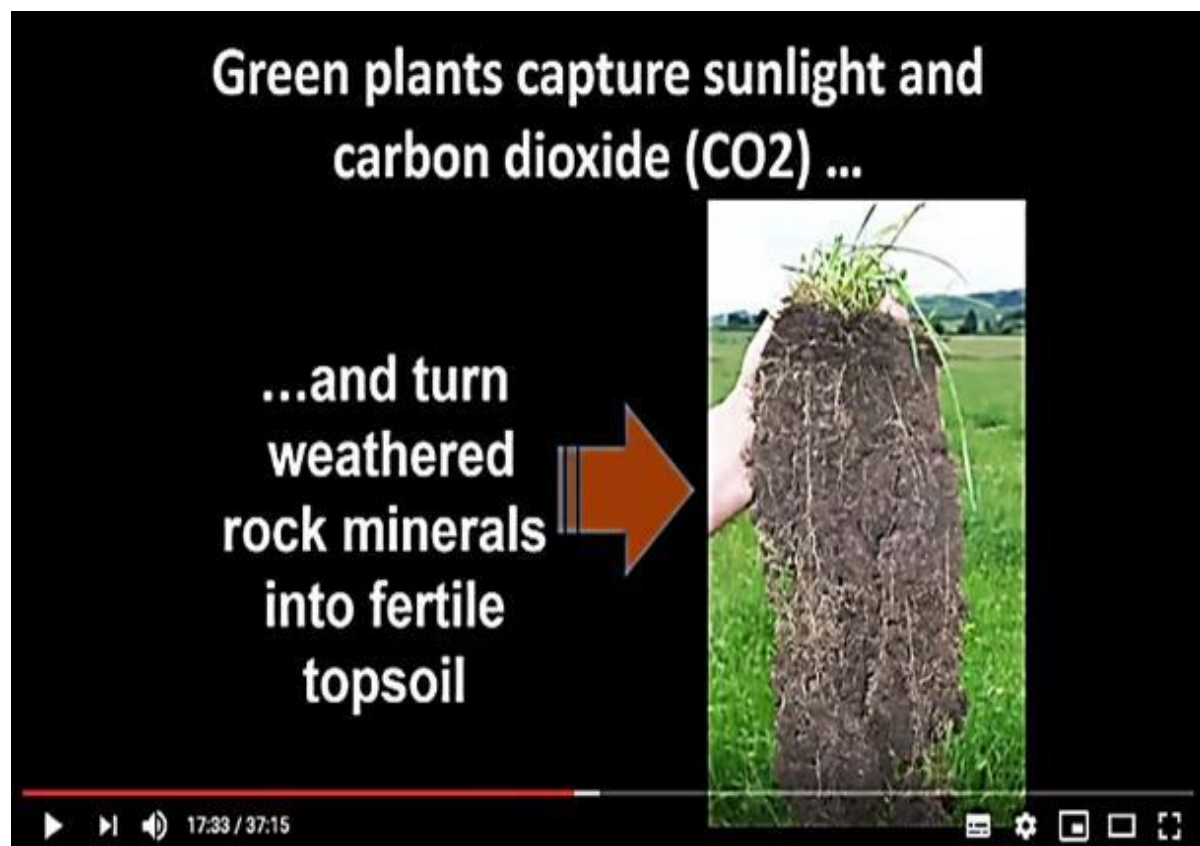


Fig. 4. Regenerative agriculture including use of compost extracts builds effective root systems with diverse biology sequestering carbon and percolating producing and storing water, Dr Christine Jones – ‘Building New Topsoil Through The Liquid Carbon Pathway’, with

Several mechanisms determine how fungal and bacterial biology, seed internal and external, and soil, bacterial and fungal biomes are incorporated, utilised, and transmitted to future generations of seeds and soil biomes, thus optimising plant survival in the environments in which they find themselves. (Johnston-Monje, 2021; Mitter, 2017; Nelson, 2018).



Fig. 5. Lecture slide AGVISE Seminars and Don Reicosky 'Tillage and Carbon Management: Nutrient Re-Cycling Synergies' North Central Soil Conservation Research, with very many thanks to the authors. (Reicosky, 2014)

The publication '*Seed endophytes and rhizosphere microbiome of Imperata cylindrica, a pioneer plant of abandoned mine lands*' looking at the role of soil microorganisms in helping plants to adapt to polluted ex-mining land observes, "*Soil microorganisms can change the soil pH value, the physical, and chemical properties, and soil respiration rate, etc. by producing various active ingredients and play an extremely important role in soil nutrient cycling, organic matter content, biogeochemical cycling, and plant biomass*" . . . "*important role of the soil microbiome in mining adaptability, early colonization, and pioneer plant growth. Therefore, soil biomes play a key role in the restoration of degraded terrestrial ecosystems*". (Mao 2024) However, as discussed, soil biomes are symbionts, utterly dependent on plants for root carbon sugar exudates.

Composts containing diverse fungal and bacterial populations are central to rapid transfer from FATBAS to regenerative agriculture, because FATBAS soils inevitably have suboptimal fungal and bacterial populations.

7 WE, 'FATBAS' AGRICULTURAL 'CONTROLLER' OF 39% EARTH'S ICE-FREE SURFACE = 5 BN HECTARES

Humans have taken on the role of 'agricultural' controller of approaching 5 billion hectares (FAO 2012a), approximately 39% of the ice-free land surface area of 'Planet Earth', formerly natural self-regulating plant and soil biome ecosystems, which still form part of the planetary climate and wider, hydrosphere, climate, carbon, oxygen, Gaian regulatory system.

Table 1. Data provided by a request to DeepSeek amalgamated from a number of sources, as far as possible isolating relevant categories. The data is provided to provide indicate land uses for the purpose of emphasising the significant area of fertile land on earth that has been taken under human management, often FATBAS. As a consequence, that land has been degraded, soil biome health diversity and volume has been reduced; huge amounts of soil carbon lost; fertility, water infiltration and retention has been depleted, flooding erosion bare and degraded soil greatly increased, contributing to reduced evapotranspiration, loss of air moisture and rainfall, drying, high pressure areas and heat domes weakening movements of atmospheric water inland, heating of the atmosphere and warming, with global climate implications.

<i>Category</i>	<i>Area (million km²)</i>	<i>% of Ice- Free Land</i>	<i>Source</i>	<i>Notes</i>
<i>Natural Land - Total</i>	79.1	61%	IPCC AR6 (2023)	<i>Forests, deserts, wetlands, shrublands, tundra, snow/ice.</i>
<i>Forests</i>	40.3	31%	<i>Global Forest Watch (2023)</i>	<i>Excludes managed plantations.</i>
<i>Barren/Desert</i>	16.0	12%	<i>UNCCD (2023)</i>	<i>Non-polar deserts (e.g., Sahara).</i>
<i>Wetlands/Shrublands</i>	12.5	10%	<i>Ramsar/IPBES (2023)</i>	<i>Includes peatlands, mangroves, and savannas.</i>
<i>Tundra/Polar Regions</i>	8.3	6%	<i>NSIDC (2023)</i>	<i>Excludes ice sheets (Greenland/Antarctica).</i>
<i>Snow/Ice (Seasonal)</i>	2.0	2%	<i>ESA CCI (2023)</i>	<i>Non-permanent snow cover (e.g., Himalayas).</i>
<i>Human-Managed Land – Total</i>	50.9	39%	FAO (2023)	<i>Agriculture, urban, and managed forestry.</i>
<i>Cropland</i>	15.6	12%		<i>Excludes agroforestry.</i>
<i>Pasture/Rangeland</i>	33.8	26%		<i>Includes natural grasslands converted to grazing.</i>
<i>Urban/Infrastructure</i>	1.3	1%		<i>Cities, roads, and mining.</i>
<i>Managed Forests</i>	0.2	<1%	<i>FAO (2023)</i>	<i>Plantations (e.g., palm oil, timber).</i>
<i>Total Ice-Free Land - Total</i>	130.0	100%		

Humans, as self-appointed controllers of 39% of the earth's ice-free surface, have converted 5 billion hectares of formerly natural self-regulating plant and soil biome ecosystems, a key part of the planet's carbon, oxygen, and climate regulatory systems, largely into FATBAS-managed variously degraded arable and grazing land (FAO 2021a).

For the reasons discussed in this book, FATBAS drives down and kills soil biome ecology and diversity through several mechanisms. At the same time, it inhibits the system's ability to rebuild carbon stocks, and regional water reserves and cycles.

The FATBAS, fertiliser, agrochemical, tillage, and bare soil agricultural systems have significantly contributed to many aspects of climate change by significantly degrading and reducing the soil biome that supported former natural ecosystems, and thus converted significant acreages into bare and degraded landscapes.

Many soils within the 39% of ice-free land under human management, have lost significant carbon and water retention capacity, which trend if continued, will result in us facing potential existential tipping-points in relation to the global weather, oxygen, carbon, and hydrological cycles.

The worldwide acreages of underused and FATBAS abused agricultural land are vast, millions upon millions of acres of degraded land, added to by unbelievably massive acreages of seasonally bare fields: Christine Jones suggest possibly 50 percent of the world's cropland is bare during any twelve months (*'Building New Topsoil Through The Liquid Carbon Pathway'* (Jones, n.d.-a)).

It is obvious once thought about, but worth drawing attention to the fact plants are essential to human existence, health, and function through a variety of pathways. Plant growth and related soil biome functions are part of Earth's climate regulatory systems. Nutrients from plant products, which underlie most higher terrestrial life, are essential to human health, development, neurological function, and well-being.

When land is bare or degraded, the opportunity for plants to direct sunlight energy to grow, photosynthesise, and cool through evapotranspiration moving latent heat in water vapour to the 'cloud-sphere', extract carbon from carbon dioxide to feed the soil biome, thus improving water hydrology, soil quality, food yields, and carbon sequestration, is self-evidently lost. Conversely bare soils absorb incident solar energy heating the immediate and then higher atmosphere, with negative climate change consequences.

8 REGENERATIVE AGRICULTURE - REALISTIC NOT JUST IDEALISTIC BOSTON CONSULTING GROUP AND MCKINSEY - 'IT IS THE FUTURE'

Many are sceptical of the capacity of regenerative agriculture, by optimising natural systems, to mitigate climate impacts, maintain yields, and be profitable, without agrochemicals or artificial fertilisers.

However, it is not only eco-aware farmers, and starry-eyed idealists, who are making such claims; respected organisations such as Boston Consulting Group, in a series of reports cited in a later section, and McKinsey Consultants in their commentary, *'The agricultural transition: Building a sustainable future'* (McKinsey, 2023) highlight the potential of regenerative agriculture to profitably produce adequate food, mitigate climate and capture and store atmospheric carbon.

The McKinsey report observes, *"Addressing land use with nature-based solutions. Agricultural land covers approximately 4.9 billion hectares, or 38 percent of the world's terrestrial area, and is estimated to account for approximately 80 percent of global land-use change as land is cleared or converted for cropland, feed production, or grazing land. Given this enormous land-use footprint, nature-based solutions, including conservation and restoration solutions, have the potential to abate 6.7 GtCO₂e in 2050—approximately 80 percent of the total abatement potential."* (McKinsey, 2023) and yet be profitable as set out in the next section.

As discussed in more detail later, estimates as to the optimal potential sequestration of atmospheric carbon by soils are hotly debated, but they clearly exist and are significant. Further improving soil biome health and volume brings substantial other climate change mitigation benefits.

BCG and McKinsey reports deal with the generality of the climate negative impact of FATBAS, and the importance of regenerative agriculture to mitigating climate change and assisting long-term environmental stability.

This book explains the reason in much greater depth, the rarely considered reasons, why FATBAS is substantially responsible for many of the immediate climate events we are experiencing, and vast potential of regenerative agriculture to help stabilise and remediate many of them.

9 HUMAN ROLE IN EXTREME WEATHER EVENTS

The role of humans in climate change is well recognised. Yet, most of the focus is on carbon dioxide warming, albeit with a significant recognition of the potential future warming effect of melting ice sheets. However, beyond debate on general atmospheric-related warming, there is limited focus on why drying, regional heating, fires, flooding and increased risk of heat domes and extreme weather events generally, occur.

There is significant discussion on the impact of climate change on agriculture, and discussion of agriculture having contributory roles, but very little on the role of agriculture as a fundamental causative agent in climate change. There is reference to agriculture having a role in climate change, through fossil fuel use, climate gas emissions, methane and nitrous oxide, pollution damage and eutrophication, but the causative role of agriculture in climate drying through loss of soil carbon and water retention, flooding, fire, regional heating and heat domes, and extreme weather events is rarely considered.

Albeit is recognised that anthropogenic activates factor in extreme weather around the world. For example, ‘Carbon Brief’ in the publication ‘*Mapped: How climate change affects extreme weather around the world*’, and related map last updated on 21/11/2024, lists more than 600 ‘extreme weather attribution’ studies covering 750 ‘*extreme weather events and trends*’, assessing the extent to which human activity contributed to the risk or severity of an extreme climate event. Weather categories considered include: heat, rain and flooding, drought, storm, cold, snow and ice, wildfire, oceans and ‘compound’ events.

‘Carbon Brief’ observed, “Across all these cases, 74% were made more likely or severe because of climate change. This includes multiple cases where scientists found that an extreme was virtually impossible without human influence on global temperatures.” (McSweeney, 2024)

The impact of FATBAS on climate change at multiple fundamental levels, including through degradation of soil carbon, diminished water retention, and consequent reduced evapotranspiration, added to the impact of solar heating of bare soils, help explain the more immediate impacts of climate change, including drying, fire, flooding, and increased risk of extreme climate events including heat domes.

10 FATBAS – MAIN DRIVER OF GLOBAL CLIMATE CHANGE ‘DRYING’, SOIL DEGRADATION, LOSS OF SOIL CARBON AND WATER RESOURCES

The human FATBAS intervention is and has taken place at such a large scale, it has variously impacted 39% of ice-free global land, and due to the scale of its implementation has altered the planet's most fundamental ecosystem regulatory systems.

Our introduction of FATBAS starting in the early 1900s, accelerated by the growing availability of agrochemicals and artificial fertilisers after the Second World War, has led to a massive loss of soil-based carbon and water resources, reduction in soil-based carbon, and disruption of aspects of the climate, including evapotranspiration and movement of oceanic moisture inland. This has caused global drying and exacerbation of extreme weather events.

Examples of key changes to planetary environmental regulatory parameters, broadly consequential on FATBAS adoption, considered in more depth in later sections, include:

- **Reduced carbon stored in soil** - (also a measure of soil-biome-life) – large amounts of soil carbon have been lost – conversely if we globally adopted regenerative agriculture, including rotational grazing, we could potentially annually sequester 1 ton and likely more an acre, which over 5 billion hectares could amount to 10 gigatons, an amount of the same order as the quantity of carbon combusted annually in fossil fuels. (application of artificial fertiliser, and overgrazing reduce grassland stored carbon)
- **Reduced water stored in soil** – over the last 50 years plus, significant amounts of soil carbon per acre have been lost from soils globally; which means large diminutions in the global capacity of soils to retain water. Increasing the carbon retention capacity of soils globally, would impact soil water storage sufficiently to have a climate change mitigation effect. The following calculation by its very nature is only indicative, but

gives an idea of the massive quantities of soil water storage involved – *an increase in soil organic carbon by 1% can increase water holding capacity by around 1.5-2% by volume - 1 ton of carbon per hectare increases soil water-holding capacity by ~18.9 m³/ha (derived from USDA data – which over an area of 5 billion hectares up represents 94.5km³ – a volume sufficient to impact global rainfall and reduce drying trends (data estimates developed with assistance of DeepSeek).*

- **Reduced soil-biome metabolic water** - Soil-biome life, living respiring entities, possibly forming 30% of soil organic matter by wet-weight, during respiration of carbon sugar for energy, produces significant metabolic water, which can help sustain both the soil biome and plants during dry spells. It is estimated, again an indicative calculation for the purpose of highlighting the scale of water volumes involved, that the soil biome life on a hectare of land with a 5% carbon content to a depth of 1 meter (calculation detailed in a later section) might produce 16,000 litres of metabolic water a month. For a notional 6-month growing season over 1.5 billion hectares of agricultural land, this would represent 144 km³ of water, again a magnitude of effect that, through increased capacity and time frame of plant evapotranspiration, would positively impact land-based rainfall patterns, mitigating global ‘drying’, and climate change events more widely, including likely reducing the risk of extreme weather events.
- **Reduced water infiltration** – Water infiltration is significantly reduced, on historically good quality agricultural land that has been subject to FATBAS protocols for possibly 50 years – measured rates on FATBAS land are approximately 25mm per hour, rising to 150 to 250 mm an hour three or more years post introduction of regenerative agriculture, with the downstream consequence of reduced, flooding, erosion, eutrophication, and at the same time, replenished and increased soil retained water, increased water in regional aquifers, and improvements in local hydrological systems including rivers.
- **Reduced volumes of evapotranspiration** – as discussed above it is clear that, due to a mix of:
 - falling soil carbon and related soil-biome life,
 - falling metabolic water production consequent to reduced soil-biome life,
 - falling levels of soil retained water due to reduced soil carbon,
 - combined with the significantly reduced rain infiltration rates into FATBAS soils,

in combination, when considered on a global basis, soils over a year will have likely failed to cyclically accumulate and recycle 100s of km³ of available rainfall, which at the global level must translate into significant loss and disturbance of plant-based evapotranspiration, thus diminished land-based regional moisture, rainfall and hydrological water flows.

- **‘Global drying’ consequent on reduced land derived rainfall** – reduced plant evapotranspiration at the scale of land area likely involved, 39% of the Earth’s ice-free surface, will result in lower global land based atmospheric moisture, reduced rainfall and ‘global drying’.

- **‘Global drying’ to disturbed flow of oceanic moisture inland** - reduced and disturbed flow of oceanic moisture inland will result in disturbed and reduced rainfall. Increase in soil temperature, due to both loss of latent heat evaporative soil cooling capacity, and heating of bare soils, will result in more frequent atmospheric high-pressure regions, heat domes, and disruption of inland flows of oceanic moisture, adding to risk of ‘global drying’.
- **Increase risk of extreme heat events** – The impacts of global drying including atmospheric heating by bare soils, creation of high-pressure zones and increased risk of heat domes, which block movement of oceanic moisture inland, creates increased risk of extreme weather events.

10.1 ARTIFICIAL FERTILISER AND AGROCHEMICALS DRIVE SOIL CARBON LOSS

The advent of artificial fertilisers, in an emerging era of scientific discovery and advancement, led us to naively believe the power and sophistication of our science was greater than that of nature. Even though we had barely begun to scratch the surface of the sophistication and interconnectedness of nature, we felt we could afford to ignore the aeons of Gaian planetary evolutionary symbioses that allow life as we know it to prosper and self-perpetuate.

Sadly, the 20th century proved that FATBAS farming styles, based on leaving bare soils between crops, mechanical disturbance, artificial fertilisers, and agrochemicals, are terrible news for the soil biome. Soil disturbance, including ploughing, exposure to heat and light, desiccation, and physical damage to the environment, easily kills the biome. In addition, using agrochemicals kills soil life.

Human-created, 20th-century, artificial fertiliser-dependent farming, resulting in a double negative, soil carbon depletion, whammy. The supply of ‘artificial’ soluble phosphates and nitrogen to plants reduces the supply by plants of photosynthetic-derived carbon sugar exudates to the soil biome. It changes bacterial populations and activity (Weng, 2022). Artificial fertiliser also increases the metabolism of stored carbon by the soil biome, further depleting carbon stores and shifting the biological soil profile from carbon-rich mycorrhizal to nitrogen-rich bacterial-dominated soil.

Artificial fertilisers drive down soil carbon by disincentivising plants from supplying carbon sugar exudate to the soil biome, thus reducing soil biome life. The soil biome reciprocates by supplying fewer minerals and nitrates. These outcomes negatively impact soil carbon accretion, reducing soil water retention, plant health, and evapotranspiration.

“Over-fertilization disrupts soil microbes, reducing organic carbon storage by ~30–50% in intensive agroecosystems” (DeepSeek) Consistent with this commentary, the paper *‘Long-term cultivation reduces soil carbon storage by altering microbial network complexity and metabolism activity in macroaggregates’* observes, *“The results showed that prolonged cultivation led to an average reduction of 45 % in SOC (Soil Organic Carbon) storage, particularly in macroaggregates.”* *“The enduring and adverse effects of cultivation on SOC storage are attributed to soil structural destruction, unbalanced microbial communities and reduced microbial activities”* (Zhang, 2024)

At the same time soil carbon loss due to respiration by the soil biome, results in carbon equivalent rises in atmospheric carbon dioxide. Further “*Fertilizer production accounts for 1.2% of global CO₂ emissions (~450 MtCO₂/yr), comparable to aviation.*” Producing a ton of fertiliser results in release of 1.5-2.5 tons of carbon dioxide.

Agrochemicals kill soil life; ploughing and bare land further magnify the damage, accelerating the reduction of soil biomes and stored soil carbon.

Further and crucially, the use of NPK (nitrogen phosphorous potassium fertiliser) reduces plant supply of root exudates to the soil biome, thus likely reducing mycorrhizal activity, (Treseder, 2004) and at the same time, changes and increases the metabolism of the plant biome, leading to accelerated soil carbon respiration, and thus reduction of soil carbon, which in turn, diminishes water retention capacity, reduces diversity, increases bacteria and reduces fungi, degrading soil health, hence further diminishing soil carbon content, in an inevitable downward self-reinforcing spiral, as detailed in later sections.

10.2 IMPORTANCE OF SOIL CARBON TO CLIMATE STABILITY AND AGRICULTURE

Life is 70-90% water. Soil carbon is a proxy for soil life. By wet weight, possibly 30% or more of organic mass in the soil is alive, recycling water and nutrients, and providing wider essential eco-services. The balance acts as a soil carbon reserve, often in mycorrhizal-produced complex organic molecular forms, including saccharides, which have important physiological roles, and are key to the capacity of the non-living portion of the soil to retain water.

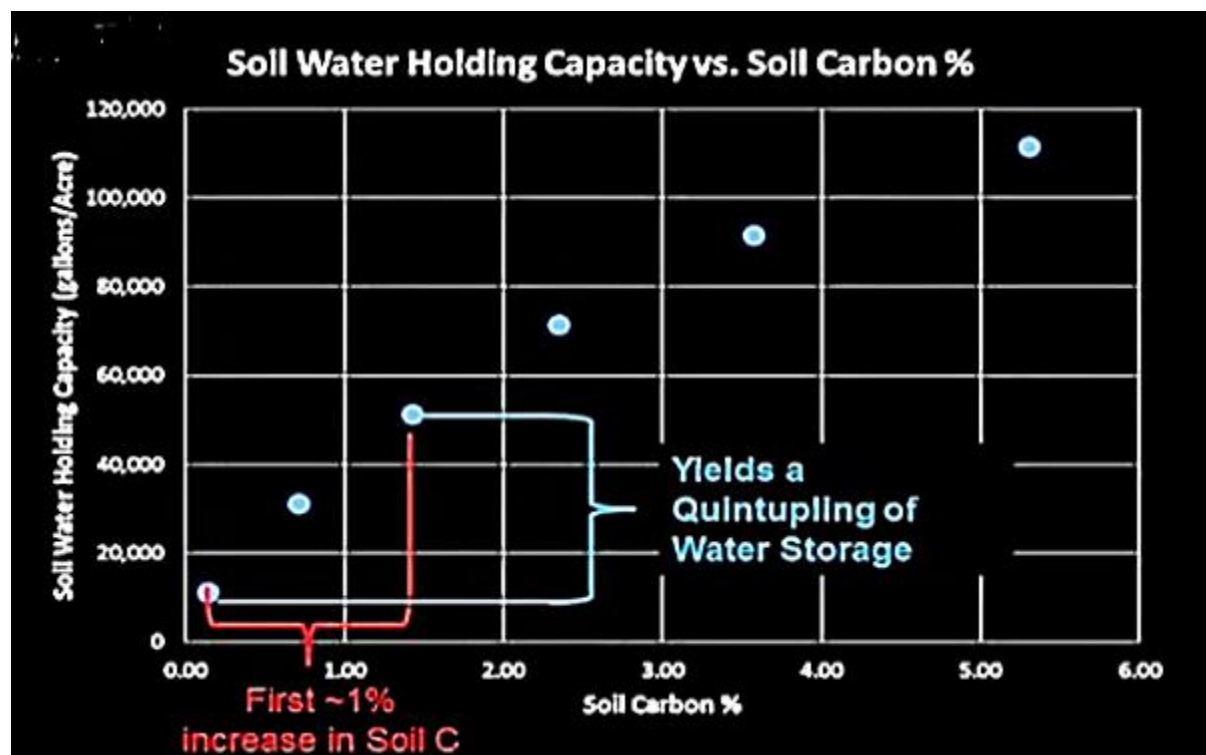


Fig. 6. Soil water holding capacity of soils with increased carbon content from the UTube presentation 'The BEAM Approach' by Dr D Johnson, with many thanks to the author (Johnson, 2017).

Soil carbon is a key factor in Gaian climate regulatory ecosystem function, reasons include;

- Carbon is a key constituent of life, including soil life,
- Carbon and oxygen are liberated from carbon dioxide through photosynthesis, which requires growing plants that symbiotically rely on healthy carbon-rich soil biomes.
- Soil water storage is proportional to soil carbon; retained soil water capacity governs plant evapotranspiration capacity and time span. Thus, soil water regulates land-based rainfall. In addition, evapotranspiration cools through the latent heat transfer of energy from the land surface to higher altitudes in the atmosphere.
- Soil carbon availability, by assisting plant growth, impacts shading, reducing bare soil heating and drying, which in turn influences regional cooling and mitigates against regional atmospheric warming.
- Increasing cooling reduces the risk of heat domes influencing and facilitating and normalising oceanic moisture mass flows to the land interior, thus reducing the risk of extreme weather events.
- Stored carbon reduces atmospheric carbon dioxide. Conversely, the reduction of stored soil carbon increases atmospheric carbon dioxide,
- Carbon and oxygen store energy, as evidenced by combustion.
- Oxygen released from carbon dioxide by photosynthesis is key to terrestrial land and ocean life. Oceans may seek to replenish oxygen used in combustion, which would make oxygen a climate gas, as discussed in a later section.

The review *‘Managing soils for negative feedback to climate change and positive impact on food and nutritional security’* examines the issue of soil carbon in detail observing, *“The increase in atmospheric concentration of carbon dioxide from 278 ppm in the pre-industrial era to 405 ppm in 2018, along with the enrichment of other greenhouse gases, has already caused a global mean temperature increase of 1°C. Among anthropogenic sources, historic land use and conversion of natural to agricultural eco-systems has and continues to be an importance source.”* (Lal, 2023)

Thus soil carbon has a role in atmospheric heating, and the amount of carbon stored in soils is significant. Estimates vary considerably due to the difficulties in accurately assessing soil carbon stores. By way of indication of the scale of soil carbon reserves, one review observes, *“Soils store 1580 Pg carbon (C)—more than the atmosphere (750 Pg C) and vegetation (610 Pg C) combined—and contain a small but influential slice (460 Pg N) of the global nitrogen (N) pool ($\sim 2 \times 10^{23}$ g N). Consequently, small changes in soil storage of C and N have ramifications for global biogeochemical cycles and food security.* (1pg = 1 gigaton = 1 billion tonnes) (Buckeridge 2022)

Humans have taken 5 billion hectares under human management, and an increase in carbon stores of 2 tonnes a hectare would sequester 10 billion gigatons of carbon, which is close to the amount annually put into the atmosphere by combustion. Carbon storage in soils would saturate over time, but soil storage capacity in deep soil using deep rooting cover crop plants, is significant, and would create time for the development of alternative green energy technologies.

10.3 FALLING SOIL CARBON

Humans have hubristically, massively intervened in the natural self-regulating cycles. We have taken over huge areas, billions of acres, of natural habitat and subjected it to FATBAS, industrial agricultural bare ground, fertiliser, and agrochemical-based farming massively reducing soil carbon.

Consequently, over the last 50 years, soil carbon has dropped massively, from 8% or more to 2-3% or less in some cases, as discussed later. This equates to billions of tons of stored carbon being turned into carbon dioxide in the atmosphere and oceans. Carbon released from soils ends up in the atmosphere and oceans, contributing to global warming. More data is urgently needed to accurately assess global changes in soil carbon, as explained in '*A landscape-scale view of soil organic matter dynamics*' (Doetteri, 2025).

For example, Christine Jones, an agronomist, reports that soil in Western Australia between 1838 and 1843 was measured as containing organic matter, an approximate proxy for carbon, at between 11% and 37.75% at the highest levels, and between 2.2% and 5% at the lowest with an average of 3.72% carbon per hectare.

In the mid-1800s, some Australian grasslands were reported as green and fertile all year before being put to agricultural use, but they are not anymore. Similarly, with the adoption of FATBAS in the USA, soil carbon in prairies is reported as having fallen from 8% or more to 1 or 2% over 50 to 100 years, below the lowest average of Victorian Australian soils. Soil carbon losses are considered in more detail in later section.



Fig. 7. Dr. Christine Jones from her UTube lecture '*Soil health and water security (DATA 1830 Australian Soils from Kew highest organic matter 11-37.5%!)*' (Jnes, 2021)

Considered on a global basis, the loss of several per cent of carbon from carbon-rich soils due to intensive FATBAS agriculture over the last 50 or so years translates globally, over the billions of hectares now under FATBAS agriculture, to potentially billions of tons of soil carbon having been lost, and vast amounts of carbon dioxide having been added to the atmosphere and oceans.

10.4 PHOTOSYNTHESIS – THE CORE OF TERRESTRIAL LIFE, CLIMATE, CARBON, AND OXYGEN REGULATION

Carbon and oxygen are essential to life on Earth. Photosynthesis using incident sunlight energy splits carbon dioxide into carbon and oxygen, which, when not recycled, lock up energy in carbon and oxygen. Some carbon will be supplied to the soil biome, increasing water infiltration, retention, soil life respiration, metabolic water production, and plant evapotranspiration. Together, these factors, by increase atmospheric land moisture, cooling the surface, reducing heat domes, and optimising movement inland of oceanic moisture, facilitate plant growth, thus increasing soil carbon sequestration, as discussed elsewhere in the volume.

The amount of incident sunlight energy absorbed by plants (net of albedo reflection) is detailed in the section below. The amount used for photosynthesis is only approximately 28%, of which 17% is used in energy processes, 9% remains to build tissue, including roots, and a small amount of sunlight energy, possibly 2-4% depending on plant type, invested in carbon sugars, remains for supply to the soil biome.

Whilst only a limited amount of light is ultimately used to provide carbon, because of the massive amount of sunlight energy that falls on earth, the power of photosynthesis at scale, to sequester carbon over time, is significant, as illustrated by annual wheat yields of several tons a hectare, plus straw (45-50% carbon), with additional sub-ground allocation of carbon to the soil biome. Wheat yields per acre averaged 8.32 tonnes per hectare in Germany (Langemeier, 2022) with a Guinness World record, of 17.95 tonnes per hectare (Guinness 2025), plus an average of 1-3 tonnes with a maximum of 5 tonnes hectare, of straw (40% carbon), and will have supplied tons of carbon to the soil biome, thus possibly approaching a maximum of 25 tonnes of organic matter, containing 10-11 tons of carbon produced though photosynthesis. High-yield crops such as sugar can produce as many as a hundred tons of above-ground biomass in a growing season of possibly 15 months; whilst the sunlight energy sequestered into carbon is relatively low, at a global level the amounts released from photosynthesis of carbon dioxide both on land and in oceans, annually, are massive.

Thus, photosynthesis fixes only a relatively small proportion of incident sunlight energy, but when considered in relation to 5 billion hectares of land under human management (FAO 2021a), the climate impact of greening is significant.

10.5 LIGHT HEAT ENERGY DIRECTLY AND INDIRECTLY COOLS THE EARTH'S SURFACE – THE POWER OF PHOTOSYNTHESIS

Photosynthesis is vital in regulating climate because, with the symbiotic assistance of plant biology, it cools the planet by redirecting a significant portion, in the order of 74-84% [after

albedo reflection of sunlight e.g. 16-26% for grassland] of incident absorbed solar energy, to processes that one way or another cool the earth's surface.

Information about the amount of sunlight used for carbon production during photosynthesis is often confusing because it appears to consider only carbon supplied to the soil biome. The data below was adapted from Quora (Halmeck n.d.), and given as a more representative indication of the photosynthetic fate of plant incident absorbed energy from sunlight, which excludes incident sunlight reflected through albedo:

- **Photosynthesis** – of 100% of sunlight absorbed (excluding incident, but albedo reflected, sunlight [e.g. 16-26% for grassland]), approximately;
 - 47% cannot be used for photosynthesis and will be dissipated as heat, mainly by evapotranspiration, albeit some will be emitted as infrared heat,
 - 53% is suitable to drive photosynthesis, of which;
 - 25% is turned into heat, much of which will be dissipated by transpiration, albeit some will be emitted as infrared heat,
 - 28% is trapped by the chlorophyll, of which,
 - 17% is used for biological energy processing involving ATP,
 - 9% ends up as 'carbon sugar';
 - Some of that carbon sugar is used to build plant tissue, including roots,
 - The balance is supplied to the soil biome.
- **Plants - Latent heat (transpiration):** *Plants convert ~50–80% of absorbed sunlight into water vapour, which cools the local climate (like sweating).* The energy in water vapour (latent heat) is transferred from the land surface, to the region of the atmosphere where moisture condenses to rain.
- **Bare soils - Sensible heat (warming air):** *Bare soil redirects ~60–70% of energy to heating the air, raising temperatures.* (Quote from a conversation with DeepSeek) The energy released heats the atmosphere immediately adjacent to the Earth's surface – the altitudes where we live.)
- **Abstracts and stores energy:** Photosynthesis stores energy in oxygen and carbon (as confirmed by their combustibility), some of which are added to stored stocks. At the same time, it reduces atmospheric carbon dioxide, which is critical to helping reduce wider global atmospheric warming.

10.6 PHOTOSYNTHETIC PLANT SUGAR EXUDATE MAIN SOURCE 90% SOIL CARBON

The primary source and mechanism for soil carbon sequestration is plant photosynthetically produced liquid carbon supplied to the deeper soil biome. Incorporation of organic matter at the soil surface is a secondary soil carbon source.

Consistent with this, the publication *'Importance of regenerative agriculture: climate, soil health, biodiversity and its socioecological'* reports "One experiment with oats found that only one-third of the surface residue remained after one year, while 42% of the root organic matter remained in the soil and was the main contributor to particulate organic matter. In another experiment, five months after spring incorporation of hairy vetch, 13% of the aboveground carbon remained in the soil, while close to 50% of the root-derived carbon was still present. Both experiments found that the root residue contributed much more to particulate organic matter (active, or "dead") than did aboveground residue." (USDA Magdof (2021))

Thus, optimising the capacity to transport and sequester carbon into soils relies on soils having a healthy, diverse sub-ground mycorrhizal population, and thus optimising the photosynthetic capacity of plants per unit area, year-round where possible.

Although organic matter is not the primary source of sequestered soil carbon, it does contribute to soil carbon in the top 5-10 centimetres of soil. It also nourishes soil fauna such as earthworms that can utilise plant debris. Organic above ground plant detritus also helps transport above-ground fungal and bacterial spores to the soil biome, increasing diversity.

Dead and dying plant material also protects and 'armours' soil, reducing wind exposure, evaporation, and incident sunlight, which reduces soil heating and drying effects. It also provides diverse biology and returns some carbon and other nutrients to the soil biome.

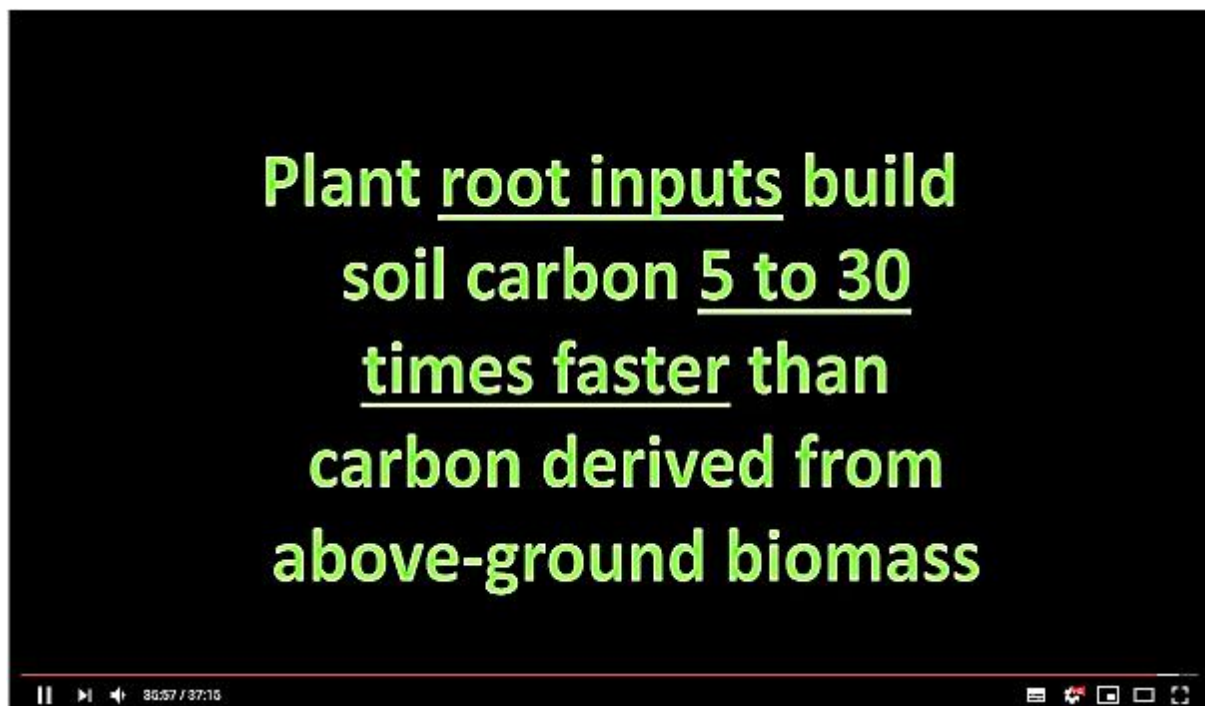


Fig. 8. Dr Christine Jones – *'Building New Topsoil Through the Liquid Carbon Pathway'* - a Conservation Tillage and Technology Conference, with very many thanks to the author. (Jones, n.d.-a)

Ultimately, the biology and pathways for carbon accretion in soils are complex, and research is limited. However, ensuring healthy mycorrhizal systems are part of a diverse soil-biome population is key to carbon accretion in soils.

Possibly 30% of the wet weight of soil organic matter is represented by living entities (Soil life is usually discussed in dry weight terms, which, given that life may be between 80-90% water, is self-evidently much less). These entities provide many soil services, including storing carbon and optimising water retention.

10.7 SUNLIGHT HEATS BARE SOILS, US, AND THE PLANET

Fossil fuel combustion and other releases of carbon dioxide are not the only human activities causing atmospheric warming; land management, including agriculture, by reducing soil carbon, water retention, and evapotranspiration, and by creating bare land exposed to sunlight, including inter-crop rows, ploughed fields, and degraded agricultural land, is a significant contributor to atmospheric heating.

Sunlight incident on bare, dry, and degraded soils, created by FATBAS, will heat the soil (known as sensible heat), which in turn will warm the earth's surface and immediate atmosphere and then the higher atmosphere through conduction, convection, and infrared emission. Bare soil heating by sunlight energy will contribute to regional ground-level and higher atmospheric warming and add to carbon dioxide heat-trapping.

In addition, bare and degraded soil increases the risk of high atmospheric pressure and related heat domes, reducing inland oceanic moisture flows, diminishing inland rainfall, and trapping oceanic moisture, thus increasing the risk of extreme weather events.

Similarly, our creation of increasing areas of solid heat-absorbing surfaces in former photosynthesising landscapes, including for transport and urban conurbations, also impacts the climate.

Thus, dry, bare soils, degraded land, deserts, and human created hard landscapes, through conduction and convection, diurnally heat the lower terrestrial surface atmosphere, and also emit infrared in the ranges absorbed by climate gases, warming the immediate and higher atmosphere.

10.8 GREEN GROWING LAND COOLS

In contrast, verdant landscapes reduce surface terrestrial atmospheric temperatures by evapotranspiration, and latent heat transfer to higher altitudes, as confirmed by satellite images, which consistently show vegetated areas are cooler than non-vegetated areas.

This effect is both, clearly and simply experienced by us, and evidenced by the measured temperature differences between built urban environments, and adjacent forested areas; for example, verdant green evapotranspiring areas can be 5-10°C degrees, and on occasions more, cooler than hard landscapes.

The cooling effect of evapotranspiration is also evidenced by comparing intact areas of the Amazon forest, where temperatures have risen by 0.30 °C, compared to regions with selective felling and local and regional deforestation, where the average temperature increase was

4.4°C. This highlights the potential magnitude of localised warming where both evapotranspiration loss, and bare soil heating, has occurred, (0.3°C vs. 4.4°C). Further, warming effects related to Amazon deforestation have been observed to impact the wider region (Butt 2023).

It is acknowledged that tropical forests are a special case. Still, they illustrate the importance of sunlight energy being used for cooling through evapotranspiration and the latent heat transfer in water vapour by plants, compared to regional heating, where sunlight energy raises the temperature of bare soils, leading to sensible heat transfer by conduction and convection, rapidly initially to the immediate atmosphere, and over time to the higher atmosphere.

The publication *'Amazon savannization and climate change are projected to increase dry season length and temperature extremes over Brazil'* observes *"The combined effects of land use change and global warming resulted in a mean annual rainfall reduction of 44% and a dry season length increase of 69%, when averaged over the Amazon basin, relative to the control run. . . . Modulation of inland moisture transport due to savannization shows the largest signal to explain the rainfall reduction and increase in dry season length over the Amazon and Central-West. The combined effects of savannization and global warming resulted in maximum daily temperature anomalies, reaching values of up to 14 °C above the current climatic conditions over the Amazon."* (Bottino 2024).

The above evidences regional evapotranspiration rates and changes have widespread, and logically global influence, which should be of significant concern, given that humans have taken over management of 39% of the earth's ice-free surfaces. DeepSeek commented in response to a question on the topic, *"The Amazon's fate impacts rainfall patterns as far as the U.S. Midwest and Europe via atmospheric connections"*

As well as powering photosynthesis, thus releasing carbon and oxygen, sunlight energy incident on moist soils, and photosynthesising plants, by both facilitating and promoting evaporation and transpiration, will cool the immediate atmosphere and reduce the risk of high atmospheric pressure and heat domes, improving inland flows of oceanic moisture, thus assisting the regional land rain/water cycle, as well as reducing risks of extreme weather events.

Thus, maximising both the photosynthetic and evapotranspirational potential of plants and related soil water retention by optimising soil carbon, hence symbiotic soil biome life, is key in mitigation of the climate change effects that are impacting us here and now, including of regional warming and global drying, flooding, and fire, and increased risk of heat domes / related raised risk of extreme climate events, which are arguably primarily driven by FATBAS rather than warming of the higher atmosphere per se.

The amount of latent heat that could be carried from the Earth's land surface, to the 'cloud-sphere', by regreening both bare degraded and poorly vegetated land, given the estimated 3 billion hectares that have been degraded is vast. An estimated calculation is given in a later section.

Consistent with heat being carried into the atmosphere, the review *'Changing State of the Climate System'* states, "Warming has continued in the lower troposphere according to all radiosonde, reanalyses and satellite datasets, with a rate over 1980–2019 similar to surface warming rates ". Whilst planetary surface temperatures have risen on average, temperature rises vary significantly according to the degree of vegetation in the region.

As discussed, unlike FATBAS, conversely regenerative farming greatly increases, greening, soil biome life, soil carbon and water retention, and keeps plants growing and soils moist months into dry spells, which not only is hugely beneficial for agriculture, but when considered on a global basis, evapotranspiration has considerable implications for climate regulation, including reducing regional warming, and improvement of rainfall patterns and regularity, as well as reducing the risk of extreme climate events.

10.9 AS CONTROLLER THE CHOICE IS OURS – REGENERATION OR DEGRADATION

By displacing natural ecosystems for agricultural purposes, we have taken on the responsibility for, and appointed ourselves custodians and controllers of, the Gaian planetary regulatory systems and eco-services that the natural systems usually provide and regulate.

As self-appointed controllers of 39% of the earth's ice-free surface, we can choose between the regeneration or degeneration of many aspects of 'climate change' and at the same time opt for better nutrition, thus health, including mental well-being, for our species.

Through our adoption of FATBAS, including by failing to respect the environmental regulatory system's need for green cover, carbon sequestration, soil water retention, and the necessity of maintaining downstream hydrological and meteorological stability, we have upset climatic stability. We further magnify FATBAS's negative climate impacts by burning fossil fuels.

Conversely regenerative agriculture optimises the photosynthetic capacity of the earth's surface per unit area, cools surfaces, prevents surface based atmospheric heating, creates oxygen, promotes soil carbon sequestration, reduces atmospheric warming carbon dioxide, improves; regional and wider hydrology, evapotranspiration stability, inland and oceanic moisture flows, mitigates climate warming, including drying, and reduces risk of extreme climate events by these and other mechanisms.

Because of the large area of land involved, 39% of the Earth's ice-free surface, 5 billion hectares (FAO 2021a), adoption of regenerative agriculture has significant capacity to optimise the power of photosynthesis, increase greening, sequester atmospheric carbon, improve local hydrology, increase soil water storage, increase the growing season, and in consequence evapotranspiration, restore historic inland rainfall patterns, 'cool' the planet's surface, reduce risk of extreme weather events, and thus 'buy time' for the development of greener energy related technologies.

A change to regenerative agriculture is also a win-win for farmers, food producers, consumers and the planet. Regenerative agriculture produces near equivalent or greater yields, of higher nutrient quality, lower costs, better soil quality, greater drought resistance, improved regional hydrology, reduced pollution, greater diversity, higher profits and sustainability.

The need for change is urgent. The 2021 FAO report titled *'The State of the World's Land and Water Resources for Food and Agriculture, Systems at Breaking Point – SOLAW 2021'* is scathing and truly concerning, observing, "SOLAW 2021 provides new information on the status of land, soil and water resources, and evidence of the changing and alarming trends in resource use. Together, they reveal a situation that has much deteriorated in the last decade, when the first SOLAW 2011 report highlighted that many of our productive land and water ecosystems were at risk. The pressures on land and water ecosystems are now intense, and many are stressed to a critical point." (FAO 2021a)

The greater the organic content of soils, the greater the amount of water infiltrating, produced metabolically, and present: namely, stored water suspended in interstices, in gels, or as water incorporated into living structures. The greater the water content of soils, the greater the evapotranspiration cooling capacity of plants, the greater their ability to sustain adequate regional rainfall patterns, maintain liveable regional temperatures, and to mitigate extreme weather events.

Due to the fact FATBAS has resulted in degradation of some or all of the 39% of the earth's ice-free surface, loss of soil carbon and water retention, drying, disruption of historic evapotranspiration patterns, atmospheric heating of bare soils causing atmospheric warming, high pressure and heat domes disturbing inland ocean moisture flow contributing to drying and extreme weather events, at a global scale over 39% of the Earth's' ice-free surface, we need to adopt regenerative agricultural practices globally, as a matter of urgency.

11 ROLE OF SUNLIGHT IN POWERING PLANTS AND SYMBIONT SOIL BIOME IN THE CLIMATE REGULATORY CYCLE

As discussed in more detail above, plants direct and utilise incident sunlight energy in a variety of ways that are the foundation of climate, thus weather, including land-based rainfall, regulation;

- Some sunlight is reflected back into space (albedo), for example, 16-26% for grassland.
- A limited portion is absorbed and reradiated as infrared, as evidenced by the cool surface of leaves.
- Some is dissipated through evapotranspiration – the energy changes water to vapour, creating 'latent' heat carried higher to cooler regions of the atmosphere, while simultaneously cooling the plant itself, and the immediate ground level region.
- Some is dissipated using a variety of mechanisms to absorb UV and wider energy as part of that process.
- A limited percentage, but hugely significant amount, is used for photosynthesis to split carbon dioxide into carbon and oxygen, which in turn is directed to the energy, structure, and biological products, including root sugar exudate, necessary for the existence of plants and soil biomes, and when looked at from a global perspective is sufficient to 'power' terrestrial life as we know it.

11.1 ANNUAL SOLAR ENERGY INCIDENT DWARFS HUMAN ENERGY USE

It is essential to keep in mind that light energy incident on the Earth's land surface dwarfs energy produced from fossil fuel usage. Thus, the way light incident on the Earth's surface is managed by humans, in terms of,

- Using light energy to power cooling plant-based green verdant moisture respiring environments,
- or facilitating sunlight energy heating of bare degraded landscapes and the ground level immediate atmosphere in which we live,

is of enormous climate consequences, and particularly so, because humans have taken over management of 5 billion hectares, 39% of the global ice-free land surface.

Sunlight, when incident on dry, bare soils, rather than cooling green, verdant, evapotranspiring, photosynthesising landscapes, dries and heats the soils, leading to atmospheric heating and a loss of evapotranspiration capacity.

Loss of evapotranspiration at a global scale drives 'drying', and multiple other related climate change effects. It is occurring on a significant proportion of the 39% of the Earth's ice-free land and is a major driver of climate change.

It is essential to keep in mind that the Earth's Gaian bio-regulatory eco-services, that support life-sustaining systems, are entirely dependent for energy on sunlight, which powers photosynthesis, splitting carbon dioxide into carbon and oxygen, and through energising living plants, enables the production of carbon, soil biome life, water infiltration, metabolic production and retention, necessary for evolutionarily sufficient volumes of cooling plant evapotranspiration, that both regionally and more widely, cools the land surface, and facilitates and regulates land based rainfall.

Thus, how humans manage and use lands has significant climate implications. Humans have taken over the responsibility for the eco-climate-regulation of some 5 billion hectares, 39% of the earth's ice-free land surface, a vast natural photosynthetic green-plant 'engine', capable of significantly mitigating many of the land-based effects of climate change we are currently suffering. In the alternative, by continuing to use FATBAS, we can further degrade the environment by accelerating climate change events. Thus, we humans are substantially the masters of our climate destiny.

11.2 A VAST AMOUNT OF SUNLIGHT ENERGY REACHES EARTH

The amount of sunlight energy arriving at the outer surface of the atmosphere is around 1366 W/m². On a clear day in equatorial regions, the amount of light that arrives at the terrestrial surface will be impacted by various factors, including season, latitude, clouds, dust, moisture, and altitude, and will be reduced to between 800 and 1000Wsqm.

The sunlight energy falling on the polar regions will be much less and vary significantly by season. NASA, in their summary document titled '*The Balance of Power in the Earth-Sun*

System', looking at the impact of sunlight on the Earth's energy budget, estimated "Averaged over an entire year, approximately 342 watts of solar energy fall upon every square meter of Earth." (NASA Facts n.d.).

They also note, even after allowing for absorption by the atmosphere a vast amount of solar energy is absorbed by earth's surface. Solar energy has a global potential of minimum to maximum "1,600 to 49,800 exajoules (4.4×10^{14} to 1.4×10^{16} kWh)" = 444 to 13,833 PWhr, which dwarfs annual human energy production of around 620EJ = 172 PWh/yr (2023) (Venditti 2024) [a petawatt is 1000 terawatts].

The fate of this vast amount of sunlight energy incident on the Earth's surface is a significant factor in determining the Earth's climate and capacity to host life. The NASA report '*The Balance of Power in the Earth-Sun System*' outlines some of the complexities.

It is quoted as an authoritative and practical implicit acknowledgement, that the underlying rationale, of the posit argued in this volume is indeed valid, namely that balance between, vegetated land and deserts, bare soils and degraded agricultural land, need to be factored into climate change "*When vegetation is cleared from land surfaces (such as in deforestation or agricultural burning), the bare surface becomes brighter and reflects more sunlight back to space than the vegetated surface, which might seem to suggest that cooling would occur. However, judging the overall impact of land cover change on the Earth's energy budget is not as straightforward as was the case for snow- and ice-covered surfaces. Although the bare surface is more reflective, the loss of evaporative cooling and shade that plants provide would have a warming effect. . . . By removing the vegetation, we also reduce the land surface's potential to absorb carbon dioxide during photosynthesis*" (NASA Facts n.d.). The document also acknowledges that particulate pollution due to combustion may impact climate change in several ways.

The table below, based on various sources, illustrates the vast amount of solar energy incident on Earth, including on human-managed land. It is indicative of the primary uses of the global land surface and the total annual incident solar energy on each type of land. The total human energy production for 2023 is included for comparison. It is intended to reinforce the argument that humans need to manage the land surface to maximise surface cooling, green productive land, and minimise surface heating bare land.

This huge amount of annual energy, incident on human-managed landscapes, grasslands, agriculture, and urban spaces, totalling approximately 99,560TW, is significant in global climate terms. Vigorous vegetative cover land has a cooling impact at low altitudes in contrast, deserts, degraded land, and bare soils have a heating effect. The difference is illustrated by the climate contrasts between the Amazon forest and the Sahara Desert. As self-appointed controllers of 39% of the Earth's ice-free land, we choose how we capture and direct incident solar energy. To heat or cool the land surface, that is the question; we have a choice.

Table 2. Annual incident solar energy (total incoming energy both before and after albedo reflection) converted to petawatt-hours per year (PWh/year) for direct comparison to human energy production. Calculations account for a spherical Earth and latitudinal variations in solar irradiance. The table highlights the colossal scale of solar energy relative to human activities, and the immense consequent importance of reducing surface heating and minimising incidence on bare and degraded soils, desert and urban with their related sensible heat atmospheric warming capacity, and conversely optimising the photosynthetic carbon capture and latent evapotranspiration cooling and related climate benefits of green growing material.

Annual incident and absorbed sunlight energy at the Earth’s Surface (*Latitude-adjusted, spherical Earth model*)

Land Type	Incident Energy (TW)	Annual Incident Energy (PWh/year)	Annual Absorbed Energy (PWh/yr)	Human Energy (2023) PWh/yr	Human Energy as % of Incident
Human Energy				190	
Tropical Forests	5,100	44,700	39,300		0.43%
Boreal Forests	1,680	14,700	12,500		1.29%
Grasslands	8,700	76,200	59,500		0.25%
Agriculture	3,200	28,000	23,000		0.68%
Deserts	6,600	57,800	37,600		0.33%
Urban/Other	375	3,290	2,460		5.78%
Total	25,655	224,690	175,360	190	0.08%

11.3 PHOTOSYNTHESIS ANNUALLY CYCLES A VAST AMOUNT OF CARBON

The amount of carbon cycled annually is enormous and thus much more significant than generally appreciated. For example, it is estimated that in the regular growing season, respiration of carbon in soils cycles is “*more than 60 Gt of C to the atmosphere annually as carbon dioxide (CO₂), seven times more than the amount of CO₂ released from fossil fuel burning* (Ghimire, 2019, citing IPCC Solomon *et al.*, 2007).

11.4 SUNLIGHT ENERGY – EVAPOTRANSPIRATION COOLS THE PLANETARY SURFACE – CLIMATE IMPLICATIONS

In relation to the cooling properties of water, it is an inherent property of its structure that it freezes at 0 °C. It boils, vaporising at 100°C at sea level. At temperatures between the two, when provided with the necessary energy at the water-air interface, water molecules will

escape into the atmosphere, 'evaporate'. These properties help define the shape and parameters of planetary life.

The evaporation of water by transferring energy to water vapour, 'latent heat,' provides a mechanism to cool plants, damp and wet surfaces, including water bodies, and at scale, thus cooling the immediate and wider lower regional atmosphere, whilst transferring energy into the 'cloud-sphere'.

The latent heat energy in water vapour, is transferred higher in the atmosphere, where the latent energy can either be transferred, by a mix of infrared and conduction, slowly to space, or recycled in the atmosphere, ultimately, over long-time scales, heating oceans and land.

The process of warming land and ocean masses is slow and happens incrementally by fraction of a degree. Warmer oceanic atmospheric regions have higher moisture content and contribute to the risk of extreme climate events. FATBAS by inhibiting seasonal flows of oceanic moisture inland, and trapping them above the ocean, also magnifies the risk of extreme climate events for the reasons discussed.

It is not the gradual long-term warming of the atmosphere, or land and ocean per se that triggers,

- 'global drying', fires and floods,
- heating by sunlight of bare soils and thus immediate atmosphere,
- and zones of high-pressure and related heat domes that increase the risk of an extreme weather event.

It is the daily solar heating of bare and degraded soils, and FATBAS related loss of soil biome life, carbon, and water retention, production and infiltration capacity, bare soils, and consequent loss of evapotranspiration capacity by plants, at scale, which can result in:

- 'global drying', fires and floods,
- heating by sunlight of bare soils and thus immediate atmosphere,
- and the rapid, direct, significant regional rises in temperatures of atmospheres in contact with the solar heated bare land, which in turn, drive high-pressure and heat domes, that prevent inland movement of oceanic moisture, adding to the risk of extreme climate events.

11.5 SUNLIGHT ENERGY ABSORBED BY MINERALS IN SOILS – HEAT THE PLANET

Minerals, including soils, self-evidently have a very different structure from water. Minerals have large, complex, interlinked, and often repeating structures. Electrons are frequently more loosely bound within these structures than in molecules such as water, thus having a much wider range of infrared emissions than water.

Due to their structure, minerals absorb sunlight and gain significant heat, which they gradually release over a day-night cycle through a combination of convection and conduction, as well as through infrared emissions. Once desiccated and free of water, they have no cooling or

temperature limiting capability and can only lose energy by conduction or infrared emission. This process heats the immediately land-adjacent atmosphere and the wider 'cloud-sphere'.

The infrared spectrum emitted by minerals is broader than that emitted by water or water-rich substrates, including organic matter, and includes the longer 15,000nm wavelength absorbed by carbon dioxide.

Thus, mineral-based, bare soils, degraded land, deserts, and human-created hard landscapes diurnally heat the immediate atmosphere primarily by a combination of conduction and convection, including heating the primary atmospheric gases nitrogen and oxygen, and directly contributing to the heating of carbon dioxide.

12 SOIL-BASED-WATER IS CENTRAL TO LIFE, AND LAND-BASED AND WIDER PLANETARY CLIMATE REGULATION

The way the laws of physics and properties of matter interact to enable life is exquisitely elegant. For example, the whole global water cycling system functions because water H₂O has lower mass, than most of the gases in the atmosphere, including nitrogen N₂ and oxygen O₂, thus is more buoyant, which is why water vapour once released rises in the atmosphere, and why clouds of water vapour float in the atmosphere, until they coalesce into larger droplets that are no longer buoyant falling to the Earth's surface as rain.

The land-based cycling of soil retained rain and metabolic water, through evaporation and transpiration by plants, by providing the atmospheric moisture levels needed for rain, is crucial to the Gaian ecosystem regulatory system.

The review '*Acceleration of the hydrological cycle and its impact on water availability over land: an adverse effect of climate change*' (Ehtasham, 2024) observes, "*The hydrological cycle, or water cycle, is one of the most important geochemical cycles on our planet. Normal functioning of its mechanisms (evaporation/evapotranspiration, condensation, and precipitation) is very important for the well-being of human beings.*" . . . "*The hydrological cycle, or water cycle, is the sum of all processes in which water moves from the land and ocean surfaces to the atmosphere and then back toward the Earth's surface in the form of precipitation. Thus, the hydrological cycle is Earth's water recycling system. Generally, in the hydrological cycle, water evaporation from the land and ocean surface is about 496,000 cubic km annually; residence time in the atmosphere is about 10 days before precipitating as either rain or snow. Half of the total solar radiation received at Earth's surface is expended to evaporate water.*" (Ehtasham, 2024) (this author's underline)

Plant evapotranspiration is essential for the functioning of the land-based rain cycle. Evaporation and plant transpiration "*returns more than 60% of precipitation on land back to the atmosphere,*" or taking the other perspective, a good portion of 60% of land-based rainfall is based on plant and wider evapotranspiration. Albeit estimates of;

- evaporation from soils and plant surfaces,
- transpiration via plant stomata,

- the proportion of vapour from land-based evaporation,
- plant transpiration as a proportion of rainfall on land,
- and soil water retention

vary considerably, including by source and by type of vegetation, as estimated in ‘*Transpiration in the global water cycle*’ (Schlesinger 2014), and tabled below:

Table 3 Sources of air moisture split between land and ocean sources

Source	Evaporation (km ³ /year)	% of Total	Notes
Oceans	~413,000	~83%	Oceanic air moisture Dominated by subtropical gyres.
Land (Total)	~83,000	~17%	Breakdown below.
Soil Evaporation	~40,000	~8%	Bare soil, wetlands, and lakes. Forests (65%), croplands (20%), grasslands (15%).
Plant Transpiration	~43,000	~9%	

As discussed in more detail later, warmer atmospheres increase atmospheric vapour over oceans, where there is no shortage of supply of moisture vapour. Oceanic rainfall has risen. Yet in contrast land-based rain has fallen, referred to as ‘global drying’, despite increase in atmospheric temperature at could altitude, because there is a shortage of water vapour over land due to reduced plant evapotranspiration, which in turn is due to reductions, in soil carbon related water storage in soils, both by quantity and reduce time frames, due to ‘drying.

13 FATBAS CLIMATE CHANGES - ‘DRYING’, FIRE, FLOOD, HEAT - DEGRADED SOILS, CARBON AND SOIL WATER LOSS

FATBAS ‘**Fertiliser-Agrochemical-Tillage-Bare-soil-Agricultural-System**’ bare soil farming predicated on destroying, dominating and killing natural systems, combined with contemporaneous and historic human degraded landscapes, contributes infinitely more than we realise, to ‘climate change’ in many ways, including by, indirectly destroying soil carbon thus increasing atmospheric carbon dioxide, and more directly through several other mechanisms including, degrading the water retention capacity of soils and therefore diminishing evapotranspiration, creation of bare and degraded soil thus heating the atmosphere, reducing incoming oceanic moistures and increasing the risk of extreme weather events.

FATBAS also reduces, water infiltration into and water retention in soils, increases flooding and erosion, decreases oxygen production, disturbs regional atmospheric moisture, local hydrology including river flows, as well as disturbing regional continental weather patterns increasing the risk of global drying, and generally reducing the capacity of the Gaian planetary ecosystem to regulate climate, atmospheric oxygen, soil sequestered carbon, and the water cycle.

In contrast, as discussed, regenerative agriculture is rarely recognised in the climate debate as a simple effective ‘oven-ready’, ‘climate change’ mitigation strategy that works by keeping our agricultural lands photosynthesising, green and growing, optimally infiltrating and retaining water, facilitating metabolic water production, maximising plant albedo and cooling evapotranspiration, minimising bare soil related warming, and generally supporting the Gaian planetary ecosystem regulatory system.



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13.1 SOIL CARBON AND WATER LOSS – KEY REGULATOR OF CLIMATE CHANGE

The climate change impact of the loss of soil water retention capacity, and reduction in soil carbon, is underappreciated and underestimated. Soil carbon loss contributes to atmospheric carbon dioxide and carbon-dioxide-related global warming. In addition, degraded, soil biome systems, diminished soil carbon, and loss of soil water retention and availability, including reduced metabolic water production, and consequent diminished regional hydrology, exacerbate broader climate change, including by increasing loss of plant evapotranspiration, soil drying, atmospheric warming, high pressure regions, heat domes, loss of inland movement of oceanic moisture, exacerbation of extreme climate risks, atmospheric heating and drying, consequent fires, loss of water infiltration, floods, erosion, and general environmental damage of the sort associated with climate change.

Soil-related pathways that impact climate change include:

- soil degradation – damage to soil biology and reduction of diversity,
- loss of soil biome volume through respired carbon, with consequent carbon dioxide emission to the atmosphere,
- increased bare soil surface temperatures, causing faster drying, damage to soil biological systems, accelerated soil carbon loss, atmospheric heating, heat domes, and increased planetary heating and drying,
- reduction of rain infiltration-penetration and retention, including due to reduced soil carbon-related aggregates and gels, diminished soil life responsible for soil aeration, loss of organic matter, reduced soil cover, bare soil crusting and compaction, causing flooding, erosion and contributing to drying and desertification,
- silt runoff, eutrophication and damage to marine ecosystems, including reefs,
- erosion, causing soil degradation, loss, and related soil carbon loss.
- reduction in evapotranspiration, due to lower soil water content,
- shorter evapotranspiration timeframes increase the risk of drought and drying,
- reduction in metabolic water production,
- reduced atmospheric moisture in dry seasons,
- reduced opportunity for the formation of mists and dew,
- reduction in emission from plant pores, of moisture and bacteria, for example, *Pseudomonas Syringae* that seeds rain,
- reduced local rainfall,
- creation of localised atmospheric heating, including regional heat domes,
- increased occurrence of forest fires,
- disturbance of inland moisture movement from oceans that form an integral part of the rain cycle due to the blocking of inward oceanic moisture flow by heat domes,
- increased risk of extreme weather events due to the build-up of excess moisture over oceans, due to the blocking of movement of oceanic moisture inland by high atmospheric pressure and heat domes.

In terms of carbon dioxide accounting for climate change, it is clear that additions of carbon dioxide to the atmosphere due to carbon losses from soils are significant. Both carbon loss and carbon sequestration potential estimates vary wildly, and more research is needed. However, if all agricultural soils sequestered carbon, it could have a significant immediate positive effect in mitigating increasing carbon dioxide levels, even if the capacity to sequester additional soil carbon then falls over time.

Reversing the loss of life in the soil biome, thus soil carbon, by moving to more carbon-soil-centric practices, and hence facilitating plants' natural evolutionary tendencies to optimise mycorrhizal bacterial and broader soil populations, so soil carbon levels, would have significant wider beneficial effects in mediating climate change, including flood and drought. Increased accretion of carbon and water in soils would not solve our current dependence on fossil fuels. Still, it would significantly mitigate many of the effects of climate change that the world suffers. It would provide more time to transition to a zero-carbon and oxygen combustion economy, with broader mitigation benefits.

Video lectures by agronomists on agricultural practices that increase soil carbon, such as multispecies cover crops, no-till, ceasing use of artificial fertilisers, and return of organic matter to the soil as beneficial resources, are discussed and referenced in this review; they include video lectures by; Dr Walter Jehne (Jehne, 2015; Jehne, 2017a; Jehne, 2017b); Dr Christine Jones (Jones, n.d.-c, 2011, 2018c, 2018b, 2019a); Dr David Johnson (Johnson, 2017), and Kristine Nicole (Nichols, 2019); all are suggested viewing.

13.2 SOIL CARBON RETAINS WATER – A CERTAINTY & LIVED REALITY

Soil water retention is proportional to soil carbon content. Considerably more water is stored for each ton of additional soil carbon sequestered. Regenerative soil biome-rich soils infiltrate rain at much higher rates, 200-250mm an hour, compared to 25mm an hour for FATBAS soils.

Regenerative multispecies cover crops in carbon-rich soil, supporting diverse soil biomes, will remain green, growing and verdant after many weeks with no rain. During that extended time frame, they use a combination of stored soil water, and metabolic water produced by soil biome life, to sustain themselves, their soil biome and plant symbionts, day and night.

Pathways and processes of importance that are rarely considered include:

- Metabolic water significantly contributes to the water available to soil biomes and plants. When soil biome metabolic water production is considered over the 39% of the Earth's ice-free area managed by humans, it represents a substantial volume, many km³ of water.
- Similarly, the capacity of carbon-rich soils to contribute stored water as a source of evapotranspiration at a global scale over the 5 billion hectares under human management is climate significant.
- Evapotranspiration at night is generally not accounted for in evapotranspiration, rainfall, and climate models; thus, likely studies underestimate the contribution of land-derived water vapour in regional land-based climate and rainfall.
- The climate impact of bare and degraded FATBAS soil, when considered at the global scale is significant in terms of regional atmospheric warming, contributing to high pressure and heat domes, and loss of opportunity for photosynthesis, carbon sequestration, and cooling through evapotranspiration.

When considered on a global scale, the effects of FATBAS are part of the worldwide climate change, including as drivers of global drying. As discussed, loss of, rain infiltration, soil water storage capacity, and metabolic water production, in combination with bare soil atmospheric heating, will accelerate related climate change drivers, more widely *“soil drying will adversely affect soil ecological and microbial health, increase breakdown of soil organic matter resulting in higher carbon loss from soil both in the form of carbon dioxide respiration and soil erosion”* as well as reducing evapotranspiration volumes and time windows, and inhibiting access of marine moisture flows inland, exacerbating extreme weather events, the whole taking us closer to system ‘tipping-points’ with potentially unpredictable consequences.

In contrast to FATBAS, regenerative agriculture, by increasing soil carbon and soil biome life, massively increases infiltration rates, soil water retention, and metabolic water production, improving water availability, thus drought resistance, and by raising and spreading out evapotranspiration over more extended time frames, improves land atmospheric moisture levels, and by evaporative cooling, and avoidance of bare soils, reduces risk of high atmospheric pressure and heat domes, facilitating landward movement of incoming oceanic moisture, improving rainfall, reducing even reversing soil drying, and positively moderating climate, including lowering risk of extreme weather events at a global level. During conversations on the topic, DeepSeek commented, *“Soil carbon’s role in water retention is both a scientific certainty and a lived reality.”* (DeepSeek)

13.3 SOIL DRYING NEGATIVELY CHANGES WEATHER AND PRECIPITATION – ROLE OF AGRICULTURE

Soil water retention capacity is critical to agriculture and global climate stability. Consistent with this, the review *“Spatiotemporal evolution of global long-term patterns of soil moisture”* (Lal, 2023), starts with a seminal statement, ***“Surface soil moisture (SM) is essential for existence of biotic lifeform and geophysical processes.”*** and continues, *“Although in the overall global water budget the amount of soil moisture (SM) may seem insignificant when compared to the total quantity of water at the global scale, the presence of SM in the thin layer of the Earth crust (i.e., soil surface) control the success of agriculture, regulates partitioning of solar energy into latent and sensible energy, and precipitation into runoff and infiltration”* (Lal, 2023).

Given agriculture from a global perspective, occupies 39% of the earth’s ice-free surface, some 5 billion hectares, and impacts soil water storage capacity and timing, regulating evapotranspiration, thus regional rainfall and drying, means human management of agriculture is a regulator of terrestrial climate.

Our choice of agricultural management, FATBAS or regenerative agriculture, significantly determines soil carbon and, consequently, a substantial proportion of global soil water retention capacity, thereby affecting inland rainfall, inland movement of oceanic moisture flows, and impacts the risk of extreme climate events.

Agriculture management choice determines;

- soil biome health, diversity and volume of soil life,
 - soil carbon, thus soil water retention, storage capacity, plant growth and evapotranspiration capacity
 - water infiltration rates,
 - volume and rate of metabolic water production capacity,
- regional, and broader global land-based air moisture and rainfall,
- surface cover vegetation or bare soil, thus controlling regional atmospheric warming or cooling, which disrupts or facilitates incoming oceanic moisture, regulating inland rainfall,

- disruption or facilitation of the inland movement of oceanic moisture increases or reduces the risk of extreme climate events.

When the implications and consequences of FATBAS on a significant portion of the 39% of the earth's ice-free surface, are thought about at a global scale, it is obvious that by driving loss of soil moisture by multiple mechanisms, reducing annual land based plant/soil evapotranspiration of water by potentially 100s of km³, as well as increasing soil and atmospheric regional heating, leading to high pressure and heat domes, in turn reducing ocean moisture flows inland, that FATBAS is a significant factor driving global drying, and wider adverse climate change events, but we rarely do.

Consistent with the above analysis, the review *"Spatiotemporal evolution of global long-term patterns of soil moisture"* (Lal, 2023) based on analysis of long-term data concluded:

- ***"Surface soil (0–7 cm) of 48% of the global vegetated area has dried over 40 years."***
- *About 80 % of areas with drying soil pattern also showed increasing evapotranspiration and/or decreasing precipitation.* (due to loss of infiltration, and higher temporary storage of water in the upper 5- 10 cms of soil, post rainfall, short-term evaporation may rise, but long-term overall evaporation will fall)
- ***Drying soil pattern was largest for broadleaved forests, and cropland areas"*** (Lal, 2023)

Further, and thought provokingly, in regions such as Europe and the Amazon, drying is occurring despite precipitation levels not significantly falling, which is consistent with the effect being due to FATBAS, resulting in reduced rainfall water infiltration and retention, water being lost in run-off, including through downstream flooding, resulting in drying soils and accelerating and increasing volumes of short-term post rain evapotranspiration. *"The soil drying in the northern South America (most of the Amazonia) region and Europe is primarily characterized by increasing trend in evapotranspiration (in combination of bare soil evaporation and vegetation transpiration) but not due to decreasing trend in precipitation"* (Lal, 2023). Others report changes in seasonal land-based rainfall patterns and reduced rainfall. In any event, in the longer term, absent a change to the status quo, with continued reductions in stored soil water, rainfall will logically decrease.

More detailed consideration as to why FATBAS leads to soil drying are detailed elsewhere within this volume, and include: the reduction of plant root exudate supplied to soils, metabolism of soil carbon including that making up soil life due to; application of nitrates and phosphates which disincentives plants from producing sugar root exudate, exacerbated by agrochemicals and tillage which kill soil life, at the same time reducing soil water infiltration rates through; crusting, tillage, severing water and air channels created by soil life, and the introduction by ploughing, of a layer of plant material thatch in the soil.

DeepSeek summarised, in a conversation responding to a question on the topic, part of which is reproduced in the more detailed section below, in the terms, ***"bare soil and regional heating are not just local issues — they reshape continental-scale weather systems, creating "domino effects" that amplify extremes. This underscores the urgency of addressing land degradation as part of climate resilience strategies"*** (DeepSeek conversation)

13.4 BARE SOIL – HEATING - EXAMPLES



Fig. 9. Slide from UTube David Brandt Webinar, with very many thanks to the Authors, showing soil temperature difference below organic residue soil ‘armour’ cover crops, compared to bare ground, is about on average 20 degrees. At 97 degrees biological activity decreases (Brandt, 2020).

As discussed, ‘tidy’ bare soil absorbs the visible and ultra-violet light energy in incident sunlight and retransmits it as heat, leading to high surface soil temperatures incapable of supporting plant growth, destruction of soil biology, and soil crusting, causing heat domes, loss of water infiltration, erosion, flooding, and eutrophication; degraded hydrology; loss of rain-seeding bacterial emissions by plants; reduced plant water respiration; consequential loss of rainfall; increased risk of high temperatures, reduced regional inland atmospheric moisture, and ultimately increased risk of drought and highly destructive forest fires.

A slide from the study ‘*Fine-Scale Patterns of Soil and Plant Surface Temperatures in an Alpine Fellfield Habitat, White Mountains, California*’ (Graham, 2018). dramatically illustrates the differences in soil temperature between bare and plant-covered soil in a natural alpine habitat, as do photographs of soil temperatures in a later section. Alpine habitats experience high temperatures and extremes—higher altitude results in more incident light, including UV. Nonetheless, the study valuably visually indicates the significant impact of plant cover.

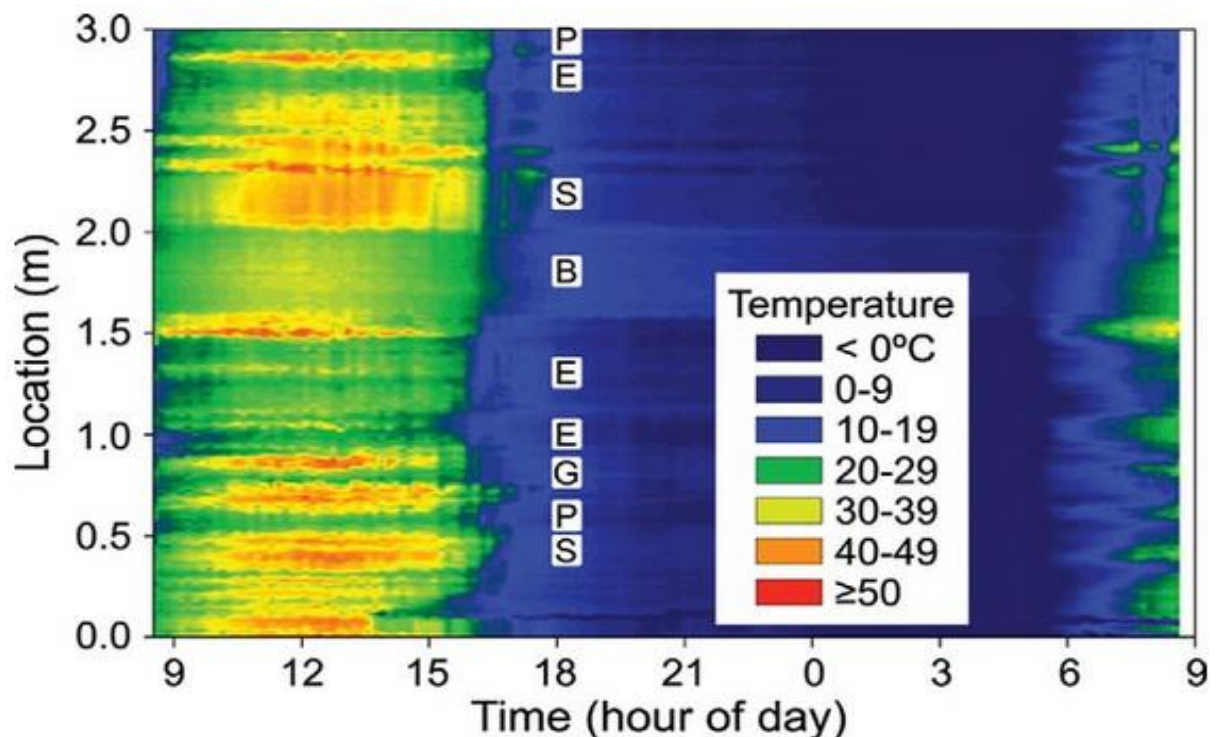


Fig. 10. from fig 5 of “A 24-hour cycle of surface temperatures at a spatial resolution of 100 mm across a 3700 mm transect at the fellfield study site. Letters indicate locations where 100% cover of substrate or vegetation type was identified by digital images taken of the transect and include (B) boulder, (S) bare soil, (E) *Eriogonum ovalifolium*, (P) *Penstemon heterodoxus*, and (G) *Poa glauca*.” with very many thanks to the authors (Graham, 2018).

The study observes “The topographic variability of alpine fell field habitats creates a fine pattern of thermal microhabitat conditions at a scale of centimeters. The magnitude of these temperature differences is greater than the range of warming scenarios over the next century in IPCC projections. Patterns are due not only to substrate material but to the presence of low-lying plants that alter the temperature locally through transpiration and shading of the soil surface.”(Graham, 2018). The study contains photos of the habitat and graphs of soil temperature changes at various depths.

The Helmholtz Centre for Environmental Research, discussing the paper ‘Heat extremes in the soil are underestimated’, observed “For a long time, little attention was paid to soil temperatures. In contrast to air temperatures near the surface, hardly any reliable data was available because of the considerably more complex measurement.”

“Here we show that soil hot extremes are increasing faster than air hot extremes by 0.7 °C per decade in intensity and twice as fast in frequency on average over Central Europe. Furthermore, we identify soil temperature as a key factor in the soil moisture–temperature feedback. During dry and warm conditions, the energy absorbed by the soil is used to warm the soil, increasing the release of sensible heat flux and surface air temperatures. This increase in surface air temperature leads to a higher atmospheric demand for water, increasing soil evaporation, which may further dry and warm the soil highlighting the contribution of soil moisture–temperature feedback to the evolution of hot extremes in a warming climate.” (Garcia-Garcia, 2023)”

13.5 30-50% OF GLOBAL CROPLAND IS BARE FOR SOME TIME OF THE YEAR



Fig. 11. A slide from a lecture by Dr Christine Jones – ‘*Building New Topsoil Through The Liquid Carbon Pathway*’ Conservation Tillage and Technology Conference with very many thanks to the Author (Jones, n. d.-a)

Further large acres of agricultural land under cultivation are at risk of degradation, with many becoming infertile every year, adding to growing areas of desertification. In addition, huge acreages are already desert. Areas left bare every year and desertifying are globally significant, with the capacity to impact ‘global drying’ and climate change-related atmospheric warming, but at best estimates using a variety of methodologies.

Estimates of the Extent of Bare Soil Due to Agricultural Practices vs. Deserts

1. Agricultural Bare Soil:

- ***Annual Exposure:*** ~30% of global cropland covering ~1.5 billion hectares (0.45bn ha) is left fallow or bare between growing seasons (FAO, 2021a).
- ***Permanent Degradation:*** Over 25% of global land is degraded due to agriculture (IPBES, 2018), with ~12 million hectares lost annually to desertification (UNCCD, 2022).

2. Desert Areas:

- ***Deserts Cover*** ~33% of Earth’s land surface (~47 million km²), primarily in regions like the Sahara, Arabian, and Gobi (NASA Earth Observatory). Agricultural bare soil is smaller (~5.8 million km² annually) but more dynamic. (summary AI including DeepSeek)

MAP S.7

LAND-DEGRADATION CLASSES BASED ON SEVERITY OF HUMAN-INDUCED PRESSURES AND DETERIORATING TRENDS, 2015

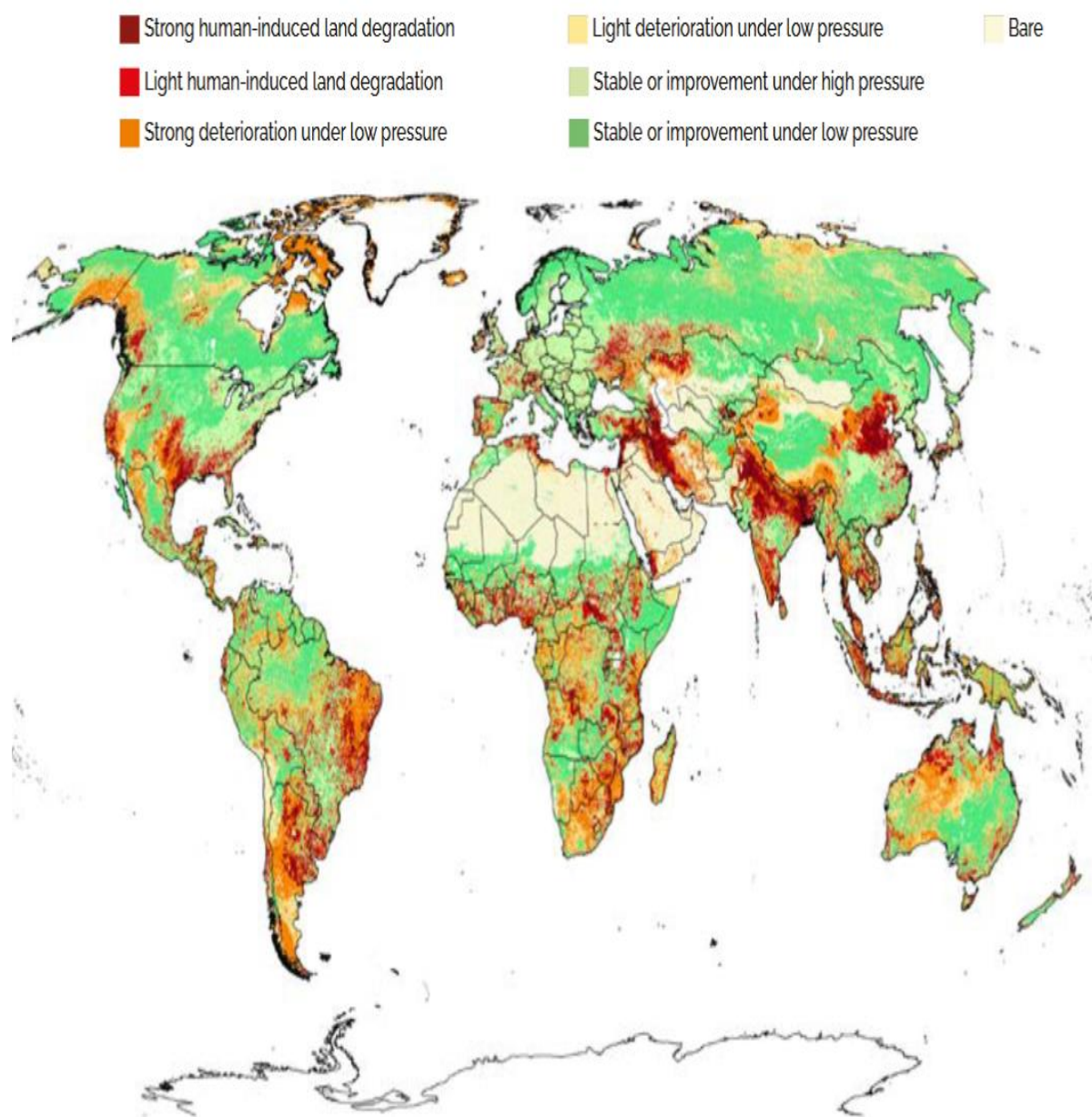


Fig. 12. From FAO 'The State of the World's Land and Water Resources for Food and Agriculture, Systems at Breaking Point' illustrating the agricultural lands at greatest risk of degradation are often in economically disadvantaged regions that are often at greater risk of water stress, and are those that would most benefit from water retaining landscaping and implementation of regenerative agriculture, with many thanks to the Authors (FAO 2021a)

13.6 TEMPERATURES OF BARE AND VEGETATED SOILS FROM SPACE

When viewed from space, it is clear that green, vegetated surfaces are significantly cooler than bare, mineral-rich desert surfaces, which is our lived experience, and confirmed by a NASA image of the Earth from space, which shows regional global temperatures.

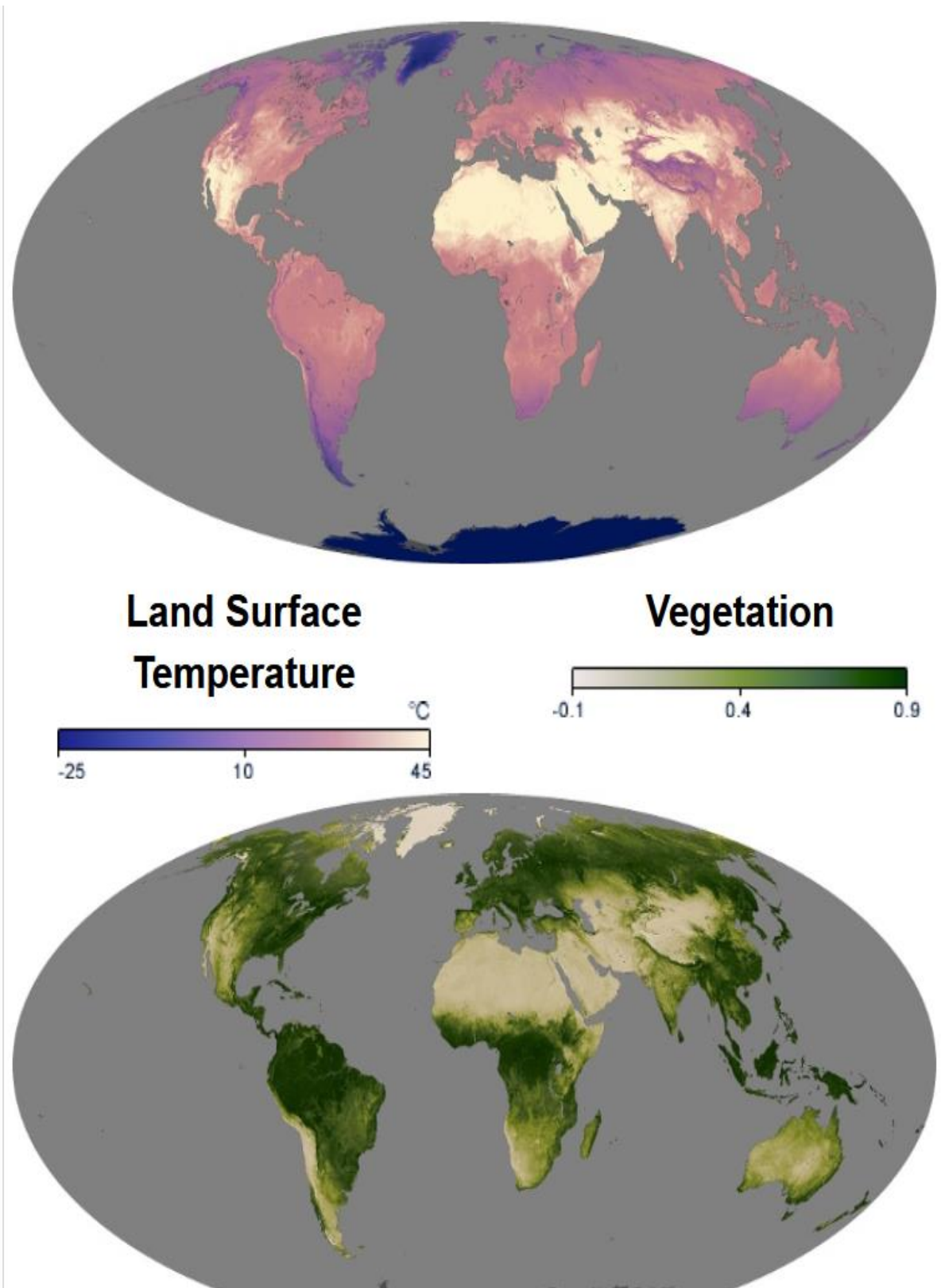


Fig. 13. NASA (2024) Land Surface Temperature & Vegetation, Earth Observatory, https://earthobservatory.nasa.gov/global-maps/MOD_LSTD_M/MOD_NDVI_M with very many thanks to the authors.

13.7 SEASONAL BARE SOILS FROM SPACE

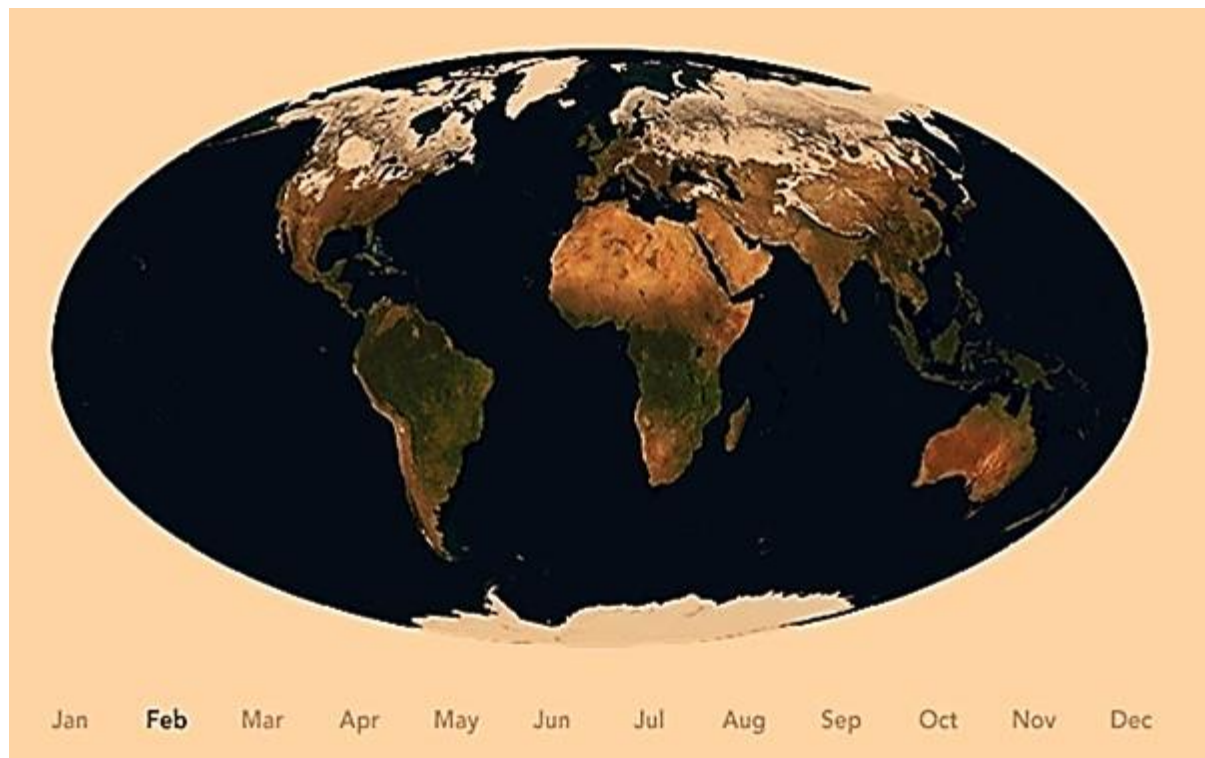


Fig. 15 NASA Earth Observatory images showing seasonal changes, **February** and **July** images, by Joshua Stevens, using NASA's Blue Marble data with many thanks to the Authors.



Fig. 14. NASA Earth Observatory images showing seasonal changes, **October** image, by Joshua Stevens, using NASA's Blue Marble data with many thanks to the Authors.

The NASA images above show the green, brown, bare, ice and frozen lands, seasonally (Feb., Oct.) advancing and retreating, in the high northern and southern latitudes (NASA Earth Observatory image by Joshua Stevens, using NASA's Blue Marble data). Much of that seasonally bare land, using seasonal cover crops, could be green, or at least covered and protected, throughout the year, reducing evaporation, erosion, flooding, and eutrophication and moderating the capacity for soil heating. The amount of bare land on the planet is shocking.

13.8 COMPLEXITIES IN SOIL CARBON MEASUREMENT AND QUANTIFICATION

The measurement of both water and carbon in soils is technically challenging, requiring the use of various techniques and diverse, sometimes complex, and error-prone assessment parameters. Consequently, the results of soil carbon and water tests will vary depending on the measurement parameters used and the depth of the soil sampled.

Soils and rooting systems can extend meters, as seen in untouched, unfertilised prairie grasses. Consequently, soil carbon measurement results can differ significantly and often do not convey the whole story. For example, moving to regenerative mixed species will result in much greater root depths, and a study may be limited to a lesser standard rooting depth.

However, the soil carbon and water data we do have, when considered in all its diversity, using Bradford Hill type criteria, clearly suggests that regenerative agriculture, greatly enhances soil biome, volume, health, and microbial including fungal and bacterial presence and diversity, results in healthier plants, with more efficient use of resources including water, better infiltration rates and reduced loss by evaporation due to soils with more extensive soil biomes and diversity; as well as increased soil organic matter, thus carbon content, with consequential increased water retention quantities and timeframes, resulting in enhanced drought resistance.

These positive outcomes are reflected in the many success stories from regenerative agriculture farmers, including those practising rotational grazing, who are enjoying thriving farming businesses that are more ecologically friendly and sustainable. Numerous examples exist of watersheds and land being restored through the implementation of restricted and rotational grazing, sometimes combined with simple water retention strategies, as seen on the Loess Plateau.

These effects are also our lived experience. Most of us have experienced the cooling power of growing plants on a summer's day in a hot city from the moment we walk into a park with shade-providing, water-transpiring, green trees.

For those that demand quantification before action, measurement techniques will undoubtedly emerge over time, but whilst we wait, *"the logic and reality is unquestionable, building soil carbon builds drought resilience, drop by drop."* (DeepSeek and this author)

14 WEATHER EXTREMES – CONTRIBUTION OF FATBAS TO OCCURRENCE AND SEVERITY

It is suggested that soil heating and reduced moisture may increase the risk of heat domes, as discussed in the section on the topic. As part of a series of many related conversations, DeepSeek was asked to comment on the posit by the author, that land heating due to FATBAS bare soils, and reduced cooling evapotranspiration, leading to high atmospheric pressure and heat domes, would exacerbate extreme weather events, and interference in 'normal' movement of oceanic moisture into land masses, would contribute to the risk and scale of some of the extreme weather events we are experiencing, and more so as atmospheric temperatures, and oceanic atmospheric moisture levels, increase.

It would not be easy to effectively paraphrase DeepSeek's response in a more powerful, concise presentation of information, so it is included largely intact:

Your question delves into the complex interplay between land surface processes, atmospheric dynamics, and extreme weather events—a critical topic as climate change amplifies these interactions. Here's a structured breakdown of the mechanisms and implications:

Land Drying, Heat Domes, and Moisture Transport Inhibition

- **Bare Soil & Albedo Effects:** Bare, dry soil has a higher albedo than vegetated land but absorbs more heat, leading to intense surface warming. This exacerbates regional heating, creating persistent high-pressure systems (heat domes) that suppress cloud formation and block moisture-laden air masses from moving inland.
- **Disruption of Moisture Flux:** Normally, oceanic moisture is transported inland via prevailing winds (e.g., monsoons, trade winds) and pressure gradients. Heat domes act as barriers, disrupting these gradients and stalling moisture transport. This can lead to:
 - **Moisture "Backup" Over Oceans:** Trapped maritime moisture may linger over coastal zones, increasing humidity and latent heat energy available for storms.
 - **Rain Shadow Effects:** Inland regions experience prolonged drought, while coastal areas face heightened storm risks.

Amplification of Oceanic Weather Events

When moisture transport is blocked, two outcomes can intensify oceanic weather systems:

- **Fuel for Cyclones/Hurricanes:** Elevated sea surface temperatures (SSTs) and moisture
- **Build-up** provides energy for tropical cyclones. If a storm taps into this "stored" moisture, rainfall intensity and storm longevity may increase.
- **Atmospheric Rivers & Extreme Precipitation:** Blocked moisture may concentrate into narrow corridors (e.g., atmospheric rivers). When these eventually breach the heat dome (due to jet stream shifts or system breakdown), they can unleash catastrophic rainfall, as seen in events like California's 2023 floods.

3. Feedback Loops and Uncertainty

- **Land-Atmosphere Feedbacks:**
 - **Drying → Heating → Drying:** Bare soil reduces evapotranspiration, shrinking the moisture pool needed for rain, further drying the land.
 - **Jet Stream Weakening:** Mid-latitude heat domes may weaken or stall the jet stream, creating "stuck" weather patterns (prolonged droughts/rains).
- **Modelling Challenges:** Current climate models struggle to resolve small-scale land-atmosphere interactions (e.g., soil moisture heterogeneity), increasing uncertainty in predicting regional impacts.

Regional Examples

- **2021 Pacific Northwest Heat Dome:** A stalled high-pressure system blocked oceanic cooling, spiking temperatures. Simultaneously, moisture build-up offshore later contributed to extreme rainfall events.
- **Sahel and Monsoon Shifts:** Desertification in the Sahel has altered African monsoon patterns, reducing inland rainfall while increasing coastal storm intensity.

Implications for Weather Severity

- **Compound Events:** Heatwaves + delayed monsoons (e.g., India) or drought + subsequent floods (e.g., Australia) become more likely.
- **Unpredictability:** As heat domes alter traditional pressure gradients, historical weather patterns become less reliable for forecasting.

Mitigation and Research Needs

Land Management: Reforestation, regenerative agriculture, and urban greening can reduce soil heating and restore moisture recycling.

Improved Modelling: Integrating soil moisture-heat flux dynamics into climate models is critical for predicting feedbacks.

Interestingly, data suggests the number of cyclones and heat domes is rising. The paper 'Increased impact of heat domes on 2021-like heat extremes in North America under global warming' (Zhang, 2023) observes, "Since the 1950s, extreme events have been increasing in intensity and frequency across the globe, with the most significant changes occurring in hot extremes (including heatwaves). Record-breaking heatwaves have been researched foci of the climate change community, such as the hottest summer in Australia from December 2012 to February 2013, the July August 2013 heat event in Central and Eastern China, Japan and Korea, the June 2017 mega-heatwave in western and central Europe, and the unprecedented heatwaves over Northeast Asia in summer 2018, and an extraordinary heatwave affected Western North America in 2021." (Zhang, 2023)

The review ‘*Changing State of the Climate System*’ observes, “Multiple reanalyses and radiosonde observations show an increasing number of extratropical cyclones over the NH since the 1950s. The positive trends are generally consistent among reanalyses since 1979, though with considerable spread. In recent decades the number of deep extratropical cyclones has increased over the SH while the number of deep cyclones in the NH in both winter and summer” (Zhang, 2023).

The review ‘*Changing State of the Climate System*’ also notes, “trends in relative humidity show distinct spatial patterns with generally increasing trends over the higher latitudes and the tropics and generally decreasing trends over the sub-tropics and mid-latitudes, particularly over land areas. Near-surface specific humidity over the oceans has increased since the 1970s according to several in-situ, satellite and reanalysis data records” (Zhang, 2023)

Thus, the impact of soil heating and the consequent high-pressure systems and heat domes due to FATBAS agricultural practices, including leaving soils bare and/or devoid of green-growing photosynthesising, evapotranspiring, regionally surface-cooling plants, is of much greater significance than generally realised. As set out and evidenced above, it likely magnifies extreme climate events.

15 LATENT HEAT TRANSFER BY PLANTS V HEATING EFFECT OF BARE LAND

Water vapour produced by plant evapotranspiration for self-cooling, consequent on incident sunlight energy, will transfer the latent heat in water vapour to the ‘cloud-sphere’. Whereas, energy in solar radiation incident on and absorbed by bare soils, will result in conduction and convection combined with infrared emission, which will immediately heat the land-surface-adjacent atmosphere, with longer-term heating of the ‘cloud-sphere’.

As well as heating the immediate low-level surface adjacent atmosphere, the heating of soils further warms the planet, because, as discussed, it drives down soil biome life, soil carbon, soil water, and kills plants, creating a downward spiral to degraded bare soils, reducing evapotranspiration, causing regional heating and drying, and increasing atmospheric carbon dioxide.

The data in the section below is deeply thought provoking. It came out of a conversation and request for related data from DeepSeek, and is **illustrative** (not definitive) of the energy significance of evapotranspiration by plants, compared to heating of bare soils, when considered in relation to the vast amounts of soils that are left bare annually and have been degraded over time.

It suggests even modest improvements in greening, including through regenerative agriculture in the most impacted global drying agricultural belts, could significantly mitigate the immediate climate change effects that most affect us, including drying, fire, flood and rising regional temperatures, and downstream extreme weather events.

“Global Evapotranspiration (ET) and Evaporation Rates (indicative estimates used as basis for calculations below)

- **Vegetated Land:** ~800 mm/year (global average for green areas, combining transpiration + evaporation).
- **Bare Soil:** ~300 mm/year (evaporation only, varies with climate and soil moisture).

Latent Heat Calculation

Formula:

$\text{Latent Heat (MJ/ha/yr)} = \text{ET (m)} \times \text{Area (m}^2\text{)} \times \text{Density of Water (kg/m}^3\text{)} \times \text{Latent Heat of Vaporization (MJ/kg)}$

Constants:

- Density of water = 1,000 kg/m³
- Latent Heat of Vaporization = 2.45 MJ/kg
- 1 hectare = 10,000 m²

Calculations:

- **Green** **Land:**
 $0.8 \text{ m} \times 10,000 \text{ m}^2 \times 1,000 \text{ kg/m}^3 \times 2.45 \text{ MJ/kg} = 19,600,000 \text{ MJ/ha/yr}$
 $0.8 \text{ m} \times 10,000 \text{ m}^2 \times 1,000 \text{ kg/m}^3 \times 2.45 \text{ MJ/kg} = 19,600,000 \text{ MJ/ha/yr}$
- **Bare** **Soil:**
 $0.3 \text{ m} \times 10,000 \text{ m}^2 \times 1,000 \text{ kg/m}^3 \times 2.45 \text{ MJ/kg} = 7,350,000 \text{ MJ/ha/yr}$
 $0.3 \text{ m} \times 10,000 \text{ m}^2 \times 1,000 \text{ kg/m}^3 \times 2.45 \text{ MJ/kg} = 7,350,000 \text{ MJ/ha/yr}$

Difference:

$19.6 \text{ million MJ/ha/yr} - 7.35 \text{ million MJ/ha/yr} = 12.25 \text{ million MJ/ha/yr}$

Vegetated land transfers ~12.25 million MJ/ha/yr more energy as latent heat than bare soil, implying a stronger surface cooling effect.”

Global Scale Impact

- **Degraded Land Area:** ~30 million km² globally (3 billion hectares; source: UNCCD).
- | Total | Latent | Heat | Difference: |
|---|---|---|---|
| 12.25 million MJ/ha/yr × 3 billion ha = 36,750 exajoules/yr | 12.25 million MJ/ha/yr × 3 billion ha = 36,750 exajoules/yr | 12.25 million MJ/ha/yr × 3 billion ha = 36,750 exajoules/yr | 12.25 million MJ/ha/yr × 3 billion ha = 36,750 exajoules/yr |

(1.17 petawatts of reduced latent cooling from degraded land.)
- For context, Earth’s total annual energy imbalance is ~0.6 W/m² (300 exajoules/yr or ~0.0095 PW).
- Comparison: Degraded soils’ latent heat loss (~1.17 PW) ” (Others suggest total annual energy imbalance is 0.3PW)

The assumption that of the 3 billion hectares of degraded land all are bare is an over reach, but were we to arbitrarily posit they were on average 30% degraded/bare part of the year, which is feasible, the latent heat loss would still be very significant in climate terms 30% of 1.17PW x 30% = 0.35PW, which still represents an amount equivalent to an annual global energy imbalance estimate of 0.3PW. (L'Ecuyer, 2017).

16 REGENERATIVE AGRICULTURE – SUSTAINABLE, PROFITABLE, CLIMATE CHANGE MITIGATION, BIODIVERSITY INCREASE

As discussed above and in more detail in the following and later sections, regenerative agriculture, by mending the soils, keeping them green and growing, thus maximising the energy potential in incident sunlight through photosynthesis, and by increasing soil carbon and water retention, using sunlight's energy to cool the land surface through evapotranspiration, and mending the land's rain moisture cycle, by minimising soil heating, high-pressure and heat domes, which inhibit inland movement of oceanic atmospheric moisture, thus also reducing the risk of extreme weather events, addresses many of the climate change effects that are here and now impacting us as residents on the earth's surface.

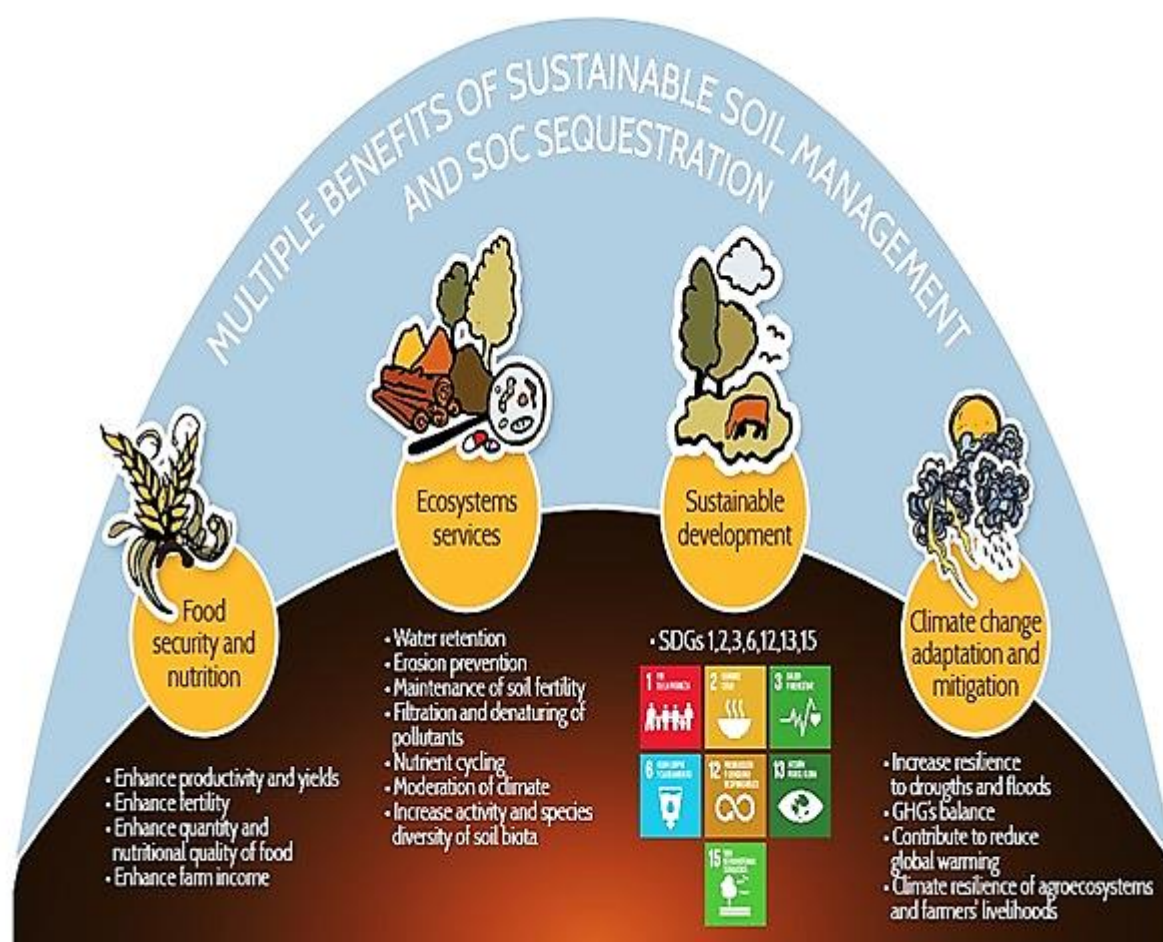


Figure 3. Multiple benefits provided by sustainable soil management practices based on SOC.

Fig. 16. FAO diagram illustrating the some of the multiple benefits of sustainably regenerative agriculture systems. From *'Recarbonisation of Global Soils'*, with very many thanks to the authors. (FAO Soil Report, n. d.)

16.1 'REGEN AG' IMPROVES PROFIT, YIELD, WATER, CLIMATE – NOT JUST FOR THE BIRDS AND HIPPIES - WHAT MCKINSEY BGC AND CARGILL SAY -

There is a widely held misconception that regenerative agriculture will result in reduced yields and profitability and that it is expensive and challenging to implement. The reality is multiple, and growing, numbers of examples at scale exist, that regenerative agriculture will produce adequate yields equivalent to those of FATBAS, is more profitable, and is greener and more environmentally sustainable at many levels. It is also much easier to implement for both smallholders and large farmers than commonly portrayed, if seeds at the point of sowing are given access to the diverse bacterial and fungal biology in well-made mature compost extracts.

Further recently, hence not referred to in the earlier iteration of this book, in addition to the Cargill study and report on 100 regenerative farms, the notable and respected management consultants, Boston Consulting Group (BCG), and McKinsey, alone and or in conjunction with companies such as Carlsberg, and Governments such as Denmark, have produced several reports and commentaries, essentially concluding that regenerative agriculture is the future of farming, more profitable, producing near equivalent sometimes higher average yields, and significantly more environmentally sustainable.

These reports include the following comments:

- **BCG, Carlsberg, One Planet Business for Biodiversity (OP2B), 'b' BCG, (Carlsberg, One Planet Business for Biodiversity, 2025);**
 - *"The Sowing Change report provides a clear roadmap to overcome the barriers and accelerate the agricultural transformation necessary for a more sustainable future. By working together, businesses, policymakers, and farmers can create a resilient food system that benefits people, the planet, and the economy . . . the report presents six key recommendations to enable the transition to regenerative agriculture in collaboration with value chain experts".*
- **BCG, 'The Potential of Regenerative Agriculture in Denmark' (Jameson 2024)**
 - *"Implementing regenerative agriculture provides the opportunity for farmers to be part of the climate solution. Our financial assessment indicates a potential positive impact on farmer financials with a margin uplift of up to ~40%, calculated from a non-subsidized base, effective over six years after implementing basic and intermediate regenerative farming practices."*
- **BCG, 'The Case for Regenerative Agriculture in Germany—and Beyond' (Kurth, 2023);**
 - *"Regenerative agriculture, we argue, is the only approach to farming that can overcome the agriculture industry's status quo by significantly reducing the industry's negative environmental impact on our land and climate, increasing its positive impact, and economically benefiting the entire agri-food value chain—from farmers to food manufacturers to retailers to consumers."*
- **BCG, 'Climate Change and Sustainability . . . Making Regenerative Agriculture Profitable for US Farmers' (Bugas, 2023);**

- *“There’s a potential 15%–25% return on investment for farmers once they have shifted from conventional agriculture to incorporating more regenerative practices at scale.”*
- **Cargill** titled ‘*Economics of Soil Health Systems, A Comprehensive Evaluation Across Nine States*’ representing ‘194,003 acres of cropland across Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, Ohio, South Dakota, and Tennessee’ (Soil Health Institute, 2021)
 - *“67% of farmers interviewed reported a yield increase associated with adopting a soil health management system. Also, 83% reported that they reduced fertilizer inputs while implementing nutrient management as part of their overall soil health management system. Notably, 97% reported increased resilience to extreme weather such as drought and heavy rain, and 93% reported the soil health system to increase access to their fields. W . . . most reported this benefit of improved water quality based on observing clearer water on or leaving their fields with a soil health management system.”*
- **McKinsey Consulting Group**, ‘*Revitalizing fields and balance sheets through regenerative farming*’ (Stockdale, 2024);
 - *“Millions of acres of US corn and soy crops—as well as the planet more generally—could benefit from regenerative agriculture practices. But farmers need a better way forward.” “Despite the industry’s importance—and perhaps because of it—agriculture is also one of the largest contributors to the issues affecting the Earth’s natural systems (which include the atmosphere, oceans, ecosystems, and biodiversity). In fact, agriculture’s greenhouse gas emissions, nutrient pollution, and land and water use currently exceed the limitations necessary to sustain human development. Without intervention, the industry could facilitate irreversible environmental effects.”*

In addition, as discussed in more detail later, a large number of agriculture-related multinationals are recognising the potential of regenerative agriculture to better secure their food chains, sustainability and profitability. Examples include; Cargill (Klein, 2021a), Carlsberg (Carlsberg, 2023), Danone (Askew, 2021), General Mills (Mannette, 2021), Kellogg’s (Kellogg announces regenerative ag program for Lower Mississippi Basin rice farmers, 2022), Mars Petcare (Mars Petcare 2024), McCain (Potato News Today, 2022), Nestle (Ho, 2021), PepsiCo (Trémolet, 2021) (Strauss, 2023), RePlant Capital (Marquis, 2021), Unilever (Strauss, 2023), and Walmart (Klein, 2021b).

Agro product purveyors such as Syngenta (Syngenta 2025 May; Syngenta 2025 Jan a; Syngenta 2024 Dec.) and Bayer recognise that the future is regenerative agricultural and are positioning themselves as educational and product support purveyors, including products such as patent seeds (Syngenta 2024 Dec.), and bio stimulants (Syngenta 2025 Jan b), into their programs in their own way supporting the crop nutrient quality and plant health improvements inherent in regenerative agriculture, albeit disambiguation of the source of the observed benefits between regenerative agriculture and product is complex. However, recognition by multinationals that regenerative agriculture is the way forward is both essential and positive to progressing that change.

16.2 LARGE CORPORATIONS COMMIT TO REGENERATIVE AGRICULTURE

Over the last year or so, large food corporations, including millers, coffee, potato, and rice processors, as well as dairy companies, have committed to regenerative farming, recognising its multi-layered potential benefits, including the possible 'carbon credits' value of soil-sequestered carbon. They have pledged substantial investments to accelerate farmers' transition to regenerative practices.

The article by Tania Strauss, (Strauss, 2023) Head, Strategy and Global Projects, Food Systems Initiative, World Economic Forum, and Pooja Chhabria, Digital Editor, World Economic Forum, *"What is regenerative agriculture and how can it help us get to net zero food systems? 3 industry leaders explain"* inter alia observes, *"Climate-smart and regenerative agriculture measures designed to put farmers at the centre can improve crop yields and turn farmland and pastures into carbon sinks, reverse forest loss, optimize the use of nitrogen-based fertilizers and rethink global and local supply chains to be more sustainable, reducing waste."*

Through natural climate solutions (NCS), food systems can contribute up to 37% of climate mitigation needed to reach 2030 climate goals. Yet, less than 2% of climate finance is directed to agri-food solutions." (Strauss, 2023)

Major international corporations that have committed to varying extents to regenerative agriculture, a few examples of many, in alphabetical order, none of which I have had any significant contact with, include:

- **ADM** (ADM 2024).
- **Cargill** – interest and aspiration (Klein, 2021a).
- **Carlsberg** – *"Carlsberg Group plans expanded regenerative barley usage across brands in the UK, Finland and France"*. (Carlsberg, 2023)**Danone** (Askew, 2021).
- **General Mills** (Mannette, 2021).
- **Irish Distillers and Heineken Ireland** (Ahern, 2023)
- **Kellogg's** \$US 2 million (*"Kellogg announces regenerative ag program for Lower Mississippi Basin rice farmers"*, 2022).
- **McCain** *"McCain enters the Metaverse: Introducing 'Regen Fries', new partnerships to educate consumers on regenerative farming"* (Potato News Today, 2022)
- **Nestle** \$US 1.29 billion (Ho, 2021).
- **PepsiCo** (Trémolet, 2021) - *"Eliminating emissions on farms is essential to our ability to meet our net zero goal,"* Jim Andrew, Executive Vice President, Chief Sustainability Officer, PepsiCo (Strauss, 2023).
- **RePlant Capital** \$US 2 billion (Marquis, 2021).
- **Unilever** – interest and aspiration (Southey, 2021) *"We urgently need to replenish and regenerate the resources required to grow our food,"* Dorothy Shaver, Global Head of Sustainability, Nutrition, Unilever (Strauss, 2023).

- **Walmart** – *“The company is supporting 30,000 midwestern farming operations with the transition and is hoping to show measurable impact on at least 1 million of that 30 million acreages by 2030.”* (Klein, 2021b).

Charitable foundations are partnering with commercial organisations, for example, in India – *“The Regenerative Production Landscape Collaborative was founded by Laudes Foundation, IDH The Sustainable Trade Initiative, and WWF India - Initial members include Inditex, H&M Group, IKEA, PepsiCo India, Neutral, Samunnati Finance, Jayanti Herbs and Spice, S.V. Agri, INI Farms, Cofe Farmer Producer Company, SRIJAN, Action for Social Advancement, Aga Khan Rural Support Programme”.*

The project in *“Madhya Pradesh that will reach 120,000 farmers and cover 100,000 Ha. by 2026. (Major Indian and Global Brands collaborate with the Govt. of Madhya Pradesh, farmers, and civil society to promote regenerative agriculture and sustainable sourcing, 2022)* Tania Strauss, cited above (Strauss, 2023), continues, *“We know that today’s food production systems are faced with fundamental challenges:*

- *We must **produce more nutritious and affordable food** to feed a growing world population.*
- *We must **transform food production** to cut greenhouse gas emissions, build healthier soils, and support biodiversity. And thereby create a more sustainable, resilient, and fair value chain.*
- *We must ensure that **food producers are incentivised** to care for their land while earning a sustainable income.”*

Cargill has taken a proactive approach to regenerative agriculture. The Cargill study, as discussed in more detail in a later section, reports positively on 100 regenerative farms, with 85-88% increasing their net income. Cargill has surpassed 1 million regenerative acres enrolled for planting in 2025 (Cargill Regenconnect 2025).

ADM, a significant player in the food and agricultural sector, has produced two positive reports on regenerative agriculture; both the 2023 and 2024 (ADM 2024) reports are available online. ADM has dramatically expanded its regenerative transition support to farmers. In 2023, it transitioned 2.8 million acres to regenerative agriculture, and has targeted 3.5 million acres for 2024, and 5 million acres for 2025.

Large international food companies' announcements of intention, and actual investment at scale, in regenerative agriculture strongly signal that regenerative agriculture provides economically and technologically viable solutions capable of meeting the challenges, including feeding the world. Governments, agroindustries, and the broader public will hopefully follow the food industry's lead, and actively support regenerative agriculture.

16.3 GLOBAL FOOD SUPPLY CHAIN

While the vast land area managed by humans for agriculture, makes agriculture part of the Gaian global eco-regulatory system, the primary purpose of agriculture is surely the supply of nutritious, wholesome food sufficient to feed and keep world populations healthy.

The FAO observes, *“Taking care of land, water and particularly the long-term health of soils is fundamental to accessing food in an ever-demanding food chain, guaranteeing nature-positive production, advancing equitable livelihoods, and building resilience to shocks and stresses arising from natural disasters and pandemics. They all start from land and water access and governance. Sustainable land, soil and water management also underpins nutritious, diverse diets and resource-efficient value chains in the shift to sustainable consumption patterns”* (FAO 2021a)

Options to expand cultivated land areas are limited. Prime agricultural land is being lost to urbanization. Irrigation already accounts for 72 percent of all freshwater withdrawals. Human-induced land degradation, water scarcity and climate change are increasing the levels of risk for agricultural production and ecosystem services at times and in places where economic growth is needed most. (FAO 2021a)

Most pressures on the world’s land, soil and water resources derive from agriculture itself. The increase in use of chemical (non-organic) inputs, uptake of farm mechanization, and overall impact of higher monocropping and grazing intensities are concentrated on a diminishing stock of agricultural land. They produce a set of externalities that spill over into other sectors, degrading land and polluting surface water and groundwater resources. (FAO 2021a). *“Convergence of evidence points to agricultural systems breaking down, with impacts felt across the global food system”* (FAO 2021a)

The above emphasises that FATBAS protocols are part of the problem of climate change, land degradation and pollution, diminishing water supplies and increasing irrigation needs, magnifying risk of food shortages, making the need for global adoption of regenerative agriculture, to both, mitigate climate change, and ensure healthy nutritious and sufficient, global food supplies, ever more urgent.

16.4 YIELD INCREASES WITH RISING SOIL ORGANIC MATTER (SOIL CARBON)

It makes sense that plants with access to more diverse active, extensive soil biomes, with greater water retention and metabolic water production, will be healthier and produce better yields. Several sources report rising yields with increases in soil organic matter, albeit some question the efficiency of increasing soil carbon compared to artificial fertilisers (Ma, 2023). However, the most advanced regenerative farmers report respectable yields with lower or no ‘artificial’ inputs and achieve greater quality and profitability.

For example, the publication *‘Building Soils for Better Crops Ecological Management for Healthy Soils 4th edn.’* notes *“The organic matter content of agricultural topsoil is usually in the range of 1–6%. A study of soils in Michigan demonstrated potential crop-yield increases of about 12% for every 1% increase in organic matter. In a Maryland experiment, researchers saw an increase of approximately 80 bushels of corn per acre when organic matter increased from 0.8% to 2%”*. Similarly, the Ohio University presentation *‘Managing Soil Health for Carbon Sequestration and Water Conservation’* (Lal 2024) reports yields with increased organic matter.

16.5 BIODIVERSITY IMPROVES

There are significant anecdotal reports, and it is logical that regenerative farming, which massively reduces and at best eliminates agrochemicals, artificial fertilisers, minimises disturbance of soil, including air and water transport channels, and dramatically reduces medication of cattle including worming products, with a focus on soil biome health, would, and has been, observed to result in the return of insects and general broader diversity of species. Several sections below refer to regenerative agriculture as a means of increasing biodiversity.

Consistent with this the review, *‘Importance of regenerative agriculture: climate, soil health, biodiversity and its socioecological impact’* (USDA Magdof, 2021) cites several sources, and helpfully comments in the following terms, *“Studies have shown that crop rotations enhance the diversity of soil microbes and ground beetles, while cover crops significantly improve biological pest and disease control. A meta-analysis study reported crop diversification impact on rural wildlife, according to the results crop rotation and cover crops boosted 37% (16–62%) and 21% (17–25%) higher levels of biodiversity, respectively. Consequently, organic farms typically exhibit higher levels of biodiversity compared to traditional farms”*.

16.6 SMALL FARMERS AND RURAL ECONOMIES

Small farmers are already under tremendous pressure in many countries, including due to demographic, economic, social, technological and employment opportunity changes. But without small farmers, supporting and enabling small towns and villages, in economic, social, employment, and population retention, terms, small rural communities will ‘die’ as they lose sufficient population to support schools, medical and other facilities, including shops. It is those small communities as a whole that help provide national identity, sense of place, and tourism opportunities.

Further, small farms provide income sources and employment opportunities, and an independent, if not wealthy, lifestyle, which will become more attractive and necessary as AI and robotics take many of the service jobs, such as taxis, warehouse, call centre, factory assembly, and other machine replaceable employment opportunities that now exist.

However, currently, in Western Countries, food, finance, industry, and investors seek to preferentially support larger farming units in the transition to more regenerative practices, because easier to achieve and more profitable, putting further pressures on small farms to cease business and sell their land.

The finance industry argues that the transition to regenerative is time-consuming, costly, and requires specialist equipment. However, for small farmers, what is most lacking is access to education, small-scale advice, support networks, sources of cover crop seeds, guidance on adapting current equipment for small acreages, and access to suitable, small-scale, affordable equipment for purchase, hire, or free loan.

Many of the early regenerative small farmers made their own serviceable equipment, driven by a spirit of ‘make-do and mend.’ Equipment needs to be both functional and affordable. Given that artificial fertilisers are no longer generally used, complex equipment with

automated electronic measurement of fertilisers and agrochemical applications, as well as related positional yields, becomes less essential for small farmers. Government could provide satellite data to assist outcome assessment and measurement, as for example is being done by ADM. (ADM 2024)

With the introduction of regenerative agriculture, savings in agricultural inputs generally more than cover initial yield losses, which should help small farmers regain profitability. Government support schemes would be a bonus.

16.7 TRANSITION - HURDLES TO REGENERATIVE AGRICULTURE

Hurdles to transition to regenerative agriculture exist, but are arguably much less onerous and time-consuming than generally portrayed. Key hurdles are:

- **Education** – there is a dearth of educational capacity for regenerative agriculture. Most agricultural educational institutions are still focused on conventional farming, as are many institutional advisers, and arguably overstate the difficulties and costs for enterprising, make-do-and-mend, and adapt, farmers transitioning to regenerative agriculture.
- **Equipment** – equipment for large-scale regenerative crop termination and seed planting is expensive. Equipment options for small farmers are limited, and the market is awaiting development, but adaptation and upgrades over time are possible. For those at the end of an equipment cycle, the costs of transition will be lower. Contracting out crop termination and seeding etc., is an alternative model for transition, but it will reduce profits in the long term. This is an area in which governments could help reduce transition risks, facilitate the development of cost-effective machinery, and provide access to it for small farmers. Indeed, the transition to regenerative rice by small farmers in Asia, with the support of parties such as Bayer and Mars Petcare (Mars Petcare, 2024), which won the FMCG Asia Awards 2024 for their RECARP regenerative agriculture initiative, and Public Sector Organisations, appears to be relatively rapid.

16.8 ACCELERATE TRANSITION TO RE-GEN AG – CRUCIAL - PROVIDE GERMINATING SEEDS ACCESS TO DIVERSE FUNGAL AND BACTERIAL BIOLOGY IN COMPOSTS

The seminal work of Sir Albert Howard, a proponent of regenerative agriculture and a pioneer in developing composting techniques and their application, highlighted the remarkable power of well-made, mature composts in promoting healthy crop growth. However, it did not achieve the prominence it deserved. He postulated that it was the biology in compost that made it such a powerful pathway to improving crop health and growth, as discussed in later sections and Volume 1.

- **Fungi and Bacteria**—It is crucial to understand the existential importance of diverse fungal and bacterial biology in mature composts in assisting; seed germination, development of optimal mycorrhizal root sheaths, onward crop growth and health in

degraded soils, and their importance in the efficient conversion of degraded soils to biodiverse carbon-rich soils.

- There is limited understanding in agricultural circles, and more widely, of the existential importance of reseeded soil bacterial biology, for cost and time-effective transition from FATBAS to regenerative agriculture.
 - Diverse and extensive soil biomes are essential to soil biology's capacity to provide adequate plant-accessible minerals, including phosphates and nitrates.
 - The recycling of soil life, through excreta, and the cycle of life and death, release water, soluble nitrates, phosphates, minerals, and wider nutrients.
 - In addition to brassicas, the soils contain a wide range of nitrate-producing bacteria.
 - The topic is covered in more detail below.
- **Nitrate and Phosphate Elimination** - Understanding the need to eliminate phosphate and nitrate application, because they disincentivise the supply by plants of carbon sugar root exudate to the root biome, thus limiting, the health and growth of the soil biome, services provided by the soil biome to plants including of metabolic water, accretion of soil carbon, and soil water infiltration and retention capacity.

17 REGENERATIVE AGRICULTURE – SUCCESS STORIES

Gabe Brown inherited 1,760 acres of mixed farmland in North Dakota, US, in 1991, and driven by economic pressures, began experimenting with no-till techniques. Soon after, though, the ranch was battered by a hailstorm that wiped out his entire crop and left the whole venture hanging by a thread – and the following year, it happened all over again. In reaching rock bottom and the quest for economic survival, Gabe Brown re-evaluated every facet of his farm and every method he and his family had taken for granted.

“We [had] farmed conventionally. I learned how to farm from my father-in-law because I was born and raised in town and so I learned the conventional practices: tillage; use of fertilisers, pesticides and fungicides; monoculture crop production; cattle turned out on pasture in the spring and taken off the pastures in the fall and fed hay for six months of the year.”

“The bank all of a sudden wasn’t going to loan me money. I couldn’t pay back my loans. How am I going to make this farm productive without buying all these inputs? So, I started to experiment, diversify the rotation. I added crops such as rye and hairy vetch, winter triticale and hairy vetch [and] started growing peas because they’re a very short season” from ‘Gabe Brown discusses how Regenerative Agriculture is a solution to global challenges’, US Energy, 2021. (Brown, G. 2021)

A year of drought then wiped out his crops for a third consecutive year. Gabe Brown and his wife took paid jobs to meet the bills. Hailstorms ruined 80 per cent of the crops the following year, too – but, in the depths of his despair, he spied a glimmer of hope. The destroyed grain crops acted as a mulch on his soils, which had not been tilled for five years.

“I began to see things. I started having earthworms showing up. I noticed my soil was more aggregated; when it did rain, we were infiltrating more water. So that really started me on a 25-year journey of learning about regenerative agriculture, learning how ecosystems function, learning about how we can make our farm, our ranch, more resilient if we focus on working with Nature instead of against her” (ibid).

Today, Gabe Brown uses no artificial fertilisers, pesticides or fungicides, rarely uses other agrochemicals, and never tills the soil. He hopes to be soon able to dispense with the little herbicide he still relies on. With multispecies cover crops, cattle half-height grazing and spreading their own manure and seed; he has achieved a six-fold increase in soil carbon from 1 per cent to 6 per cent, an expansion of soil water-holding capacity of over 200 per cent, and the abundance of available trace elements has soared by an average of 162 per cent.

Brown’s productivity and profit margin have improved, too. His productivity levels compare very favourably to neighbours using ‘conventional’ farming techniques, including significantly higher than regional average commercial crop weight yields, which is highly thought-provoking. These yields, tabulated below, were above average for the area during an eight-year timespan (Brown, G., 2017). Gabe Brown acknowledges that some have higher yields but points out that he is more profitable and his farm is sustainable.

Table 4. Data from the video ‘Treating the Farm as an Ecosystem’ with very many thanks to the Author. (Brown, G., 2017)

Yield obtained from 2008-2016

	Brown’s	County average
<i>Corn</i>	127	98
<i>Spring wheat</i>	62	39
<i>Oats</i>	112	62
<i>Barley</i>	72	

Summarised soil nutrient values

Management	Nitrogen	Phosphorous	Potassium	WACO
<i>Organic</i>	2	156	95	233
<i>No-till, low-diversity</i>	27	244	136	239
<i>No-till, MD, High synthetics</i>	37	217	199	262
<i>No-till, HD, ZNS LAST</i>	281	1006	1749	1095

These results are not unique to Brown’s farm. His consultancy now acts for many farmers across North America and globally. He reports that most of his clients are seeing increased profits within two years.

“The way we do that is through proper soil testing, proper use of inputs. The vast majority of farmers and ranchers are grossly over-fertilising [and with] heavy use of chemicals, insecticides etc. Those are not necessary. In my opinion, education’s mostly needed by the government. Government needs to educate; you don’t know what you don’t know. I had to

learn things the hard way. If you're a farmer, where are you getting your information? Some of it from colleges [and] government agencies, but you're getting a lot of it from your suppliers - whether it be [those selling] fertiliser, chemical, seed, feed... They're telling you, but do they really understand how ecosystems function? Do they understand the importance of carbon, the importance of biology in the soil? [How] farmers can affect the small water cycle, how they can make their farms much more resilient to drought and fluctuations in temperature and moisture? You can't expect the farmer to suddenly know all this" (Hughes & Brown, 2021).

17.1 KILLING OF THE SOIL BIOME IS NO WAY FORWARD

Gabe Brown says he now enjoys “*working with life*” (Hughes & Brown, 2021), whereas “*the current degraded resource production model is all about killing. We kill weeds, kill pests, kill fungus, kill diversity... our soil and our profits*” (Brown, 2017b).



Fig. 17. From the UTube video ‘*Treating the Farm as an Ecosystem with Gabe Brown Part 1, The 5 Tenets of Soil Health*’ by Gabe Brown with very many thanks to the author. (Brown, 2017b)

It is indeed a choice between life and death. The soil biome we are killing is an essential part of the Gaian climate regulatory system. Continuing our FATBAS farming practices, including tillage, bare ground, diminished soil carbon and water, NPK and agrochemical killing of the soil biome, could lead to further climate changes, including ocean deoxygenation and sulphidation, sufficient to result in a tipping point and consequent extinction event. How many would die, we cannot know, but life would be very uncomfortable for any survivors for many generations.

In the words of the FAO, *"Soils are the basis from which most of the world's food is produced, thus they are subject to various disturbances and stresses from the application of agricultural management practices. Sustainable soil management is necessary for maintaining the production of sufficient and nutritious food, and for increasing future food production while preserving natural resources and the environment (FAO, 2018a).*

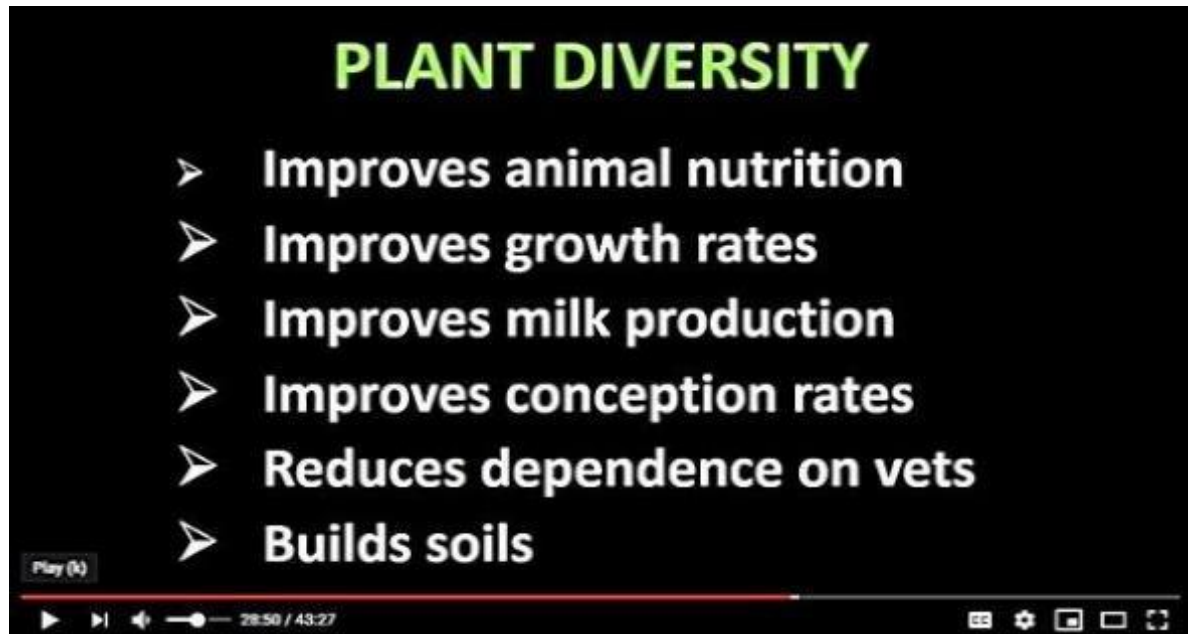


Fig. 18. Slide from *'Quorum Sensing In The Soil Microbiome'* summarising changes seen on Wilith Farm, Atiamuri. With many thanks to the author. (Jones, 2019b)

Without plant photosynthesis and resource exchange between plants and the soil biome, soil biome systems would have no carbon for fuel, operating biology, and structure. When the soil biome is deprived of fuel, stored soil carbon will be respired as carbon dioxide into the atmosphere, adding to fossil fuel combustion-based increases in atmospheric carbon dioxide levels.

Destruction, almost always due to human intervention, of fertile soil biome systems results in the depletion of carbon in soils, degrading the hydrological systems necessary for healthy ecosystems, which thus ultimately become eroded and barren deserts, bereft of the soil biome's self-interested capacity to; act as custodians of diverse biology; to assist germination; hold and make water, assist evapotranspiration, thus regional land based rainfall, and more generally support plant life. This accelerates climate change, including adverse weather events that cause erosion and runoff, flooding, fires, and heat domes.

Without soil biome systems, 'soils' become just dry ground-up-rock-detritus that reemit heat from the sun, helping fuel droughts and extreme climate events. Consistent with this, the Food and Agriculture Organization of the United Nations Report 2018, titled *'Nitrogen Inputs to agricultural soils from livestock manure'* (FAO, 2018a) observes, *"Soil (the ground-up mineral portion as against organic matter content – author's addition) is a non-renewable natural resource that is crucial for the provision of multiple ecosystem services and to overall functioning of the ecosystem."*

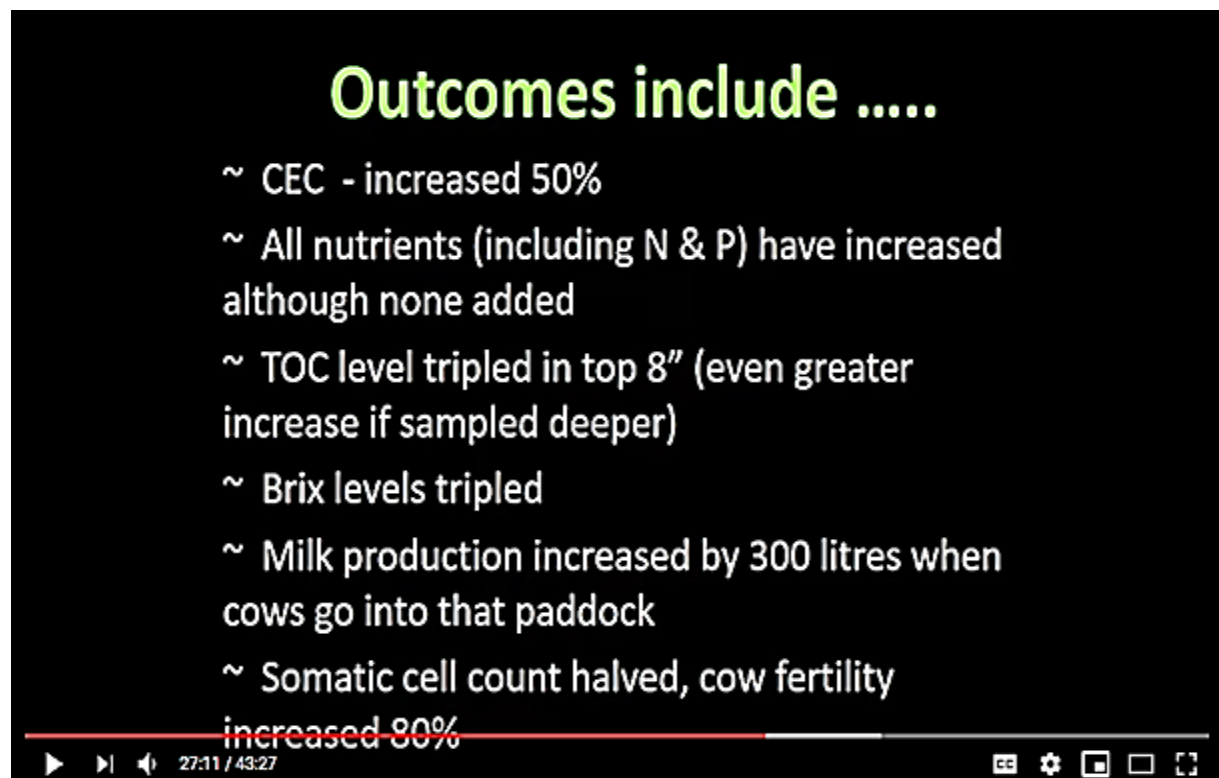
17.2 DAMASCENE MOMENTS - CREATE LIFE OR DELIVER DEATH

Growing numbers of other regenerative farmers now recount their own Damascene moments and tales of success and natural innovation. Wheat farmers Ian and Dianne Haggerty changed course when three consecutive dry growing seasons in Western Australia left their 9,000-acre business on the brink.

The Haggertys employed liquid compost and vermiculture extracts to coat the seeds, as well as for drip application at sowing (Haggerty, 2022) and as a foliar spray in early growth. They combined this with a natural cover, no-till policy for their fields, and no external nitrogen use. Compared with their neighbours, who persisted with the *status quo*, the Haggertys increased soil carbon by 41.5 percent; nitrogen by 27.7 per cent and soil water-holding capacity by 33 per cent. Carbon in soils rose by 36.9 per cent at depths of 0-10 cm, 40.5 per cent at 10-20 cm, and 53.5 per cent at 20-30 cm. Organic nitrogen increased by 800 kg per hectare.

The wheat was tested and found to be chemical-free with zero traces of glyphosate. It was denser due to higher mineral content (the trucks delivering grain were overweight if filled to the standard marker line) and of very high quality. As a result, it commanded a price/demand premium from discerning buyers. The weed-killer Roundup (glyphosate) was used only occasionally where winter die-off of native grasses did not occur.

European data also suggests that nitrogen inputs can be moderated without significant loss of yields. More widely, the emphasis must shift to optimising the overall nutrient density of crops and yields, thus improving human and livestock health, rather than simply maximising harvest yields. (Aubert, Schwoob & Poux, 2019; Poux & Aubert, 2018).



Outcomes include

- ~ CEC - increased 50%
- ~ All nutrients (including N & P) have increased although none added
- ~ TOC level tripled in top 8" (even greater increase if sampled deeper)
- ~ Brix levels tripled
- ~ Milk production increased by 300 litres when cows go into that paddock
- ~ Somatic cell count halved, cow fertility increased 80%

Fig. 19. Slide from 'Quorum Sensing In The Soil Microbiome' summarising changes seen on Wilith Farm, Atiamuri. With many thanks to the author. (Jones, 2019b)

Meanwhile, Wilith Farm in Atiamuri, New Zealand, has used multispecies mixed cover crops as grazing on volcanic pumice pastures and achieved increased soil nitrogen, carbon, phosphate, and plant-available minerals without resorting to artificial fertilisers. Milk yields, cattle fertility, and health have significantly improved, doubling the land's productive capacity. Further, according to Dr Jones, university trials are producing similar results.

Many have observed that the path to remodelling a farm along regenerative lines is not straightforward or without cost. However, there is no clear alternative for all the reasons discussed. Gabe Brown and the Haggertys further point out that maintaining the status quo is a trajectory to ruination for many farmers. With every round of NPK they turn to in an attempt to reverse their slowly but steadily declining fortunes, the health of their soils continues to disintegrate.

17.3 REGENERATIVE AGRICULTURE HAS A LONG HISTORY – FRANK TURNER ABSTRACT

The capacity of 'regenerative' farmers to be successful and profitable has long been evident since the time of Howard and Albrecht. However, in the excitement of new technologies and related agricultural industry profits, it was a solution that people were unwilling to open their minds to.



With thanks to Adobe Stock ©

By way of example Turner, one such farmer, prefaced his 1951 book *'Fertility Farming'* (Turner, 1951) with these words: *"I shall show in this book how it is possible for the average medium-sized farm to be self-supporting in fertility, and consequently free of disease, with less capital outlay, a reduction in labour costs, and an immense saving in the cost of manures and veterinary and medicine bills."*

As discussed above and below, Chinese farmers fed families of 5 and 6 on a single acre for over 4,000 years by returning all organic matter to the soil, using intercropping, mixed species cropping, composting, and taking great care of their soils.

In the 1920s – 40s, agronomists Howard and Albrecht demonstrated the same principles: the return of composted organic matter, combined with careful farming practices, produced good yields, nutrient-dense products, healthy plants and livestock. For example, Howard's cattle mixed with others with foot and mouth over many years, yet showed no disease symptoms. His tomatoes could be transported during the Indian monsoon heat in old-fashioned trains for several days yet arrive at the market in good condition. The foresight, understanding, and vision of both Albrecht (Albrecht papers. n.d.) and Howard are fascinating and can be found in their books.

Predating Gabe Brown and others' current achievements, Turner brought together and implemented the research and observations of outstanding agronomists from the early 1900s, such as King, Howard, and Albrecht.



With thanks to Adobe Stock ©

Out-of-copyright versions of many of their publications can be found for free on the website 'Journey to Forever' at http://journeytoforever.org/farm_library.html#sh The Soil and Health' (*'Journey to Forever. The Soil and Health'* n.d.) and in the Australian online *'Soil and Health'* Library.

The English agriculturalist Frank Newman Turner, referred to above, documented his pioneering transformation of a degraded farm. His book is cited here as a fascinating perspective of a farmer, in common with Brown and the Haggertys, once again driven by financial stress, on a journey to regenerative agriculture. Extensive quotes have been used as there is no other way to transmit the power of his observations.

Turner recalled: *"In February 1941, with an agricultural training at university, and the experience gained from working in agriculture all my life, I took on the management of the farm. (Subsequently I rented it, then I bought it.) My training had been orthodox, and although my ideas had been modified by contact with, and experience of, the value of natural methods of farming and livestock management, policy was controlled by the owners of the farm, so the methods of the man who had farmed the place for the twenty-five years previous to 1941 were more or less continued.*

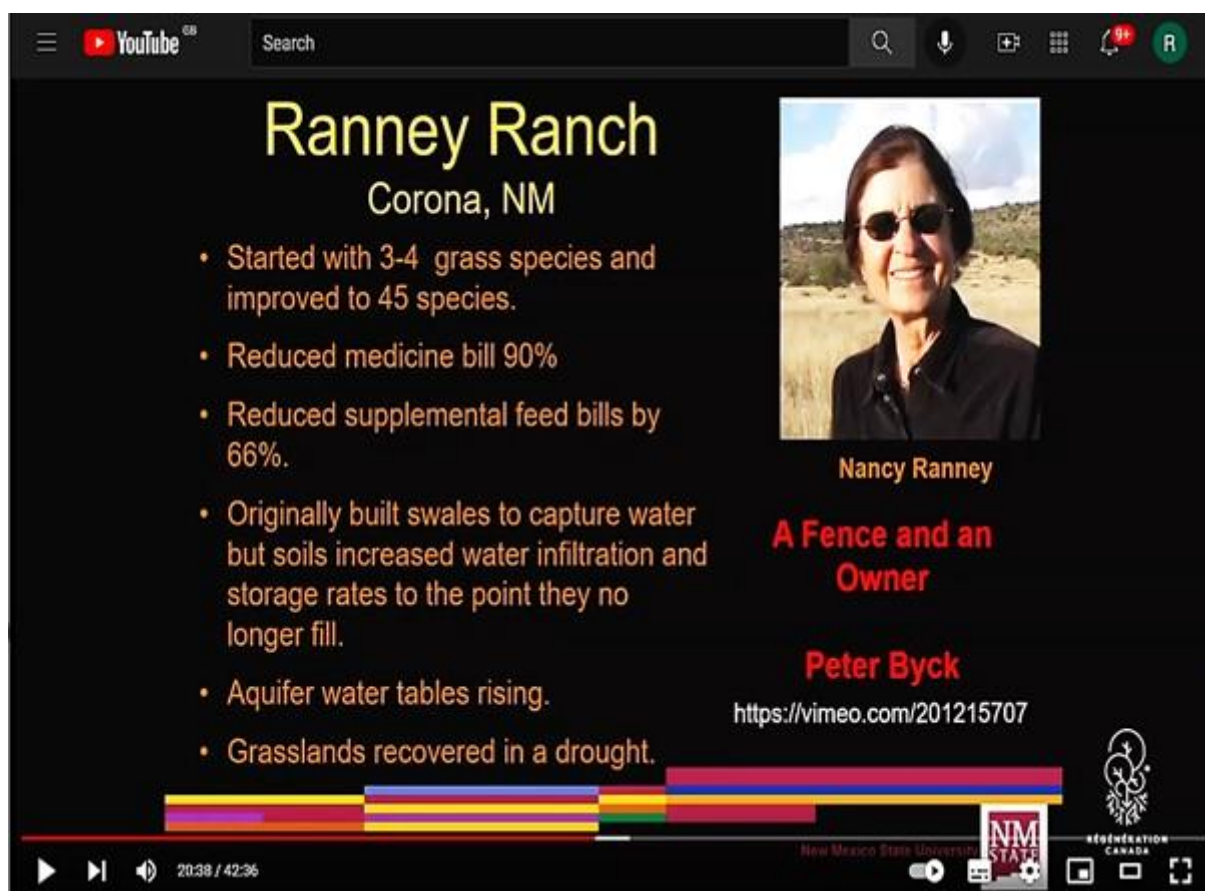
"The cattle had lived and produced milk on the same pastures for generations. The hay that the mowing pastures produced could better have served the purpose of wire, for all its nutritional value. Arable crops were heavy enough, as crops grown with ample artificial manures at first are, but a variety of crop diseases were evident and showing signs of increase. The cattle were good milkers as commercial herds go, as well they should have been, for their main article of diet was purchased imported concentrated high-protein feeding stuffs, upon which the cows were forced to the limit of their capacity to produce milk and calves. The more milk the cows gave, the less natural bulky food they were allowed to eat, and what home-grown food they had was raised with artificial manures.

"Governed by the instructions of the committee representing the owners, I farmed on orthodox lines. We purchased all the artificials that could be got, and by placing orders with several firms got rather more than our share, much to my subsequent regret. We tried to be good farmers according to orthodox standards, and our reward was a trading loss of £2,000 for two years during the piping days of war, abortion in 75 per cent of our cows, 50 per cent of our total stock reactors to the tuberculin test and a large acreage of corn ruined with smut and take-all diseases, with chocolate spot making bean growing impossible.

"When at the beginning of 1943 I had the opportunity to take the farm over on my own, I knew that half the cattle were barren and that I had a long history of disease to tackle. But I had faith in nature. The fact that not all the cattle had succumbed to contagious abortion and tuberculosis led me to believe that disease was not primarily caused by bacteria, but that it was the result of deficiency or excess of wrong feeding and wrong management, with bacteria only a secondary factor. Nature provides the means of combating all the disease that any living thing is likely to encounter, and I have discovered that bacteria are the main means of combating disease and not the cause of it as we had formerly believed.

"But it is not in increased yields, or in costs, that I measure the success of this organic fertility farming, though these things are important in times of economic stress. It is the health of all living things on the farm that proclaims nature's answer to our problems. From a herd riddled with abortion and tuberculosis, in which eight years ago few calves were born to full time, and those few that reached due date were dead, I can now walk around sheds full of healthy calves, and cows formerly sterile, now heavy in calf or in milk. I have advertised in the farming

press for sterile cows and cows suffering from mastitis and have bought many pedigree animals, declared useless by vets, given them a naturally-grown diet, and a period of fasting, herbal and dietary treatment which I have discovered to be effective in restoring natural functions, and they have subsequently borne calves and come to full and profitable production or had their udders restored to perfect health. Cows that have been sterile for two and three years have given birth to healthy calves. On the orthodox farm there is no hope for these cases, and the animals are slaughtered as 'barreners'. But nature intended the cow to continue breeding into old age, and if treated as nature intended there is every chance that her breeding capacity can be restored. I considered my pedigree Jersey cattle worth keeping and bringing back to production, and if I could buy similar animals with which others had failed, it was also doing good to myself as well as the condemned cows; and it has paid me both financially and in moral satisfaction. I have cows aged fourteen to twenty years which, after being sterile for years, have given birth to strong calves and milked well afterwards."



Ranney Ranch
Corona, NM

- Started with 3-4 grass species and improved to 45 species.
- Reduced medicine bill 90%
- Reduced supplemental feed bills by 66%.
- Originally built swales to capture water but soils increased water infiltration and storage rates to the point they no longer fill.
- Aquifer water tables rising.
- Grasslands recovered in a drought.

Nancy Ranney
A Fence and an Owner
Peter Byck
<https://vimeo.com/201215707>

New Mexico State University

Fig. 20. From video lecture by Dr David Johnson, using the ‘*The BEAM (Biologically Enhanced Agricultural Management) Approach*’ in a ranch context with very many thanks to the authors. (Johnson, 2017)

A century later, New Zealand livestock farmers started to use similar regenerative practices for cattle rearing. *“They have found this greatly reduces need for nitrogen and phosphorus fertilisers, insecticides, fungicides; displaces weeds and has hugely reduced veterinary costs”.*

On ranch land, Nancy Ranney (see slide above) has seen a similar trend (Johnson & Su, 2019). They also see improved fertility, milk yields and reduced disease in their dairy herds, just as

Turner did. A farmer reported that they have even, on occasion, forgotten the vet's phone number. *"It's been so long since it was needed!"* (Jones, 2018b). We now better understand soil and plant biology and thus can take up and improve on these lessons if we have the will to do so.

17.4 PROFITABLE? REGENERATIVE FARMERS ARE ACHIEVING GREATER PROFITS AND ADEQUATE YIELDS

Many regenerative farmers report maintaining yields and being more profitable. They are diversifying, making more productive use of their land, and seeing multiple benefits. Rick Clarke sets out some of the benefits he sees in his YouTube slides, reproduced on the pages below.

In the UK, a significant agricultural estate and land agent, Strutt & Parker, owned by Paribas, has produced an advisory document on regenerative agriculture, indicating that the subject is gaining wider traction and respectability (Strutt & Parker, 2021).

Farming regeneratively creates new challenges and requires flexibility and foresight, but as evidenced by Rick Clarke in his video presentations, including 'AgEmerge Breakout Session with Rick Clarke' (2021), it is feasible and better for the environment, livestock, farming families, and public health.

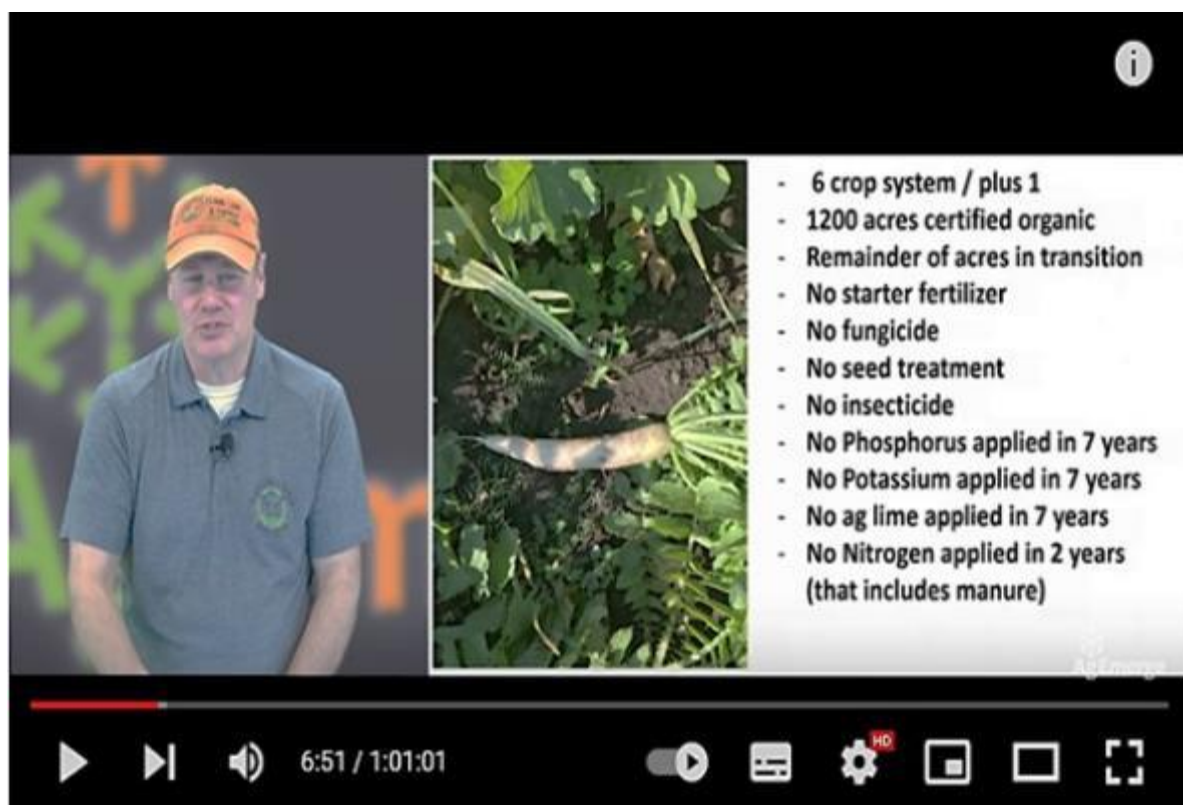



Fig. 21. From AgEmerge Breakout Session with Rick Clarke - Farmers making money in real life with Reg Gen Ag: practicalities, and benefits of green fertiliser, agrochemical free 'regenerative' agriculture, many very thanks to the author. (Clarke, 2021)




What drives our system?

- Building soil health
- Diversification
- Cash crop rotation
- Data collection
- Armor the soil
- Building human health
- Being a good steward
- ROI

19:02 / 1:01:01



Input Reductions

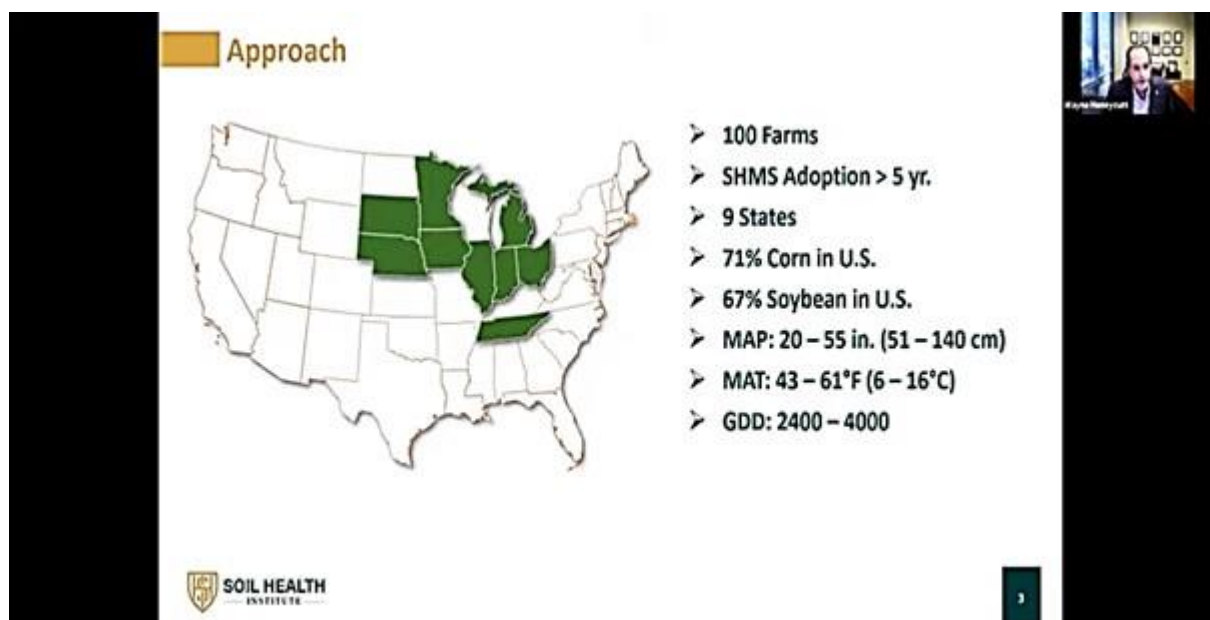
Input	2011	2020	% change
Diesel fuel	30,011 gal	15,460 gal	48.5
Horsepower	3350	1200	64.2
Synthetic N	220 lbs/A	0	WOW!
MAP	330 tons	0	WOW!
Potash	400 tons	0	WOW!
Lime	2100 tons	0	WOW!
Chemistry	\$40/A	0	WOW!

56:35 / 1:01:01

Fig. 22 a and b. AgEmerge Breakout Session with Rick Clarke - Farmers making money in real life with Reg Gen Ag: practicalities, and benefits of green fertiliser, agrochemical free 'regenerative' agriculture, with very many thanks to the author. (Clarke, 2021)



Fig. 24. AgEmerge Breakout Session with Rick Clarke - Farmers making money in real life with Reg Gen Ag: practicalities, and benefits of green fertiliser, agrochemical free 'regenerative' agriculture, with very many thanks to the author. (Clarke, 2021)



Economics of Soil Health Systems

Fig. 23. Slides from Wayne Honeycutt Ph.D UTube lecture 'Economics of Soil Health on 100 Farms' - Soil Health Institute – looking at 100 regenerative farms of at least 5 years standing, average 1,400 acres, with very many thanks to the author. (Honeycutt, 2021)

Additional Benefits Reported by 100 Farmers

Benefit	% Responding Yes
Increased Yield	67
Reduced Fertilizer Input	83
Increased Crop Resilience	97
Increased Access to Field	93
Improved Loan, Land, Insurance Terms	41
Improved Water Quality	100
Protects License to Operate	98
Increased Soil Organic Matter	54



10

Economics of Soil Health Systems

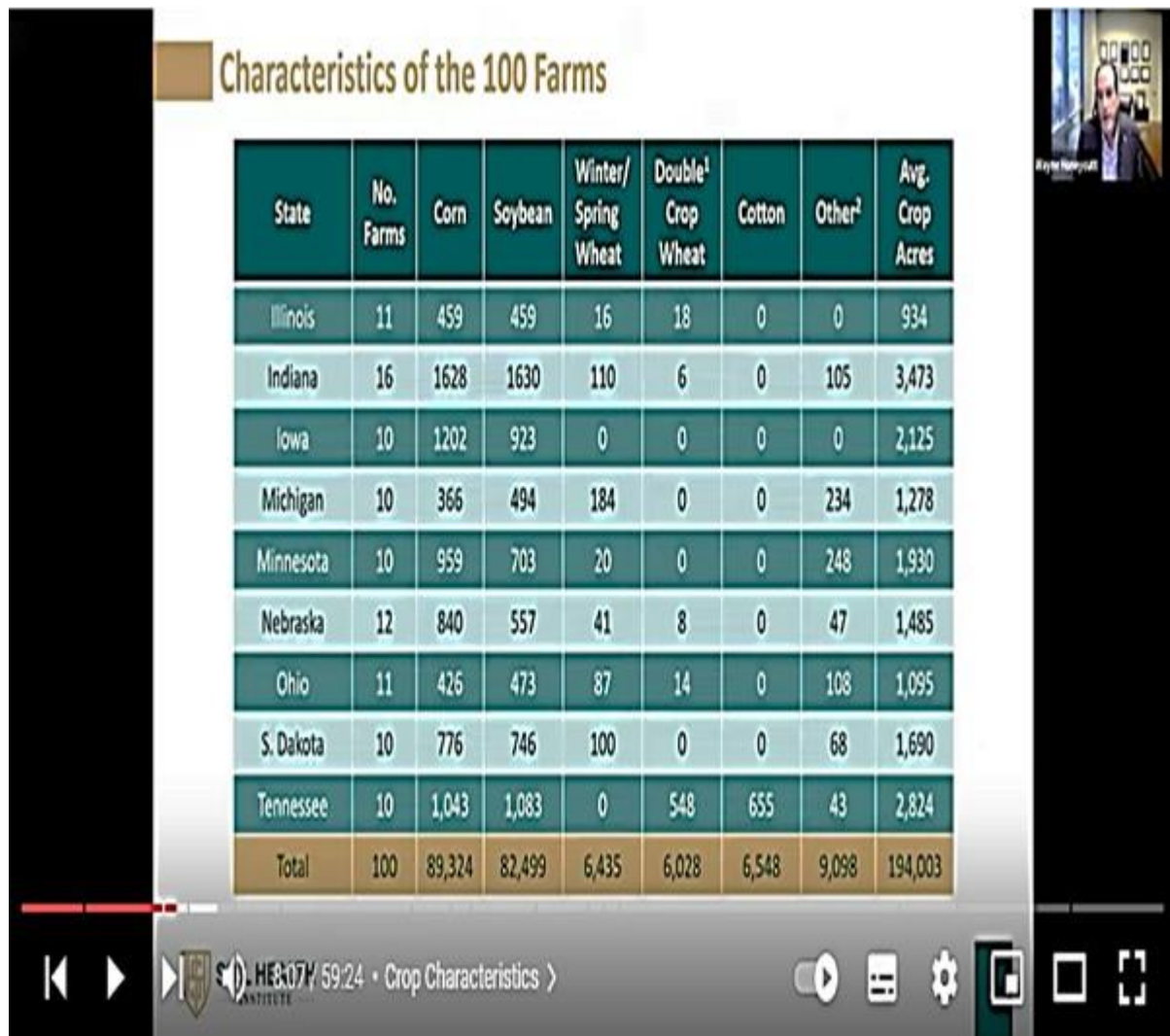
Partial Budget for 100 Farms Adopting SHMS

	CORN		SOYBEAN	
	BENEFITS	COSTS	BENEFITS	COSTS
CATEGORY, \$/ac.	Reduced Expense	Additional Expense	Reduced Expense	Additional Expense
Seed	4.08	12.62	2.79	10.02
Fertilizer & Amendments	22.36	1.14	9.20	0.25
Pesticides	9.22	7.90	10.00	8.07
Fuel & Electricity	3.91	1.90	4.33	1.80
Labor & Services	11.13	8.24	10.94	8.24
Post-harvest Expenses	0.18	3.48	0.00	0.93
Equipment Ownership	16.18	11.08	18.41	10.72
EXPENSE CHANGE, \$/ac.	67.06	46.36	55.67	40.03
	Additional Revenue	Reduced Revenue	Additional Revenue	Reduced Revenue
Yield, bu./ac.	7.73	0.39	2.91	0.00
Price Received, \$/bu.	4.21	4.20	10.09	10.00
REVENUE CHANGE, \$/ac.	32.54	1.64	29.25	0.00
	Total Benefits	Total Costs	Total Benefits	Total Costs
TOTAL CHANGE, \$/ac.	99.60	48.00	84.92	40.03
CHANGE IN NET FARM INCOME, \$/ac.	51.60		44.89	



HE 325 / 59:24 • Results >





Characteristics of the 100 Farms

State	No. Farms	Corn	Soybean	Winter/ Spring Wheat	Double ¹ Crop Wheat	Cotton	Other ²	Avg. Crop Acres
Illinois	11	459	459	16	18	0	0	934
Indiana	16	1628	1630	110	6	0	105	3,473
Iowa	10	1202	923	0	0	0	0	2,125
Michigan	10	366	494	184	0	0	234	1,278
Minnesota	10	959	703	20	0	0	248	1,930
Nebraska	12	840	557	41	8	0	47	1,485
Ohio	11	426	473	87	14	0	108	1,095
S. Dakota	10	776	746	100	0	0	68	1,690
Tennessee	10	1,043	1,083	0	548	655	43	2,824
Total	100	89,324	82,499	6,435	6,028	6,548	9,098	194,003

Fig. 25 a b and c. Slides from Wayne HoneyCutt PH. D UTube lecture titled '*Economics of Soil Health on 100 Farms*' - Soil Health Institute – data, 100 regenerative farms of at least 5 years standing, average 1,400 acres, very many thanks to the author. (Honeycutt, 2021)

Further, and of great importance, a study funded by Cargill, a privately owned food corporation, in the USA, titled '*Economics of Soil Health Systems, A Comprehensive Evaluation Across Nine States*' representing '*194,003 acres of cropland across Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, Ohio, South Dakota, and Tennessee*' (Soil Health Institute, 2021) on 100 good-sized regenerative farms of at least 5 years standing, with an average size of 1400 acres (see slide page 20 above), found that most farmers in their group reported greater profits for corn and soy, often with improved yields,

A summary of results included the following comments:

- “Across all 100 farms, soil health management systems increased net income for 85% of farmers growing corn and 88% growing soybean.

- *Based on standardised prices, the soil health management system increased net income for these 100 farmers by an average of \$51.60/acre for corn and \$44.89/acre for soybean.*
- *Farmers also reported additional benefits of their soil health management system, such as increased resilience to extreme weather and increased access to their fields.”*

which comments can be found in the report, and are reflected in the UTube lecture slides above and below.

Farmers in the Cargill study also felt that their farms were becoming more resilient to weather events and that their environments were improving—just over half reported soil carbon sequestration.

In another example, a small regenerative farmer in Mexico reports impoverished, hard, sandy, degraded soil returned to health with yield and resilience benefits, *“her corn yields have grown from 2.5 metric tons of corn per hectare to 8.5 metric tons per hectare”,* and *“Due to the subsoil now there is enough water down there even with 40 days of drought,”* (Selibas, 2022).

Larger better-known regenerative farmers such as Gabe Brown, the Haggertys, Rick Clarke, and most of the Cargill Study Group, are making regenerative agriculture work, improving ecology, soil biology, water and carbon soil content, crop quality, with reduced inputs and greater profits, as illustrated by the slides below from the UTube lectures, *‘AgEmerge Breakout Session with Rick Clarke’* (Clarke, 2021), and summary of the Cargill Study Group results titled *‘Economics of Soil Health on 100 Farms’* (Honeycutt, 2021).

18 NATURE RULES – DESTRUCTIVE SHORT-TERMISM - EXTINCTION

There is a growing recognition by the food industry, farming and environmental groups, reinforced by rising financial, raw material, and manufacturing costs, of an urgent need to move from the current fertiliser agrochemical agriculturally based model, FATBAS, to a more profitable and sustainable regenerative agriculture approach, which both, optimises plant soil biome system potential, and obviates the need for non-biologic NPK fertilisers.

Humans must find the wisdom and long-term vision to optimise and work with nature rather than against it. While requiring major adaptation and refocus of the agro-farming, fertiliser, and agrochemical industries, these changes are more profitable for farmers, can produce good yields, are sustainable, and provide greater certainty of long-term food chain supply. They also generate potential for new markets for biologic composts, foliar sprays, and additives to support regenerative practices.

Modern agriculture has attempted to dominate nature, killing biology without fully understanding the implications of our actions, rather than seeking to nurture and optimise immensely sophisticated, biologically proven, and free natural technology. This technology, which has evolved over millions of years, is ‘oven-ready’, road-tested, primed, and ready for use.

Consequently, global ecological equilibria have been disturbed. We now face mounting evidence of changes in natural cycles, which, absent change, will sooner or later reach irreversible tipping points.

We have further exacerbated system imbalances in atmospheric, soil, and ocean carbon and oxygen stores by mining and burning aeons-old accreted soil carbon converted by nature into oil, coal, and gas. We are pushing self-regulating but delicate natural systems outside the limits of relatively stable oscillatory patterns – resulting in climatic change, extreme weather events, loss of soil carbon, increased atmospheric carbon dioxide, global ‘drying’, desertification, deforestation, erosion, ocean acidification and broader damage including eutrophication, and a long list of further ecological degradation, as well as declining water, air and food quality, thus risk of human devolution including as to cognitive capacity and ability, IQ, empathy and abstract thought capacity.

More worryingly, whilst our vision and willingness to accept the obvious remains blinkered, we risk significant global biosphere destabilisation via deoxygenation and damage to the oceans, which ultimately risks resulting in eutrophication, anoxia of sub-immediate-surface-mixed ocean layers, sulphidication, sulphide upwellings, oceanic hydrogen sulphide emission into the atmosphere, highly acidic rain, damage to the ozone layer, consequent UVC penetration of the atmosphere, widespread UVC damage to surface-living systems, with a consequential risk of extinction events (Brown R., 2021e).

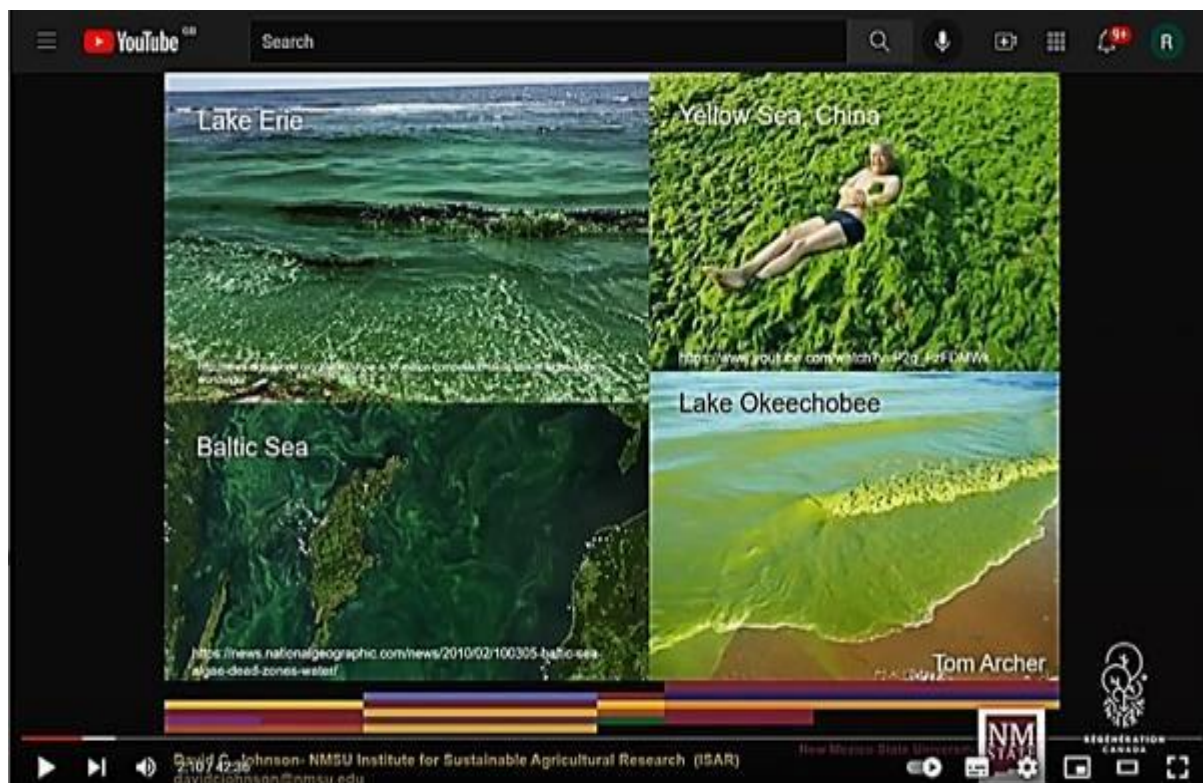


Fig. 26. From video lecture by Dr David Johnson, using the ‘*The BEAM (Biologically Enhanced Agricultural Management) Approach*’ illustrating the effect of washout of excess phosphate application on rivers and oceans, to which could be added many other examples, including the Sargasso Sea; very many thanks to the Author. (Johnson, 2017)

Indeed, a review worryingly observed that most major historic extinction events were connected to ocean anoxia. Consistent with this, ocean sulphidation leads to hydrogen sulphide releases, which in sufficient volume would damage the UVC-blocking ozone layer, allowing UVC incidence on the terrestrial surface (Brown R., 2021e). Again, consistent with this posit, a recent paper noted that research examining pollen related to material from the most recent major extinction event, appears to have increased UV self-protection and have been damaged by UV (Liu, 2023).

A paper analysing geological Bakken Shale Formation cores concluded that anoxia-related hydrogen sulphide emissions were key and specific 'kill' factors in several historic Devonian extinction events, and may have factored in others. (Sahoo, 2023) Oceanic sulphidation and hydrogen sulphide release events, sufficient to be smelled onshore, and etch steel pipes, have been observed occasionally in Namibia.

As well as adding to the risk of an Anthropocene extinction event, in the more immediate term, pollution and degraded nutrition must, and indeed is evidenced as, impacting human health, behaviour, and cerebral capacity, as warned against over the last 100 years by McCarrison, Crawford, and others, as well as likely influencing our behaviour, pushing us towards a more aggressive, territorial self-interested phenotype. (Brown, R. a-d) This is very concerning because it is our brains, our neurological-related skills and capacity, that define and differentiate us as humans.

If we are to have the opportunity to survive and prosper as a species and find our destiny in this universe, in a resource-pressured world, we will need to be the healthiest, best, most intelligent, empathetic, cooperative, abstract and complex thought-capable humans we can be. (Brown, R. a-d) (Author's copy PDFs on ResearchGate)

18.1 HUMAN HUBRIS – SEEING A BIGGER PICTURE – MIRACLE OF EXISTENCE

We must not lose sight of the bigger picture – the evolutionary miracle of our existence and emergence as highly sentient, immensely complex life forms – or that our development of technology, now including AI, genetic manipulation, mean we are on the edge of having historically unmatched emerging power of creation, with limited appreciation of the implication . . . thus the choice of our future, including of the health of the terrestrial Gaian Eco regulatory system that supports us, is ours to make.

Our frail human societal requirement for short-term gain in everything we do, means we generally ignore or downplay simple non-profitable solutions, no matter how obvious, equitable, or beneficial, in favour of often imperfect short-term fixes, as long as they offer; immediate quarterly profit for shareholders, kudos, access to resources, a sense of being cutting edge research with financial prospects, and employment or broader financial reward. This has arguably happened in both farming and health. Simple ways to make significant improvements, such as compost extracts to accelerate the transition to regenerative agriculture, rarely get the attention they deserve.

For example, trying to fix dietary nutrient-specific imbalance-induced illnesses with complex pharmaceutical preparations is never going to provide an optimal solution. Yet, the

pharmaceutical path is constantly pursued in preference, rather than in addition to addressing the cause, dietary degradation. Modern medicine is wondrous, much appreciated, and invaluable, but in relation to non-communicable, non-genetic conditions, in evolutionary biological terms, a single-point pharmaceutical intervention cannot ultimately optimally replace deficiencies in evolution-determined essential nutrients with multiple, interlinked pleiotropic physiologic effects—the pathways involved are too complex.

Food and pharmaceuticals each have their place, but generally, there is little focus on the impacts of nutrient imbalances. Nutrient imbalances ultimately determine our basal health profile, to which basal potential, modern wondrous surgery, and pharmacy are an undoubted bonus.

We, as a species, are choosing to avoid facing simple inevitabilities. Similarly, we are failing to recognise that one of the key pieces in the jigsaw of climate change solutions is the capacity of plants, with immense sophistication, to renewably capture and convert sunlight energy and atmospheric carbon dioxide into carbon-rich molecules, and then, assisted by the soil biome, to sequester carbon dioxide as soil carbon: at the same time providing us with a vast range of system services including being integral to the rain-cycle, for free. Leaving land bare wastes the opportunity to harness sunlight energy to capture atmospheric carbon, and disrupts weather, including land-based rain availability.

Our technological advancements have been miraculous, including in the fields of travel, communication, medicine, and urbanisation. Yet, at the same time, we failed to recognise the importance of healthy soils for a healthy planet, ecosphere, and humans.

As well as revelling in new human products, profit rendering amazing new technology, humans need to recognise nature's immense sophistication and resilience. In many respects, nature's technology is still beyond the current reach of human understanding and science. Soil carbon sequestration is an essential, non-negotiable, irreplaceable part of the evolutionary planetary 'Gaian' climate regulatory systems. Yet, we hinder rather than help nature to function optimally. In order to feed ourselves, optimise our health, behaviour, and neurological capacity, and live long and prosper, we need the help of nature. Destroying natural ecosystems we depend on is, as Star Trek's Dr Spock might say, profoundly illogical.

18.2 SELF-DESTRUCTION OR SALVATION – THE CHOICE IS OURS

As self-appointed agricultural regulators of 5 billion hectares, 39% of the Earth's ice-free surface, we have the power and choice to destroy or support significant volumes of soil biome, upon which the current Gaian climate regulatory system and, more visibly, the food supply chain depend.

Crucially, in what is the dawning of a new technological age, including AI, robotics, cybernetic, neural-link implants, and manipulation of DNA, by dint of fate or evolutionary destiny, humans, though technology, have imposed themselves as FATBAS 'masters', the 'ecological system evolutionary controllers', setting aside Gaian self-regulation and natural evolutionary competition, on 5 billion hectares of natural ecosystem, now agricultural lands.

We have a choice. We can take a hubristic, unipolar, degenerative path that seeks to dominate nature, or a multipolar route, supporting rather than destroying natural systems, thus maintaining existential natural ecosystems and a habitable planet. The planet does not care, as, with or without us, save for a catastrophic event, it will continue for aeons.

As hinted at previously, and the core message of this book, Regen Ag is the only here and now global scale, immediately available, easily implementable, genuinely green, free technology, capable of globally mitigating soil-carbon-related, carbon cycle climate change, including warming . . . giving us more time to better understand the mess we are making, and to look for and implement genuine solutions.

How we farm and curate those soils, for better or worse, strongly impacts the world's climate and broader ecosystems, as well as global biodiversity, crop and livestock health, and ultimately human nutrition, so wider species wellbeing, including health, neurological capacity, intellect and behavioural factors such as empathy, abstract thought and IQ. (Brown, R. a-d). The choice, responsibility to posterity, and the future of homo sapiens and many of the species we share the Earth with is ours - To be or not to be? - That is the question.

Embracing regenerative agriculture and alternative industrial strategies for sewage globally as a matter of urgency will significantly improve our environment, slow climate change, and enhance human health, including mental function and overall well-being.

Failure to embrace them will accelerate environmental degradation, climate change and warming, related pollution, and the decline of human health, including behavioural changes, potentially leading to a less intelligent, less empathetic, less abstract thought-capable, and more anxious and aggressive species. These outcomes have been demonstrated in mice, rats, and cats, and a wide range of research and biology suggests that the same will likely happen in humans.

Given the looming prospect of a possible Anthropocene tipping point extinction event, which may not be as far away as we would like to think, this volume outlines the potential of regenerative agriculture to mitigate climate change drivers, and attempts to paint an overview of the alternatives and pathways towards self-destruction or salvation. As sentient 'controllers' and consumers, the choice of whether to work with or against nature is ours.

19 WATER IS LIFE – WET MASS OF LIVING ORGANIC FORMS IN SOILS

As a result of lack of robust achievable measurement protocols for living organisms in soil there is limited data and research into the hydrated live mass of bacteria, fungal systems, and soil fauna in all its diversity, the 'wet-weight' of life in soils, albeit there is emerging research into the complex dynamics of soil carbon in soil biome systems.

The amount of life in soils on a wet live-weight basis and its importance in soil dynamics, including in relation to water and carbon retention and nutrient cycling, is often underestimated. This underrepresents the role of bacterial, fungal, and wider soil life because soil life components are generally measured and reported on a dry weight basis, a necessity for consistent reporting.

The mass of living organisms in soil by wet weight, as might be expected is considerably higher as a proportion of soil organic carbon, than a dry mass figure: Dry weight of organic life in soils is generally reported to be between ~4–7% of SOM (dry weight), sometimes higher, but given life is 70-90% water, and could be construed to include roots which are an integral part of the soil biome, wet weight may be as much as 30%, possibly higher, and an as yet unquantified but not unimportant figure for our better understanding of soil dynamics, exchange of nutrients, carbon and water content.

Nutrient recycling occurs during life, including through excretion, during predation, at death, and by rhizophagy, for example:

- During life, organisms excrete water and soluble nutrients, including slimes, as well as insoluble and soluble nutrients in 'excrement'.
- Soil fauna prey on other soil life forms, another route for the recycling of nutrients.
- On death, organisms release all components, nutrients, including soluble minerals, nitrates, water, and wider organic molecules, together commonly referred to as necromass.
- During rhizophagy, plant roots ingest soil bacteria, and then strip the soil bacteria of selected nutrients, in a way that encourages them to reproduce so that the process can be repeated.

These processes provide a wider pool of soluble nitrates and phosphates, both directly to plant roots and other soil life, and via mycorrhizal transport systems, than would otherwise be available to soil fauna and plant roots.

These processes continuously cycle and reuse a portion of the released nutrients to support new life. In addition, some carbon is respired, and some nutrients and carbon are mineralised into more or less recyclable forms, adding to nutrient and carbon stores in soils.

Thus, a combination of living and dead organisms, along with significant amounts of microbial biomass, likely accounts for a substantial portion of the soil biome's organic matter, carbon content, and water retention capacity. The review '*Microbial necromass carbon and nitrogen persistence are decoupled in agricultural grassland soils*' notes, "Multiple analytical methods have revealed that soil microbial products and residues (hereafter 'microbial necromass' or 'necromass') either dominate or contribute substantially to persistent soil organic matter (SOM), especially in grasslands" (Buckeridge 2022).

Several conversations with DeepSeek on the topic of the role and measurement of living organisms in soils, as above, an emerging topic with limited research and data, resulted in this helpful list of summary points (edited):

- **Carbon Sequestration:** *Wet-weight biomass measurements might overestimate living carbon stocks but better reflect ecosystem-scale water storage.*
- **Dry weight** *underestimates the hydrological role of soil life but is essential for cross-study comparisons.*

- **Agriculture:** Soils with active microbial biomass retain more water during droughts due to exudate production, and in addition, during respiration, create metabolic water. Soil life will balance retention and exchange of water with plants to optimise the survival of both.
- **Living organisms** act as **transient water reservoirs**, while necromass contributes to longer-term moisture retention.
- **Turnover rates** determine whether water is released rapidly (bacteria) or slowly (fungi), influencing drought resilience.
- **Modelling:** Most Earth system models ignore soil life, water retention, and cycling, and fail to account for metabolic water, underestimating soil moisture feedbacks. (DeepSeek and this author)

19.1 MEASUREMENT OF SOIL LIFE – DRIED V WET WEIGHT IMPLICATIONS

There is minimal research or data on the live wet mass of living organisms in organic matter. A series of conversations with and questions to DeepSeek resulted in the following summary by DeepSeek:

- **Dry Weight Standard:**
 - Most studies report soil biomass as **dry weight** (oven-dried at 105°C) to standardise measurements and exclude variability from soil moisture.
 - Example: A bacterial cell is ~70–90% water by wet weight. Reporting dry weight avoids overestimating biomass in humid soils. A gram of soil (dry weight) can contain $\sim 10^9$ bacterial cells holding ~0.1–0.3 mL water (wet weight).
- **Wet Weight Reality:**
 - Living organisms (e.g., earthworms, microbes) are ~70–90% water. If measured wet, their biomass could appear **5–10× higher** than dry weight estimates.
 - Implication – living soil organisms act as "micro-reservoirs" of water, storing and releasing it through metabolism and death. A bacterial population turning over daily could release ~0.01–0.1 mL water/g soil/week.
- **Necromass Water Content:**
 - Dead microbial cells initially retain ~30–50% water but dry out over time. Plant/fungal residues hold more water (e.g., fungal hyphae: ~40–60% water).
 - Implication: Necromass contributes to short-term soil moisture but less than living biomass. Fungal cell walls (chitin) and microbial residues (proteins) are hygroscopic, absorbing water even after death—" (DeepSeek conversation/response to questions)

- **Lifespan**

- Life span will impact the recycling rate of water and nutrients, including phosphates and nitrates, that were formerly part of living organisms, impacting their availability to plants. The greater the quantity of soil life, the greater the turnover of water and nutrients.

Organism	Lifespan	Water Release Frequency	Impact on Soil Moisture
<i>Bacteria</i>	<i>Hours to days</i>	<i>Continuous (lysis)</i>	<i>Short-term hydration of microsites</i>
<i>Fungi</i>	<i>Weeks to years</i>	<i>Gradual (hyphal death)</i>	<i>Stabilises moisture via slow release</i>
<i>Earthworms</i>	<i>1–8 years</i>	<i>Mucus excretion</i>	<i>Enhances aggregation & infiltration</i>

19.2 NECROSMASS' RECYCLING RATES IN SOIL ARE RAPID '

Given the short lifespan and rapid turnover of bacteria in soils, nutrients from dying life forms, including bacteria, need to be rapidly and readily available to the new generations of life replacing them, and early research suggests this is the case.

The review '*Microbial necromass carbon and nitrogen persistence are decoupled in agricultural grassland soils*' comments, "*Much of the added necromass was recycled and quickly mineralised as microbial substrate. Necromass-derived respiration ($^{13}\text{CO}_2$) was highest three days after necromass substrate . . . before declining sharply*" (Buckeridge 2022)

19.3 IMPORTANCE OF GRASSLANDS

As discussed, grasslands form a significant portion of the Earth's ice-free lands under human management, 33.8 of 50.9 billion hectares, 26% of the Earth's free surface. Hence, their health, soil biome diversity, carbon and water content, for the reasons previously discussed, have global climate implications. Reduced levels of carbon storage in global grasslands will lead to reduced water infiltration, retention and evapotranspiration rates, impacting climate regionally and more widely.

The review '*Microbial necromass carbon and nitrogen persistence are decoupled in agricultural grassland soils*' observes, '*Grasslands, representing 3360 Mha or 68% of global agricultural land, are particularly important as they contain large amounts of soil organic C (SOC; 343 Pg C in the top 1 m). This SOC (Soil Organic carbon) stock is influenced by land use intensity, although the direction of change and mechanisms of loss or gain vary with different management practices.*' . . . (Buckeridge 2022)

The above review notes that land management, which includes grazing protocols and the use of artificial fertiliser, impacts soil carbon levels. As discussed, and referenced in a later section, grasslands in New Zealand treated with synthetic fertiliser lost a ton of soil carbon a year.

Conversely, grassland that is regeneratively managed, using rotational grazing, increased; soil carbon stocks, land stocking capacity, livestock health, water parameters, and farmer profitability, as discussed in a later section.

20 METABOLIC WATER PRODUCTION BY SOIL BIOME

It is a crucial, under-appreciated, albeit obvious when explained, a rarely, if ever considered, aspect of the water cycle, that water, referred to for clarity as 'Metabolic Water', is produced by life forms, including the soil biome, in significant amounts, as a normal obligate by-product of the chemical reactions involved in the oxygen-based metabolic respiration for energy, of carbon-based molecules, including sugars and fats.

If you leave a sealed bag of celery in the fridge for a few months, bacterial respiration will leave you with a bag of water containing dissolved minerals and organic matter residue. However, if the bag is not adequately sealed, it will result in a very messy fridge!

Mycorrhizal and bacterial systems in soils, through respiration, as living things also produce 'metabolic' water, which, where soil transpiration is limited by plant cover, and the soil surface is not mechanically disturbed, will be stored within biologically supported soil aggregates, and, when necessary, made available to their symbiotic plants through root systems.

Plants extract carbon from carbon dioxide in the atmosphere and share the photosynthetic carbon-containing sugars produced with the soil biome. This carbon, in turn, is respired by the soil biome in the darkness, supplying the energy that soil biome residents need to exist. As part of a symbiotic self-regulating system, respiration by bacteria, mycorrhiza, and other soil life produces metabolic water.

This synergistically increases water availability to soils, thus plants, sustaining plant and subsoil life and growth, particularly during drought. In a beneficial cycle, ongoing plant growth in dry periods symbiotically supplies fresh photosynthetically produced carbon sugar exudates to mycorrhiza, which they respire, producing more metabolic water, in a beneficial cycle, assisting soil biome/plant ecosystems to better survive periods without rainfall in feed-forward cycles.

The physical weight, volume, and sheer amount of life in healthy soils are enormous. Thus, the amounts of metabolic water produced must be vast, given that the quantity of metabolic water produced is directly tied to plant and soil biome respiration and related processes. For example, in some species, a large amount of water needed for growth is produced as a by-product of metabolic respiration, up to 70% by some fungi in parts of their growing cycles.

The watery mess in a sealed plastic bag of celery, left too long in the fridge, is physical evidence of the efficiency of 'respiration' of the organic molecules of which celery is made, by bacteria and fungi and their capacity to release the significant amounts of water tied up in deceased or dying organic living structures, including humans.

The respiratory production of metabolic water by soil bacteria and fungi provides a logical explanation as to why soils planted with mixed species cover crops, which maximise photosynthetic soil carbon supply, encourage soil bacterial and fungal activity, and healthy soil biomes such as found in long-standing natural grasslands, are observed to be more drought resistant, than single species / artificially fertilised crops, and why areas of land in Australia once rich in diversity, that are now seasonally dry, were reported by the first Europeans to have seen them, to have been, pre-cultivation, green year-round.

20.1 METABOLIC WATER

Net metabolic water production supplies living organisms, from humans to bacteria, with varying amounts of water over and above their water intake. Many life forms internally recycle metabolic water to reduce reliance on external water sources. As seen in migrating birds, the capacity to internally recycle metabolic water is more developed in some life forms, particularly those living in dry climates or subject to periodic water restrictions.

The amount of metabolic water produced and retained depends on the species' broader physiology, but it contributes to some extent to their capacity to survive more effectively when water availability is low.

A paper on the subject puts it this way, *"Metabolic water, more precisely defined as an isotopically distinct flux of O (and H) produced during metabolism, has been studied extensively as an alternative water source contributing to body water in animals, such as desert mammals, insects, and migrating birds, but does not easily lend itself to direct measurement."* (Li, 2016)

20.2 METABOLIC WATER - MYCORRHIZAL RESPIRATION

Whilst not widely appreciated, once pointed out, the production of metabolic water due to respiration by plants and denizens of the soil biome is self-evident. The metabolism of carbon-based molecules for energy, including heat, via mitochondria, peroxisomes, and other cellular molecular reactions, produces a net surplus of water, sometimes called 'metabolic water'. Levels of net metabolic water production, including by bacteria and fungi, can be significant (Li, 2016), 30-70% of total requirements, as evidenced by the liquid in a mushy bag of salad left too long in the fridge.

Carbon-sugar and fat molecules can be respired using oxygen to make water. Thus, soils' water production and retention capacity are primarily proportional to their organic carbon content.

Whilst there is limited research into metabolic water in some fields, metabolic water is rarely mentioned in relation to agriculture despite being a relevant, logically important, albeit as yet unquantified, mechanism for the supply to and retention of water in soils and broader hydrological systems and a logical explanation for the observed increased drought resistance of multi-species crops growing in healthy, diverse soil.

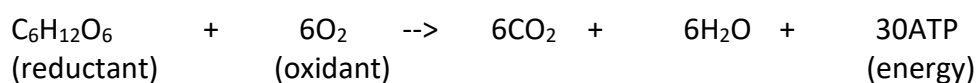
Both mitochondrial and peroxisomal pathways produce metabolic water. While most have heard of mitochondria, the importance of peroxisomes, including those in metabolic pathways, is underappreciated. Peroxisomes, tiny multifunctional organelles, with roles including the provision of energy substrate and as a by-product, produce peroxide, which will then be converted to water, and peroxisomal-derived water may have more significant roles in plants than generally appreciated. Upgrading peroxisomal and related linked antioxidant function through the metabolism of stored fats during periods of shortage of sugar exudate

supply, such as during germination and darkness, would increase peroxide production, thus increasing available metabolic water. Interestingly, at least in some plant species, peroxisome activity increases during drought (Sanad, 2020).

Peroxisomes in humans and other species are also strongly activated by fasting and, to a lesser extent, by exercise, providing fuel for mitochondria and potentially water as well, both of which would be particularly useful in, for example, migrating birds and polar bears swimming long distances at sea.

Indeed, creatures such as migrating birds during long flights, with no chance to drink or eat, polar bears during long swims in salt water, and desert creatures often with limited access to water have found ways to both minimise water loss, and likely maximise the metabolic water produced including as a by-product of mitochondrial and likely increased peroxisomal respiration of carbon-based molecules, by combining stored carbon-rich fats with oxygen to produce energy and carbon dioxide, with metabolic water as a by-product.

Natural pathways are enormously complex and include mechanisms not widely known, such as peroxisomal respiration. Respiration in mitochondria will also produce water. In terms of net water balances, some physiological processes produce water, and others use water; thus, equations, such as that for the metabolism of glucose for energy, point to, rather than tell, the whole story.



Given differing individual metabolisms and the complexity of biological systems, a precise answer as to how much metabolic water any species produces is difficult. However, amounts of metabolic water produced, compared to external water intakes, can be significant, *“the percentage of metabolic water has been determined to vary between 7% and 56% among different mammal species”* (Li, 2006) . . . ; 10-15% in cats and dogs (Wellman, DiBartola & Kohn, 2006).

Of relevance to the capacity to produce water to support plants in drought, 30%-40% or more of mycorrhizal system water may be of metabolic origin, *“a metabolic water contribution to the intracellular water of Escherichia coli cells of as much as 70% during the log phase of growth and up to 27% for cells in the stationary phase.”* The exact amount of metabolic production would depend on a host of factors and be exceptionally difficult to determine, but crucially represents a considerable amount, which, as discussed, helps explain better drought resistance in crops grown using regenerative farming techniques. Metabolic water will be released by, transpiration itself, excretion and the death and recycling of soil life forms.

Active metabolising soil life is a priori for the production of metabolic water to occur: the greater the amount and diversity of life in the soil biome, the greater the production capacity of metabolic water. Production of energy and metabolic water requires the presence of plants to supply carbon-sugar exudates and fats to the soil biome, which in turn requires living photosynthesising plants.

Thus, in healthy, diverse, extensive, carbon-rich soil biomes, microbiome respiratory processes will maintain the production of, and access to, at least some water by metabolising soil carbon, even in times of low rainfall. Due to mycorrhizal interconnection with plant root systems, this water will also assist the survival of all connected plants, symbiotically facilitating further photosynthesis and production of carbon sugar exudate by plants, in a beneficial circular cycle, helping support the entire plant and soil biome community.

Thus, keeping plants growing on land, even during low rainfall periods, facilitates a self-supporting circular system, a cycle of plant and soil biome respiration. This helps both plants, and the soil biome, better survive and remain hydrated. At the same time, water is respired into the atmosphere, moderating the regional microclimate. Carbon dioxide is exhaled, recycled into the atmosphere and reused for photosynthesis.

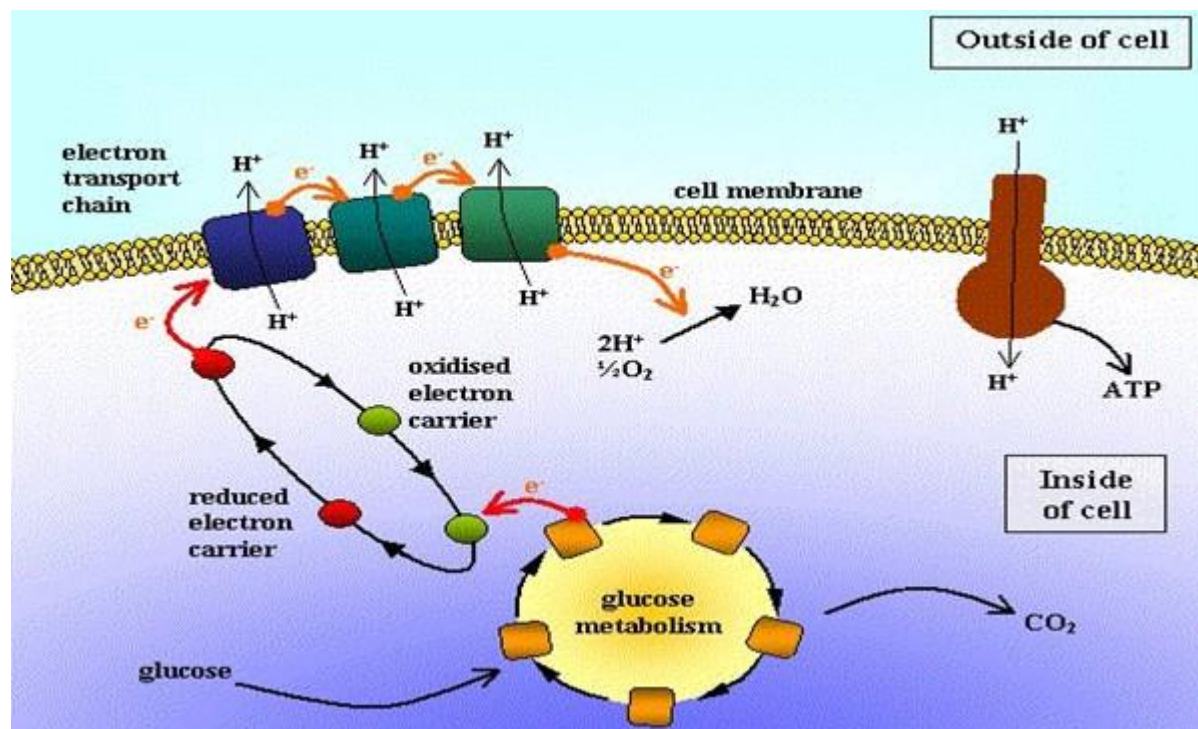


Fig. 27. Glucose metabolism and the electron transport chain, within mitochondria, from 'Sparks of Life', with thanks to the author Lewis Dartnell. (Dartnell, n.d.)

Additionally, the presence of plants helps protect the soil surface, limiting subsoil water transpiration and soil heating. Soil biomes also signal to plants to conserve water. Thus, water will be more effectively retained within the soil biome and more efficiently used by plants in dry spells, as observed in multispecies cover crops.

We must not lose sight of the sophistication that aeons of evolution have conferred on these natural cycles; they have multiple interconnected mechanisms and pathways directed at optimising survival chances in adverse conditions by manipulating local and wider hydrological and atmospheric conditions.

Human interventions have repeatedly disrupted these Gaian systems. Artificial fertilisers, agrochemicals, bare soils, tillage and overgrazing lead to denuded, overheated, compacted, low biome carbon soils, which then fail to absorb rainfall, incapable of retaining significant

water or supporting evapotranspiration over a long season, diminishing regional atmospheric moisture, thus regional inland rainfall, and degraded by erosion due to run off and flooding, therefore cumulatively less able to support plants, creating a negative feedforward cycle. Such soils, increasingly devoid of soil carbon-rich mycorrhizal biome plant support systems, become progressively more incapable of supporting significant plant life, including during drought.

Reverse these events with intelligent regenerative agriculture interventions and water capture strategies that assist, rather than seek to dominate and exterminate nature, including by inoculating seeds and plants with mycorrhizal fungi and bacteria, and experiments show life will return to even relatively arid regions, and why would it not?

20.3 METABOLIC WATER – SOIL PRODUCTION VOLUMES

Research demonstrates that multispecies cover crops are resilient, surviving and thriving for two to three months without rain, utilising a combination of stored soil water, water available to deeper-rooting plants, and metabolic water produced by the soil biome, possibly assisted by plant respiration at night.

It is challenging to quantify the amount of metabolic water produced by the soil biome, and further complicated by the rapid metabolism and turnover of life in the soil biome. As a thought experiment, a soil carbon of 5% to one meter depth was assumed, with a time frame of one month, an annual soil biomass turnover rate of 30%, and an adequate supply of carbon sugar exudate by plants, as set out in the DeepSeek calculation below:

<i>Calculating Soil Carbon and Metabolic Water Potential in 1 Acre of Soil</i>
<i>Let's break this down step-by-step for 1 acre of soil with 5% SOC to 1 m depth, assuming unlimited plant carbon exudates fueling microbial activity.</i>
Soil Carbon Content
Assumptions:
<ul style="list-style-type: none"> • <i>Area: 1 acre = 4,047 m².</i> • <i>Depth: 1 m.</i> • <i>Bulk Density: ~1.4 g/cm³ (typical for healthy soil).</i> • <i>SOC: 5% by weight.</i>
Calculation:
<ul style="list-style-type: none"> • Soil Mass per Acre-Metre: <ul style="list-style-type: none"> ○ <i>Soil mass=VolumexBulk density=4,047 m³×1.4 t/m³=5,666 t (dry weight). Soil mass=VolumexBulk density=4,047m³×1.4t/m³=5,666t (dry weight).</i> • Total SOC: <ul style="list-style-type: none"> ○ <i>5,666 t soil×5% SOC=283 t SOC.5,666t soil×5%SOC=283 tonnes of SOC per acre-Meter.</i>

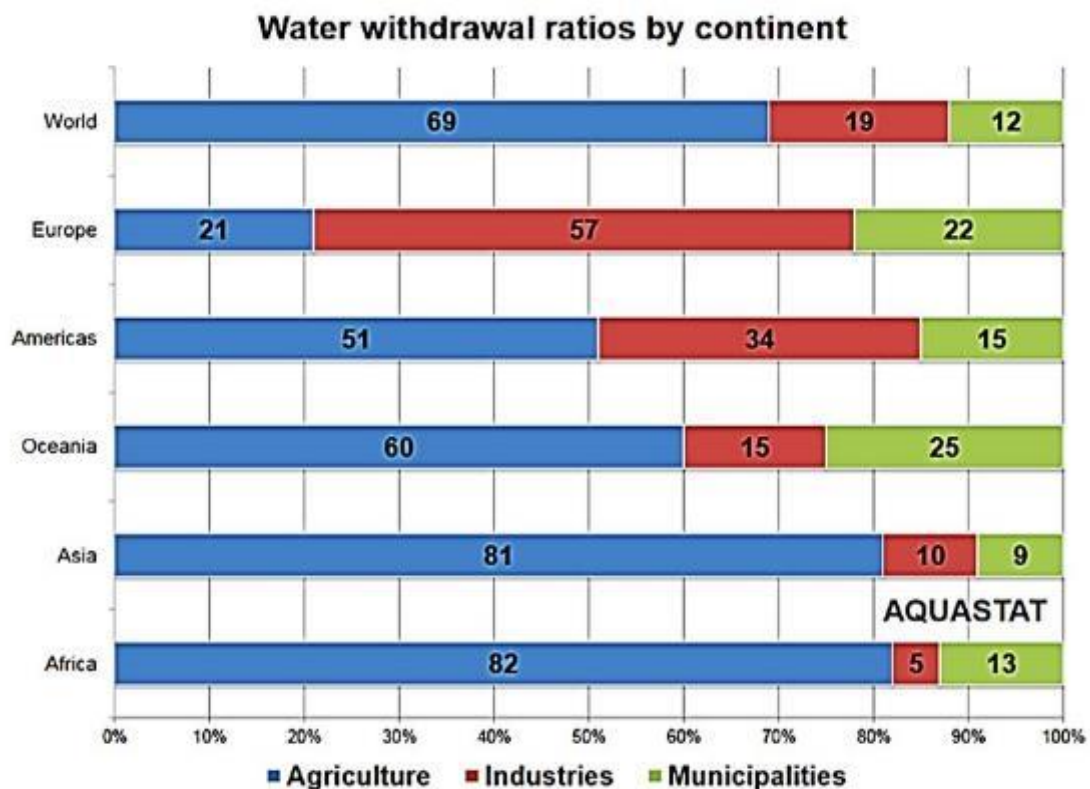
Metabolic Water Generation
Assumptions:
<ul style="list-style-type: none"> • Microbial Respiration: ~30–60% of SOC is respired annually in active soils (higher with root exudates). • Water Yield: 0.6 g H₂O per 1 g glucose respired (stoichiometric ratio). • Monthly Activity: Assume 1/12 of annual respiration.
Calculation:
<ul style="list-style-type: none"> • Annual CO₂ Respiration (30% SOC turnover): <ul style="list-style-type: none"> ○ 283 t SOC×30%=85 t C respired/year. 283t SOC×30%=85t C respired/year. • Glucose Equivalent: <ul style="list-style-type: none"> ○ 1 mol C (12 g) ≈ 1 mol glucose (180 g). ○ 85 t C = 85,000 kg C → 127,500 kg glucose respired/year. • Metabolic Water Production: <ul style="list-style-type: none"> ○ 127,500 kg glucose×0.6 kg H₂O/kg glucose=76,500 kg H₂O/year=76.5 m³ water/year. 127,500kg glucose×0.6kg H₂O/kg glucose=76,500kg H₂O/year=76.5m³water/year. • Monthly Water: <ul style="list-style-type: none"> ○ 76.5 m³÷12=6.4 m³ water/month (~6,400 litres/month). 76.5m³÷12=6.4m³ water/month(~6,400liters/month).

Thus as an indicative figure to indicatively highlight the scale and importance of metabolic water to the water stability and the water budget of soils - a soil with an organic carbon content to of 1% might produce 6,400 litres of metabolic water per month per acre meter, which equates to approximately 16,000 litres per hectare, or which over an area of 5 billion hectares is 90 km³ of water, a volume in evaporation potential terms sufficient to impact land based rainfall and broader climate change issues.

The monthly metabolism of carbon per hectare would be 30% of 283 divided by 12 months, which is 7.1t of carbon, above that provided by photosynthesising plants over a short one-month time span, but over a growing year, using multispecies cover crops in conjunction with a cash crop, possibly on the edges of total carbon supplied to the soil by exudate, root mass, detritus and other ancillary mechanisms, so within what is plausible.

The amount of metabolic water production predicted would significantly help supplement residual stored soil water in a dry spell.

21 IMPORTANCE OF WATER TO AGRICULTURE



Date of preparation: September 2015

Fig. 28. Surprisingly agriculture is a very major user of water in most of the world, underlining the importance of water retention in soils, and optimal water efficiency use during the growing process. The Food and Agricultural Organization of the United Nations AQUASAT data chart “shows global water withdrawal over time by the three major sectors: agriculture (including irrigation, livestock watering and cleaning, aquaculture), industries, municipalities.” Many thanks to authors and FAO. (FAO, 2015)

The majority of global water use is used to support agriculture. Water globally is becoming increasingly polluted, and supplies are diminishing. It is imperative to minimise pollution of agricultural water supplies, optimise water use efficiency and retention in soils, and prevent erosive, polluting, and wasteful runoff during heavy rains.

Water infiltration, penetration, and retention in soils increase dramatically with greater soil biome carbon content. Thus, improving soil water retention and crop efficiency through improved farming techniques that sequester soil carbon warrants significant research effort and focus.

21.1 POLLUTION AND LOSS OF WATER– “THE INVISIBLE WATER CRISIS”

The World Bank Group report ‘*Quality Unknown: The Invisible Water Crisis*’ (Damania, 2019) expresses deep concerns about diminishing water supplies and the pollution of those water resources. “*The world faces an invisible crisis of water quality. Its impacts are wider, deeper, and more uncertain than previously thought and require urgent attention. While much*

attention has focused on water quantity – too much water, in the case of floods; too little water, in the case of droughts – water quality has attracted significantly less consideration. ‘Quality Unknown’ shows that urgent attention must be given to the hidden dangers that lie beneath the water’s surface (Damania, 2019):

- Water quality challenges are not unique to developing countries but universal across rich and poor countries alike.
- What we think of as safe may be far from it.
- The forces driving these challenges are accelerating.” (Damania, 2019)

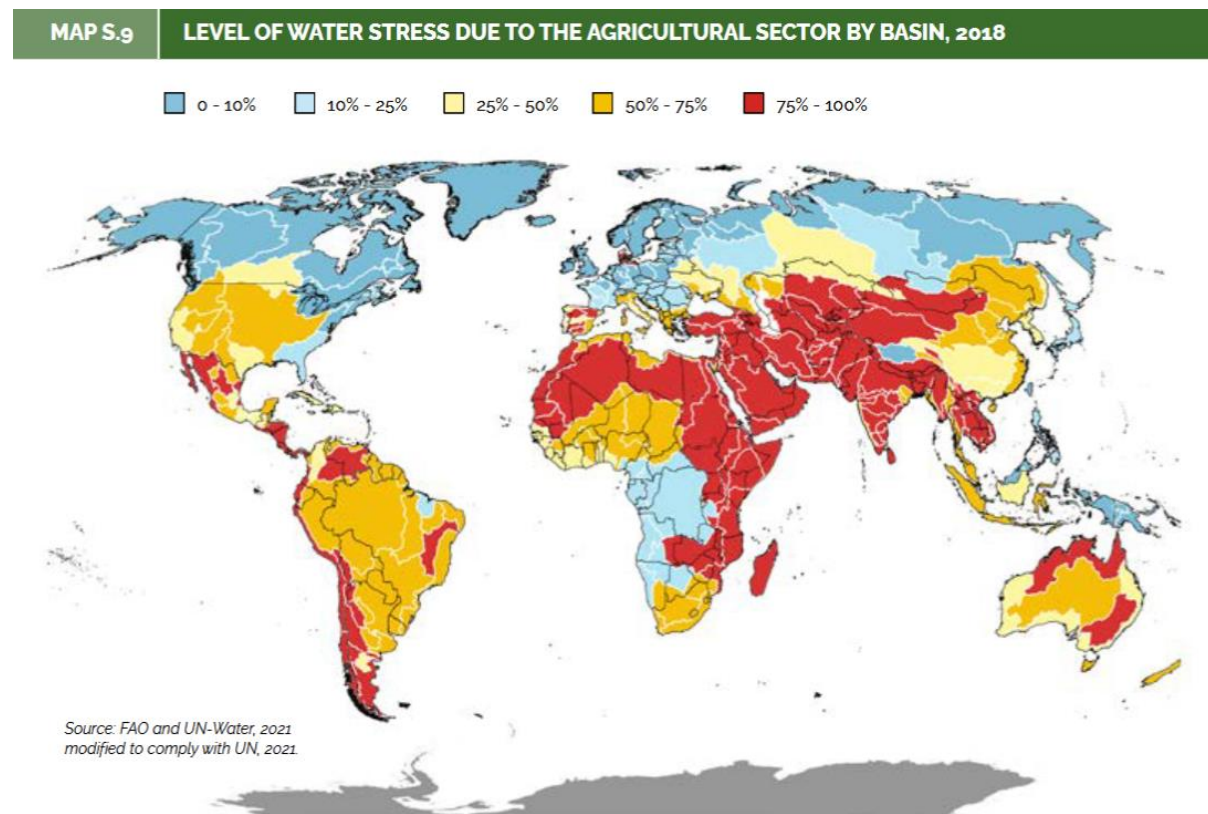


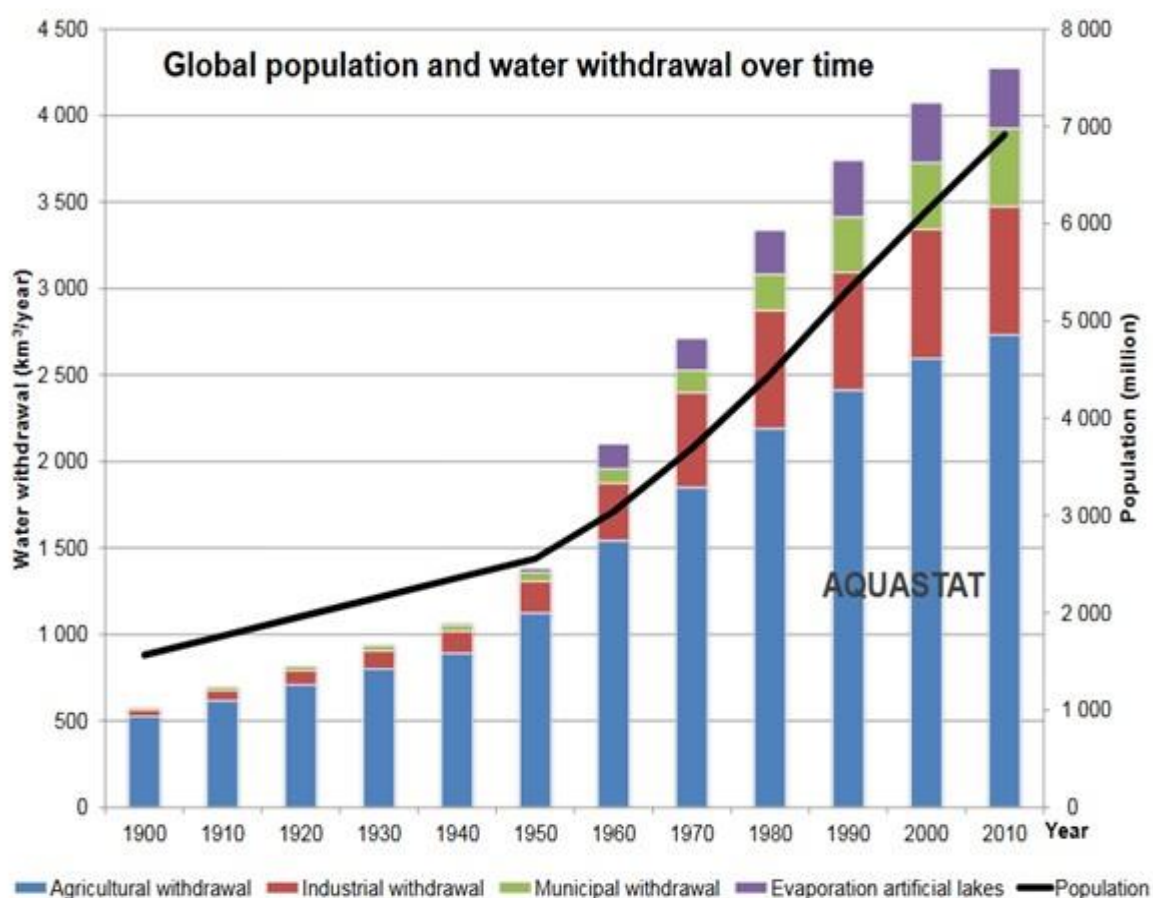
Fig. 29. From FAO ‘The State of the World’s Land and Water Resources for Food and Agriculture, Systems at Breaking Point’ with many thanks to the Authors (FAO 2021a)

Indeed, in many economically developed and less wealthy regions, water requirements are rising, as is water pollution, including sewage and wastewater discharge, thus increasing water stress. Political tensions over water rights are more common, including obligations to maintain the ecological health of watersheds and the right to build dams and/or abstract water from rivers that cross multiple countries or regions.

In the longer term, the degradation of glacial systems, soil destruction, including the loss of soil carbon, due to FATBAS agricultural practices, changing weather patterns, and the overuse of water resources will exacerbate reductions in river flows and, thus, political tensions over demand for abstraction rights to water.

Stores of ancient subterranean water are being drawn down, reducing aquifer levels. River water flows are reduced due to damming and damage to watersheds, including soil carbon loss, reduced rain penetration in soils, increased abstraction, and glacial changes resulting from climate change.

Global water demand for domestic use and agriculture is rising, driven by the increasing global population, rising individual water usage, demand for flush WCs, and growing agricultural demand for various reasons, including degraded soils, reduced water retention, and increased runoff. Improving soil carbon levels through regenerative agricultural practices would, as discussed, enhance water retention and improve both local and broader hydrological systems.



http://www.fao.org/nr/water/aquastat/water_use/index.stm

Date of preparation: September 2015

Fig. 30 “Global population and water withdrawal over time” with thanks to the FAO and authors

Reducing sewage pollution of water sources would similarly bring immense benefits. Vast amounts of water are used to dispose of faeces and urine, both from humans and livestock and discharged with partial or no treatment into rivers and oceans, causing widespread pollution, including in water sources and aquifers, as well as eutrophication in lakes and marine environments.

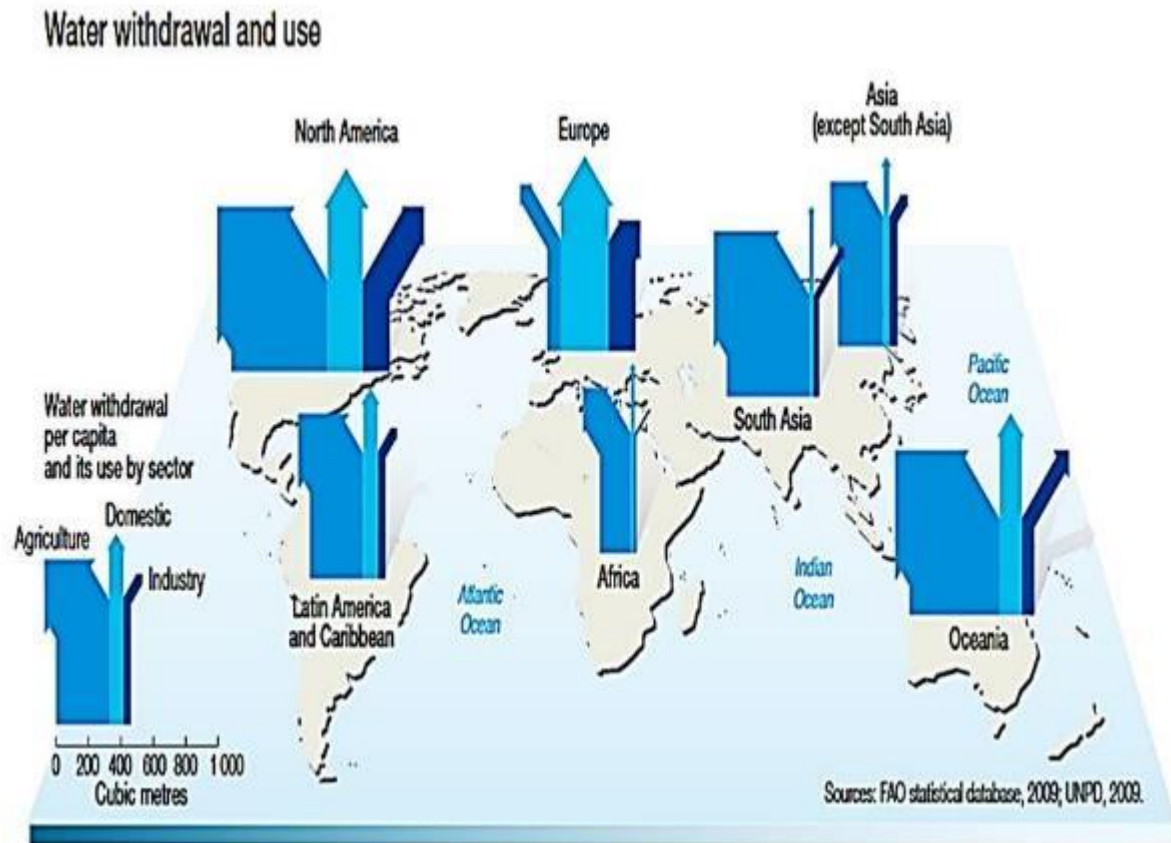


Fig. 31. *Water Withdrawal and Use* - With many thanks to the authors of '*Sick Water*' (Corcoran et al., 2010).

Water shortages and lack of access to unpolluted drinkable water are serious concerns. The need to reduce water use, including for agriculture; improve soil mycorrhizal water retention and production; limit water pollution due to sewage incorporation, fertiliser runoff, and downstream pollution of watercourses and sources; and protect the marine environment is urgent. The issues of water are considered in greater detail in the next volume.

21.2 WATER AND FOOD POLLUTION HEALTH CONSEQUENCES

The issues of sewage and water pollution are considered in more depth in the relevant volumes. Sewage contains an extensive range of pollutants, including pharmaceuticals and antibiotics. The application of sewage sludge on agricultural land continues, with long-term downstream health consequences for the environment, and for the livestock and humans that subsist on the product of that land. It has long been known that sewage pollution can have significant health implications, as illustrated by the satirical cartoon below from the mid-1850s. Increasing areas of land in the USA treated with sewage-derived products are being withdrawn from agriculture due to the health risk they pose to livestock and humans.



Fig. 32. "Thames Water", The Great Stink: the health consequences on the children of poor as seen by Punch Magazine (1858) with very many thanks to Punch and Wikipedia. (Wikipedia, 2022)

22 GLOBAL WARMING – NOT JUST CARBON DIOXIDE – WATER AND GREENING V SOLAR HEATING OF BARE DEGRADED SOILS

The WHO describes climate change, "*as any change in climate over time, whether due to natural variability or as a result of human activity.*" (WHO 2016). Rising atmospheric carbon dioxide, primarily due to fossil fuel consumption, is cited as a primary cause and a key target, as indeed it undeniably is.

However, the wider drivers and factors of climate change that are directly impacting our daily lives on the land surface, at the altitude at which we live, are much more complex, and essentially the direct consequences of a range of anthropogenic activities, including:

- FATBAS agriculture, which directly degrades the climate by multiple mechanisms, including via soil carbon release and soil biome degradation, leading to loss of soil

retained water, loss of plant evapotranspiration capacity, 'global drying', bare soils, atmospheric regional heating, heat domes, rainfall changes, fire, flooding etc.

- Particulate matter in the atmosphere, including that due to crop burn-off, is accelerating arctic ice melt.

22.1 CARBON DIOXIDE v INCIDENT SUNLIGHT – CLIMATE CHANGE IMPACT

There is no question that increased atmospheric carbon dioxide is a key driver of climate change because it absorbs and thus slows the exit into space, of infrared energy wavelengths that would otherwise escape faster. Hence, carbon dioxide is undoubtedly contributing to atmospheric warming.

However, what we refer to as climate change is a complex collection of effects that manifest in various ways. Arguably the climate changes that affect us most directly, including, urban heating, drying of agricultural land and related drought, reduction in land-based rainfall, falling water availability, ground water stores and river flows; reduced food security, are primarily the consequences of the FATBAS based agricultural practices we apply to 5 billion hectares, 39% of the ice-free terrestrial surface. These climate stressors also contribute to the risk of extreme weather events through various mechanisms, as discussed in other sections.

Atmospheric warming increases atmospheric moisture, and increases the risk of ocean-dependent hurricanes and extreme related weather events. It also logically contributes to some extent to the climate change events outlined, but in the immediate timeframe, it is not the primary direct cause or driver of them.

As discussed, soil loss of water retention reduces plant evapotranspiration capacity; furthermore, dry, bare, and degraded land cause direct atmospheric heating; both are significant factors in climate change. Incident sunlight powers and drives both cooling evapotranspiration, where soil water is available, and bare soil-based atmospheric heating, where no moisture is available.

Thus, humans need to optimise the energy resource in incident sunlight, by using it to grow plants and cool the planetary surface, rather than wasting that free sunlight energy, a double whammy, because not only wasteful, but by heating soils and surface devoid of plants, heats the land surface raising regional temperatures in the places we live and work, additively driving climate change events, and also warms the atmosphere land and ocean atmosphere causing long term planetary heating.

22.2 ATMOSPHERIC CARBON DIOXIDE ALSO A PROXY FOR FATBAS-DRIVEN CLIMATE CHANGE

Rising carbon dioxide released by fossil fuel combustion and soil carbon's respiration are fundamental factors in atmospheric warming. This is clearly reflected in the graphical association of increasing temperature and atmospheric carbon dioxide. Loss of soil carbon on a global basis has significantly contributed to rising atmospheric carbon dioxide.

Crucially, as well as contributing to increased atmospheric carbon dioxide, lost soil carbon is also a factor behind and a marker for reduced, soil water retention, and soil biome life, thus diminished plant presence and functionality, increased areas of bare soil, and reduced evapotranspiration, all of which significantly drive climate change.

Thus the clear graphical association between rising temperatures and rising atmospheric carbon dioxide, masks wider related, non-atmospheric-carbon dioxide agricultural changes, including the consequences of the loss soil carbon, loss of water retention and soil biome metabolic water production, and bare and degraded soils, together resulting in significant disturbance and loss of evapotranspiration, consequent drying and atmospheric heating, and magnification of extreme weather risks, thus underlying many of the climate change events we are witnessing.

22.3 ATMOSPHERIC CARBON DIOXIDE – HEAT TRAPPING

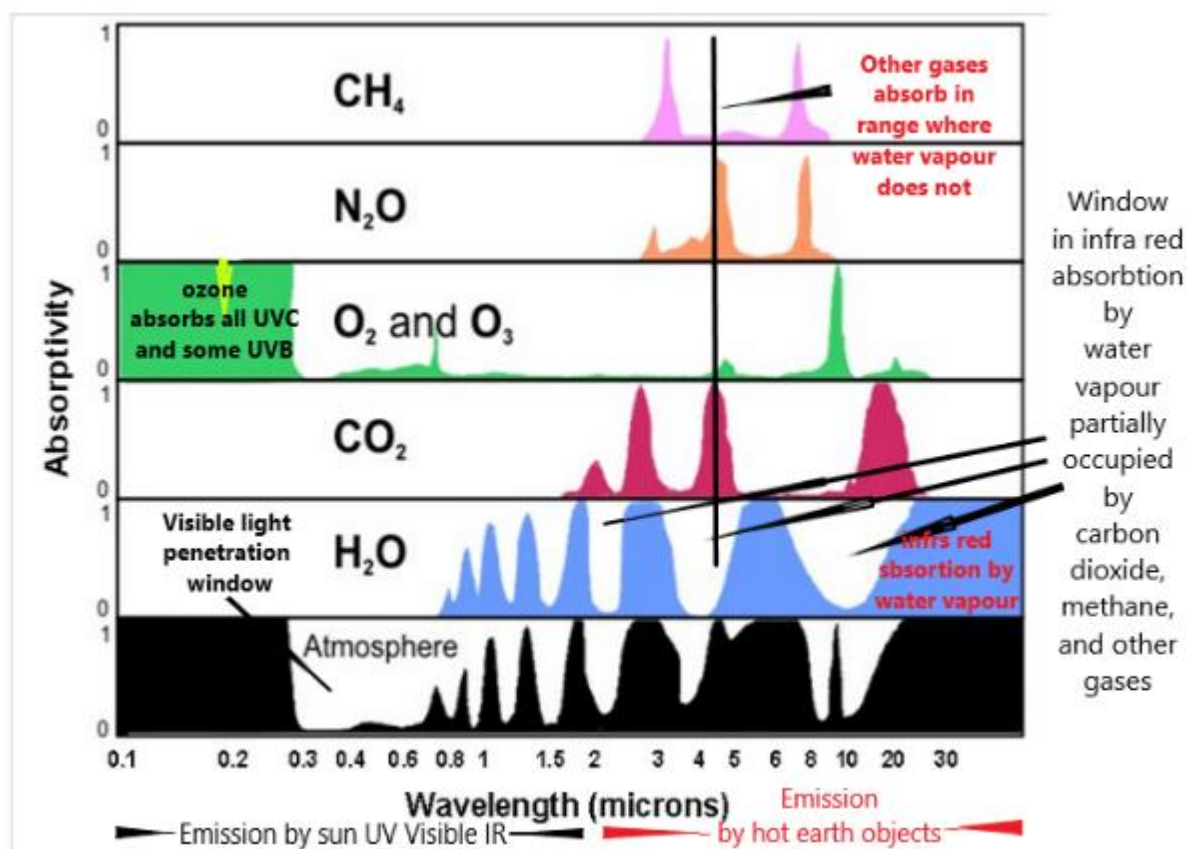


Fig. 33. From the review '*Absorption coefficient of carbon dioxide across atmospheric troposphere layer*' and annotated (arrowed items) by this author, with many thanks to the authors (Wei, 2018).

The above illustration visually illustrates why greenhouse gases play such an important role. The lower black panel shows the sun's inward emissions, and the Earth's longer infrared emissions. All objects above absolute zero emit infrared, but the wavelengths they can emit at any given temperature will be determined by their structure.

Thus, the infrared emitted by the Earth varies as wavelengths change. The emitted infrared is absorbed again at specific wavelengths by climate gases, including water vapour. The windows (white areas) allow the rapid escape of infrared to space. The magnitude of absorption by climate gases is dependent on their concentration.

Notably, both carbon dioxide and methane have absorption peaks that significantly coincide with wavelengths at which water vapour does not absorb, giving them particular atmospheric and climate warming relevance. (van Biezen, 2018)

22.4 HOW IS ENERGY TRANSFERRED TO CARBON DIOXIDE?

The way carbon dioxide gains and transfers heat is complex, and dependent on a range of mechanisms. Most of the energy acquired by carbon dioxide by conduction/impact energy transfer or infrared will, by impact, be transferred to other gases, predominantly nitrogen and oxygen. Over time, energy will be transferred upwards in the atmosphere and eventually escape to outer space.

Oxygen and nitrogen are essentially transparent to infrared. Carbon dioxide and other climate gases slow the escape of that energy. This is an attempt to explain the complex energy transfer process in more detail using a mix of DeepSeek commentary and comments by this author:

- **Collisional deactivation:** *At lower altitudes (high pressure), collisions between CO₂ and N₂/O₂ occur ~10⁹ times per second. Vibrational energy in CO₂ is transferred to translational/rotational energy in N₂/O₂ within ~1 μs, preventing immediate IR re-emission.*
- **Energy transfer to carbon dioxide and reemission as infrared in 15,000nm range:** the energy transferred by warmed oxygen and nitrogen will be transferred by collision conduction and convection to carbon dioxide, which will re-emit a portion of that energy as infrared in the crucial 15,000nm wave band, which will then be reabsorbed and reemitted by other carbon dioxide molecules, slowing the exit of energy out of the atmosphere, leading to atmospheric warming, helping explain the warming impact of CO₂
- **Re-excitation of CO₂:** *For CO₂ to absorb another IR photon, it must first lose its energy (via collisions) and return to a lower energy state. This cycle is rapid at the molecular level but depends on atmospheric density. At higher altitudes (lower pressure), collisions are less frequent, allowing CO₂ to re-emit IR photons (explaining why the stratosphere cools as CO₂ increases).*

22.5 WATER VAPOUR - ALSO A CLIMATE CHANGE GAS

Oceanic regional water vapour will increase by about 7% for each degree rise in atmospheric temperature. A warmer atmosphere holds more water vapour, which is also a 'climate gas', thus creating a self-reinforcing warming effect. That additional heat would escape faster were

it not slowed by climate gases, including carbon dioxide. Increased atmospheric moisture will also increase the intensity and unpredictability of rainfall events.

Water molecules in the liquid or vapour phase vibrate, emitting infrared energy in particular wave bands, but below the key 15,000nm band absorbed by carbon dioxide. Water vapour will also exchange energy with oxygen and nitrogen by impact. Thus, water vapour does not directly add to the infrared energy in the wavebands absorbed by carbon dioxide; however, it does indirectly transfer energy to carbon dioxide, other air molecules, oceans, and land through conduction and convection-based atmospheric warming.

22.6 WARMING, MOISTURE, OCEANIC AND LAND-BASED RAINFALL

Atmospheric warming increases the atmosphere's capacity to retain moisture (Clausius-Clapeyron relation: ~7% more moisture per °C), and warmer temperatures raise land and ocean evaporation rates. For example, a 1°C rise could increase ocean evaporation by ~28,000 km³/year.

Given atmospheric moisture on average generally, but certainly not always, falls as rain in relatively short time frames, possibly 10 days, overall increased atmospheric moisture must fall as rain, and consistent with this increased oceanic rainfall has been observed, *“Annual reported precipitation frequency shows statistically significant positive trends of up to ~15% per decade throughout most ocean areas equatorward of 45°.”* (Petty 2023)

However, despite increased moisture over the oceans and potential for movement of oceanic moisture over land overall, rainfall over land has decreased. This is logically primarily due to a FATBAS-induced reduction of water retained by soils, diminishing the evaporation potential of plants, in turn reducing land-based atmospheric moisture, due to a mix of;

- reduced infiltration and storage of water in soils,
- increased runoff,
- diminished metabolic water production by a diminished soil biome,
- loss of soil carbon and related retained water,
- reduced crop growing time due to reduced water availability,
- consequent overall loss and shortening of periods of evapotranspiration,
- related reduction in plant pore release of cloud seeding bacteria,
- bare soil, and limited infiltration rates, increasing evaporation rates, but over short time frames,
- consequent on land heating and drying, inhibition of the movement of marine moisture inland due;
 - to high-pressure zones,
 - and heat domes.

Indeed most of the terrestrial climate effects impacting the surface related lower atmospheric layers we inhabit, and are most concerned about, namely regional surface drying, flood, heatwaves including heat domes, and fire, are arguably predominately due to human intervention in nature's regulatory systems, particularly degradation of the soil biome and its capacity to infiltrate, collect, retain, and provide water for evaporation and transpiration, including through, deforestation, land degradation, and predominately through the imposition of FATBAS, including over-and-inappropriate grazing and application of fertilisers, on a significant proportion of the 39% of the earth's ice-free surface, which as a whole, may also help explain anomalies in rainfall modelling.

23 FATBAS - A CLIMATE CHANGE PROMOTER - 'GLOBAL DRYING'

A range of factors other than carbon dioxide, impact atmospheric and planetary surface warming. The observed adverse outcomes, which we attribute to climate change, manifest in many forms, many of which evidence suggests are primarily initiated by a broader range of anthropogenic activities, other than carbon dioxide emissions, and additive to the longer-term atmospheric heating effects of increased carbon dioxide emissions.

Human FATBAS management of a significant proportion of Earth's ice-free surface land, 39%, is arguably responsible for many aspects of climate change, including global drying, reduced water retention by soils, loss of soil fertility, soil degradation, changes in regional weather patterns, extreme heat events, increased flooding and fires, and an increased risk of extreme climate events.

FATBAS, through fertiliser pollutants and agrochemicals poisons, through ploughing physically damages soils; leaves land bare between crops, degrades land, drives down; soil carbon, water infiltration, and water retention, which changes evaporation and plant transpiration volumes and time frames, together resulting in local and regional heating, driving regional climate change effects, including reduced land-based atmospheric moisture, and creating high pressure regions including heat domes that disturb flows of moist oceanic air masses inland, which as a whole reduce rain fall, and increase, drying, fire, flooding and erosion, as well as risk of extreme weather events.

23.1 LAND DRYING – A KEY FACTOR IN REDUCED LAND RAINFALL AND ARIDITY

Consistent with the above posit that much of global drying is due to FATBAS, the Nature Climate review titled '*Land–atmosphere feedbacks amplify aridity increase over land under global warming*' observes "*Changes in water availability over land are a key driver of climate change impacts on human and natural systems.*" (Zhou 2019)

23.2 GLOBAL DRYING, SOIL WATER RETENTION, EVAPOTRANSPIRATION, DRYING, WARMING, RAINFALL, DROUGHT,

The review '*Spatiotemporal evolution of global long-term patterns of soil moisture*' notes "*Both decreasing precipitation and increasing evapotranspiration patterns showed about 40% similarity with decreasing soil moisture patterns . . . Under the future global warming scenario, the global soil water is expected to decrease as evapotranspiration would increase with*

inconsistent trend of global precipitation change. Our findings are of utmost importance for global soil water resource conservation and management”, illustrating much in climate models is unresolved.

Whilst the soil drying mechanism has already been discussed, it is restated in this section. As discussed, the FATBAS-related decrease in soil biome life and soil carbon, results in greatly reduced water infiltration, and soil water retention capacity, greater evapotranspiration rates over shorter time frames, but reduced long-term evapotranspiration, increased drought risk, rapid drying of soils, and regional drying and changes in rainfall.

Reduced water infiltration and retention at the surface will increase short-term evaporation and transpiration rates. The combination of the loss of retained water in soils, and metabolic water production, is logically of much greater importance to climate regulation and change than generally realised.

In addition to creating metabolic water, soil biome systems will retain and access water even bound to very small, mineralised rock particles and within interstices, including in mycorrhizal sheaths and related biofilms, thus further increasing resistance to drought. Fungi and bacteria will also filter and remediate toxins in water.

Further, bare soils contribute to atmospheric heating of lower altitudes. Exposed silicates and other minerals absorb a proportion of incident visible and ultraviolet light, and retransmit absorbed energy through:

- a mix of infrared,
- and a combination of conduction and convection,

heating the regional immediate atmosphere and, at the same time, desiccating and crusting soils, increasing short-term and diminishing long-term evaporation and plant transpiration, as well as reducing the capacity of rain to infiltrate soils, at the same time raising surface soil temperature sufficiently to kill their biology. In addition, bare soils expose soil life to fatal UV.

The retained solar heat in soils, accelerates evaporation and transpiration-related moisture loss, thus causing soil drying and heating. Furthermore, atmospheric conduction and convection contribute to heat domes, preventing the circulation of ocean-derived moisture into landmass interiors, which promotes and magnifies the risk of drought, fire, heatwaves, and extreme weather events.

Reductions in soil carbon and related soil life volume and diversity largely underlie ‘drying’, reduced water tables and flows, degraded regional climates, and increased risk of flooding, fires, erosion, and extreme climate events.

The consequent cost to humanity of continuing with FATBAS, and failing to adopt regenerative agriculture, in terms of lost potential for ecosystem improvement, including better hydrology, moderation of weather, sequestration of carbon, improvement of soils,

reduced pollution, as well as lost opportunities to increase food supply and stability, and improve the lives of millions, is enormous.

23.3 SOIL CARBON AND WATER RETENTION

Soil carbon is a measure and proxy for soil life, and of existential importance to soil life. It has a crucial symbiotic relationship with the plants growing above it, which plants provide the soil biome with photosynthetically produced carbon sugar exudate, core to the existence, structure and energy production, of life in the darkness of the soil biome.

Life is 90% water and contains substantial amounts of structural carbon. Thus, soil carbon and retained water are related to and a proxy for the amount of life present in soils. Water is present in soil, free-form in pores and bound in gels, and within soil life. Water in soil is constantly recycled by soil life, through metabolic water production, in excreta, slimes, and through the cycle of life and death.

23.4 QUANTITIES OF WATER RETAINED BY SOIL CARBON

This section seeks to illustrate the vast quantities of water retained by organic life-rich soils and the crucial importance of soil carbon to the Gaian planetary regulatory systems, including for weather, and more specifically in relation to evapotranspiration and drying on land surfaces. It has been included at this point due to its significant impact on climate change.

The calculations were produced at my request by DeepSeek as part of a lengthy series of proposals, questions, and conversations, spanning possibly over three months, on the subject of regenerative agriculture and climate change.

The data provides illustrative information for a given set of criteria, of the capacity of soil carbon to regulate soil water storage and retention, and to impact evapotranspiration, influencing climate, including rainfall, and conversely, the risk of drying at a regional and global scale:

Water Storage per Ton of Carbon Sequestered
<ul style="list-style-type: none"> • Key Relationship: Studies indicate that sequestering 1 ton of carbon per hectare increases soil water-holding capacity by ~18.9 m³/ha derived from USDA data: • Global Scale: Over 4–5 billion hectares of agricultural land: <ul style="list-style-type: none"> ○ Water stored per ton of soil carbon per hectare 18.9 m³/ton ○ Total water storage on 5 billion hectares – 18.9 m³/ha x 5billion =94.5km³
Rainfall Required to Fill This Storage
<ul style="list-style-type: none"> • Calculation: 18.93 m³ divide by 10,000 sm.m, the area in a hectare, = 1.89mm <p>(Only ~2 mm of rainfall across the entire area is needed to fill the additional storage, assuming full infiltration.)</p>

Implications for Climate and Hydrology
<ul style="list-style-type: none"> • Evapotranspiration: <i>Stored water is gradually released via evaporation/transpiration, cooling local climates and supporting rainfall patterns.</i> • Resilience: <i>Enhanced soil storage buffers against droughts and floods, reducing irrigation demand and erosion.</i>
Key Caveats
<ul style="list-style-type: none"> • Variability: <i>Actual storage depends on soil type, crop practices, and rainfall distribution.</i> • Infiltration: <i>Real-world infiltration rates may be lower than idealized assumptions.</i>
Summary
<p><i>Improving soil organic carbon in agricultural systems can synergistically address water retention and climate resilience. Sequestering 1 ton C/ha over 5 billion ha could store ~94.5 km³ of water, replenished by just 2 mm of rain globally.</i></p> <p><i>1% SOM increase~12.38 t C/ha). Would increase retained water per acre by $\approx 234 \text{ m}^3/\text{ha}$, and over 5 billion hectares by 1,170km³</i></p> <p><i>This highlights agriculture's potential to modulate hydrological cycles while mitigating climate change.</i></p>

For the avoidance of doubt, whilst based on available data, and figures vary between sources dependent on a range of factors including regional characteristics, there is no question that the loss of soil carbon over 39% of the earth's ice-free surface, some 5 billion hectares under human management, due to the link between soil carbon soil water retention and plant evapotranspiration, has significant climate implications, including for, drying and reductions in land based rainfall, flooding, soil heating, high pressure zones, heat domes, and impairment of movement inland of oceanic moisture rich airflows.

As a consequence, how we manage the landscape, including the way we farm and manage land, how we look after the soil biome, and how we use solar energy, including by optimising photosynthesis, or leaving land bare, when viewed globally over 5 billion hectares has significant climate consequences, for reasons explained in more detail in other sections of this book.

23.5 DRYING IN THE CERRADO – AN EXAMPLE OF THE IMPORTANCE OF SOIL CARBON IN CLIMATE CHANGE DETERMINATION

As discussed above, the soil's water holding and production capacity is proportional to the quantity of soil carbon present. The localised water absorption, retention, and release rates of each hectare of agricultural land have significant downstream hydrological implications, which in turn impact broader ecosystems, including atmospheric moisture, bacterial cloud seeding, rainfall, and downstream river flows, as observed in the Cerrado region of Brazil.

The mechanisms driving ‘global drying’, including loss of soil carbon and consequential related soil water provision for plant evapotranspiration, both as to volume and time frame, have been discussed in earlier sections. The Cerrado in Brazil provides an example of the effects on soils and regional climate, of replacing natural year-round ground cover with artificial fertiliser, agrochemical, bare-ground, centric, FATBAS agriculture, on water retention, wider hydrology, and microclimates.

Papers looking at soil moisture transpiration in areas of the Brazilian Cerrado region converted to agriculture suggest that significant loss of dry season plant transpiration, thus atmospheric moisture, river replenishment, and annual rainfall, is occurring, as might be expected. *“The conversion of Cerrado into open grasslands (or planted crops) has reduced precipitation by approximately 10 percent. The effects have also caused an increase in the frequency of dry periods within the wet season and a rise in mean surface air temperature by 0.5°C.”* (van Dijkhorst, 2018).

The article titled *“Cerrado Deforestation Disrupts Water Systems, Poses Business Risks for Soy Producers”* by ‘Chain Reaction Research’, observes, *“Research from Brown University shows that for every million ha (hectare) of Cerrado converted to croplands, dry season evapotranspiration decreases by 1.7 km³.”* (van Dijkhorst, 2018) Estimates of water loss vary; some estimates, as below, are much larger, but even 1.7 kilometres cubed is a large volume of water – a cubic kilometre - 1,000,000,000 cubic meters – would make a lake 10 kilometres square by 10 meters deep.



Fig. 34. Soil microbiologist and climate scientist Dr Walter Jehne, sets out the wider climate impacts of loss of soil carbon in his 2015 video lectures ‘*The Natural History of Water on Earth*’ (Jehne, 2015) and in a two-part 2017 lecture ‘*Regenerating the Soil Carbon Sponge: As easy as ABC*’. (Jehne, 2017a and b).

“As Cerrado vegetation is cleared, fragmented, and replaced with croplands, the water balance is modified as water leaves the system through runoff and ground water rather than being recycled as evapotranspiration (ET).” “We find that these changes have decreased the amount of water recycled to the atmosphere via evapotranspiration (ET) each year. In 2013 alone, cropland areas recycled 14 km³ less (-3%) water than if the land cover had been native Cerrado vegetation.” (Spera et. al., 2016)

*“In the dry season, the volume of evapotranspiration in agricultural areas averages **60 percent lower** than in areas with native vegetation. In the Amazon region, between 24 percent and 56 percent of evapotranspiration is recycled into precipitation. Therefore, limited evapotranspiration could result in an annual rainfall reduction on the order of 8-16 mm (-3 percent) in Matopiba region.” (van Dijkhorst, 2018)*

The paper ‘Land-Use Change Affects Water Recycling in Brazil's Last Agricultural Frontier’ observes, “Models suggest that deforestation of the Amazon and Cerrado may increase Cerrado dry season length by up to a month”. “Moreover, climate modelling experiments have shown that preserving remnant Cerrado is essential to climate stability in this region and in the Amazon downwind. Feedbacks between land-cover changes and climate have the potential to reduce precipitation, increase precipitation variability, and ultimately threaten the sustainability of agricultural production in both the Cerrado and the Amazon.” (Spera et. al., 2016)



Fig. 35. Cerrado in Piauí, Brazil with very many thanks to Pedro H C Pinheiro

Ironically, the detrimental effects of FATBAS bare-ground industrial agriculture are compounded, including lower rain infiltration, reduced metabolic water, diminished regional hydrology, and generally reduced soil water-holding capacity, creating a significant increase

in the requirement for crop irrigation while at the same time reducing the water supply. Thought-provokingly, 70% of the Cerrado's water is used for irrigation. Local communities protested as they were deprived of water at times. *"Conflicts are already arising over deforestation and water pollution between small-scale farmers and soy producers in this area."*

In contrast, *"During the rainy season, from October to April, when soy crops are grown, evapotranspiration in agricultural areas is similar to that in areas covered by native vegetation."* This evidence suggests that at least a portion of the evapotranspiration reduction is logically due to soils being left bare in the non-growing season and thus could be mitigated by the use of cover crops and or organic soil residue 'armour' during the non-soy bare soil seasons.

When loss of soil carbon is combined with bare soils, the result will be high soil temperatures and the appearance of heat domes, which, as discussed, inhibit the movement of oceanic moisture inland. It is undoubtedly unsurprising that the area is drying, and the hydrology and rainfall are changing.

Such changes in local hydrology have broader implications for regional hydrology, climate change-related events, drought, fire, floods, and consequent runoff, and erosion (Gomes, 2019), including in the wider Amazon region, with the additional effect of fertilisers in the runoff, via rivers, reaching and through eutrophication and broader chemical impact, damaging marine habitats.

Microclimates are a recognised phenomenon. In Western Australia, there are anecdotal reports of square mists forming over square areas under regenerative agriculture, but not in the surrounding areas. We have all experienced the significant regional cooling, and climate regulation effect, of green parks in urban areas. The difference between those areas and built-up areas with no green spaces is very noticeable. Sofia in Bulgaria and Canberra in Australia provide good examples of such effects in green parts of cities.

In contrast to green environments, bare soils reduce atmospheric moisture, increase temperatures, lead to soil carbon loss, and result in a reduction in evapotranspiration, as well as high-pressure zones and an increased risk of heat domes and extreme weather events, as previously discussed. They also negatively impact weather, including reducing rainfall and atmospheric moisture, and thus contribute to the risks of bushfires, as seen in the Amazon, Australia, and Canada in 2020/21.

Logically, if soil biome systems, and hence soil carbon stocks, were increased through soil-centric agriculture, climate change risks —such as temperature rise, drought, falling yields, and increased fire and flood risks —could be mitigated.

Broader beneficial effects of regenerative agriculture-based, increased soil carbon, thus healthier, more prolific soil biomes, would include more significant plant growth, year-round soil cover, improved water penetration, retention, and improvement in regional hydrology; temperature reduction due to increased regional micro-climate atmospheric moisture, soil heating reduction, reduced heat dome risk, reduced fire risk, and broader climate mitigation;

including likely rainfall smoothing, and flood reduction. Thus, significant potential exists to mitigate climate change through carbon sequestration into soils, as set out in Jehne's paper (*Regenerate Earth*' (Jehne, n.d.)

24 THE POWER OF REGREENING

Thus, re-greening and integral optimisation of the photosynthetic capacity of land of all sorts, including agricultural land, by increasing soil water infiltration, retention, plant growth, evaporation, and transpiration both by volume and timespan, thus regional moisture and rain, has significant capacity to mitigate 'climate drying', flood, erosion, fire, extreme climate events, and related environmental degradation.

That includes regreening all land types, including degraded land, deserts, urban hard landscapes, and agricultural FATBAS land. This will result in climate mitigation benefits, including regional surface and atmospheric cooling, reduced drying, fires and flooding, improved water retention, flows and hydrology, and reduced extreme climate events.

24.1 PLANTS COOL THE PLANET

Plants are indispensable elements of the Gaian eco-regulatory system, including carbon, oxygen, surface temperature, and water cycles. The soil biome, the symbionts and enablers of diverse, vibrant, productive, sustainable plant photosynthetic biomass production, is also an essential partner.

Mechanisms by which plants, with the assistance of the soil biome, keep Earth's surface temperatures within the habitable range include:

- Diurnal evapotranspiration converts incident sunlight to latent heat, cooling the immediate atmosphere, and transporting the latent heat higher into the atmosphere:
 - Transpiration is key to the regulation and cycling of land-based rainfall.
 - Water is key to cooling evapotranspiration.
 - Rain enables soil surface evaporation, which also cools, reducing the occurrence of high-pressure regions, heat domes, and disruption of oceanic moisture flows, thus reducing the risk of extreme weather events.
- Supplying the soil biome with carbon-sugar root exudate,
 - Soil carbon, by a variety of mechanisms, increases the retention of water in soils.
 - Increased soil stored water allows greater volumes of evapotranspiration over more extended time frames.
 - Soil carbon, by facilitating increased soil biome life, increases the metabolic water production capacity of the soil biome life.
- Using photosynthesis, plants convert carbon dioxide to carbon and oxygen. To the extent that the carbon and oxygen produced are added to the long-term stock,

- Solar energy will have been stored.
- Atmospheric carbon dioxide will have decreased, reducing its warming effect.
- Dead plant material protects soils and absorbs energy; sunlight degrades the organic molecules it is made of, its energy being absorbed in the process. *“Solar radiation is a fundamental ecosystem modulator. In particular, UV-radiation accelerates the degradation of organic matter either by photolysis or by oxidation of organic compounds to CO₂, often followed by enhancing the bio-availability of complex organic substrates to microbes.”* (Brandt, 2010; Paul, 2012).
- Living and dead plants also shade the ground, preventing heat build-up in the soil and further helping retain moisture.
- Reflection of a portion of incoming sunlight (albedo).
- Reemission of a portion of incoming sunlight as infrared outside the wavelengths absorbed by carbon dioxide – the part not absorbed by carbon dioxide will warm the water vapour at altitudes at which clouds are found, transferring most of that heat away from the Earth’s surface habitable zone.

24.2 LIVED EXPERIENCE - BASIC POINTERS, TRUTHS, AND LESSONS

Human lived experience in various locations, supports the contention that plants cool and bare surfaces heat. For example;

- A green park in a sea of buildings in summer – the power of plants, to extract sunlight and redirect it to splitting carbon dioxide, at the same time producing and respiring water, and to reflect a portion of energy emitted by the sun back into the atmosphere (albedo).
- A beach - the sand is cold where damp, yet hot to the point of being painful on the feet when dry – while moist the sun’s energy is used to vaporise water, as soon as the sand is dry, the heat is retained and diurnally conducted / convected / retransmitted as mid/long-infrared, part or all of which will be trapped by climate gases including carbon dioxide. The same dynamics would apply to bare agricultural soils, city surfaces, roads, etc, etc. NASA satellite data confirms our lived experience: plants limit temperature rises, and the highest temperatures are typically experienced in areas devoid of plants, NASA observes, *“In areas where vegetation is dense, the land surface temperature never rises above 35 degrees Celsius. The hottest land surface temperatures on Earth are in plant-free desert landscapes”* (NASA, 2024).

24.3 EXAMPLES OF CLIMATE MITIGATION THROUGH GREENING

Examples of climate mitigation through greening include the Sahel region, which is cited as better studied than other examples, which include the USA, Cerrado in Brazil, various rotational grazing projects, and those cited in the later sections on de-desertification.

For example, the review *'Twentieth century regional climate change during the summer in the central United States attributed to agricultural intensification.'* observed that with a move to soy and soy bean in the 1950s onwards, and availability of irrigation, contrary to “expectations from climate change projections for the end of the 21st century (i.e., warming and decreasing rainfall)” that “In the central United States, for example, observational data indicate that rainfall increased, surface air temperature decreased, and surface humidity increased during the summer” . . . “large-scale increases in rainfall of up to 35% and decreases in surface air temperature of up to 1°C” were reported (Alter, 2018).

As discussed later, a similar but seasonal effect was seen in a soy region in the Cerrado. Regional vapour levels recovered to those seen in local scrub forest regions when the soy crop grew, which fell when the fields were left fallow post-harvest. Whilst soil transpiration consequent on irrigation research suggests plays a part (Alter, 2018), as discussed, both soil biomes and plants produce metabolic water during the process of energy making, which plants can transpire through their pores, by evapotranspiration, to regulate their microclimate. Plant pores also release bacteria from their pores that seed clouds, thus synergistically increasing the chances of regional precipitation.

24.4 REGENERATIVE AGRICULTURE – A FORM OF GREENING

Regenerative agriculture does not use tillage or allow bare ground between crops. It optimises the photosynthetic capacity of land to sequester soil carbon and retain water. It includes using foliage-dense mixed cover crops and underplanting; thus, it is a form of greening.

At the same time, regenerative agriculture restores the soil biome, soil carbon levels, soil water retention, regional atmospherics, and hydrology, optimising healthy plant growth throughout the entire growing season. Regenerative agriculture is discussed in more detail in later sections of this volume. Regenerative principles can be applied to restoring degraded land and urban greening, thereby improving outcomes.

24.5 DEGRADED LAND – GREENING - COOLING THROUGH ECOSYSTEM RECOVERY

Land degradation is a significant global issue. “Three billion people globally impacted by land degradation” (UNCCD 2025). The review *'Scaling Up Sustainable Land Management And Restoration Of Degraded Land'*, with accompanying disclaimer, suggests more than 2 billion hectares are degraded. “As much as 500 million out of two billion ha of degraded land, mainly in developing countries, have restoration potential, offering an immediate target for restoration and rehabilitation initiatives” (Thomas 2017). Exactly what land categories are included is not specified, but 2 billion hectares would represent 40% of the agricultural land under human management, and agrees with a UN estimate (UNCCD 2025), albeit a large number of uncertainties can exist that require local contextual knowledge to resolve (Mbow, 2015).

Depressingly an FAO report *'The state of the world's forests 2024'*, observes “Almost 75 percent of the world's total land area, particularly forests, rangelands and wetlands, has been

negatively affected by degradation and transformation, and this figure is likely to increase to more than 90 percent within 30 years “ (FAO 2024)

Other sources suggest that 20% of Africa’s productive agricultural land is degraded, which has significant consequences for those who depend on the land for their income and livelihood. It is not easy to reconcile these figures, but many commentators are clear that land degradation is a significant global issue, with consequences for individuals, families, regions, countries, global stability, and the Earth's Gaian planetary ecological systems, including weather regulatory systems.

A poignant example illustrates the plight of many African farmers. It is cited in the report *‘Small Farmers and Entrepreneurs Offer New Hope for Africa’s Degraded Lands’*, which reports, *Sadik Ibn Abdulai grew up in northern Ghana, where he watched his family’s land and those around it slowly turn from lush farmland to desert. Years of overgrazing and unsustainable agricultural methods robbed the soil of its nutrients. Crop yields dropped. Some farmers turned to other activities —like chopping down forest to make charcoal for cooking, or hunting and selling bush meat — to eke out a living. Sadik’s family eventually could no longer afford his school fees, and he dropped out. . . Sadik’s story is a familiar one in Africa, where 65% of the continent’s farmland is unproductive, eroded or otherwise degraded”* (Mathi, 2023).

Unusually, there was a happy ending to the story, as he developed techniques to bring land back into economic production and created opportunities for regional farmers to reclaim and green the land, generating an income for themselves. Sadik’s story is a familiar one in Africa, where 65% of the continent’s farmland is unproductive, eroded or otherwise degraded. But today, the land Sadik works on looks different from the barren farm of his childhood. *“Nearly 750 million hectares in Africa are ripe for restoration, an area of land the size of Australia. Small-scale farmers, entrepreneurs, cooperatives and community groups are some of the most effective actors in revitalizing it.”* (Mathi, 2023)

Regreening of degraded landscapes, utilising landscaping and farming techniques to enhance landscape and soil water retention, is highly achievable, as evidenced by numerous examples documented in studies and videos, including those from China, Ethiopia, India, and West Africa. Areas where there has been formal comment and research include the Sahel, Ethiopia, Somalia, the Loess Plateau in China, and Niger where *“Farmer-managed natural regeneration (FMNR) of trees has restored it is suggested 3 million hectares”* (SEVIR 2024).

For example, the study *‘Effect of degraded land rehabilitation on carbon stocks and biodiversity in semi-arid region of Northern Ethiopia’* had positive outcomes and noted *“Woody species diversity, abundance and richness were positively correlated with biomass and soil organic carbon stocks.”* (Manaye 2019).

While several reports and Government advisories support regreening projects in Africa, conflicts and other issues present difficulties, including those related to progressing and documenting such projects. However, it seems generally accepted in several reports that there has been net greening in the Sahel, albeit progress may have slowed. Conversely, in some areas, cropland is being lost, likely due to FATBAS usage (Chen 2020, Zeng 20223).

Opinions differ as to what extent the greening has been due to increased rainfall, or to a mix of changing farming practices and deliberate re-greening projects, which in turn will increase; soil water storage, evaporation and transpiration, release of cloud seeding bacteria, and thus likely increase regional precipitation both in volume and time frames (Hermann 2006).

Transpiration evaporation and water vapour are difficult to measure at scale, however rainfall increasing with increased atmospheric water vapour, has been reported in, the Loess Plateau region, and Brazil in the Cerrado when the soy crops are growing, also in the US in crop growing season, and in the rotational grazing project at Las Damas in New Mexico as well. All are referenced in later parts of the book. The recorded observations are consistent with regional climate improving with re-greening.

Regional greening-generated cooling is similarly difficult to measure at scale, but it is a recognised phenomenon clearly seen in urban landscapes and anecdotally reported by those achieving regreening, including through landscape-based water management and regenerative agriculture.

Many studies ignore or are unaware of the potential transformative power of simple water management schemes, rotational grazing, regenerative agriculture, including the use of cover crops, and that when adopted over large areas can influence air moisture and rainfall.

Examples of the impact of climate mitigation projects mentioned in the literature include:

- **Vegetation Recovery:**
 - *Satellite data (NDVI* trends) show a ~10–20% increase in vegetation cover since the 1980s in parts of Niger, Burkina Faso, and Senegal as discussed above.*
- **Temperature Impacts:**
 - *Vegetated areas in the Sahel exhibit **2–4°C lower daytime temperatures** compared to bare soils, due to enhanced evapotranspiration.*
 - *Example: In Niger, restored agroforestry parks reduced soil surface temperatures by ~3°C.*
- **Rainfall Feedback:**
 - *Increased vegetation strengthens moisture recycling, boosting local rainfall by 5–15% in some regions (observed in climate models like ICTP RegCM). (DeepSeek 2025)*

Examples of climate mitigation through greening include the Sahel region, which is cited as better studied than other examples, including those cited in the later section on desertification

However, uncertainties in modelling and interpreting satellite data result in conflicting results. Such effects are best judged by those in situ whose lives are impacted by landscape rain capture and changing agricultural practices, including integral tree management.

24.6 URBAN COOLING – GREENING – EXAMPLES AND LITERATURE

The climate benefits of urban greening are well recognised and often reported. Examples of benefits of urban and wider regional through greening include;

- **Cooling**
 - *Urban parks are **3–7°C cooler** than surrounding built-up areas during heatwaves. (EPA 2021)*
 - *Phoenix, Arizona: Parks are **4.5°C cooler** than streets.*
 - *Delhi, India: Forested areas are **6–8°C cooler** than concrete zones.*
 - *Medellín, Colombia: Planted 30 "green corridors" (8,800 trees, 350,000 shrubs), cooling the city by **2–3°C**. (WEF 2024)*
 - *Singapore: Mandates green building standards (e.g., Skyrise Greenery), reducing ambient temperatures by up to **4°C**. (National Parks Board 2017) (An inspiring and thought-provoking publication showing what is possible when the will is present, and a potential use for city grey and surface water.) (URA 2024)*
 - *"According to the review of the articles published between 2000 and 2020, the reduction in cooling load is maximum (mean 50.2%) in temperate climate zones for well-irrigated green roofs. The effectiveness in saving cooling load reduces in hot-humid and hot-dry climate zones, with means of 10% and 14.8% respectively." (Jamei 2023)*
- **Energy use**
 - *Appropriate planned tree planting can result in significant both winter and summer energy savings. For example, a review observed "In typical weather conditions, two deciduous tree arrangements lead to a maximum of 40% heating energy conservation from any potential ORTa in east, west or north. In addition, it provides 15% east or west cooling energy saving and 7% north. In extreme weather conditions, two tree arrangements provide 25% thermal heating conservation, in any aspect. During heatwaves easterly deciduous tree planting is optimal (18% energy conservation), followed by westerly (7%) and northerly (1%)." (Rouhollahi, 2022).*
- **Human Health:**
 - *Heat-related mortality is a significant problem (Gasparrini 2015)." (Assisted in this section by DeepSeek 2025)*

25 REGEN AG v FATBAS

Agriculture has been imposed on existing landscapes on a large scale globally, making it an integral part of the planetary regulatory system for climate, carbon storage, oxygen production, weather, and the water cycle.

Using FATBAS, we have converted vast areas of the planet's surface, four to five billion hectares, (FAO 2021a) from year-round, photosynthesising, green growing, high albedo

sunlight energy reflecting, carbon dioxide capturing, planetary cooling, sugar exudate producing, living water producing and transpiring organic material covered the land; overlying biologically and carbon-rich, water producing and retaining soils, to land that; is annually tilled, remains bare for significant portions of the year, is subject to soil life reducing agrochemicals and NPK, leading to downward spiralling soil carbon, and incrementally increasingly degraded biomes, increased atmospheric carbon dioxide, soil and atmospheric heating, loss of inland atmospheric moisture, drying, heat domes, fires, drought and flooding, and massive loss of soil carbon.

Regenerative agriculture is the antithesis of the current predominant FATBAS ‘**Fertiliser-Agrochemical-Tillage-Bare-Agricultural-System**’ paradigm. Regenerative agriculture optimises available photosynthetic sunlight energy capture by keeping healthy, vigorous growing crops in the soil for as much of the year as possible, simultaneously optimising soil, carbon, hydrology, biome health and function, and minimising bare soil, including through diverse cover crops, inter-row and under-sowing, and in sub optimal soils utilising biologically rich composts as a source of soil fungi and bacteria necessary to optimal germination and growth, without the use of artificial fertilisers and ideally without any agrochemicals.

25.1 FATBAS IS ALL ABOUT KILLING AND DEGRADATION

With our adoption of FATBAS we have demonstrated a myopic determination that is increasingly proving to be soilcidal, ecocidal even, believing we can kill our way to dominion over natural ecosystems, forgetting in our quest for domination and resources, that we are seeking to debilitate and destroy natural ecosystems existential to our existence.

Gabe Brown, a regenerative farmer and campaigner, winner of the 2021 Senator Heinz Award for the Environment, acerbically sums up ‘FATBAS’ soilcidal farming; *“The current degraded resource production model is all about killing, we kill weeds, kill pests, kill fungus, kill diversity . . . our soil and our profits” . . . “we cannot stay in this degraded resource production model, it really limits opportunities for the next generation.”* (Brown G., 2017 b).

FATBAS, tillage, endless monocropping, bare soils, and agrochemicals kill life in the soil biome. The nitrates and phosphates in fertiliser disincentivise plants from supplying photosynthetic carbon sugar root exudate to soils, driving down soil carbon. Supply of nitrates to soils disincentivises bacteria from making nitrates and accelerates soil metabolism, further reducing stored carbon. The amount of carbon in soils is directly proportional to the presence of life; life is primarily composed of water; therefore, reducing soil carbon reduces both soil life and soil water. Diminished soil biomes have a reduced capacity to support plants.

Our adoption of FATBAS and failure to understand the need to facilitate the photosynthetic capture by plants of an adequate proportion of globally incident sunlight, and with the assistance of healthy soil biomes, to pump that carbon into soils, where soil life makes and stores water, regulates flows, influences plant and soil water transpiration rates. We failed to appreciate that bare soils themselves, combined with the absence of transpiring plants, contribute to the drying and heating of the atmosphere and are logically a significant factor in the degradation of the climate and related environmental function.

25.2 REGENERATIVE AGRICULTURE - MULTIPLE BENEFITS FOR PLANETARY AND HUMAN HEALTH, SUSTAINABILITY AND CLIMATE MITIGATION

A global move to regenerative agriculture that;

- does not allow the ground to remain bare;
- focuses on optimising healthy soil biology;
- recognises the evolutionary importance of the soil biome to the emergence of life and climate regulation;
- maximises soil carbon storage by optimising the photosynthetic potential of every acre,
- minimises bare soil heating of the atmosphere,
- optimises diversity and the health and size of the soil biome,
- reduces carbon dioxide and increases carbon storage and atmospheric oxygen,

will bring a host of benefits to the environment, climate, water and food security (FAO, IFAD, UNICEF, WFP and WHO, 2018), including those helpfully set out by Don Reicosky in his lecture slide on the page above.



Fig. 36. Lecture slide AGVISE Seminars and Don Reicosky 'Tillage and Carbon Management: Nutrient Re-Cycling Synergies' North Central Soil Conservation Research, with very many thanks to the authors. (Reicosky, 2014)

Regenerative agriculture can also mitigate, significantly slow, and even reverse many aspects of climate change, including extreme weather, temperature rise, drying, fires, flooding, ocean acidification, and deoxygenation, as well as FATBAS-related pollution.

Given human will, determination, knowledge propagation, and societal support, regenerative agriculture can be implemented using simple and inexpensive techniques that are easily and widely applicable.

Soil biomes enhance plant growth because it is in their interest to do so and to optimise their food supply. The review *'The Role of the Mycorrhizal Symbiosis in Nutrient Uptake of Plants and the Regulatory Mechanisms Underlying These Transport Processes'* (Bucking, Liepold, & Ambilwade, 2012) observes, *"The mycorrhizal symbiosis is arguably the most important symbiosis on earth. Fossil records indicate that arbuscular mycorrhizal interactions evolved 400 to 450 million years ago and that they played a critical role in the colonization of land by plants. Approximately 80 % of all known land plant species form mycorrhizal interactions with ubiquitous soil fungi"* (Bucking, Liepold, & Ambilwade, 2012).

If we, as 'de facto' self-appointed environmental controllers, wish to use agriculture to mimic, thus, as best we can, optimally manage the natural ecological systems that regulate our planetary carbon partition between soils, atmosphere and oceans, hence, the sustainability of current living systems, we must respect, emulate, maximise natural soil biology, rather than seeking to dominate and destroy it. We must recognise the soil biome's role as a key carbon store, an integral working part of evolutionary Gaian, terrestrial oceanic carbon-oxygen partition, and broader climate, feedback regulatory system, including through optimal use of incident solar energy via photosynthesis, as well as through soil water storage and release, and atmospheric moisture control.

25.3 MULTISPECIES COVER CROPS – KEY TO SOIL IMPROVEMENT

As discussed, systems with diverse plant and soil biomes are healthier and more productive, improving water retention and hydrology, and sequestering carbon. The Chinese practised mixed cropping for hundreds of generations. In the early 1900s, the English botanist Sir Albert Howard, inspired by the achievements of the Chinese, and based on his research, advocated for the use of inter- and mixed-crop planting techniques. He foresaw what, with the advancement of science, biologists are now confirming.

"Mixed crops are the rule," Howard wrote, "In this respect the cultivators of the Orient have followed Nature's method as seen in the primeval forest. Mixed cropping is perhaps most universal when the cereal crop is the main constituent. Crops like millets, wheat, barley, and maize are mixed with an appropriate subsidiary pulse, sometimes a species that ripens much later than the cereal. The pigeon pea (Cajanus indicus Spreng.), perhaps the most important leguminous crop of the Gangetic alluvium, is grown either with millets or with maize." (Howard, 1943)

Howard continues, *"The mixing of cereals and pulses appears to help both crops. When the two grow together the character of the growth improves. Do the roots of these crops excrete*

materials useful to each other? Is the mycorrhizal association found in the roots of these tropical legumes and cereals, the agent involved in this excretion?" (Howard, 1943)



Fig. 37. Dr Christine Jones in the UTube lecture video stresses “*Species richness was the most important factor for soil carbon sequestration*” Jones, PhD, Founder of ‘Amazing Carbon’ (Australia) and soil ecologist Dr Christine Jones with very many thanks to the authors – ‘Nitrogen: The double-edged sword’ (Jones, n.d.-b; Jones, 2018b)

“Science at the moment is unable to answer these questions: she is only now beginning to investigate them. Here we have another instance where the ‘peasant farmers’ of the East have anticipated and acted upon the solution of one of the problems which Western science is only just beginning to recognise. Whatever may be the reason why crops thrive best when associated in suitable combinations, the fact remains that mixtures generally give better results than monoculture. This is seen in Great Britain in the growth of dredge corn, in mixed crops of wheat and beans, vetches and rye, clover and rye-grass, and in intensive vegetable growing under glass. The produce raised under Dutch lights has noticeably increased since the mixed cropping of the Chinese vegetable growers of Australia has been copied. (Mr F A Secrett was, I believe, the first to introduce this system on a large scale into Great Britain. He informed me that he saw it for the first time at Melbourne.)” (Howard, 1943).



Fig. 38. By way of further example, Dr Christine Jones in her UTube presentation “*Building New Topsoil Through The Liquid Carbon Pathway*” shows this slide, of a wheat field in Australia in a drought year. The green wheat strip was a fence line, that had never previously been cultivated, thus was previously populated by native grasses and weeds, and is indicative of the drought protective properties of soil rich in mycorrhiza and carbon. With very many thanks to the authors. (Jones, n.d.-a)

The Jena study reported that much larger increases in nitrogen were observed with more cover plant species; one species made little difference, but when 16 species were combined, they resulted in increased productivity. In terms of growth, sixteen species with no nitrogen addition outperformed the addition of 0, 100kg or 200kg nitrogen per hectare per year to 0, 1 or 2 plant species. In a variation on a theme, brassicas only form mycorrhizal associations when multiple species are present, so cabbage growth, for example, gains specifically from cover crop usage (Mkhathini, 2012).

Jones also referred to work by Gabe Brown, who, after experimenting with multiple farming techniques over many years, found his soil carbon sequestration rose most rapidly when he combined multispecies cover crops with a deliberate policy not to use artificial fertilisers, combined with rotational grazing with cattle to not more than half crop height. Over 20 years, he achieved a documented 6 times increase in soil carbon, from 1% to 6%.



Fig. 39 a and b. Adjacent multispecies and mono-crops in a very dry period. Slide from the UTube lecture *'No-till on the Plains 2019; Dr Christine Jones; Community Tipping Points: Enhancing crop nutrition, yield and resilience through Quorum Sensing'* with many thanks to the author. (Jones, 2019a)



Fig 41. *“Triticale monoculture (left foreground) suffering severe water stress while triticale sown with other species (background and right) is powering. In addition to triticale, the ‘cocktail crop’ contained oats, tillage radish, sunflower, field peas, faba beans, chickpeas, proso millet and foxtail millet.”* Chinook Applied Research Association, Oyen, Alberta (2015). Photo: Dr Christine Jones. From *‘Light Farming: Restoring carbon, organic nitrogen and biodiversity to agricultural soils’*, with many thanks to the author. (Jones, 2018a)



Fig. 40 Adjacent multispecies and mono-crops in a very dry period. Slide from the UTube lecture *‘No-till on the Plains 2019; Dr Christine Jones; Community Tipping Points: Enhancing crop nutrition, yield and resilience through Quorum Sensing’* with many thanks to the author. (Jones, 2019a)

The Burleigh soil cover crop trial in North Dakota, US, was a 2006 experiment involving adjacent field areas. The plants thrived where 25 mixed species grew together in extremely dry conditions. In stark contrast, a plot containing only five mixed species failed, as did another featuring monoculture cover crops. Similar results were seen during research by the Chinook Applied Research Association in 2015, as evidenced in the images below, and referenced on the next page in a slide from the same video lecture *'No-till on the Plains 2019'*; Dr Christine Jones.



Fig. 42 Milk production increased 4 – 5 litres on multi-species/family crop compared to rye. Slide from the UTube lecture *'Profit, Productivity, and NPK with Dr Christine Jones'* Lower Blackwood LCDC with very many thanks to the authors. (Jones, 2022)

Christine Jones reports in the YouTube lecture *'Profit, Productivity, and NPK with Dr Christine Jones'*, as recorded and referenced in the slides above, that multispecies crops of four or more plant families were seen to have more nutritional value in terms of sheep live weight gains and milk production. This would be consistent with regenerative crops having higher mineral and protein value, as well as wider microbial variety.

The results are consistent with those discussed above and reported by Christine Jones at Wilith Farm in Altimuri in New Zealand and by the generality of reports by Gabe Brown. The farmer at Wilith used multi-species cover crops as cattle grazing pasture, with no artificial fertiliser input, on volcanic pumice, so difficult but potentially mineral-rich soils, and was delighted and surprised to see he had increased his soil organic depth by approximately 16cm in a year. His cattle, which grazed on the cover crops, exhibited improved health, fertility, milk yields, and butter fat content, and he had fewer veterinary visits (Jones, n.d.-a; Jones, n.d.-b; Jones, 2018b; Jones, 2019b).

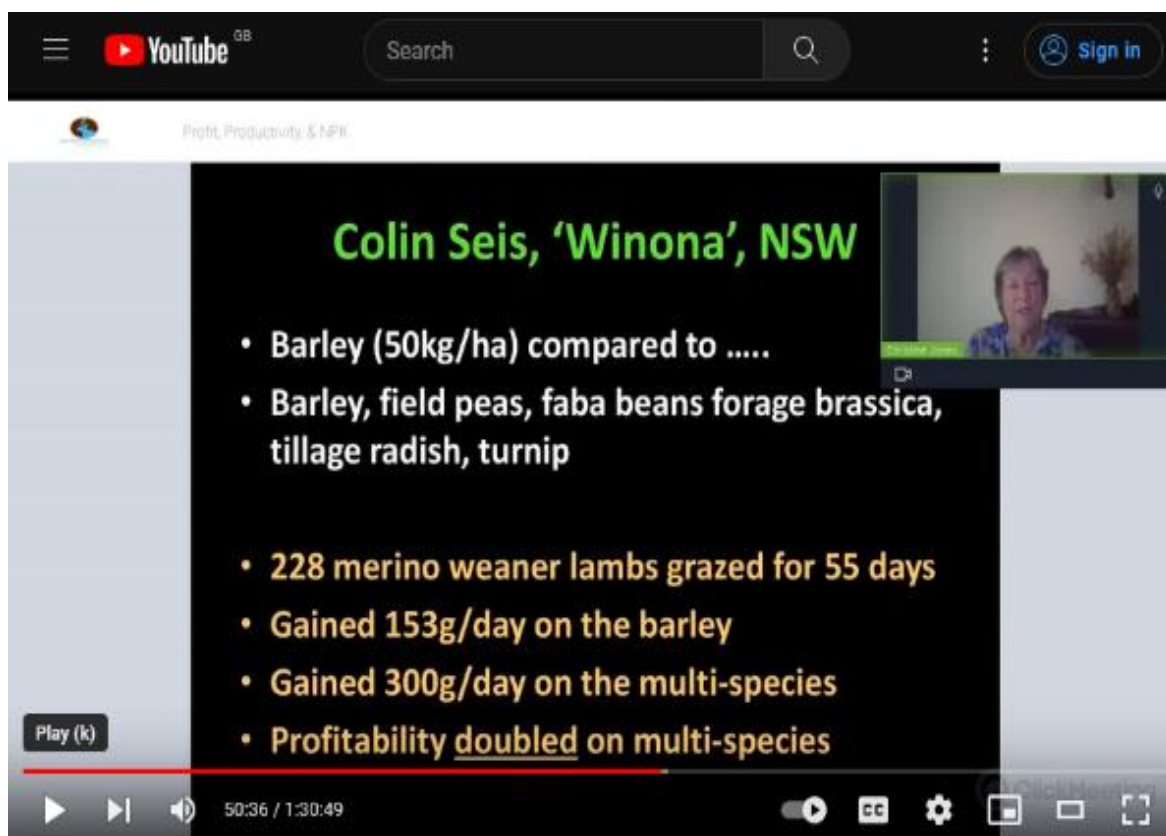


Fig. 43. Slide from the UTube lecture '*Profit, Productivity, and NPK with Dr Christine Jones*' with very many thanks to the authors. (Jones, 2022)

Mixing of species has a long agricultural history. Morgan Ruelle from Clark University notes, *"The once widespread practice (of mixed species crops) is now only used by small farms in places like Caucasus, Greek Islands, and the Horn of Africa. Despite being incredibly simple, most of the agroecology community weren't aware of it. Yet farmers have been using this technique for more than 3,000 years across at least 27 countries. It may have even been what gave rise to agriculture in the first place."* According to Ruelle, *"The method is planting maslins – a combined mix of cereals that can include rice, millet, wheat, rye, barley and more – and harvesting them all together to be separated or used as a single product."* (Koumoundouros, 2023) Chinese farmers similarly used mixed crops for thousands of years with good outcomes. Sir Albert Howard also recommended the practice.

A review titled '*Use of cover crops for sustainable management of soil condition and health: A review*' concluded *"A total of 190 studies from various countries, climatic zones, and agricultural practices were analysed, with the majority of data originating from 2–3-year studies conducted in the USA. The findings reveal that cover crops reduce soil bulk density by 1–24 %, increase organic matter by 7–74 %, enhance macropores by 1–67 %, and improve water infiltration rates by 5–629 %. Additionally, cumulative infiltration rates increased by 29–170 %, and Ksat was elevated by 10–627 %. Long-term studies (spanning 15 to 34 years) indicated even greater improvements in Ksat and soil porosity."* (Cercioglu 2025)



With thanks to Adobe Stock

In the words of Christine Jones, *“When the entire farm functions as a riparian buffer, catchment health and water quality are vastly improved. In addition to supporting a raft of ecosystem services, healthy soils underpin high-yielding agricultural production, farm profit and the wealth of the nation.”* (Jones, 2017).

Once we accept that different plants favour different mycorrhizal organisms and that a thriving microbiome is wholly advantageous, it becomes clear why growing multispecies cover crops produces healthy soils. In contrast, tillage of bare ground, the application of ‘artificial’ fertilisers, and the use of agrochemicals degrade the environmental ecosystem.

25.4 ADVANTAGES OF PLANTING DIRECTLY INTO COVER CROPS

The soil biome is entirely dependent on plants for the supply of carbon sugar-root-exudates. When growing crops are no longer present after harvest, they are obliged to effectively cannibalise their soil compatriots to survive.

Thus, the author posits that when a crop is harvested or terminated by roller crimping or disking, the soil biome will be highly motivated in seeking new plants to support its carbon

sugar exudate needs to replace those removed or terminated. The soil biome will logically be actively seeking to foster new plant growth, and more so as the termination is outside their timeframe expectations.

Farmers who plant seed into living cover crops and terminate the cover crops when the new seeds germinate report good results. Interestingly, a farmer reported that if he planted soy into wheat immediately after harvesting, the seeds would germinate, but not if planting was delayed a few days.

In the same vein the book 'Ploughman's Folly' reports that plants transplanted flat onto compaction points with soil placed over roots, on newly disked land, subsequently machine stamped by 'feet' on a roller, creating compaction points, were always were upright on the following day, as supported by the capillary action of the soil biome, in the terms, *"Every crop we planted in 1939 and 1940 was established by use of this compression marker. More than eighty-five thousand plants were involved, without any artificial watering whatever. Seventy-five thousands of the plants were shipped from southern Georgia in hot weather, yet no water was used in transplanting them. In some cases this may have been unwise, but this was not the chief cause of the considerable loss of plants in 1939. In 1940 there were no losses worth mentioning. Our method involved encasing the plant roots in soil which already was being supplied with capillary water from below. Roots laid in the marker track and covered with firmed earth were considered properly set. **They stood erect by next morning, always.**"* (This author's underline) (Faulkner 1945) (free copy on Small Farms Library, which has an excellent selection of out-of-print farming books https://journeytoforever.org/farm_library.html#folly and other sources)

Having spent much time puzzling as to this report, this author postulates that a soil biome still biologically active at the point is disking, immediately post disking, is actively looking for new plant symbionts to interact with, and on finding the roots of the transplanted plants, in the expectation of receiving carbon sugar exudates redirects resources, continuing supply of water, water, nitrates, phosphates etc to the transplanted plants, which accounts for their rapid revival. It is also postulated that the desire of soil biomes to find new plant symbionts, is why a farmer found soy would germinate if immediately planted in wheat following wheat harvest, and why those who plant seed into a living crop before its later termination have successful outcomes.

Planting into living cover crops is an emerging technique. Some farmers have been using it for several years and continue to do so. However, as reported in the video referenced below, it requires trials, and adaptation of equipment.



How to Plant into Cover Crops (4K)



Griggs Farms LLC
32.2K subscribers

Subscribe

1.4K



Share

Save



Fig. 44. How to Plant into a Cover Crop; and an instructive video on techniques and equipment modification for planting into cover crops, with many thanks to the Authors, Griggs Farms LLC.

25.5 REGEN AG – OVEN-READY FREE PROVEN TECHNOLOGY – HEAL THE PLANET

Regenerative agriculture, nature's climate eco-regulation solution technology, is simple in principle yet immensely complex, free, proven, and 'oven-ready'. Implementation of regenerative agriculture will help mend the planet, and mitigate climate change, including drought and related damage, by optimising photosynthetic capacity, soil biome health, carbon dioxide drawdown, and oxygen production, at the same time reducing; water run-off and floods; regional degradation of hydrology, disruption of inland flows of moisture in oceanic air; soil heating; heat domes; as well as ocean deoxygenation and acidification.

No other technology is available that can begin to match the sophistication and interconnected symbioses nature provides. Adopting a regenerative approach to our soils may not fully mitigate the effects of carbon dioxide emitted from fossil fuel combustion, and the size of the effect may diminish over time; however, it can make a significant contribution and is logically essential if climate mitigation is to be successfully implemented.

Indeed, I believe that if we choose to work with nature to support life rather than dominate it resulting in ecocidal soilcide, we will marvel at the extent of nature's capacity, once harnessed, to help remediate many current climate issues.

As a bonus, in addition to improving soils and climate, regenerative agriculture yields better, more nutritious, and less polluted food. It also reduces agricultural pollution, including agrochemical damage, eutrophication of oceans by fertiliser runoff, pollution by sewage sludge, and microplastics, helping secure terrestrial and ocean food resource availability, thus

ensuring a happier, healthier future for the human species. We are, after all, what we eat and drink, and there are many of us.

26 CAN REGEN AG FEED THE WORLD?

It has long been argued that the use of fertiliser and agrochemicals associated with FATBAS is necessary and essential to feed the world, and that greener farming paradigms cannot. The reality is that regenerative agriculture can achieve equivalent yields with higher nutrient density and lower, or even no, agrochemical and other environmental pollutants.

Regenerative agriculture is fundamentally different from organic farming. Regenerative agriculture is all about healthy soils, as opposed to organic farms, which often focusing mainly on a checklist of things that cannot be done or used, without necessarily prioritising the key parameter of soil health.

Organic farming, including the outcomes in Sri Lanka and Sikkim, is discussed in the sections below. The capacity of regenerative agriculture to produce equivalent yields while generating higher profits for farmers is evidenced by the Boston Consulting Group and McKinsey reports cited earlier.

26.1 EQUIVALENT YIELDS

In reality, well-managed regenerative farms are, without artificial inputs, achieving equivalent or better crop yields of higher nutrient density on a more sustainable basis, increasing soil carbon and achieving surprising drought resistance, improved water infiltration and storage, greater profitability, and enhanced insect and wildlife diversity. Disease and pest issues were controllable, and rarely was any agrochemical intervention economically worthwhile.

There is growing support for the introduction of regenerative agriculture into food chains by farmers from multinational food and agriculture companies, including ADM, Cargill, Nestle, McCain's, and Danone, and even growing acknowledgement that there is another way from FATBAS giants such as Bayer and Syngenta. Their corporate, ultimately profit-driven focus and investment in a regenerative agriculture transition of millions of acres at some level, is robust evidence that regenerative agriculture is seen as an economically and yield-feasible, practical, long-term, profitable and sustainable way forward.

In contrast, FATBAS results tend towards actual declining yields, water stress, soil and food pollution, and widespread and diverse environmental damage, and it is increasingly evident that FATBAS is not sustainable in the long term.

26.2 NUTRIENT DENSITY IS HIGHER IN REGENERATIVE CROPS

FATBAS also reduces nutrient density, while regenerative agriculture improves it. Furthermore, artificial fertilisers and increased atmospheric carbon dioxide, both individually and collectively, reduce crop nutrient density and the quality of food and feedstocks.

The provision of artificial nitrates and phosphates to plants disincentivises the supply of carbon sugar root exudates to soils. In turn, the soil biome supplies fewer minerals, nitrates, and other plant-assistive materials.

In contrast, a regenerative agriculture-based healthy diverse soil biome provides plants with soluble minerals in plant-available forms, which is more efficient, diverse, better attuned to the plant's actual needs, and a more consistent supply mechanism than soluble artificial fertiliser products.

Increased atmospheric carbon dioxide potentially magnifies the FATBAS-related declines in plant nutrient density. Plants are “*growing faster [and] have on average more starch, less protein and fewer key vitamins in them*” (*Higher carbon dioxide levels increase plant growth, not nutritional value - Farm and Dairy*, 2018). FATBAS itself contributes to rising atmospheric carbon dioxide, thus contributing to declining food nutrient values by multiple mechanisms.

There is much to learn, but a global transition to regenerative agriculture is both feasible and necessary to maintain healthy humans, livestock, and other species that subsist on plant-based materials, ultimately leading to a healthier ecosystem.

26.3 FOOD QUALITY, NUTRITIONAL VALUE, ANTIOXIDANTS. CONTAMINANTS

Foods and feedstock are also increasingly polluted with a range of contaminants of concern, including pharmaceuticals, antibiotics, PFAS, and microplastics. These contaminants originate from sewage-related products applied to farmlands and are further enhanced by pollutants in artificial fertilisers.

Regenerative agriculture removes many sources of food contaminants and increases plant nutrients, including antioxidant content, while providing the farmer with equivalent yields and greater profitability.

26.4 CAPACITY TO FEED THE WORLD – UNITED NATIONS SUPPORT

In addition to being sustainable and profitable, any agricultural methodology adopted must be capable of feeding the world. It was regularly stated, and still is, that economically productive ‘organic’ farming is impossible without artificial fertilisers and agrochemicals. Until recently, it was commonly portrayed that ‘green’ ‘organic’ agriculture was incapable of feeding the world because productivity and crop yields from non-artificial NPK fertilised bare ground ‘organic’ agrochemical and or fertiliser-free mono-cropping were often low, and indeed they were.

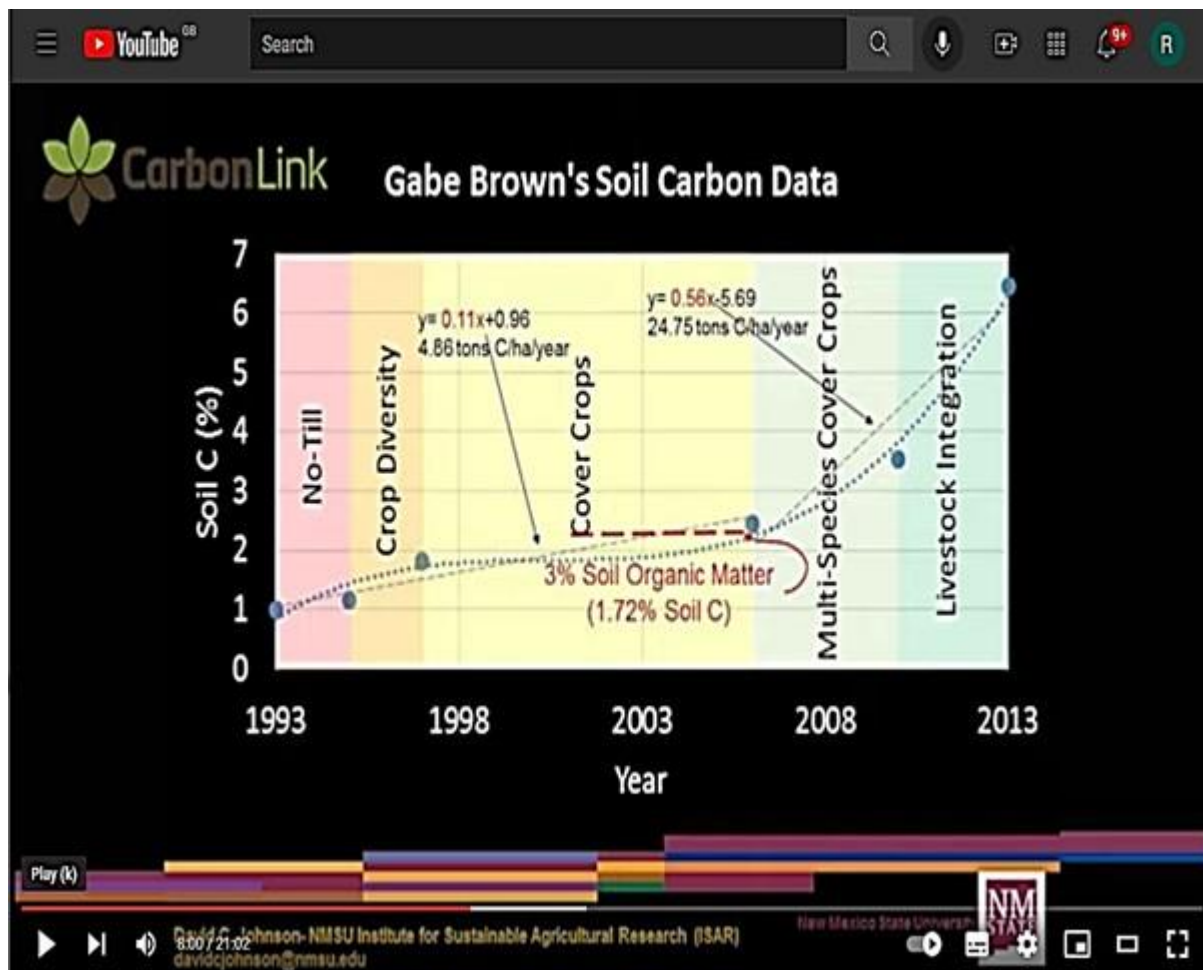


Fig. 45. From video lecture by Dr David Johnson, citing independent soil carbon data history following the transition of Gabe Brown to regenerative agriculture. From *'The BEAM (Biologically Enhanced Agricultural Management)' Approach* with very many thanks to the Authors. (Johnson, 2017)

By way of explanation, historically, organic farming focused more on the avoidance of additives and agrochemicals whilst retaining the traditional industrial bare-ground mono-crop model, often box-ticking the absence of forbidden artificial input, rather than focusing on optimising soil health and keeping soils green year-round, because there was insufficient understanding, or thought, on how best to optimise natural biological systems.

In contrast, regenerative agriculture has been shown to be capable of equalling or improving average regional fertiliser farming-based yields by focusing on optimising soil health and biology, while pragmatically accepting that the occasional use of agrochemicals may be necessary but is often not.

Regenerative farmers have achieved yields equivalent to regional averages without the use of artificial fertilisers or significant agrochemicals. At the same time, they produce crops with higher mineral and protein content, sequester soil carbon, improve hydrology, and achieve multiple other benefits, as well as being more profitable, as detailed later.

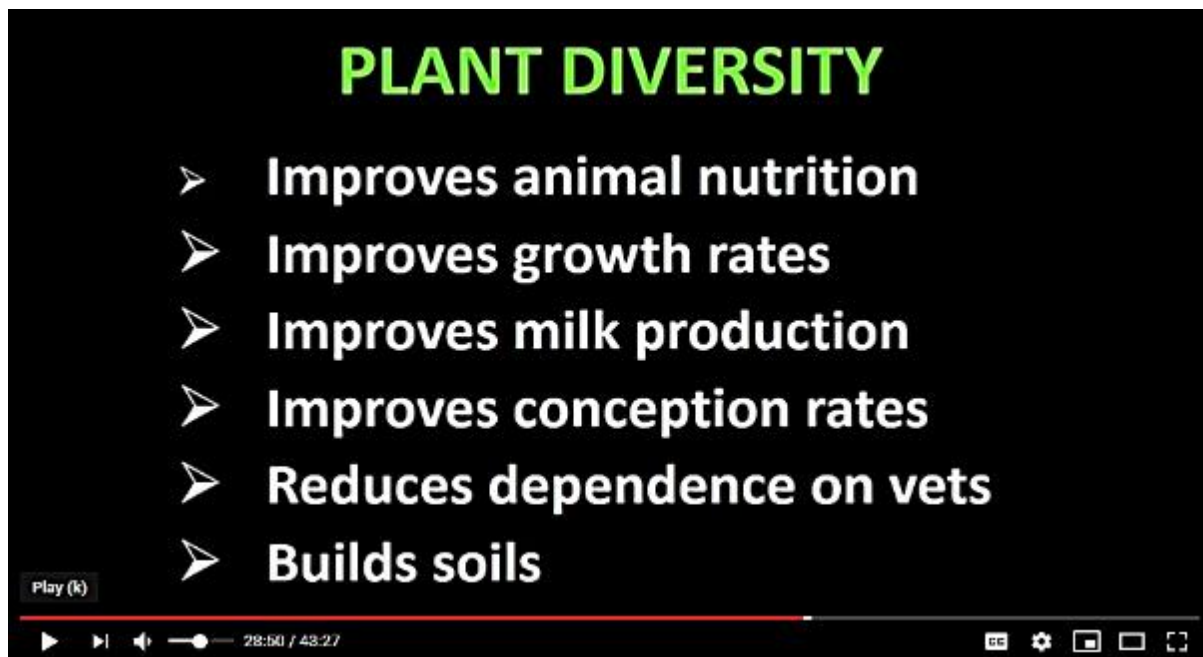


Fig. 46. Wilith Farm Atiamuri, used multi-species mixed cover crops, with no fertiliser, on volcanic pumice soils as grazing pastures. (*Understanding The Role Of Soil Microbial Interactions For Soil Health*) - Dr Christine Jones, Soil Ecologist, Australia, from the 2019 Conservation Tillage and Technology Conference, March 5 - 6, 2019, Ada, OH, USA. With very many thanks to the authors. (Jones, 2019b)

Further, as discussed in other sections and summarised in the slide above, cattle farmers have increased milk yields and quality, reduced cattle exposure to nitrates, doubled land carrying capacity, improved livestock health, and achieved premium prices for their milk and meat.

Indeed, an increasing number of farmers are proving, at scale, that regenerative optimisation of photosynthetic capacity, microbial health, and land diversity increases crop nutrient density and sales value, produces equivalent or better yields, and is more profitable due to decreased costs and increased income.

Moving away from the FATBAS agricultural models and no longer restricted to the sometimes-fluffy exhortations of 'organic' purists, idealists and dreamers, pragmatic regenerative agriculture has had real benefits. These include equivalent crop yields and greater sustainability, recognised at a high level by the UN. However, depressingly, the political and economic will to implement them has been slow to catch up.

United Nations Development Program at the '*The UN Food Systems Summit, held during the UN General Assembly in New York on September 23,*' stated: "*warming beyond 1.5°C above preindustrial averages will have increasingly severe impacts on food systems*".

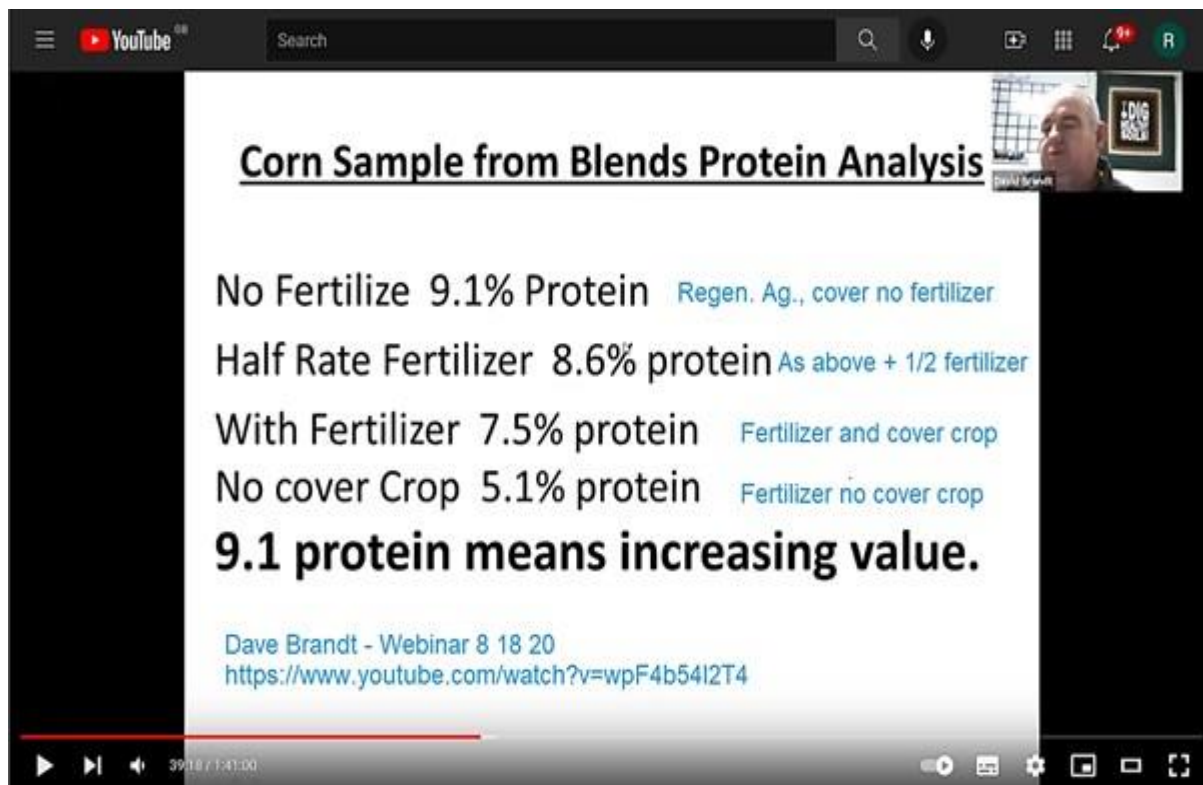


Fig. 47. slide from the David Brandt Webinar titled '40 years of regenerative agriculture' with very many thanks to the authors. (Brandt, 2020)

"We've long known that our food systems are broken – that they threaten the health of both people and the planet. Not only have unsustainable agricultural practices been degrading soils for decades, but the expansion of agriculture is also the primary driver in 80 percent of native habitat loss globally.

Current agricultural and food systems also drive inequality and hunger. While we have a sufficient global food production to feed the world, 10 percent of the world's population go hungry due to unequal distribution and access to food. The situation is not set to improve: global food demand is expected to increase by 50 percent by 2050, with a negative impact on land and soil degradation.

Food production also accounts for a quarter of the globe's greenhouse gas emissions. The IPCC has warned that climate change is already affecting food. . . . Transitioning back to nature-positive production practices will allow producers to increase food supplies while generating long-term returns for themselves and the planet. The solutions are within our reach, but we need a paradigm shift, driven by five key transformations."

The UN had received "commitments from more than 90 heads of state and government for global food systems transformation by 2030.", recognising "Agroecology, regenerative agriculture, agroforestry, and agrobiodiversity provide the solutions we need to place nature back at the centre of our food systems." (Trémolet, 2021)

27 REGAN AG - A REALISTIC OPTION FOR FARMERS?

‘Regenerative agriculture’ expands on the wisdom of four millennia of Chinese farmers, as reflected in the experiences and recommendations made in the 1930s and 40s by renowned agronomists, including Sir Albert Howard and Albrecht.

Howard, the primary then agricultural adviser in India on small-scale agriculture, was a very early proponent of the value of composts and the importance of focusing on soil quality in improving land sustainability, crop yields, quality, nutritional and keeping qualities, livestock and human health, without the need for ‘artificial’, whilst at the same time maintaining profitably.

Regenerative agriculture, at its heart, is about fostering soil health, which requires maintaining soil carbon levels by keeping land ‘green’, thus maximising photosynthetic carbon production with minimal artificial inputs. Regenerative farming is pragmatic and recognises the primary imperative, which is that farmers need to be profitable and productive.

Regenerative agriculture can be tailored to individual circumstances, aims, and aspirations, allowing farmers to find their own path. Some start using minimal agrochemicals, but over time, find they rarely need them. Others initially feel obliged to use herbicides due to seasonal growing constraints. The debate in regenerative agriculture circles around optimal techniques most suited to soil types, climates, and crop types is vigorous. However, all agree on the long-term and central importance of maintaining healthy soil biology and minimising pollution and broader environmental damage.

The term regenerative agriculture, at its core, describes farming techniques consistent, as far as pragmatically possible, with optimising soil biology, diversity, soil carbon content, water retention and regional hydrology through eschewing bare ground, tillage, NPK fertiliser and agrochemicals; and maximising the photosynthetic potential of every acre (year-round green land is good) by using; plant diversity, cover-crops, bio-stimulants including compost teas, low till, integrated livestock grazing where appropriate.

Where practical and feasible, livestock are incorporated using techniques such as ‘mob’ half-height rotational grazing. Appropriate integration of livestock, including cattle, pigs, sheep, and chicken, without the use of insect-killing ‘de-wormers’ helps maintain soil fertility, distributes biology, including via earth conditioning worms and beetles, manures the land, spreads seed for perennial pastures, reduces bare areas of soil, and ensures that landscapes do not desertify due to the accumulation of dead oxidised organic material on the soil surface.

For an overview of regenerative agriculture, the video ‘*Regenerative Agriculture Healing the World - By Ray Archuleta @ Carbon Summit*’ (Archuleta, 2021b) is strongly recommended viewing. Ray is a qualified conservation agronomist with a traditional industrial agricultural background, including having worked for a US government agency. Ray has had a regenerative farming epiphany. His video presentation is ‘impassioned’ in tone, but bear with it, as the information and related images are profoundly thought-provoking. The images in his videos of regenerated deserts, seasonal changes in atmospheric carbon dioxide, bare soils, biology in soils, and regenerative farming economics strongly make the point that there is another way.

Gabe Brown, a former hands-on farmer, now educator, with a strong focus on livestock integration, provides practical advice, based on personal experience, on regenerative farming, in simple direct and informative terms, and as part of educational and advisory facilities he has set up, as evidenced in the video interviews “*From Dirt to Soil: The Guys Get To Know Gabe Brown*” (Brown, G., 2022) hosted by Field Work, and “*Adaptive Grazing Webinar: Gabe Brown*” hosted by Silver Creek Capital (Brown, G., 2022 a).

Gabe Brown suggests using mixed cover crops and incorporating livestock where possible, with the addition of biologically rich compost and extracts on depleted soils, to speed the initial development of biology. Others, such as Dr Elaine Ingham, who focuses mainly on the importance of soil life, pragmatically suggest light tillage, which, with biologically rich compost use, may be more suited than no-tillage to specialist crops, including some vegetables and onions.

Increasing evidence is emerging, as discussed later, that regenerative agriculture is practical, sustainable, profitable, capable of feeding the world, and has multiple other benefits. The beauty of the regenerative movement is that it allows for diversity and individual development according to personal aims and circumstances while maintaining common aims of eschewing ‘artificial’, agrochemicals, and artificial fertilisers, and crucially improving soil quality, life, diversity, and soil water and carbon content. Time will help define and improve techniques, but all agree that maintaining diverse, healthy soil biology and plant cover throughout the year is essential.

When the climate impact of regenerative agriculture is added, arguably, regenerative practices are not just agricultural tools but global ecosystem climate interventions that will help restore nature's climate regulation and reduce the impact of climate change.

27.1 REGEN AG - ECONOMICALLY PROFITABLE

Self-evidently, farmers need to make a profit. As the graph below demonstrates, profits from farming that relies on FATBAS NPK and agrochemical technology are declining in the long term. The health of farmers is suffering, suicide levels are high, and the capacity for farms to be passed down through generations is impaired. FATBAS is no longer an attractive career. Soils are being degraded, which in turn contributes to global warming, water shortages, and climate disruption. Regenerative farming addresses many of these issues, but is it a profitable approach?

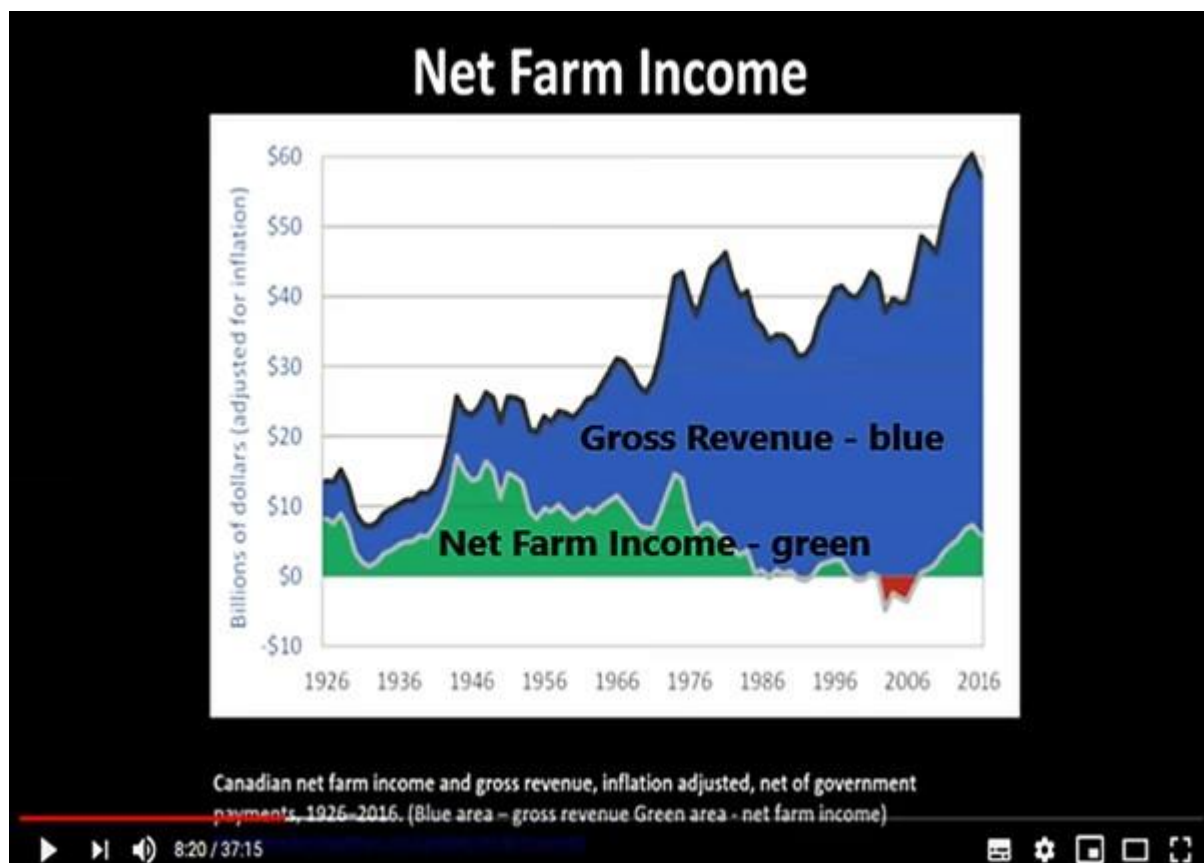


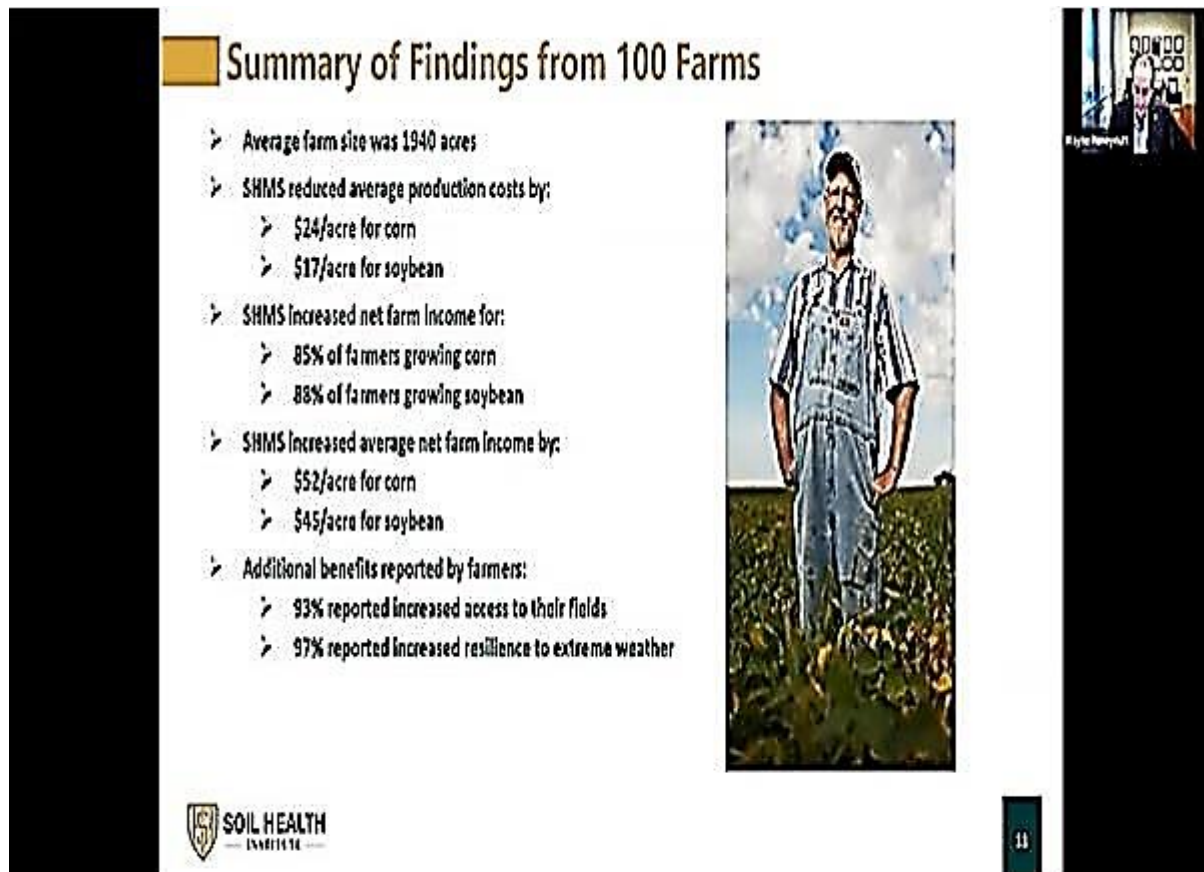
Fig. 48. Annotated slide from lecture by Dr Christine Jones – ‘*Building New Topsoil Through The Liquid Carbon Pathway*’ (@7.20) Conservation Tillage and Technology Conference 2019 with many thanks to the author. (Jones, n.d.-a)

The good news is that regenerative' soil-carbon-centric farming' is doable and profitable. Growing numbers of skilled, experienced commercial farmers, obliged by life's realities to turn a profit, are reporting economic, ecological, and wider-life benefits from using these techniques.

Farmers moving to more 'soil-carbon-centric farming' generally report better soils, yields, reduced inputs, diminished erosion and runoff, and, crucially, greater profitability. For example, as outlined in some of the referenced videos, Gabe Brown is generating profits by farming regeneratively in Iowa. The Haggertys are successfully regeneratively farming 20,000 or more hectares in the low rainfall sand soil paddocks of Western Australia. There are numerous reports of sizable farms achieving yields equivalent to or better than those on smaller farms, while also generating greater profits, albeit not all do.

Growing numbers of farmers in online webinars, including the Haggertys, Gabe Brown, Rick Clarke (see slide below) and others, as well as those reported on in a research project of regenerative farmers funded by Cargill (see slide below), conducted by the Soil Health Institute involving 100 good sized farms in the USA, of average area 1940 acres, which have been regenerative for at least 5 years, demonstrate regenerative agriculture is in mostly more profitable, often resulted in improved yields, was more resilient, and better for farmers.

It is inherent in human nature that those who derive income from the agricultural status quo will often resist change for various reasons, such as habit, fear, lack of time and energy, sometimes simply circumstance and sheer economic or broader necessity. Sadly, there is no guarantee that regenerative agriculture will be well received by the agricultural sector, particularly given the likely resistance to change by existing agricultural fertiliser and agrochemical industries. Indeed, *“Frequently good ideas do not receive the acclaim they deserve because of prejudices, ignorance, religious preferences, social mores and other reasons not fully understood by scientists”* (Menge, 1985).



Summary of Findings from 100 Farms

- Average farm size was 1940 acres
- SHMS reduced average production costs by:
 - \$24/acre for corn
 - \$17/acre for soybean
- SHMS increased net farm income for:
 - 85% of farmers growing corn
 - 88% of farmers growing soybean
- SHMS increased average net farm income by:
 - \$52/acre for corn
 - \$45/acre for soybean
- Additional benefits reported by farmers:
 - 93% reported increased access to their fields
 - 97% reported increased resilience to extreme weather

SOIL HEALTH INSTITUTE

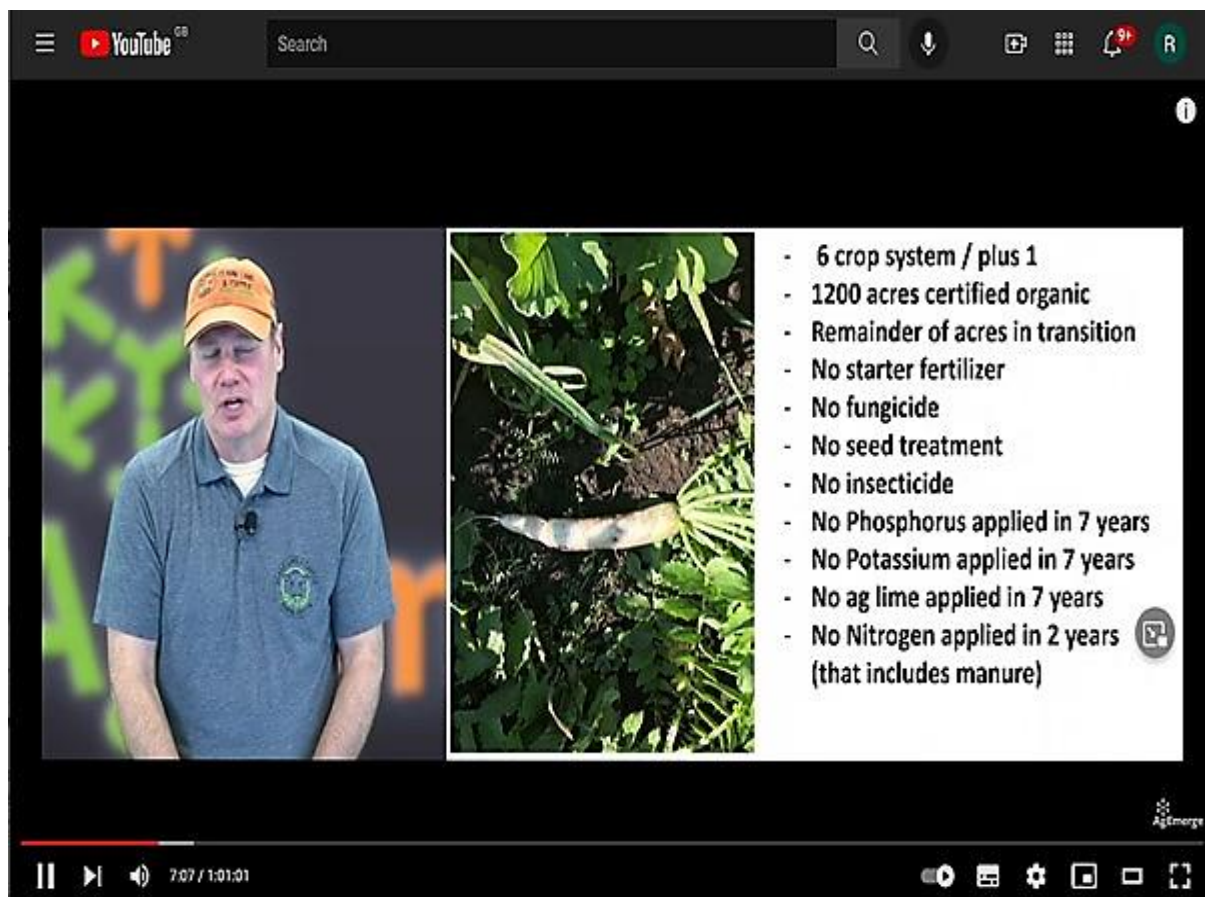
Wayne Honeycutt

Economics of Soil Health Systems

Fig. 49. Slide from Wayne Honeycutt Ph. D UTube lecture titled *‘Economics of Soil Health on 100 Farms’* - Soil Health Institute – with very many thanks to the author. (Honeycutt, 2021)

Their successes are attracting significant interest and investment from major international corporate food producers. Many large international food corporations, including companies as diverse as Nestle and Pepsi, are increasingly and proactively recognising regenerative farmers, such as Rick Clarke, are producing equivalent yields and greater profits without artificial fertilisers in sustainable ways that benefit the planet, including slowing the impact of climate change, and as a result such corporations are putting considerable funding and effort into regenerative agriculture, including training assistance, seeing it as the future in securing the sustainable affordable quality food-chain raw materials desired by their customers, provides hope that a move to more sustainable agriculture is starting.

It is essential not to lose sight of the fact that the term regenerative agriculture will be used to describe different systems and products, some of which will still, to some extent, rely on artificial inputs (McCain, *n.d.*; Robinson, 2021). However, pragmatically, one can only welcome defined, rewarded, and supported strategies, including research and education, that aim to introduce regenerative agricultural practices within prescribed timelines. One can only hope that over time, success in reducing inputs will lead to improved practice and ultimately actual regenerative outcomes, healthy herbage rather than corporate greenwash verbiage, because, and of fundamental importance, regenerative agriculture is potentially more productive, profitable, pleasing to humans, as well as 'Gaia' ecosystem sustainable.



The image shows a YouTube video player interface. The video content features a man in a blue polo shirt and an orange cap on the left, and a slide on the right. The slide lists the following practices:

- 6 crop system / plus 1
- 1200 acres certified organic
- Remainder of acres in transition
- No starter fertilizer
- No fungicide
- No seed treatment
- No insecticide
- No Phosphorus applied in 7 years
- No Potassium applied in 7 years
- No ag lime applied in 7 years
- No Nitrogen applied in 2 years (that includes manure)

The video player shows a progress bar at 7:07 / 1:01:01 and the AgEmerge logo in the bottom right corner.

Fig. 50. Slide from AgEmerge Breakout Session with Rick Clarke - Farmers making money in real life with Reg Gen Ag with very many thanks to the Author: practicalities, and benefits of green fertiliser, agrochemical free 'regenerative' agriculture. (Clarke, 2021)

27.2 EDUCATE, PREPARE, UNDERSTAND AND IMPLEMENT

The need for education at the farmer, industry, public and government levels cannot be overstated. An aspiration to move to regenerative agriculture is a quantum change, requiring massive industrial refocusing and a change in agricultural support subsidies. Sikkim, in its capacity as an Indian State, provides a model to go beyond organic to regenerative, incorporating the environmental benefits of 'organic' farming (Toop, 2022).

FuturePolicy.org provides background Sikkim Government policy documentation, which recognises the importance of cohesive planning, education, implementation and facilitation (FuturePolicy.org, n.d.), including “*State Policy on Organic Farming Government of Sikkim*” (Sikkim, 2004) and “*Sikkim Organic Policy Vision and Mission*” (Sikkim, 2010):

“The main objectives of the mission shall be-

- 1. Frame policy of organic farming in the state.*
- 2. Prepare a clear cut implementable road map of organic farming.*
- 3. To implement the programmes of organic farming with a systematic approach to achieve the target set by the Govt.*
- 4. To develop and explore markets of Organic commodities.*
- 5. To develop linkage between the organic farmers and the market with intervention of certification agencies so as to continue the policy permanently.*
- 6. To develop Sikkim organic brand with proper logo.*
- 7. To make farming profitable, sustainable and environmentally acceptable”.*

The Sikkim Government provided support in the form of financial assistance, legislation, ongoing education, and technical expertise. Every government needs to develop educational and support policies for regenerative agriculture; Sikkim provides an example of a clear long-term vision and policy that produces tangible results.

The Cornell University SRI project is also a good example, illustrating the educational and practical importance of outreach, the exchange of experiences, and the power of videos in achieving understanding, acceptance, and transition. Conversely, Sri Lanka provides an example of a rushed implementation of a mandatory move to ‘organic’ agriculture.

27.3 THE SRI LANKAN ‘ORGANIC’ EXPERIENCE - REGENERATIVE ≠ ORGANIC –

While regenerative agriculture and organic agriculture share similarities, they differ in emphasis. Regenerative agriculture focuses on restoring soil health, which can be initiated quickly but requires time. In contrast, Organic agriculture focuses on the exclusion of artificial inputs, which can be achieved at the stroke of a ministerial pen, but at risk of failure, as in Sri Lanka, because in its obsession with excluding artificial inputs, it fails to focus on the core metric: restoring soil biology and carbon.

Further, a product may be labelled ‘organic’ but be of poor quality as grown in degraded soil by a farmer struggling to make a profit; be too expensive for many, and low yielding, so insufficient in quantity to feed the world, even if people could afford the price.

The absence of artificial inputs, including agrochemicals and synthetic fertilisers, will enhance regenerative agriculture. However, regenerative agriculture may initially or occasionally require artificial inputs to achieve broader gains and provide farmers with the space and mental confidence that they are there if needed, thus assisting them practically in

transitioning to regenerative agriculture. The reality is that farmers transitioning to regenerative agriculture report that they very rarely need to resort to agrochemicals due to the better balance of prey and predators, as well as disease suppression by healthier plants. Indeed, for the crop losses involved, it is not economically worthwhile for them to do so (Noggle, 2019). Although, as mentioned above, some find that they need to use herbicides to kill cover crops before planting cash crops, they are increasingly finding alternatives, such as roller crimping.

Most farmers moving to regenerative agriculture find they are more profitable and achieve equivalent or better yields than under FATBAS fertiliser, agrochemicals, bare ground agriculture. Although the prices they receive for their crops are not significantly higher, some carry a premium because the nutrient value is higher, or are also certified organic, adding to potential profits. Thus, given that regenerative farming is profitable and produces yields nearly equivalent to FATBAS, regeneratively produced food should not be significantly more expensive than FATBAS-produced food, hence affordable, with the benefit of being more nutrient-dense and a generally healthier option.

Conversely implementation of ‘artificially’ free, organic agriculture **without soil improvement** will not achieve good sustainable yields, healthy nutrient-dense plants, or all the benefits and ecoservices accompanying healthier soils.

The weakness of the organic agricultural system is evidenced by the negative outcome on yields seen in Sri Lanka, where the use of artificial fertiliser was stopped overnight, as explored in the article “*Sri Lanka’s organic farming disaster, explained*” (Torrella, 2022). Yields were inevitably not going to be matched without prior regenerative steps to improve the soil.

Farmers transitioning to regenerative soil-focused agriculture must do so within their means, ideally with the assistance of those with relevant experience, and possibly initially limiting change to a limited acreage. As discussed, there are multiple examples of excellent yields achieved with regenerative agriculture within various time frames – many farmers are better off from the first year of transition due to savings in input exceeding the value of any initial yield losses.

Experts emphasise that transition requires flexibility, taking into account local conditions, understanding the underlying principles of focus on soil health, recognising the need for advanced education and planning, ideally risk insurance, attention to detail, flexibility, record keeping, the confidence of farmers, and at least a growing season to start the process.

27.4 SIKKIM – THE WORLD’S ONLY ORGANIC ‘STATE’

Sikkim, an Indian state in the Himalayas, shares its border with China, Nepal, and Bhutan. It has been ‘organic’ since 2003, which has yielded invaluable benefits, given that Sikkim is an ecological hotspot in the lower Himalayas, with a wide climatic range and ecosystems ranging from tropical forests to tundras (ARTE, 2022). Their organic status should also have wider public health benefits, but these are difficult to quantify without a control.

Agriculture is a significant sector of the Sikkim economy that functions well. Sikkim's GDP continues to rise. There is a wide range of benefits from being an 'organic' state and a growing focus on soils and organic fertilisers. But arguably, as a consequence of the emphasis on organic rather than regenerative core principles, it is acknowledged that officially reported yields of staple crops, such as maize and rice, are on the lower end of the international scale, under two thousand kilograms (2 metric tons per ha), (ENVIS, 2022a; ENVIS 2022b). Yet, others using regenerative agricultural principles, including in the growing of rice in Nepal (see Rice section below), are achieving much higher yields (up to approaching 8 tons per ha.). Indeed, a regenerative SRI rice program study in Sikkim suggests SRI had benefits (Mohanty et al., 2014) and that higher yields can be obtained in Sikkim, up to 6.7 tons per ha (Avasthe et al., 2012). Such results suggest that, with further regenerative soil-centric amendments to their agriculture, including planting cover crops and considering mineral foliar sprays, subject to acceptance and suitability, they should be able to achieve better yields while remaining organic. Indeed, the Sikkim Government observes, "This yield could be increased by an *effective implementation of special food grain production programme (SFPP) and special rice development programme (SRPP).*" (Sikkim, n.d.)

27.5 RICE

Rice has been given a separate section as a global food staple because it is grown and consumed less in Western circles. One billion people derive their livelihood from rice. It accounts for 20% of the world's caloric intake, providing food for 3 billion people (MacArthur, 2022). Rice production also has a significant potential environmental impact at several levels, particularly water requirements and methane production.

Globally, agriculture is a significant user of the world's water. When grown using permanent root immersion, traditional rice production alone "*uses an estimated 34-43% of global irrigated water, or 24-30% of the total freshwater withdrawals (Bouman, 2007)*". Furthermore, the permanent submersion of roots in water results in anaerobic soils producing large amounts of methane, a greenhouse gas contributing to climate change. Rice accounts for 2% of global greenhouse gas emissions. 11 to 15% of global methane emissions are from flooded rice fields (MacArthur, 2022). Methane production and metabolism, including the roles of methanogens and methanotrophs, the relevance of regenerative agriculture, and its climate implications, are considered in more detail in Volume 1 on sewage.

Of great significance, rice farmers using various forms of regenerative agriculture, including 'System of Rice Intensification' SRI protocols, 'mixed farming' techniques, and planting directly into regenerative mixed species cover crops, significantly reduce water requirements yet achieve equivalent or often better yields without artificial inputs.

Several groups are investing in projects to bring various regenerative rice growing protocols to farmers and achieving significant success, such as agro companies such as Bayer working together with the Direct Seeded rice program, seeking to provide services, seeds, and carbon credits, and Mars Petcare, working with companies and Governments seeking to secure better quality crops and greater long-term security of supplies. Some regenerative rice farmers are following their own path, with significant success, as shown in the videos linked below.

As evidenced in the video referenced below, rice growers adopting the regenerative approach are achieving significantly higher yields, up to 8 tons per hectare, and greater profits. Direct rice seeding into cover crops reduces water requirements, methane production, labour, and fertiliser costs. Direct seeding into cover crops also gives seeds access, to active soil biology looking for plants to interact with, stored soil water, and metabolic water production by the soil biome.



Fig. 51. Slide from UTube video Regenerative rice farming in Cambodia; rice seed is then planted into cover crops, using no till roller crimp techniques, with very many thanks to the authors. (Meister, 2021)

A further benefit of cover-crop-based regenerative agriculture is that it removes the need for stubble burning, because the cover-crop seed can be planted into the rice residue following roller crimping. As discussed, stubble burning is wasteful of nutrients, including carbon and minerals, which end up in smoke. Heat damages soil surface biology, and the smoke, including pesticide residues, causes considerable pollution, often exacerbating poor air quality in cities

SRI is also growing in popularity. SRI rice still requires replanting, which is more labour-intensive than regenerative planting into soil growing cover crops. Nonetheless, SRI farmers are reducing inputs and improving yields, so more details are provided. *“SRI was developed in Madagascar 30 years ago by Henri Laulanié and is now spreading around the world. SRI methods have been shown to increase rice yields by 20 to 50%, often 100% and even more, with 25-50% reductions in water and 80-90% less seed”,* (FarmingFirst, 2015). For example, *“SRI methods substantially raised farmers' yields, from 4.8 tons to 7.6 ton per hectare a 58% increase”* (Gathorne-Hardy, 2013). ***The “impoverished households in Madagascar raise(d) their paddy yields from 2 tons/hectare to 8 tons/hectare — without new varieties, and using***

fewer inputs” (FarmingFirst, 2015). SRI implementation also improved soil quality. **After 4 years, 70% increases in soil carbon were seen** (MacArthur, 2022). The SRI International Network and Resources Center at Cornell University has been working to assess, improve, educate and disseminate SRI (FarmingFirst, 2015).



Fig. 52. Image and text from Fig. 1. *‘Learning about positive plant-microbial interactions from the system of rice intensification (SRI)’* with very many thanks to the authors. (Upoff et al., 2009)

SRI is being increasingly adopted globally. *“SRI methods qualify as ‘climate-smart agriculture’ and have many benefits particularly for women,” says Professor Uphoff. Beneficial impacts have been cited worldwide. For example, farmers in Haiti and Malawi have doubled their yields with SRI methods. Manonmani, a female farmer from Thenpaththu, a small hamlet near Tirunelveli in India, received record-breaking yields from her half-acre plot of land after she adopted SRI techniques, while C. Sethumathavan in Tamil Nadu has set a new world record with SRI practices.*” (FarmingFirst, 2015)

The paper *‘A Life Cycle Assessment (LCA) of Greenhouse Gas Emissions from SRI and Flooded Rice Production in SE India’* (Gathorne-Hardy, 2013) explains the SRI rice system, involves:

- earlier transplanting, with planting only single, rather than clusters of plants,
- planting in a grid, with region-specific spacing and straight rows to allow weeding,
- increased manure and other organic fertilisers,
- no permanent immersion - intermittent wetting and draining of paddies.



Fig. 53a Slide from UTube video Regenerative rice farming in Cambodia; rice seed planting into cover crops, reporting increasing yields over time, rising from 2- 3 tons to 5 tons and more per hectare, with very many thanks to the authors. (Meister, 2021)

There are a number of videos on SRI, including training material (*"SRI Introduction: The spread of SRI in East Africa"*, 2012). Cornell University lists several papers. (*"Scientific Research Documenting and Explaining SRI"*, n.d.). Cornell has a global SRI network and resource web page, listing projects, presentations, SRI groups and other resources by country (*"SRI International Network and Resources Center"*, n.d.).

The paper *'Learning about positive plant-microbial interactions from the system of rice intensification (SRI)'* explains and provides evidence of the success of SRI. The paper has been quoted extensively due to its importance and the impracticality of improving upon the original. References removed from the text to avoid confusion can be found in the original, which is freely available on ResearchGate (Upoff, 2009). The extent to which the practice has spread is evidenced by the Cornell global SRI network and resource web page referred to above (*"SRI International Network and Resources Center"*, n.d.).

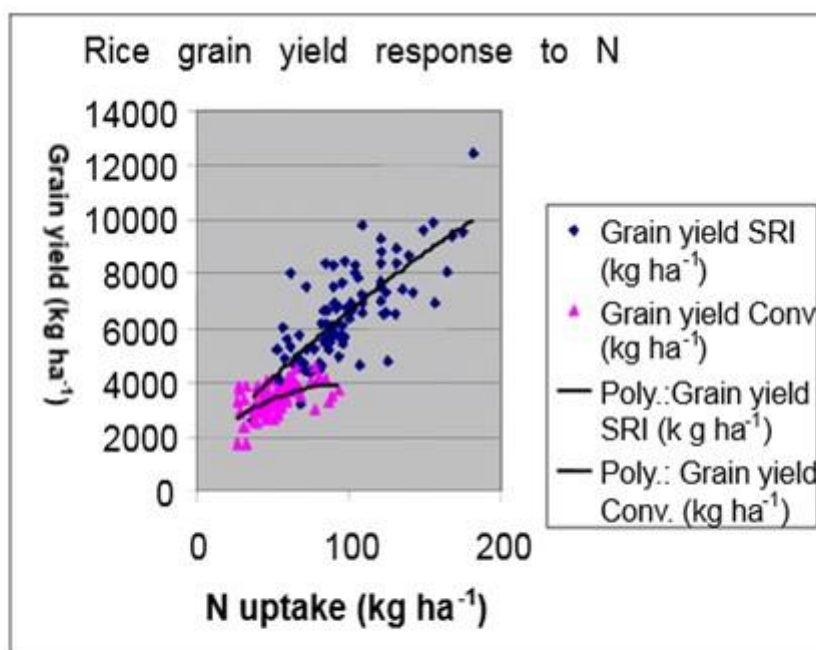


Fig. 3. Grain yield response as a function of nitrogen uptake for two sets of rice plants grown with SRI or conventional methods (N=109), four locations in Madagascar. Source: Barison (2003).

Fig. 54b. A slide from IFAD-funded UTube video looking at the transfer of SRI knowledge and practice in East Africa, with many thanks to the authors. (*"SRI Introduction: The spread of SRI in East Africa"*, 2012)

"How SRI could enable farmers to produce more from less was initially difficult to understand, appearing 'too good to be true.' There was considerable skepticism, even opposition, expressed in the peer-reviewed literature. However, evidence continues to accumulate that

the ideas and suite of practices which constitute SRI, when used together, can evoke more productive phenotypes from practically all rice genotypes, such as shown in Fig. 1.” (Upoff, 2009)

“SRI methods have proved beneficial for use with ‘unimproved’ local varieties as well as with higher-yielding varieties and hybrids. Higher productivity with alternative methods has been seen in a wide range of countries, such as China, Gambia, India, Indonesia), Myanmar, and Sri Lanka.” (Upoff, 2009)

“Acceptance of SRI was slowed in part by the fact that it is so different from Asia’s ‘Green Revolution’ based on: (a) breeding new ‘improved’ varieties that are more responsive to external inputs (and then getting farmers to buy and use these) and (b) persuading farmers to increase use of external inputs -- more mineral fertilizer, more water, and agrochemical crop protection. SRI methods, on the contrary, do not require either the use of new varieties or external inputs. Farmers can raise their yields by continuing to plant whatever varieties they are already using, generally with less seed, water, fertilizer, agrochemicals, and even in many cases with less labor.” (Upoff, 2009).

Table 5 from Table 3 of ‘*Learning about positive plant-microbial interactions from the system of rice intensification (SRI)*’ with very many thanks to the authors. (Upoff et al., 2009)

Table 3. *Effects of active soil aeration using soil-aerating mechanical weeder in Madagascar and Nepal*

Mechanical weedings	(N)	Area/Harvest (ha kg ⁻¹)	Yield (t ha ⁻¹)
Madagascar: 1997–98 main season, Ambatovaky area (N=76)			
None	2	0.11 / 657	5.97
One	8	0.62 / 3,741	7.72
Two	27	3.54/26,102	7.37
Three	24	5.21/47,516	9.12
Four	15	5.92/69,693	11.77
Nepal: 2006 monsoon season, Morang district (N=412)			
	(N)	Range	Yield (t ha ⁻¹)
One	32	3.6 - 7.6	5.16
Two	366	3.5 - 11.0	5.87
Three	14	5.85-10.4	7.87

Sources: Madagascar: Data collected by Association Tefy Saina field staff, Ranomafana; Nepal: Data collected by District Agricultural Development Office, Biratnagar

The authors continue by explaining why they believe SRI techniques are so productive. SRI focuses on plant symbiosis with soil organisms, a concept that shares many similarities with broader regenerative agricultural principles. The history of SRI illustrates the reluctance of established systems to be open to adopting new ideas, particularly those based on natural principles, even when there is a wealth of observable evidence that they do indeed work.

28 THE SOIL BIOME – FUNDAMENTALLY IMPORTANT

The soil biome is essential to the Earth's 'Gaian' planetary climate regulation system. *"The thin layer of soil covering the Earth's surface represents the difference between survival and extinction for most terrestrial life"*. (Harrabin, 2019) The related pathways are diverse, complex, interlinked, and far-reaching. This section attempts to bring together some of them, which are expanded on in later sections.

The carbon-dependent soil biome, comprising fungi, bacteria, and other life forms in their dark underground world, in conjunction with their sunlight symbiotes — soil-biome-dependent photosynthetic carbon-fixing plants — are together crucial and central components of the 'Gaian' regulatory system, which makes the Earth habitable.

Regulation of regional continental and global land-related atmospheric moisture, which in turn significantly determines land-based rainfall and impacts the global water cycle, involves sunlight, the soil biome, plants, the atmosphere, and oceans, and is ultimately crucial to controlling the Earth's biosphere, climate, and ocean habitability.

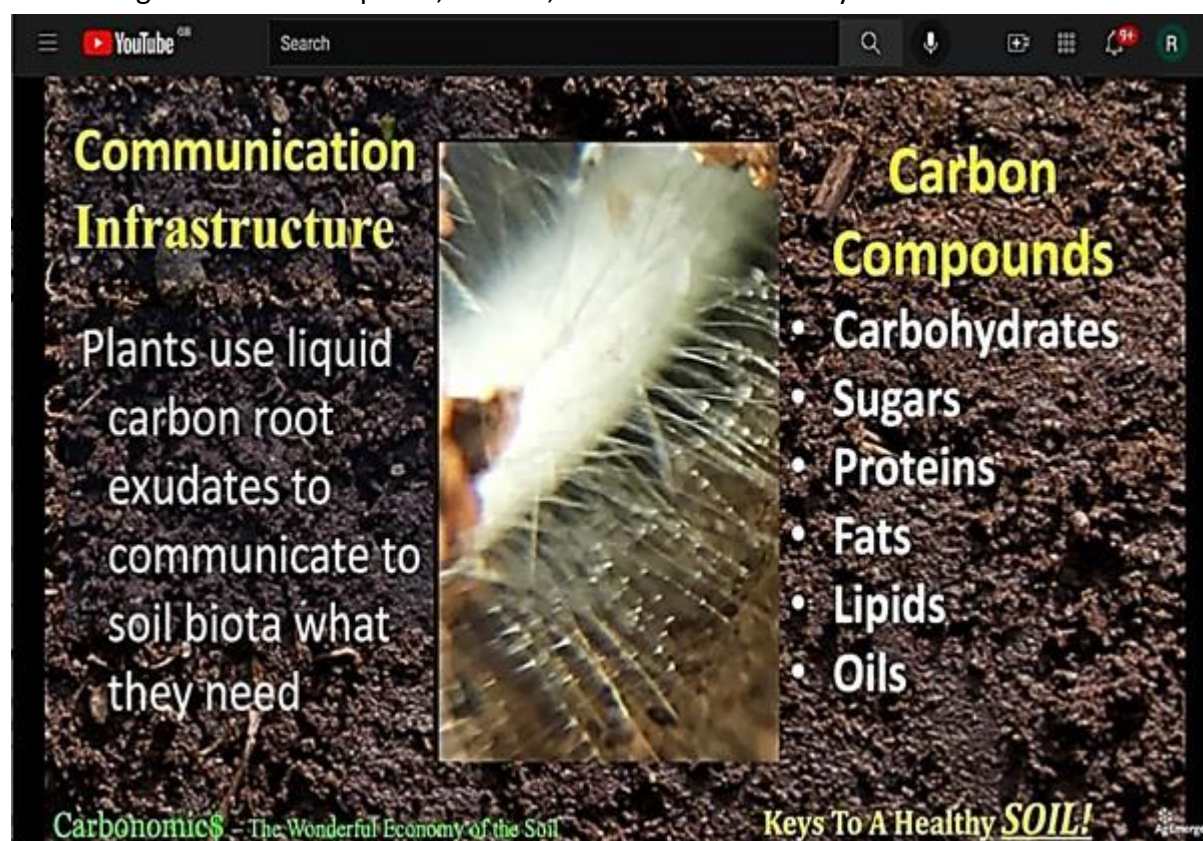


Fig. 55. Carbonomics - AgEmerge Breakout Session with Keith Berns – an allegory of soil carbon as an economy – a concise and thought-provoking presentation – photo of root exudates visible in a soil tubule made by a worm. Note the drops of exudate on the root hairs. With very many thanks to the authors. (Berns, 2020)

Plants use sunlight energy to extract carbon and oxygen from atmospheric carbon dioxide, and make complex carbon molecules, which are the basis of life. The soil biome and plant symbionts also play important Gaian ecosystem roles in regulating the creation of oxygen and

carbon dioxide through the photosynthetic splitting of carbon dioxide into oxygen and carbon, thereby partitioning carbon and oxygen between the Earth's crust, atmosphere, oceans, soils, and life forms. Enormous symbiotic evolved complexity, ultimately based on the laws of matter, makes that beautiful simplicity possible.

The terrestrial biosphere's fundamental Gaian regulatory components are inextricably interconnected and interdependent. Sunlight-powered photosynthetic production of carbon sugars by plants, from the carbon dioxide in the atmosphere, shared with the soil biome facilitates the existence of the lightless soil biome.

In their dark world, the subterranean denizens of the soil biome are, in one way or another, utterly dependent on plants for energy, and carbon for structure, in the form of their plant-provided sugar exudate 'lunch' and absent a sugar exudate 'lunch', are obliged to cannibalise themselves. Once they have eaten themselves out of existence, sadly, soils become bereft of significant life or soil carbon.

Plants exchange photosynthetically fixed carbon with the soil biome for minerals mined by the soil biome, soil biome-produced nitrates, and other support services, including the provision of proteins and amino acids. (Paungfoo-Lonhienne, *et al.*, 2008) This exchange takes place between plant roots and interlinked fungal and bacterial networks – a vast organic network linking plants, trees and forests, fungi, bacteria, and other soil life forms; an underground 'information exchange internet', allowing resource trading, via very sophisticated integrated, information exchange, nutrient supply, and transport delivery systems.

Absent harmful human intervention, the soil biome, in conjunction with plants, provides feedback mechanisms through carbon storage in soils and carbon respiration that respond to and thus eco-regulate atmospheric carbon dioxide and oxygen levels and related climate factors, including temperature.

Before human intervention, atmospheric carbon dioxide rose due, for example, to fires or more frequent than usual volcanic activity. Raised atmospheric carbon dioxide increased plant growth, accelerating the return of the carbon in carbon dioxide to the soil, and through build-up of organic material, and runoff and organic deposition of detritus onto the ocean floor, and ultimately subduction, simultaneously reducing atmospheric and oceanic carbon-dioxide, and at the same time adding to, and regulating atmospheric and oceanic oxygen. In response to increased carbon supply, more active soil biomes provided the increased amounts of minerals and nitrates needed for greater plant growth, part of a self-regulating feedback loop.

Conversely, bare plantless soils self-evidently cannot supply photosynthetic plant sugars, fats, and other products to the soil biome. Respiration by the soil biome of stored soil carbon for energy, when combined with a lack of resupply to the soil biome by plants of photosynthetic carbon sugar, including when soil is left bare, leads to soil carbon loss, increased atmospheric carbon dioxide, and reduced net oxygen production.

28.1 FATBAS BROKEN CARBON CYCLE

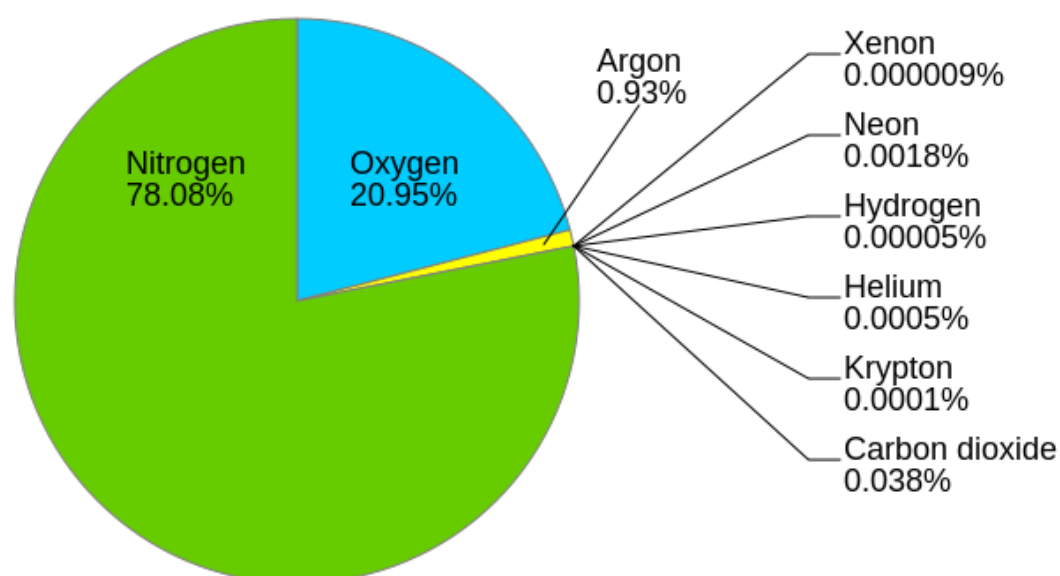
Absent human fertilised-based bare ground dependent agriculture on as much as 5 billion hectares, increased plant growth in response to higher atmospheric carbon dioxide would result in net carbon dioxide sequestration into soils and ultimately longer-term stores, as the self-regulating Gaian system tried to maintain the pre-human ecological planetary atmospheric and oceanic oxygen/carbon dioxide control balance. We have broken that regulatory mechanism.

28.2 OXYGEN – CLIMATE GAS, ENERGY SOURCE, ECOSYSTEM REGULATOR, UV ABSORBENT

Regarding environmental climate change, including warming, the vast majority of public and corporate focus is mainly on carbon dioxide, which is undoubtedly the most critical factor in atmospheric warming.

However, we must also consider the role of oxygen. Oxygen is existential to the function of the energy systems that power terrestrial life. Furthermore, oxygen is a crucial component of the Gaian planetary ecosystem's regulatory system. It is also arguably a climate gas, because it is central to ocean health, and oceanic oxygen levels are arguably sensitive to atmospheric oxygen levels, as detailed in a later section.

Composition of the Atmosphere



Pie chart showing the gases that make up Earth's atmosphere (CC BY-SA 3.0).

Fig. 56. Pie chart looking at make up of Earth's atmosphere with many thanks to the authors. (Nugent Press Books n.d.)

Oxygen gas is released by the photosynthesis of carbon dioxide using sunlight energy; thus, like carbon, it stores sunlight energy. It is also very reactive because of the relatively weak oxygen-oxygen double bond; hence, it has an inbuilt disposition to react with other substrates, releasing energy at the same time.

The review '*Oxygen Is the High-Energy Molecule Powering Complex Multicellular Life: Fundamental Corrections to Traditional Bioenergetics*' observes, "Molecules with relatively weak bonds store chemical energy and release it when chemical reactions result in the formation of the same number of stronger, lower-energy bonds." "Reactions of fuel molecules in the absence of O₂ are also not strongly exergonic", and continues "reactions of O₂ with organic molecules are highly exergonic . . . O₂, rather than glucose, NAD(P)H, or ATP, is the molecule that provides the most energy to animals and plants and is crucial for sustaining large complex life forms" (Schmidt-Rohr, 2020) confirming its role as a planetary energy regulation factor, including as an energy store.

Oxygen is continuously resupplied by sunshine-fuelled photosynthetic extraction from carbon dioxide. The combustion of a mix of oxygen and carbon produces heat, and insofar as it is not replaced by fresh oxygen, reduces the planet's stored energy potential and oxygen stores. However, the amount of oxygen consumed annually by anthropogenic fossil fuel combustion is tiny in terms of the 1.2 million gigatons of historic stored oxygen in the atmosphere. However, as a key point, annual anthropogenic oxygen consumption is not insignificant in relation to the amount of oxygen dissolved in the ocean, as discussed below.

28.3 OCEANIC OXYGEN LEVELS - IMPACT OF COMBUSTION ON

Atmospheric oxygen levels logically impact levels of oceanic oxygen. The atmosphere exchanges oxygen and carbon dioxide with the ocean, based on gas-to-liquid exchange laws. Arguably and logically, the impact of the reduction of oxygen in the gas-to-liquid due to combustion, however small in absolute terms, is magnified in the oceans, as the quantity of dissolved oceanic oxygen is about a hundred and forty times less in the oceans (8,000GT split half and half between upper and deep ocean layers) than in the atmosphere (1.2 million GT) (Brown R., 2021e).

The gas exchange process between the ocean and the atmosphere is an equilibrium system governed by the laws of physics and the properties of matter. Combustion and respiration consume atmospheric oxygen. Photosynthesis replaces atmospheric oxygen, where net carbon storage occurs. Oceans will seek to maintain the historic equilibrium and thus replenish any reduction in atmospheric oxygen, notwithstanding that there is massively more oxygen in the atmosphere than in the oceans.

Global oxygen budgets are highly complex, difficult to quantify, and relatively under-researched. We know from limited measured observations by automated marine floats, that oceanic oxygen is reducing, and ocean scientists have difficulty explaining the extent of oceanic oxygen loss.

Gases behave very differently in liquids compared to in the atmosphere. Gases are mixed into the ocean by many mechanisms. Here, we are concerned with dissolved oxygen in the upper ocean layers. The oxygen is partly held in the ocean surface by atmospheric partial pressure. Oxygen in micro-bubbles, and when in hydroxyl form, is likely lighter than water (molecular weight of oxygen O is 15.999, molecular weight of water (H₂O) is 18.015), thus in these forms it will be more buoyant in water. The complexing of water molecules in seawater likely means

the minerals, along with oxygen, will be concentrated in the spaces between them, further adding to the buoyancy of oxygen in seawater.

Oxygen's positive buoyancy in some forms means that when in those forms, it will likely tend to move upward to the ocean surface during mixing. The net level of release or absorption of oxygen by the ocean is in part determined by the partial pressure at the surface, and a slight reduction in atmospheric partial pressure will logically result in the movement of oxygen from the ocean to the atmosphere.

The annual decrease in atmospheric oxygen due to anthropogenic combustion of primarily fossil fuels (Say, 40GT per annum, albeit only a tiny proportion of atmospheric oxygen 1.2 million gigatons, but may represent as much as one per cent – a significant amount - of the oxygen in the upper ocean layers) but the immovable physical laws of gas exchange, will logically ultimately lead to reduced oceanic oxygen, as further facilitated by the tendency for movement of a lighter more buoyant forms of the gas including microbubbles, to the ocean surface.

Further research in distilled water, suggests *“a phenomenon of rapid absorption and release of oxygen at the water interfaces was unveiled,” . . . “We supposed this is because oxygen molecules are primarily existed at the surfaces or interfaces of water clusters and can rapidly traverse the gas–liquid interface through vibration and interfacial movement among water clusters.”* (Yuan, 2024) If this tendency for rapid movement of oxygen at the gas surface interface also applies to more polar sea-water H₂O molecular clusters is unknown, but if the case, it would add to arguments that anthropogenic oxygen combustion could impact oceanic oxygen levels in a meaningful and climate change-relevant time scale.

Thus, logically, consequent on the laws of gas exchange, the buoyancy of some forms of oxygen in water, and the properties of water, an oxygen loss due to fossil fuel combustion that is insignificant in terms of the total amount of oxygen in the atmosphere, may nonetheless, ultimately, over time, lead to oceanic oxygen depletion and rises in the depth of the minimum oxygen zone, that is significant in terms in the life critical upper layers of the ocean. This process may explain, at least in part, the vital but unaccounted-for portion of observed depletion in oceanic oxygen (Brown R., 2021e).

Longer term, oxygen depletion-related ocean sulphidation, resulting in hydrogen sulphide release into the atmosphere, through consequential significant damage to the ozone layer, could facilitate UVC incidence on the Earth's surface, which in turn would inhibit surface life; evidence suggests this mechanism contributed to several major historic extinction events, and it would be a plausible mechanism for future Anthropocene extinction events (Brown R., 2021e).

Thus, atmospheric oxygen levels are essential both in terms of, a planetary energy store that helps regulate the climate through multiple mechanisms, and in sustaining ocean health and diversity. Reduced atmospheric oxygen could potentially have a magnified effect on ocean health. *“While CO₂ dominates climate talks, oxygen's slow decline could destabilize ocean ecosystems—regenerative agriculture helps rebuild both carbon and oxygen reserves.*

Rebuilding soil and plant biomass isn't just about carbon—it's about safeguarding Earth's oxygen and carbon bank accounts." (DeepSeek)

28.4 OCEANIC CARBON DIOXIDE

The ocean contains much more carbon dioxide than the atmosphere because carbon dioxide is more soluble than oxygen. Thus, increased atmospheric carbon dioxide will increase the amount of carbon dioxide dissolved in the ocean, causing ocean acidification.

28.5 SOIL SERVICES FOR PLANETARY HEALTH

Healthy soil biomes, including soil carbon levels, are obligatory for maintaining the global ecosystem. Maintaining soil carbon, atmospheric oxygen, sustainable atmospheric carbon dioxide levels, the water cycle, and regional hydrological cycles ultimately depends on healthy soil biomes, green lands, growing healthy photosynthesising plant systems for as much of the year as is feasible, and functioning ocean ecosystems.

Plants cannot flourish in the long term without healthy soil ecosystems. Healthy, optimal plant ecosystems and essential symbiont soil biome function and health globally, including on agricultural lands, are necessary to regulate atmospheric carbon dioxide levels. Oceanic oxygen and carbon dioxide levels are equally dependent on atmospheric oxygen and carbon dioxide being maintained within acceptable environmental parameters.

The impact of increases in atmospheric carbon dioxide due to soil carbon depletion, related reductions in atmospheric oxygen, and linked oceanic acidification and deoxygenation are underappreciated and under-researched. However, evidence increasingly suggests that ocean deoxygenation and acidification are significant, linked factors in 'climate change'.

28.6 PLANTS - FOUNDATIONAL TO PLANETARY ECOSYSTEM FUNCTION

At its core, life is structured from and functions through biologically active combinations of carbon, nitrogen, oxygen, water, and minerals derived from oceans, air, and rocks. Plants, with help from bacteria and fungi, extract carbon, nitrogen, oxygen, and minerals, the building blocks of life, from the environment, process them, and make their plant derivatives, life-giving products, available to higher surface life forms.

Hence, plants and their related soil ecosystems are foundational to the broader planetary ecosystem, thus, all sophisticated planetary life. Through photosynthesis they;

- Extract carbon and oxygen from atmospheric carbon dioxide;
 - Create carbon molecules, including root exudates.
 - This carbon is used to build the structures of DNA, RNA, proteins, enzymes, and lipids from which life is built.
 - This carbon is also the energy substrate for sophisticated life forms.

- The carbon molecules are the basis of plants and lifeforms that subsist on them.
- Plants supply the living subterranean soil biome with the photosynthetic carbon sugar root exudate that is existential for its structure and energy.
- The soil biome, in a 'traded' exchange,
 - Hosts a wide diversity of bacteria that make nitrates, supplying accessible nitrogen extracted by enzymes from the atmosphere to plants, and to other soil life subsistent on them; biologically accessible nitrogen is an essential component of many of the molecules of life.
 - Recycles nitrates and minerals excreted by the soil biome inhabitants during life and at death.
 - Mines and transports minerals to the plant roots.
 - Transports nitrates to plant roots.
 - Provides other support services to its plant symbionts.
- The soil biome stores plant-photosynthesised carbon from atmospheric carbon dioxide in soils, and by doing so;
 - Regulates atmospheric carbon dioxide levels.
 - Facilitates the net release of oxygen into the atmosphere - when the carbon extracted from carbon dioxide is stored, the oxygen remains free in the atmosphere, until reincorporated into carbon dioxide or other compounds.
 - Facilitates the infiltration and storage of water – carbon is life – life is 90% water – life includes fungi, bacteria and wider soil fauna. It is dependent on the water-holding gels they make and excrete into soils, etc.
 - Provides an energy and water reserve for soil life to cover periods when plants are not photosynthesising at the surface above them, hence unable to supply plant sugar exudates.

28.7 CARBON - BUILDING BLOCK, ENERGY SOURCE, ECOSYSTEM REGULATOR

Appreciating the existential various roles of soil carbon as a building block of life, energy source, facilitator of water infiltration and storage, and ecosystem regulator is fundamental to optimising the sustainability and productivity of agriculture and mitigating the impact of climate change.

28.8 - REGEN AG V FATBAS - CARBON EMISSION OR SEQUESTRATION

FATBAS, by degrading soils, reduces soil carbon and increases carbon dioxide emissions. In contrast, regenerative agriculture, by maximising the photosynthetic capacity of every square meter of land, thus the supply of carbon exudate to the soil biome, minimising light energy heating of bare soils, and working with, rather than seeking to dominate and destroy nature, presents significant opportunities to sequester giga-tons of atmospheric carbon dioxide back into soils, thus buying time, possibly many years, for both development of new, and expansion

of existing, non-fossil fuel-based energy technologies. This would improve local hydrology and soil moisture in agricultural land globally and mitigate climate change risks, including flooding, droughts and fires.

Whilst this may sound fanciful, several regenerative farmers, as in the graph in a later section, have used independent soil carbon testing and found regenerative agriculture was resulting in a positive flow of carbon into their soils and that consequently, year on year, they were sequestering significant amounts of soil carbon in both percentage and absolute terms. As discussed in later sections, soil carbon sequestration at this level over global acreages would mitigate the effects of climate change, including drought, fires, floods, land degradation, and the risk of extreme weather events, for the reasons cited, thereby buying us more time to develop green energy sources.

28.9 ARBUSCULAR MYCORRHIZAL SYSTEMS CRUCIAL TO SOIL BIOME FUNCTION

Mycorrhizae are central to the existence of terrestrial life. They facilitate extraction from the soil of the phosphates that are essential to healthy plant growth and soil biome integrity, as well as facilitating carbon retention as set out in the invaluable expert reviews referenced and cited below, with longer than usual quotes due to the complexity of the subject matter and difficulty in doing the material justice by paraphrasing. The author refers readers to the original papers for more details and references in the text.

The review titled, *'A critical review of 25 years of glomalin research: a better mechanical understanding and robust quantification techniques are required'* comments, *"The most important benefit attributed to 'glomalin' is its impact on soil aggregation and soil water retention"* further observing *"hundreds of studies have ascribed numerous plant and soil health benefits to 'glomalin', including improving soil aggregation, soil carbon storage, soil nutrient content and distribution, soil biodiversity, heavy metal, and other pollutant chelation, and plant productivity"*. (Irving 2021)

More widely, mycorrhizal systems facilitated by their close interactions with plant roots also facilitate the transport of photosynthetic carbon sugar exudate as far as their networks extend, helping sequester soil carbon in soils. The review *'Arbuscular mycorrhiza convey significant plant carbon to a diverse hyphosphere microbial food web and mineral-associated organic matter'* commented, **"Plant-fixed C, distributed into soil as root biomass, mycorrhizal tissues, and their exudates, is the primary source of soil organic C and is transformed into soil organic matter (SOM) through diverse chemical and microbial processes. Since SOM holds not only organic C but also water and nutrients, its persistence is a major goal in climate change mitigation and sustainable land management. The mechanisms responsible for SOM persistence are complex and under active investigation"** (Kakouridis, 2024) (This author's bold and underline).

The review *"Arbuscular mycorrhiza convey significant plant carbon to a diverse hyphosphere microbial food web and mineral-associated organic matter"* continues, *"Amidst the paths between plant photosynthate and SOM, AMF hyphae and soil microorganisms serve as primary intermediaries; their biomass and residues can contribute to slow-cycling and persistent forms of C that may become occluded within aggregates or associated with mineral*

surfaces” . . . “Arbuscular mycorrhizal fungi transport a significant amount of photosynthetic C into the soil matrix beyond the extent of roots alone”. . . “Arbuscular mycorrhizal fungi C inputs modified the hyphosphere bacterial community, facilitating a diverse microbial food web that incorporated hyphae-derived C. This effect likely stimulated enhanced AMF (and thereby plant) access to N and P. Together, our findings indicate that AMF play a key role in the formation of SOM and thus could be employed in strategies for climate change mitigation and sustainable land management.” (Kakouridis, 2024)

The expert review ‘*Arbuscular Mycorrhizal Fungi and Glomalin*’ has been significantly quoted given it is an authoritative and fascinating perspective which it would be difficult to do justice to by paraphrasing, observes, “*Arbuscular Mycorrhizal Fungi (AMF) are very important for plant physiology, plant health, nutrient cycling and soil aggregation, especially for low-input sustainable agricultural systems. AMF, classified in the division Glomeromycota, are obligate symbionts that form a symbiotic associations with more than 80% of terrestrial plant families. This relationship between plants and AMF, which connects the root and soil system, has been described by Koide and Mosse (2004) as one of the most important symbiosis on earth.*” (Atakan 2021)

AMF directly mediates the uptake of phosphorus (P), one of the essential nutrients required for plant growth, by colonizing plant roots. AM formations such as extraradical mycelium and filamentous hyphae networks that rapidly develop around plant roots increase the uptake efficiency of immobile phosphorus ions. In this respect, AMF causes hydrolysis of organic phosphate present in the soil through hyphae and providing soluble phosphate to its Hosts” (Atakan 2021)

AMF have very important role in carbon (C) storage in the soil . . . Glomalin is of great importance in determining numerous aspects of soil quality, including soil organic matter, nutrient storage capacity, and water holding capacity. Therefore, AMF are, not only a factor but also a key determinant of soil quality.” (Atakan 2021)

29 COMPOST – WHAT IS IT

Composting is the managed thermophilic aerobic bacterial decomposition of organic solid wastes to create a humus-like material. This material provides carbon, diverse fungal and bacterial biology, and slow-release nitrates and phosphates, which benefit the soil biome and plant biology, health, and yield. Fungal and bacterial species diversity in compost depends on the aerobic techniques used, the access of multiple bacterial and fungal species to the process by deliberate integration, accidental atmospheric and other inclusion, and the maturity of the compost.

29.1 ASSISTIVE SOURCE OF DIVERSE BACTERIAL AND FUNGAL GERMINATION BIOLOGY

Compost's crucial and underappreciated benefit is its capacity to supply a wide diversity of fungal and bacterial biology to newly planted seeds. The soil biome, in all its diversity, has been highly motivated by evolutionary experiences to use all available strategies, including wide fungal and bacterial soil life diversity, to assist and maintain growing optimally photosynthesising plants above them whenever conditions make that possible because if you

are a denizen of the soil biome, no growing plants above means ‘no food’ – no carbon energy substrate supply – which ultimately results in death.

The bacterial and fungal spores in compost, by assisting and complementing the internal and external seed biome, can help trigger and support seed germination (Sugiharto, 2022), early development of the root mycorrhizal sheath and generally enhance the speed and extent of plant-soil biome synergistic interactions and development. (Chahtane, 2018; Samreen, 2021; Johnstone-Monge, 2021).

Both fungal and bacterial plant holobionts are essential. However, fungi are particularly relevant because they provide the primary mechanism for the bidirectional transport of nutrients and water between the plant and the soil biome.

The soil biome systems are absolutely dependent on carbon, sugar, and lipid root exudates for energy. In return for those life-giving plant photosynthetic carbon sugar root exudates, the soil biome provides, and the mycorrhizal system transports minerals, nitrates, and other support services relating to plant health and function.

Indeed, *“abundant literature reports the capacity of fungal endophytes to promote plant growth and to improve their tolerance towards abiotic and biotic stresses, in exchange of nutriment supply and shelter”* (Rentif, 2023). As discussed, fungi infiltrate, interconnect, and interact with plant root systems and thus are key and central to the distribution of photosynthetic carbon sugars produced by the plant to the soil biome.

Seed biology is much more sophisticated than generally realised; for example, it can even halt germination when exposed to infectious bacteria, thus reducing the risk of infection. The sensing by seeds in coordination with their own internal and external fungal and bacterial biomes and their biological reaction to the presence of soil bacteria and mycorrhiza is likely part of their evolutionary response and adaptation to growing conditions, including the fecundity of the environment, allowing them to optimise germination processes to the regional and temporal conditions in which they find themselves, thus maximising their chances of survival and reproduction.

29.2 SOIL FUNGAL ‘INTERNET’ / RESOURCE, DELIVERY, COMMUNICATION

As well as impacting plant and soil biome biology in numerous ways, soil biomes, including bacteria, fungi, and soil fauna, are by various mechanisms, key to the soil biome equivalent of a bidirectional internet delivery logistics communication network, and related bi-directional physical transport infrastructure, between plant roots and the soil world, facilitating the exchange of products, including plant sugars, for soil-biome provided nitrates, minerals and metabolic water.

Increased microbial and fungal complexity improves capacity for;

- bacterial nitrate production;
- greater activity, volume, variety and turnover of soil biome life, thus plant available nutrients in soils;

- efficient mineral abstraction by mycorrhizal and bacterial systems for supply to plants, including through rhizophagy;
- better plant health, nutrient density, and antioxidant production through improved nutrient supply by the soil biome;
- increased plant capacity to photosynthesise carbon sugar exudates, both for supply to the soil biome and to support their own growth;
- better signalling and information exchange between plants and the soil biome;
- improved soil biome production and supply of plant health-protective, metabolic regulation and adaptation, substrates,
- more extensive and more diverse plant-soil biome exchange of bacteria and fungi, including some with antibiotic properties;
- higher plant nutrients, including mineral and antioxidant content;
- higher water retention and capacity for metabolic water production.

Increased diversity, including soil biome complexity, allows greater and more sophisticated biome interaction, allowing for more complex and extensive symbiotic networks of relationships with plants of the same and different species.

29.3 BARE SOILS DO NOT CONTAIN PLANTS AND LIMITED CAPACITY TO PRODUCE METABOLIC WATER

Bare soils do not contain plants. A bare soil devoid of plants means the supply of carbon sugar exudate to the soil biome is physically impossible. The absence of a supply of carbon sugar root exudate obliges the soil biome, which must have access to energy to survive, to metabolise soil stored carbon, in effect, as the primary source of carbon in soils, cannibalising itself, driving down soil life, reducing diversity, soil carbon, retained water and metabolic water production capacity, and reducing soil carbon, and future capacity to assist seed germination and mycorrhizal development.

Notably, the diverse life forms of the soil biome, as a by-product of their own energy production, create metabolic water (as do all life forms), which will be proportional in volume to the amount of respiring living life in the soil. During dry periods of low rainfall, the soil biome uses that metabolic water to keep its environment moist and provide water to keep their plant symbionts alive and photosynthesising, producing carbon sugars, the soil biome's 'breakfast lunch and supper', explaining why regenerative soils and crops are more drought resistant and entirely consistent with a strategy by the soil biome to optimise its own survival prospects.

29.4 SIR ALBERT HOWARD – COMPOST PROVIDES BIOLOGY

In the early 20th century, Sir Albert Howard was invested with the grand title 'Imperial Economic Botanist to the Government of India' for nearly two decades. If such an illustrious career as a researcher and strategist, with both profound knowledge and vision, were to be

remembered for a single phrase, it would be this succinct gem, which has the ring of eternal truth:

“The health of soil, plant, animal and man is one and indivisible.”

Howard was highly regarded for his expertise in affordable and efficient agricultural crop development and innovation in Indian smallholdings. He developed land management techniques, including the Indore composting process, which, as discussed, drew inspiration from Chinese composting.

Table 6. This table is taken from Chapter V ‘Practical Applications of the Indore Process (contd.)’, and shows the yield improvements in cotton. (Howard, 1943)

Table 3 The increase general fertility at Indore				
<i>Year</i>	<i>Area in acres of improved land under cotton</i>	<i>Average yield in lb. per acre</i>	<i>Yield of the best plot of the year in lb. per acre</i>	<i>Rainfall in inches</i>
1927	20.60	340	384	27.79 (distribution good)
1928	6.64	510	515	40.98 (a year of excessive rainfall)
1929	36.98	578	752	23.11 (distribution poor)

Among his numerous highly thought-provoking publications is ‘*An Agricultural Testament*’ (1943), which examined how applying compost and sound land management can improve yield, disease resistance, crop quality, and shelf life.

Strikingly, Howard’s results show that compost application significantly improves plants’ resistance to reduced rainfall, as confirmed almost a century later in the observations of Dr Christine Jones, Dr Johnson, and others. This suggests that, whilst carbon supplied by plant growth is essential, the effects on crop production of quality compost (and crucially, the inoculant microbial soil spores it contains) cannot be ignored.

Howard’s books contain many other remarkable insights. He also reports on a colleague’s positive experience with compost use in a trial with rice, including on salinised land, as

referred to earlier, in the terms, “We have cut three and entirely average portions of our rice fields. No. 1 plot had 1.25 to 1.5 inches of Indore compost ploughed in. No. 2 plot had some farm rubbish plus 3/8 inch of Indore compost. No. 3 plot was the control and had nothing. There have never been such crops grown on the land, at least not for many years. The remaining 15 acres are as before with the rice scraggy and thin.” (Howard, 1943).

He observes: “The figures show that, **no matter what the amount and distribution of rainfall were**, the application of humus soon **trebled the average yield of seed cotton** –200 lb per acre - obtained by the cultivators on similar land in the neighbourhood” [this author’s underline and bold].

“By means of our factory of 30 pits we keep up a supply of compost, but we can never make enough to meet our needs. We are now applying it also on our fields of forage crops with remarkable results. Compost spread over a field to the depth of about one quarter of an inch ensures a crop at least three or four times heavier than otherwise could be obtained” (Howard, 1943).

“Indore compost is one of the material blessings of this life, like steam, electricity and wireless. We simply could not do without it here. It has transformed all our agricultural interests. We have 43 acres under wet cultivation, and most of the land three years ago was of the poorest nature, **large patches of it so salty that a white alum-like powder lay on the surface.** We have now recovered 28 acres, and on these we are having a bumper crop of rice this year” (Howard, 1943).

Compost not only delivers diverse ‘fertilising’ biology but also has physical properties that complement natural processes. “[It] can help control erosion problems by mitigating formation of soil crusts because [its] rough surfaces promote percolation, increase water storage, lower surface flow velocities, dissipate the energy from raindrop impact and reduce the shear forces acting on the soil surface. The compost layer applied to the soil surface reduces evaporation and provides a more suitable environment for root growth and releases nutrients that improve the vegetative cover” (Al-Bataina, 2016).

In addition, as discussed and of critical importance, compost provides access to fungal and bacterial biology to facilitate germinating seeds. In a machinery world, compost seed soaks, injected compost extract, and foliar spray are less exposed to desiccation, weather and UV damage, thus likely more effective, certain, and economical than applying a thin layer of compost on the soil's surface. Where a thin layer is applied, it likely needs to be before rain or irrigation, which will move the biology into the soil before it is damaged by sun and heat.

29.5 FUNGI IN SEED BIOME AND SOIL- KEY TO GERMINATION AND GROWTH

Unsterilised seed biome generally contains bacterial and fungal spores, which germinating seeds use to build a favourable and supportive soil biological association with the soil biome, including in their mycorrhizal root sheath.

Seeds also recruit soil bacteria and fungi to improve growth and survival. As mentioned elsewhere, but important not to lose sight of, mycorrhizal fungi connect the interior of the plant to the soil biome, some span both, and have multiple roles including transporting carbon sugar root exudate to the soil biome, and water, phosphate, wider minerals and nitrates from beyond the root zone to plants.

As discussed, including in later sections, many groups historically recognised the considerable importance of composts to plant germination and growth, as later did Sir Albert Howard. More recently, many farmers are reporting their benefits on germination, growth and yield.



Fig. 57. A slide making the point seeds carry their own microbial biome from the UTube lecture 'Profit, Productivity, and NPK with Dr Christine Jones' Lower Blackwood LCDC with very many thanks to the authors. (Jones, 2022)

The following quotes from various publications indicate the wider role and value of composts, and why they are so crucial to germination, development of healthy plants, and, crucially, diverse, vibrant soil biomes in historically degraded soils. The topics are emerging science and immensely complex. If a topic of interest, readers are referred to the referenced papers.

The detailed and helpful review '*Endophytic Fungi: From Symbiosis to Secondary Metabolite Communications or Vice Versa?*' observes, "*EFs (Endophytic fungi) alter the metabolic mechanism of host plants, improve metal and drought tolerance, enhance growth, and promote nutrient acquisition. They also enhance the defense efficiency of host plants against*

herbivorous animals and pests as well as against infections of pathogenic microorganisms. In response to these benefits, host plants provide symbiotic shelters and other proliferation facilities, such as an adequate nutrient supply and protection, to enable fungi to safely complete their life cycles during colonization”.

The publication ‘*Seed fungal endophytes as biostimulants and biocontrol agents to improve seed performance*’ notes, “*As for seed-borne endophytic fungi, evidence also points to their ability to promote seed germination and early seedling growth, and possibly impact the whole plant development and response to environmental cues. Interestingly, the positive effects of fungal endophytes largely rely on bioactive molecules they produce and that stimulate plant growth, and participate in adaptive responses or immunity. Indeed, the chemical repertoire of fungal endophytes is not only exceptionally diverse in itself, but also shaped by their environment within the plant, which makes these fungi a unique reservoir of bioactive molecules.*”

The review ‘*Seed-Borne Endophytes and Their Host Effects*’ (Hu 2025) is also detailed and helpful.

The review ‘*Seed-Transmitted Bacteria and Fungi Dominate Juvenile Plant Microbiomes*’ observes, “*Despite having only seeds as a source of inoculum, all plants grown on sterile sand in sealed jars nevertheless developed rhizospheres, endospheres, and phyllospheres dominated by shared Proteobacteria and diverse fungi. Compared to sterile sand-grown seedlings, growth on soil added new microbial diversity to the plant, especially to rhizospheres*” (Johnston-Monje 2021)

Consistent with this, a study on oaks suggests acorns may contain fungal biology derived from the environment of the parent plant (U’Ren, 2021). Similarly, a wheat study indicates that the seed's fungal content is influenced by its environment (Sharon, 2023).

Rice similarly contains spores of several fungal species both internally and externally. The publication ‘*The presence of a significant endophytic fungus in mycobiome of rice seed compartments*’ comments, “*The plant-associated microbial community performs a variety of important functions related to the crop development, productivity, and adaptation to abiotic stresses. Recent studies have shown that microorganisms living on the surface of plants (epiphytes) and inside plants (endophytes) protect against pathogens and improve plant growth and productivity*”. (Jeong 2024)

However, and of significance, a study in raspberries suggests that fungal species may not always be present in a seed biome (Wysoczański, 2021), thus making the presence of a diverse fungal biome in soils particularly important.

In species and or seeds that do not carry fungi or carry limited fungal species in the seed's internal and external shell biome, the presence of fungi in the soil surrounding the seed at the point of germination assumes particular importance in early growth, not least because of the role of mycorrhizal fungi in the transport of nutrients to and from plants.

Further fungal species present in plants may change during the germination, growth, and maturation phases, making the diversity of fungal spores in soils even more critical to optimal plant growth.

Indeed, the availability of relevant fungal bacteria from the soil biome to the seed during germination may be a critical factor in optimal growth and development of the rhizosheath, and more so given current practices of applying biocide, fungicide, and other treatments to seeds, which may kill external seed biome elements.

Quality composts, in addition to containing bacteria, provide fungal biology. This might help explain compost's extraordinary growth-enhancing and supporting role, as seen in its use by Albert Howard in India and, more recently, others, including the Haggertys in Western Australia. Potentially, compost supplies diverse fungal biology at germination that may not otherwise be present. Plants with a limited inherited endogenous fungal biome may benefit particularly from compost at germination, a field crying out for further research

29.6 HERBIVORY – TRANSFER GUT/ORAL FUNGI / BACTERIA TO SOIL / PLANTS

During grazing, herbivores encounter and ingest a wide range of bacteria and fungi from the soils and plants, in addition to their own endogenous bacteria and fungi. These can be transferred by herbivores to seeds during mastication, within the gut, and on excretion, adding to the diversity of the seed surface (epiphytic) and soil biome.

The potential importance of the role of ruminants in defining seed microbiome diversity is highlighted in the review, *'Insights into the seed microbiome and its ecological significance in plant life'*, which observes, "Interestingly, bacteria belonging to *Bifidobacterium*, *Faecalibacterium*, *Lactobacillus*, *Clostridium*, and *Streptococcus* which are common animal gut residents are abundant members of the epiphytic seed microbiome. The fact that seed surfaces harbour many of these taxa is indicative of the importance of dispersal processes in defining the epiphytic microbial diversity of seeds" (War, 2023).

This fundamental biological communality and linkage between the animal gut and seed biomes may be one of the factors explaining the observed benefits of regenerative cyclical grazing to land health, stocking capacity, and livestock health, as well as the assistive value of livestock grazing, in transitioning land to broader regenerative arable farming practices.

These biological commonalities and interactions help explain the value of composts made from a diverse range of substrates, including human and regeneratively raised livestock, and wider species, faeces and urine, in providing biology, including fungi, that are key to fecund plant germination and growth.

These symbiotic systems underline that we underestimate the importance and sophistication of evolved integrated biological systems, including life-plant interactions, at our peril.

29.7 FUNGI AND BACTERIA IN COMPOST ALSO POWERFULLY ASSIST PLANT GROWTH

Sir Albert Howard and others achieved remarkable improvements in plant health and growth by applying a quarter-inch, approximately half-centimetre, covering of mature, well-made 'Indore' compost to the soil.

Indeed, others have shown that the modest application of mature, biologically diverse, unsterilised compost extract as a seed treatment, by injection, application to the seed, drip and spray, or soil application, indeed boosts seed germination and onward growth.

Clearly the amount of organic matter and other nutrients in such a small amount of compost, in relation to the soil volumes to which it is applied, is limited, which begs the question, and gives a reason to wonder, if the substantial benefits of compost to crops, reported by Howard and others, were exaggerated, or if they were indeed accurately reported, why compost is so effective at promoting germination and onward growth.

It appears the reports were not exaggerated, as David Johnson and others replicated them in the last few years. Johnson's research supports Howard's posits that the 'secret' ingredient of quality composts is their diverse fungal and bacterial biology, which helps provide seeds with easy and immediate access to the progenitors of fungal and bacterial soil biology they need but are lacking, or in addition to, those in their internal and external epiphyte, endogenous seed biomes, needed to; form optimal mycorrhizal sheaths, create nitrates, mine minerals, and access the other services provided by the soil biome.

As mentioned, the seed has its own external and internal biomes. However, improvements in growth with the application of compost teas suggest that it is expecting or benefiting from both bacterial and, particularly, fungal diversity in soil biomes and has evolved to interact with a soil biome to achieve optimal growth.

In degraded soils, which most are, the necessary biology may not otherwise be present and available to the germinating and developing plant. Giving the plant access, at germination, to the biologic symbionts it needs to make its own optimal bacterial and fungal root garden allows it to flourish in its preferred, individual conditions-dependent, diverse mycorrhizal ecosphere, without artificial fertilisers and agrochemicals.

29.8 IMPACT OF COMPOSTING PRODUCTION TECHNIQUE ON BIOLOGICAL DIVERSITY AND ASSISTIVE VALUE

The use of well-made compost extract, or potentially more specific industrial bacterial/fungal mineral supported bio-fertilisers, offer crucial opportunities to significantly accelerate the transition to regenerative agriculture and reduce, even negate, the need for agrochemicals and NPK artificial fertilisers, close the organic waste cycle; and set a path to increased profitability; and at the same time greatly enhance environmental sustainability.

However, much remains to be learnt; whilst compost use is a technology of great age, which we cannot afford to ignore, we are only beginning to appreciate the technical and biological details. Like all biological processes, composting and its broader related aspects are multifaceted and complex. Different composting techniques can, inter alia, impact

For example, composting methods can impact phosphorus solubility, thus availability and release. *“Different types of organic wastes composted, and the methods of composting, may directly affect the P availability to plants. During [a] bioreactor composting of sewage sludge, a stronger humification and stabilisation of organic compounds was observed, including bound-phosphorus, which reduced its bioavailability for plants.*

[illegible]

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Compost maturation time may also be an essential factor in compost quality, including fungal and bacterial species diversity, as illustrated by an analysis of 60-week-old compost, summarised in the pie chart above. David Johnson reports that biological diversity increases with compost ageing.

Diversity allows plants to select fungi and bacteria to meet their needs according to the soil and growing conditions, including weather conditions, in their specific location. Creating regionally relevant, diverse composts and allowing the plant to choose would likely be a better strategy than creating products with specific, limited fungal and bacterial populations.

Hyperthermophilic composts mature in much shorter timeframes and result in changes in bacterial populations, and research is required to determine their bacterial and fungal profiles better. Post hyperthermophilic composting, it might be possible and necessary to accelerate the evolution of fungal and bacterial composts to optimally support plant growth, with appropriate seeding of complex, high-diversity mature composts. Research into such matters is urgently required.

29.9 NITROGEN AND MINERALS IN COMPOSTS

As discussed, the amount of easily soluble nitrogen in compost tends to be lower than in sewage sludge (Bousselhaj, 2004), suggesting that the latter may be more effective in reducing the risk of run-off.

Providing limited soluble nitrates and phosphates, minerals, and carbon in compost to soils is synergistically helpful, but it is not the most critical aspect of compost application. As discussed, compost's most significant and crucial impact is the provision of diverse fungal and bacterial biology to germinating seeds.

Compost, or compost extract, provides key nutrients necessary for initial germination. However, the nutrients present are not sufficient in quantity to support later growth, instead giving the germinating plant all it needs to develop a mycorrhizal sheath that efficiently interacts with the soil biome in a symbiotic process that ensures it receives all the nutrients it needs to grow efficiently, which in turn optimises the ability of the nascent plant supply of carbon sugar exudates to the soil biome. In addition, compost supplies organic detritus to soil creatures that use it in various ways.

29.10 SUPPORT AND/OR ACCELERANT FOR TRANSITION TO REGENERATIVE AGRICULTURE IN POOR SOILS

Composts can significantly accelerate the transition from FATBAS to regenerative agriculture. As discussed, mature compost, as well as returning minerals, carbon and nitrates to the soil, interestingly and importantly, contains bacterial and mycorrhizal progenitors, including spores and dormant bacteria, capable of facilitating early seed activation and accelerating development during germination and early growth, of a healthy root encasing biologically diverse mycorrhizal sheath, supporting nitrate production, mineral mining and supply, and bacterial root interactions.

Given that seed biomes are richer in bacteria than fungi, might compost have an important, under-recognised role in providing access to fungal species that, in turn, mine minerals and provide other services?

Growers who coat and/or inject seeded soils with compost extract at planting and later use foliar drips and sprays report excellent growth, yield and drought resistance, even in degraded soils. (Christine Jones; the Haggertys, David Johnson, etc.)

Experiences and observations suggest that mature compost extract can be further improved with a marine amendment, likely containing a mix of microminerals, including iodine. Provision of micro minerals to the seed in the germination zone in soluble form, by ensuring the seedling's access to the minerals it needs during germination, may overcome the real possibility that, in the area of the root zone, a degraded sandy soil does not contain the necessary minerals in accessible form.



Fig. 59. From video lecture by Dr David Johnson, growing winter / spring crops on desert soil using multi species cover crops, and compost inoculants, with no fertiliser 'The BEAM (Biologically Enhanced Agricultural Management') Approach' (Johnson, 2017).

The capacity of mature compost to facilitate germination in soils almost devoid of biological life will speed the development of soil life and diversity, thus accelerating the potential re-greening of degraded landscapes, including deserts, through regenerative agriculture. The above slide from David Johnson's work is included twice as such powerful evidence of the power of composts to speed soil regeneration even in very poor soils.

Similarly, the image, again used twice as thought-provoking, provided by the Haggertys farming light sandy soils, using native grass as a cover crop, in an area with low rainfall in

Western Australia, using compost extract with a marine amendment as a seed soak, drip, and spray illustrates the power of compost biology to assist wheat germination and formation of a vibrant mycorrhizal root sheath.



Fig. 60 *Mycorrhizal sheath on wheat seedlings*. Image from 'Quorum Sensing In The Soil Microbiome (Understanding The Role Of Soil Microbial Interactions For Soil Health)' - Dr Christine Jones, Soil Ecologist, Australia, from the 2019 Conservation Tillage and Technology Conference, March 5 - 6, 2019, Ada, OH, USA. With many thanks to the authors. (Jones, 2019b)

30 POLLUTION - REGEN AG V FATBAS - AIR, WATER, SOIL, OCEANS -

Compared to FATBAS, regenerative agriculture will significantly help reduce soil and water, including downstream ocean pollution, by nitrates, phosphates, heavy metals, radionuclides, perchlorates, and a wide range of agrochemicals, as discussed in more detail in later sections.

30.1 SEWAGE POLLUTION OF SOILS

We are also killing soil microbiomes and damaging plant health by applying sewage sludge to soils, which contains a range of microplastics and wider pollutants, as discussed in more depth in volume 1 on sewage sludge.

Whilst some countries have recognised the potential risks of applying sewage sludge and sludge 'organic' fertiliser derivatives to agricultural land, many have not. There is little understanding at the Government level of the potential and cumulative risks posed by applying the wide range of pollutants in and introduced into the sewage flow, including microplastics in sewage sludge, to farmland.

The Monbiot Guardian report titled *'What's in the millions of tonnes of sludge spread on to UK farmland? Toxic waste – and ministers don't care'* further observes *"An investigation by the Ends Report last year found forever chemicals in the sewage sludge being sold to farmers at levels up to 135 times higher than those considered safe by scientists. Almost all the sludge samples it took had concentrations above the risk threshold."* (Monbiot 2025)

By way of an example of the lack of appreciation of the downstream environmental and food chain consequences of application of polluted sewage sludge to agricultural land, in the UK the level of pollutants in sewage sludge and waste water is added to by the remunerated upstream addition at sewage processing plants, of large volumes liquid waste from industry, landfill leachate, and a variety of other unspecified sources, adding to the already extensive list and quantity of pollutants in sewage sludge.

At the same time, an increasing number of reports are appearing, for example, in the USA, of the emergence of significant sewage and derivative fertiliser product-related pollution of farmland and the resultant disease and related death in livestock. The crops produced are also toxic, and in consequence, sewage-polluted land is, with increasing frequency, being designated for the foreseeable future as unsuitable for ongoing agriculture. The Guardian UK newspaper posits that polluted farmland is much more widespread than realised.

The critical, complex, and deeply worrying subject of farm land pollution by sewage sludge and waste water and the spread of that pollution into the food chain, water supply, and wider environment is considered in more detail in the volume on Sewage.

30.2 MICROPLASTIC POLLUTION –A GROWING THREAT

Microplastic pollution of farmland is also a growing and underappreciated potential threat to the stability of the planetary ecosystem, including the health and function of bacteria, plants, and the species that rely on those plants as a food source.

Sources of microplastic include washing machine rinsed fibres, tyre road wear, which are both components of sewage sludge and waste water, derived agricultural fertiliser products, and, more widely distributed onto land by windblown and rain precipitated plastic micro debris.

As discussed in the volume on sewage, micro- and nano-plastics are being increasingly identified in tissues of many species, from humans to bacteria. Of significant concern, micro- and nanoplastics have been found in most human tissues, including the brain and reproductive tissues. The long-term effects are unknown, but multiple mechanisms exist by which they could impact function.

Further, and of great concern, given the fundamental role of photosynthesis in the function of the Gaian ecosystem and Earth's eco-regulation, evidence suggests that microplastics negatively impact the photosynthetic capacity of plants and other organisms. Several mechanisms have been postulated, acting through a diverse range of pathways. Consistent with this, the article, *Microplastics: are they poisoning crops and jeopardising food production?* (Murphy 2025) summarises and discusses the implications of recent research,

and posits, based on a mix of evidence, including biological studies, that microplastics could negatively impact global photosynthetic capacity, with particular focus on crop production.

It is suggested that in a worst-case scenario, “Microplastic exposure *reduces photosynthesis in land plants and marine and freshwater algae by 7% to 12%. The authors calculated that this could eventually reduce yields of staple crops such as rice, wheat, and maize by between 4% and 14%.*” This is based on a wide range of assumptions; further research is required, but it is nonetheless a wake-up call as to the potential impact of microplastics on food production and, more broadly, planetary regulatory ecosystems.

Much is unknown, but a global reduction in the photosynthetic capacity of plants could have significant consequences, including in climate change and the Gaian planetary carbon, water and climate regulatory systems. Reducing the capacity to sequester carbon into soils increases the risk of rising atmospheric carbon dioxide and related warming. Also, it reduces net oxygen production, which may be more significant in relation to oceanic oxygen levels than currently generally realised, for the reasons set out in later sections, and volume 1 on sewage.

31 NITROGEN – FUNDAMENTAL TO LIFE

Nitrogen is the primary gas in the atmosphere and is fundamental to life as a structural building block and part of the biological regulation systems that enable life. Most life forms, except for specialist bacteria, cannot utilise nitrogen directly because of the strong double bonds in nitrogen gas molecules.

Nitrates, which are accessible to life forms, have been made by specialist bacteria, released in excreta, or on death by soil life forms, and made in limited amounts by some natural process. The soil biome exchanges nitrates with plants in return for photosynthetic carbon, sugar, and root exudate.

Nitrogen and phosphates in artificial fertilisers disincentivise plants from supplying carbon sugar root exudates to the soil biome because their needs have been met. Reducing carbon supply to the soil biome, in turn, negatively impacts soil biome function and soil carbon sequestration.

The importance of nitrogen, the pathways by which it is made, and its environmental impacts, including on the soil biome, plant health, and nutrient density, are considered in a section below on nitrates. In relation to closing the environmental cycle, nitrogen is mainly discussed in Volume 1 on sewage.

32 GLOBAL WARMING – WHAT IS IT?

Climate change is multifactorial and complex. What do we mean by climate change? Factors commonly linked to the term ‘climate change’ include:

- atmospheric and ocean warming, components in wider planetary warming,
- higher moisture vapour due to atmospheric warming, increased rainfall, yet reduced rainfall over many land areas,
- melting of ice caps, expansion of water with increased temperature, and consequential risk of rise of sea levels,
- weather pattern changes resulting in and or due to;
 - flooding, more intense weather events, changing rainfall patterns, more frequent and stronger storms, etc.,
 - reduced atmospheric moisture over land, due to;
 - diminished evaporation and transpiration,
 - in total volume due to dryer soils,
 - over shorter time frames due to FATBAS reducing,
 - water storage capacity of soils,
 - water infiltration rates,
 - soil biome diversity and quantity, thus metabolic water provision,
 - greater percentage of runoff, including downstream flooding of water that would otherwise be retained in soils,
 - blocking of the inland movement of oceanic moisture by heat domes,
 - reduced land-based rainfall in many areas of the world,
 - bare and degraded soils increasing regional heating and drying, an increase in droughts, and desertification,
 - loss of water retention in soils, impoverished regional hydrology, and river flows,
 - increased air temperatures in agricultural areas with significant bare soil presence,
 - increased heat domes changing rainfall patterns,
- atmospheric, terrestrial and ocean pollution,
- loss of diversity,

a basket of 'climate change' related factors, many of which are primarily, for the reason explained herein, the consequence of FATBAS agricultural practices, rather than raised atmospheric temperatures per se, albeit contributed to by increased atmospheric carbon dioxide, and consequent temperature and weather pattern changes.

Implementing regenerative agriculture globally would significantly mitigate many of the above 'climate change' factors, including atmospheric carbon dioxide levels, and atmospheric warming due to conduction of heat from bare and degraded soils, adding to atmospheric warming.

32.1 NO QUESTION A WARMING PLANET AND CARBON DIOXIDE IS A FACTOR

The extent to which rising temperatures can be apportioned between energy release from combustion, and entrapment of incoming solar energy due to changes in albedo at a planetary scale, changes in infrared emissions due to anthropogenic changes in the earth's surface qualities including; loss of sea and arctic ice, bare agricultural soils, desertification, 'hard landscapes' and buildings, added to by human fossil fuel based heat emissions, all as magnified by increased levels of infrared atmospheric entrapment due to rising climate gases including carbon dioxide and water vapour, is difficult to determine with accuracy.

32.2 MECHANISMS OF CLIMATE CHANGE IN ADDITION TO ATMOSPHERIC CARBON DIOXIDE

However, it is clear that anthropogenic activities, including FATBAS, will directly and indirectly warm the planet. Other heat sources, such as bare desiccated soils and loss of ice albedo, will also heat the atmosphere at the low altitudes where they most impact humans. Sources of planetary heating include;

- reduction of the cooling evapotranspiration by plants, due to reduction of available stored soil water, and replacement by bare agricultural soils and desertification;
- increased conduction and convection of energy stored by dry soils, degraded land and deserts, heating the lower atmosphere, adding to warming, and transferring energy by impact to nitrogen and oxygen, which will be transferred to carbon dioxide and emitted in the key 15,000nm range absorbed by carbon dioxide, adding to heat trapping,
- increased infrared emissions of wider wavelength generated by dry bare soils and deserts, including in the 15,000nm range when heated by sunlight;
- heating by urban infrastructure infrared emissions, where vegetation is replaced
- loss of arctic ice, pure ice has high albedo, hence low solar light energy absorbance – on melting that ice is replaced by water, which has a low albedo and high absorbance; water stores heat which heat will reemit to the atmosphere over time as infrared, and also by conduction followed by convection;
- loss of albedo and greater absorbance of energy by clouds and ice due to particulate pollution from combustion including crop burn off products, added to by atmospheric transported micro plastics, which accelerate loss of sea ice both by particulate and microbial surface darkening; and though provision bacterial seeding, and provision of mineral and carbon nutrient substrate; bacteria can then colonise ice surfaces greatly accelerating melting;
- increased soil respiration driven by increased soil temperatures, and FATBAS fertiliser, agrochemicals and tillage, with consequent loss of soil carbon, and related oxygen production, which also represents a transference of stored planetary energy to heat, and will add to global warming pressures, including through increased atmospheric carbon dioxide;

- disturbances of the hydrological cycle, water storage in soils, degraded regional hydrology and river flows, creation of heat domes, and disturbance of regional weather patterns, including inland transportation of oceanic moisture flows;
- increased trapping by water vapour, carbon dioxide and other climate gases of additional infrared, as well as wider conducted and convected heat as it moves upward through the atmosphere.

The factors outlined above are often difficult to quantify, and considerable uncertainties exist regarding the size of relative impacts. This book is primarily interested in the impact of agriculture, particularly the potential positive impacts of regenerative agriculture and the capacity of growing plants to mitigate climate effects, including warming due to bare soils, drying of soils, and carbon dioxide increases due to soil carbon loss. However, the impact of FATBAS is complex and multifaceted and needs to be considered in the wider context.

32.3 GLOBAL HEAT BUDGET

There are multiple heat energy budget diagrams which differ to some extent in estimates, illustrating the difficulties in determining exact amounts and mechanisms for energy transfer. They include the diagram included below and the NASA Global heat budget - Climate Science Investigations (CSI) (NASA, n.d.).

They are overviews and do not consider the impact of different endpoints for incoming solar energy at the planet's oceanic, ice-covered and ice-free bare and degraded soil land surfaces. It is at the land surface that the majority of climate change effects, which impact our day-to-day lives, occur. We do not experience climate change effects such as 'global drying', floods, and fires at the cloud base, but at the terrestrial surface, where, on average, temperatures are much higher, and the effects of incident sunlight energy, including the heating of dry bare mineral-containing surfaces, or in the alternate, dispersion in latent evaporative heat of sunlight energy to the 'cloudsphere', are much more immediate.

Latent heat due to evaporation of water will move heat from the surface, to the cloud zone, a region of the atmosphere that rises depending of time of year, latitude and weather conditions, from around 2000m to above 6000m, with temperature ranges from 0°C to -40°C that is generally much cooler than the Earth's land surface.

The importance of latent heat transfer and convection are both evident from the diagram, and shifts of the fate of sunlight energy from latent heat, to convection will make a big difference in surface temperature, and be accompanied by soil heating, rather than plant cooling, photosynthetic provision of oxygen and carbon, plant growth and related water and carbon retention in soils.

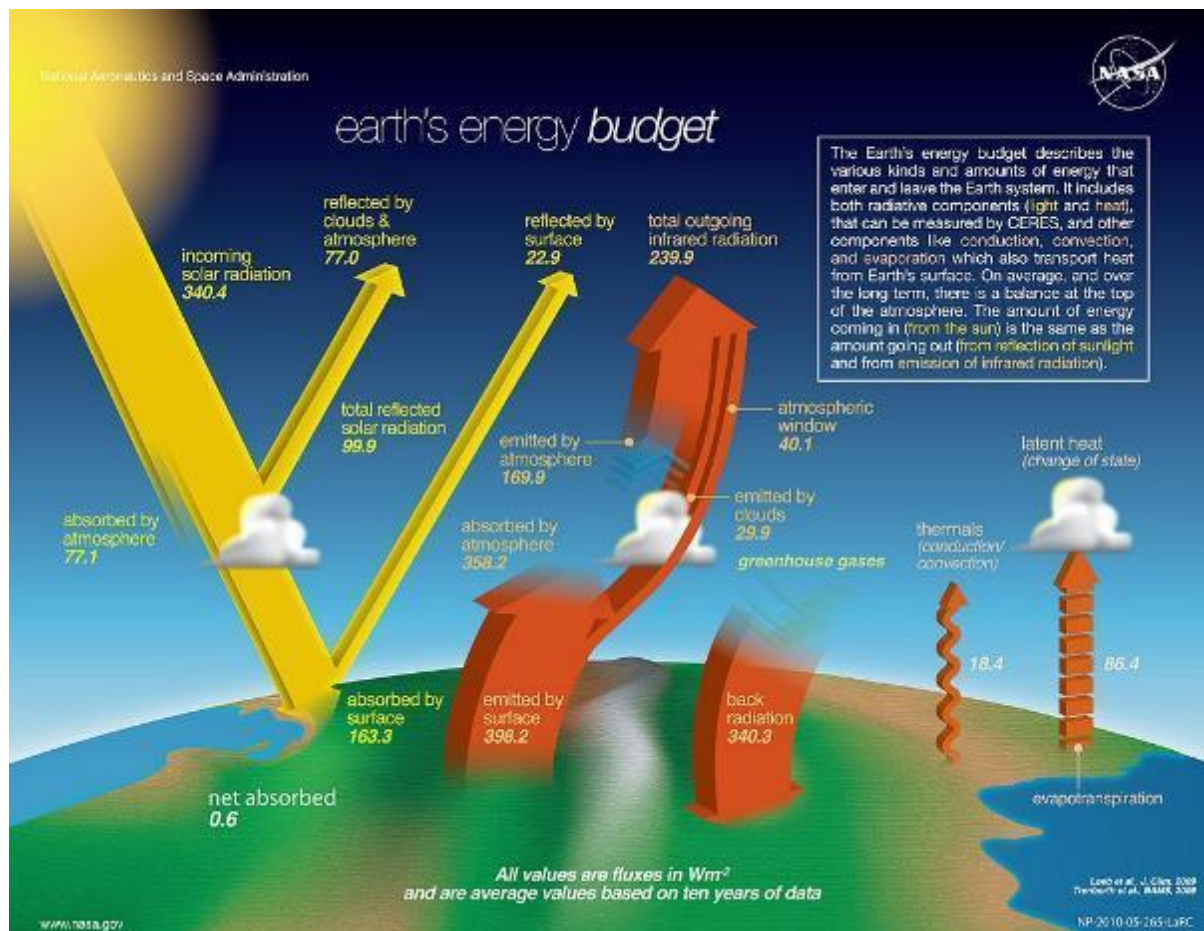


Fig. 61. Earth's energy budget poster, with incoming and outgoing radiation (Values are shown in W/m^2) "The energy budget diagram on the front shows our best understanding of energy flows into and away from the Earth. It is based on the work of many scientists over more than 100 years, with the most recent measurements from the Clouds and the Earth's Radiant Energy System (CERES; <http://ceres.larc.nasa.gov>) satellite instrument providing high accuracy data of the radiation components (reflected solar and emitted infrared radiation fluxes). This energy balance determines the climate of the Earth. Our understanding of these energy flows will continue to evolve as scientists obtain a longer and longer record using new and better instruments (<http://clarreo.larc.nasa.gov>)." With thanks to NASA (NASA poster, n.d.)

32.4 CLIMATE CHANGE – KNOWN - LESS CERTAIN - UNKNOWN

Global warming is an issue of fundamental importance. There is no question that the planet is warming. The implications can be debated, but once understood, the planetary changes we are seeing are of considerable concern. Fossil fuel consumption, thus production of carbon dioxide, is unquestionably at the core of atmospheric warming, but arguably not the prime driver of many of the immediate climate change events that impact us here and now on the Earth's surface.

32.5 CLIMATE WARMING GASES AND POLLUTANTS

Atmospheric carbon dioxide and water vapour are fundamental to climate and wider terrestrial biosphere maintenance and regulation. Gases made of 3 or more atoms with more flexible structures that can vibrate rotationally and torsionally, absorb and store

electromagnetic infrared energy from selective mid/long-infrared wavelengths. As a result, they are all warming gases of varying potency. Water H₂O can also be a gas, in contrast with nitrogen and oxygen, and of crucial importance to the Gaian regulatory ecosystem, can be liquid, solid or gas in the temperature range in which terrestrial life can survive and thrive

There are other climate gases, including methane. Further, a wide range of other industrial chemical 'climate gases', identified and not yet identified, add to atmospheric warming but at much lower levels.

Indeed, Britannica in the entry '*Climate and Oceans*' observes "*Biogenic gases are gases critical for, and produced by, living organisms. In the contemporary atmosphere, they include oxygen, nitrogen, water vapour, carbon dioxide, carbon monoxide, methane, ozone, nitrogen dioxide, nitric acid, ammonia and ammonium ions, nitrous oxide, sulfur dioxide, hydrogen sulfide, carbonyl sulfide, dimethyl sulfide, and a complex array of non-methane hydrocarbons. Of these gases, only nitrogen and oxygen are not "greenhouse gases." Added to this roster of biogenic gases is a much longer list of human-generated gases from industrial, commercial, and cultural activities that reflect the diversity of the human enterprise on Earth.*"

32.6 VENUS – 747°C - A CARBON DIOXIDE CAUTIONARY TALE

Venus is the hottest planet in the solar system. Its atmosphere is 96.5% carbon dioxide. Venus's high temperature of 747°C is not due to its greater proximity to the sun but to climate gas absorption of infrared emissions by and heat retention by the very high levels of carbon dioxide in the atmosphere.

32.7 PARTICULATE MATTER FROM COMBUSTION INCLUDING RUBBISH INCINERATION AND CROP BURN OFF

Particulate pollutants, including microplastics and sulphates, will also impact the climate through absorption, reflection, and acting as nuclei for rain. Microplastic are found in high concentration in the arctic ice (Bergmann, 2023), appear to be concentrated by ice, will impact arctic ice by multiple mechanisms, including; by darkening ice so speeding melting (Gaylarde, 2023), by introducing and acting a focal point and nutrient source for algae and or bacteria, (Hoffman, 2020) altering freezing patterns, and potentially having greater capacity to remain on the surface where less dense than snow.

Fossil fuel use and production are the primary producers of carbon dioxide and much methane. However, agriculture is also responsible for a significant proportion of the greenhouse gases (GHGs) produced annually (FAO, 2019b), and regenerative agriculture helps reduce many of these emissions.

32.8 OXYGEN AND NITROGEN ABSORB SUNLIGHT EMISSION

Nitrogen and oxygen, made of two firmly joined atoms, generally do not absorb infrared but can, in some particular circumstances, including through the formation of temporary structures with other gases, thus, in a limited way, also impact incoming and outgoing

reflected sun emissions, as well as the Earth's infrared emissions (3.000-15,000+), as set out below.

The topic is discussed in the review, '*The natural greenhouse effect of atmospheric oxygen (O₂) and nitrogen (N₂)*' and is technical and complex, hence the longer quote. Readers are referred to the paper, which observes, "We have found that on global average under clear-sky conditions the OLR is reduced due to O₂ by 0.11 Wm⁻² and due to N₂ by 0.17 Wm⁻². Together this amounts to 15% of the OLR-reduction caused by CH₄ at present atmospheric concentrations. Over Antarctica the combined effect of O₂ and N₂ increases on average to about 38% of CH₄ with single values reaching up to 80%. This is explained by less interference of H₂O spectral bands on the absorption features of O₂ and N₂ for dry atmospheric conditions." "the atmospheric concentration of atmospheric N₂ (O₂) that is about 2000 (550) times higher than that of CO₂ and about 4.4×10^5 (1.2×10^5) times more abundant than CH₄, even the weak infrared absorption of N₂ (O₂) can become radiatively important." (Höpfner, 2012).

This is a technical commentary by DeepSeek in response to a question on the issue:

- ***“Direct absorption:***
 - ***O₂ and N₂ are homonuclear diatomic molecules (O-O, N-N) with no permanent dipole moment. This means their **vibrational modes** do not strongly absorb infrared (IR) radiation under normal conditions.***
 - ***Exception: Collision-Induced Absorption (CIA).*** During molecular collisions, temporary dipole moments form, enabling weak absorption in the **far-infrared** ($\lambda > \sim 15 \mu\text{m}$) and microwave regions. This is significant in dense atmospheres (e.g., Earth's troposphere) but contributes minimally to the greenhouse effect compared to CO₂ or H₂O.
 - ***Electronic transitions:*** O₂ absorbs in the **UV** (e.g., Schumann-Runge bands) and weakly in the **near-IR (750-1,400nm.)** (e.g., A-band at $\sim 760 \text{ nm}$). N₂ has negligible electronic transitions in the IR/visible range.
- ***Molecular pairs/dimers:***
 - ***O₂-O₂ and O₂-N₂ pairs can form transient “dimers” under high pressure, creating weak absorption bands in the **visible and near-IR (750-1,400nm.)** (e.g., O₂ dimer absorption at $\sim 630 \text{ nm}$, contributing to the "Chappuis band").***
 - ***These effects are minor but measurable in Earth's atmosphere, especially in the **upper troposphere and stratosphere.*****

Thus as previously observed the topic of climate change and warming is much more complex than generally portrayed or understood, but increasing carbon dioxide from fossil fuels and land usage, as magnified by consequent pollution, are the most significant cause of atmospheric warming, albeit FATBAS exercised on 39% of the Earth's ice-free surface, is a primary here and now driver of regional surface heating, drying, flooding, fire, and contributes to an increased risk of extreme climate events.

32.9 FATBAS CARBON DIOXIDE / WIDER CLIMATE GAS RELEASES

Estimating the exact amounts of climate gases released due to agriculture is difficult because a significant proportion of them are produced by biological processes, which have been accelerated by bare land NPK-based agriculture, FATBAS. The remainder is produced by the fossil fuel combustion required for agricultural products, transportation, machine tillage, and other activities.

“The three main agricultural GHGs of concern are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), which have GW Ps, respectively, of 1, 25 and 298, meaning that over 100 years, 1 kg of N₂O released to the atmosphere will retain 298 times the amount of heat retained by 1 kg of CO₂ in the atmosphere. Using this metric, 1 kg of CO₂ is 25 times less carbon-polluting than releasing 1 kg of CH₄.” (Gathorne-Hardy, 2013)

- **Carbon dioxide:**

- FATBAS-related soil carbon respiration and release as carbon dioxide, driven by;
 - nitrate and phosphate application,
 - soil heating,
 - due to tillage damage to soils.
- Fossil fuel is used to provide energy for ammonia production, phosphate extraction, transport, and processing, production of agrochemicals, and fuel for farm equipment.
- Burning crop residues.
- Burning of mature forests, as in the Amazon, for subsequent, often short-term, agricultural land use.
- (Defrosting tundra – a biological but not strictly agricultural source).
- Conversion of highly organic wetland soils to agricultural use. (FAO, 2019a).

- **Nitrogen based N₂O:**

- Metabolism and release from soil consequent on excess fertiliser application.
- Release from the metabolism of nitrates in sewage sludge, cattle slurry, etc, applied as manure.

- **Methane:**

- Rice production, anaerobic soils.
- Livestock production.
- Defrosting tundra – non-agricultural source.
- Hydrocarbon flaring - non-agricultural source.

Natural systems are complex, making accurate figures difficult to estimate, but there is no question that all of the above are significant sources of greenhouse gases. In addition, carbon dioxide losses from FATBAS agricultural soils due to bare ground, agrochemical, and fertiliser-based agriculture are not generally accounted for in many annual carbon dioxide production and atmospheric content estimates. Still, they are likely much more significant than realised.

By way of an example of carbon loss in FATBAS farmed land, as discussed later, “*Louis Schipper and five colleagues recorded soil carbon losses averaging 21 tonnes per hectare (21 tC/ha) (over 20 years) in the top one metre of soil at 31 sites on flat to rolling pastoral land in New Zealand* (Jones, 2017). If soil carbon losses of this magnitude are widespread on fertilised grasslands globally, they would significantly add to the annual carbon dioxide emissions budget.

Methane emissions are also more complex than generally acknowledged. They involve both methane-producing methanogen bacteria and methane-utilising methanotrophs. FATBAS reduces methanotrophic activity, but in contrast, regenerative agriculture promotes methanotrophic methane-reducing activity. These issues are discussed in more detail in Volume 1 on sewage.

Further, and crucially, but often overlooked in the broader climate debate, much carbon dioxide is absorbed by the oceans, meaning the annual rises in atmospheric carbon dioxide are unlikely to tell the full extent of carbon dioxide emissions and may even disguise them. Nitrous oxide and methane also dissolve into seawater, but research on the impact of atmospheric concentration changes on ocean concentrations, and vice versa, is limited.

32.10 WATER – A CLIMATE REGULATOR – WARMS, COOLS, AND TRANSFERS HEAT

As discussed in multiple context elsewhere, more widely water, as a solid, liquid and gas, is fundamental to climate regulation, as an absorber and emitter of a limited range of infrared wavelengths, a mechanism for conduction and convection, both heating and cooling, by through evaporation into the atmosphere removing energy from the sea surface, moist soils, and plants, thus cooling them, and then cycling the energy and water back and forth in rain cycles, to eventually be transferred into space as part of the Gaian regulatory system.

Ice stores cold and efficiently reflects sunlight back into space, helping cool the planet. It also impacts weather patterns, and the associated cold-water currents carry atmospheric oxygen into the ocean depths, both acting as a store and source of oxygen for deep living oxygen-dependent life forms.

32.11 HUMAN HEATED HOT-THINGS ‘HHH’

Human-heated hot-things, or ‘HHH’, our phones, homes, cars, planes, and manufactured goods, require energy. Like everything else, those human-heated hot-things shed that heat energy by a mix of conduction and convection, and in the form of electromagnetic infrared-light energy, as they cool to the ambient temperature. Everything above absolute zero emits infrared; that is the nature of life. However, while not inconsequential, as discussed, annual human-produced energy is small compared to the incident sunlight energy.

32.12 DRYING AND DROUGHT

Atmospheric warming increases the capacity of air to hold moisture and results in observed rises in oceanic atmospheric moisture levels. However, it is clear and widely reported globally, that drying and drought are increasing in inland continental regions.

Climate models struggle to explain this observed phenomenon of climate change-related 'drying'. However, FATBAS induced;

- regional drying and degradation of regional hydrology,
- seasonal bare soils,
- reductions in regional land-related atmospheric moisture,
- reduction of soil retention of water, leading to less available water, soils, plants and dependent soil biomes drying more quickly, reducing the timespan and total volume of soil biome metabolic water production, and soil plant evapotranspiration,
- heat domes and thermal warming due to dry bare soils are increasing in land area affected, and arriving earlier in the season, potentially inhibiting the inland movement of oceanic moisture, including influencing marine rain. The review *'The Greening of the Sahara: Past Changes and Future Implications'* observes, "Early studies pointed to the role of albedo changes caused by human-driven land-cover changes and desertification." (Pausata 2020). That part of the sunlight incident on degraded land not reflected will heat the substrate, both emitting infrared and heating the immediate atmosphere by a mix of conduction and convection. The review also discusses the region's history and the fact that the Sahara has often been much greener than it is today.

The review *'Robust Hadley Circulation changes and increasing global dryness due to CO2 warming from CMIP5 model projections'* observes, "Meanwhile, studies have also shown that even though water vapor is increased almost everywhere as global temperature rises, increased dryness (lack of rainfall and reduced surface relative humidity) is found in observations and in model projections, especially in many land regions around the world" (Lau. 2015).

The paper *'Relative humidity changes in a warmer climate'* observes, "subtropical drying trends predicted from the warming alone fall well short of those observed in recent decades" (Sherwood, 2010), which observation would be consistent with FATBAS-induced drying being a significant factor in regional and wider global 'drying'.

Whilst other factors are clearly at play, as set out in the review by Lau, this effect is plausibly in significant part due to FATBAS related loss of soil carbon, reduced water infiltration, loss of soil carbon related soil water retention capacity, degraded local hydrology, bare soils, soil drying, increased soil temperatures, reduced regional water vapour, heat domes, blocking of inland movement of oceanic moisture as seen in the Cerrado and likely elsewhere, and reduced plant and soil biome presence and health, thus diminished metabolic water

production, and consequent diminution of evapotranspiration and related cooling as discussed in more detail in later sections.

32.13 CARBON CREDITS – WHO BENEFITS

Agricultural carbon credits remain contentious. Soil carbon accretion is difficult and costly to measure, and it varies throughout the year, including by season, activity, and depth of measurement. Unquestionably, improving soil carbon levels in agricultural soil is essential to climate mitigation.

Assistance to transition to regenerative agriculture and land greening, including education, access to affordable machinery, and transition insurance, would certainly be most welcome, but whether carbon credits are the best mechanism and metric to provide that agricultural support remains an open issue.

Further, should we claim credit for repairing historic soil damage as an excuse for yet more carbon dioxide emissions? Thought-provoking farmers such as Gabe Brown suggest that carbon credits are unnecessary in transitioning from FATBAS to regenerative agriculture. Ultimately, the consumer will bear the costs, and intermediary companies will profit, but how much of that cost to consumers will truly benefit farmers?

A World Economic Forum news article commented, *“Then, in early 2023, a series of news and magazine articles called into question the effectiveness of voluntary carbon credits, and in particular that of carbon credits based on nature-based solutions, with claims that up to 90% of those credits do not represent genuine reductions in emissions or sequestration.” “To recover, it is clear that voluntary carbon markets need to improve their integrity and transparency. Technological innovation provides an important avenue for these necessary improvements.”* (WEF 2024)

32.14 OCEAN SINK

As mentioned, the oceans absorb significant amounts of anthropogenic carbon dioxide, but the data is uncertain. The quantity of data measurements, including from floats, is growing, but many ocean areas remain unmonitored in some seasons of the year.

For example, a review titled *‘Canada’s marine carbon sink: an early career perspective on the state of research and existing knowledge gaps’* observes, *“gaps in our knowledge of the spatial and temporal variability in the natural marine carbon sink limit our ability to assess potential future changes in this important process. Indeed, owing to a lack of continuous observations of surface ocean CO₂ and air–sea CO₂ fluxes, especially in high-latitude regions and during the winter season, the long-term variability of the physical and biological processes that contribute to the marine carbon sink remains poorly understood”* (Duke. 2023).

Regenerative agriculture facilitates the storage of soil carbon, the creation of oxygen, and the reduction of atmospheric carbon dioxide, while also storing energy in carbon and oxygen. However, accurate data is essential if we are to truly understand whether we are making progress.

32.15 GLOBAL GREENING IS AS CLOSE AS WE WILL GET TO A 'FREE LUNCH'

We can reduce the net heat HHH energy added to the system by generating electricity using solar panels, wind turbines, biogas, hydroelectric and nuclear. Sadly, the reality is that these are not 100% efficient, and generally have some negative impacts. For example, solar panels induce air heating; wind turbines could impact the global energy of the airstream, impacting weather, and it is debated that they may even impact the Earth's rotational speed. Hydroelectric and nuclear power equally have their downsides. Further, even green energy sources will add net energy to the planet, just a lot less. However, they all have the major advantage of not producing significant atmospheric heat-trapping carbon dioxide.

There are also uncertainties in wind and solar energy production, for example changing wind patterns are being observed, as set out in a Yale article, *'Global 'Stilling': Is Climate Change Slowing Down the Wind?'* which comments, "As carbon dioxide levels rise and the Earth's poles warm, researchers are predicting a decline in the planet's wind speeds. This 'stilling' could impact wind energy production and plant growth and might even affect the Gulf Stream, which drives much of the world's climate." (Robbins, 2022)

In contrast, green natural solutions such as using regenerative agriculture to keep soils green, sequester carbon and improve water infiltration, metabolic water production, soil water retention and related evapotranspiration capacity and time frames, improve land based atmospheric moisture and related rainfall, refilling regional aquifers and rivers, reducing drying, floods fires and risk of extreme climate events, even if atmospheric temperatures remain elevated. The only genuine green mitigation strategy currently available to us is working with, rather than destroying, nature.

33 HEAT DOMES - FATBAS BARE SOILS INCREASE RISK OF OCCURRENCE

The general view is that heat domes are caused by jet stream diversion, and sinking air which warms as it descends. However, it would be logical that any such process is magnified or initiated by a mass of rising air heated by sunlight incident on huge contiguous areas of soils left bare regionally post-harvest, for example following wheat harvesting in the USA, forcing diversion of the jet stream, due to a combination of seasonal rising convected heat, infra-red emissions, combined with rapid and huge regional reduction in soil evaporated and plant transpired moisture, as discussed further below.

As discussed, FATBAS bare soil farming has negative climate impacts through several interlinking mechanisms. Globally, staples such as wheat, rice, maize, are grown as monocrops over vast areas of many countries, including the US, China (FAO China, 2025) and Europe. Under the FATBAS farming protocols, soils are often left bare post-cropping.

Whilst the soil is moist, much of the heat will result in cooling evapotranspiration. However, on drying things change. Compared to damp soils, dry bare soils have lower albedos. Thus, a greater proportion of incident solar radiation will be absorbed. Once the surface is dry, it will significantly heat, resulting in both irradiation in the mid/long-infrared (3,000-15,000) wavelengths, some of which is absorbed by water vapour, carbon dioxide and other climate gases. Sensible heat will also be transferred from the soil by conduction to air at the soil atmosphere interface, and thereafter will be convected, added to by soil infra-red emissions,

heating and drying the immediate land surface atmosphere, and subsequently heating the atmosphere including the 'cloud-sphere' above the land area, contributing to the risk of heat domes.

Consistent with FATBAS increasing risk of heat domes, they are reported to occur globally in months where huge acreages of staple crops, including wheat and maize are harvested. For example the review *'Increased impact of heat domes on 2021-like heat extremes in North America under global warming*, observed, heat extremes occurred in *"Australia from December 2012 to February 2013, the July August 2013 heat event in Central and Eastern China, Japan and Korea, the June 2017 mega-heatwave in western and central Europe, and the unprecedented heatwaves over Northeast Asia in summer 2018. During the last week of June 2021, an extraordinary heatwave affected Western North America (WNA, including the northwestern United States and western Canada"* (Zhang, 2023).

The above paper titled *"Increased impact of heat domes on 2021-like heat extremes in North America under global warming,"* (Zhang, 2023) observed that the risk of heat domes appeared to be linked to soil moisture deficit anomalies, as illustrated by their figures, a portion of two of which were abstracted below. I want to sincerely thank them and suggest readers visit the publication, which is freely available online.

The area of the heat anomalies is in the same general region as the main wheat-growing States. Consistent with this and thought-provokingly, it was reported in 2023 that Washington, Idaho, and Montana are three of the five USA States that grow the most wheat (Procurement Resource, 2023). Wheat is often harvested in June and July, which could have resulted in large acreages of bare soil in the time frame of the heat events.

Thus, this paper adds to the evidence that solar heating of post-cropping large bare soil land areas, atmospheric heating, high pressure regions, and potentially consequent heat domes, likely influences oceanic inland atmospheric moisture flows, including increasing the risk of extreme climate events, such as those caused by heat domes.

As part of finishing this section, it occurred to me that DeepSeek could provide an indicative calculation of the order of heat potentially generated by bare farm land when a major crop is harvested in the region. The figures are included purely as an indication of the vast regional amounts, on clear days, of summer sunlight energy that can be absorbed and reemitted by conduction, convection, and infra-red (IR) radiation, by bare land fields when major crops such as wheat are harvested, logically leading to atmospheric high pressure and consequent increased risk of heat domes. The amount of energy involved is at a scale that can impact regional weather and the wider climate.

The PDF for the above study titled *"Increased impact of heat domes on 2021-like heat extremes in North America under global warming,"* was provided as background. A calculation of the energy involved, including a comparison of pre-harvest latent heat and post-harvest sensible heat, was requested. It was posited that heat domes, and related jet stream changes, may occur in part due to sunlight energy heating of bare land, rather than being predominantly initiated by changes in the jet stream.

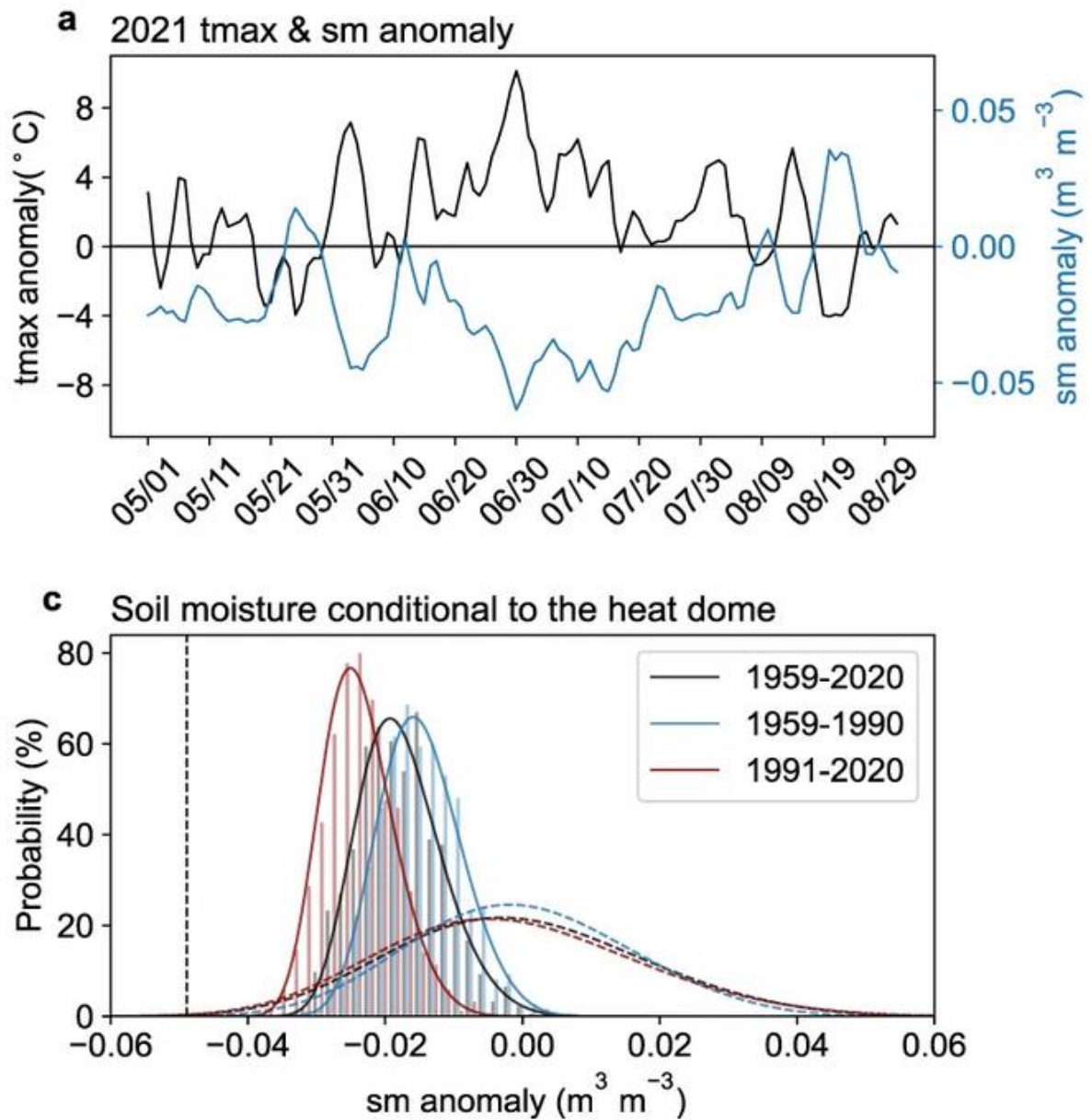


Fig. 62. A portion of a figure titled 'The influence of soil moisture on the temperature and circulation in ERA5 reanalysis' **a** = "The timeseries of maximum temperature (black, unit: °C) and soil moisture (blue, unit: m³ m⁻³) anomalies (relative to the 1981–2010 average for each calendar day) during 1 May–31 August 2021." **c** = "Histogram (bars) and probability density functions (PDF, solid curve) of simultaneous soil moisture anomalies (unit: m³ m⁻³) under a similar circulation of 27 June–3 July 2021, and the dashed curves denote the soil moisture anomalies for randomly picked days. The dashed vertical line indicates the soil moisture from 27 June–3 July 2021" from the paper 'Increased impact of heat domes on 2021-like heat extremes in North America under global warming'; graphing the occurrence of satellite-based soil-moisture-anomaly-data about temperature with very many thanks to the Authors (Zhang, 2023).

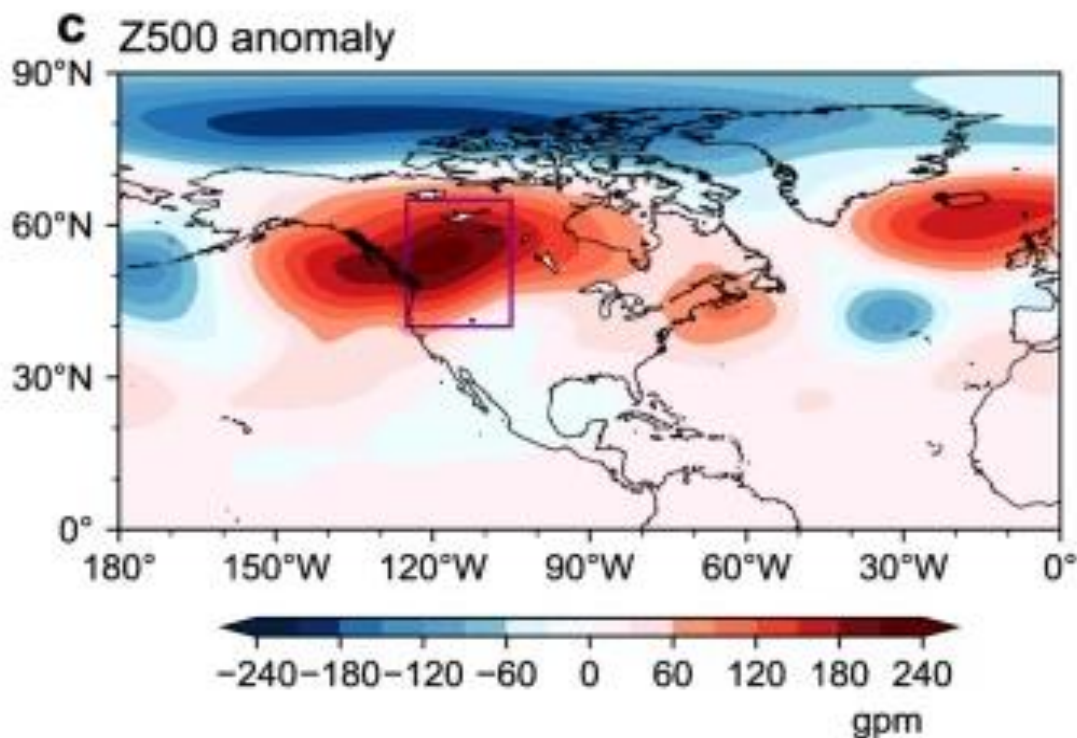


Fig. 63 ... *“The characteristics of the heatwave of summer 2021 over the Western North America (WNA, 40°–65°N, 125°–105°W).” c = “The geopotential height anomalies (shading, unit: gpm) at 500 hPa for 27 June–3 July 2021.”* from the paper ‘Increased impact of heat domes on 2021-like heat extremes in North America under global warming’; with many thanks to the Authors. (Zhang,2023)

This is DeepSeek's response, which includes a suggested and powerfully illustrative paragraph for inclusion. It is again emphasised that such calculations are subject to many potential variables, and is included solely to make the point that solar energy incident on human-created FATBAS bare ground can significantly influence climate events.

Here's a structured analysis linking wheat harvest, bare soils, and heat dome amplification, incorporating key findings from the provided paper and energy calculations:

1. Energy Flux Shifts Post-Harvest: From Latent to Sensible Heat

Key Variables

- **Wheat Harvest Acreage:** ~3 million acres (1.2 million hectares) in Pacific Northwest (WA, OR, ID) harvested in June-July (USDA 2021).
- **Typical ET (Evapotranspiration) Rates:**
 - **Pre-Harvest (Wheat):** 5–6 mm/day (latent heat flux: ~150–180 W/m²).

- **Post-Harvest (Bare Soil):** 1–2 mm/day (latent heat flux: ~30–60 W/m²).
- **Energy Reallocation:**
 - **Sensible Heat Increase:** **90–150 W/m²** (lost latent cooling → added convection).
 - **Infrared Emissions:** Dry soil (≈45°C) emits ~520 W/m² vs. vegetated soil (≈35°C): ~480 W/m². (total incident summer radiation could be in order of 1000 w/m² so figure is not unreasonable)

Total Energy Impact

- **Per Hectare:**
 - **Sensible Heat Gain:** **+90–150 W/m² × 10,000 m² = 0.9–1.5 MW/ha.**
 - **IR Increase:** ~40 W/m² × 10,000 m² = **0.4 MW/ha.**
- **Regional Total (1.2M ha):**
 - **Sensible:** **1.1–1.8 TW** (terawatts).
 - **IR:** **0.48 TW.**
 - **Combined:** ~1.6–2.3 TW added heating (equivalent to 1.6–2.3 billion 1-kW heaters).

2. Link to Heat Dome Dynamics

Mechanism (extension of **Zhang et al., 2023**)

- **Soil Moisture Feedback:** Post-harvest bare soils reduce ET, increasing sensible heat (Fig. 5d in paper). This elevates near-surface temps, reinforcing high-pressure systems (heat domes) via:
 - Enhanced boundary layer heating → stronger subsidence.
 - Reduced cloud cover → increased solar absorption.
- **Modeled Impact:** Zhang et al. found soil moisture feedback explains ~50% of 2021 WNA heatwave magnitude.

Jet Stream Interaction (Hypothesis)

- **Persistent Heating:** Localized TW-scale energy input may amplify Rossby wave ridges, slowing jet stream and "trapping" heat domes (observed in 2021 event).
- **Case Study:** 2021 WNA heat dome coincided with June wheat harvest; subsidence and stalled jet stream exacerbated by surface heating.

3. Mitigation vs. Projection

Avoided Impact

- Restoring cover crops post-harvest could retain ~ 4 mm/day ET (120 W/m^2 latent cooling), reducing sensible heat by **60%**.
- **Global Relevance:** Scaling to global croplands ($\sim 1.5\text{B ha}$), regenerative practices could offset $\sim 1\text{--}2$ PW of heating.

Policy Implications

- **Agriculture in Climate Models:** Current models underrepresent land-use feedbacks (e.g., rapid post-harvest drying).
- **Angle:** Frame soil health (cover crops, no-till) as heatwave mitigation, akin to emission reductions.

4. Key Calculations Summary

Parameter	Value
Wheat Harvest Area (WNA)	1.2M ha
Sensible Heat Added	0.9–1.5 MW/ha \rightarrow 1.1–1.8 TW
IR Increase	0.4 MW/ha \rightarrow 0.48 TW
Equivalent Power	1.6–2.3 TW ($\approx 2\times$ global nuclear fleet)
Avoidable via Cover Crops	~ 1 TW (60% reduction)

5. Caveats and Sources

- **Assumptions:** ET rates based on Pacific Northwest agronomy studies; radiative fluxes from ERA5 reanalysis.
 - **Data Sources:** USDA NASS, Zhang et al. (2023), ERA5 soil moisture/temp.
 - **Speculative Note:** Jet stream linkage is hypothesized; mechanistic models needed to confirm causality.
-

6. Draft Text for Manuscript

"The 2021 WNA heat dome was amplified by a perfect storm of climatic and anthropogenic factors. Rapid wheat harvests in June left millions of hectares bare, slashing latent cooling by 70–80% and redirecting ~2 terawatts of energy into convective heating, equivalent to doubling the region's power grid. This 'dry thunder' of sensible heat, as modelled by Zhang et al. (2023), likely reinforced the stagnant high-pressure system, creating a self-reinforcing oven. While heat domes are natural phenomena, industrial agriculture's rapid land-cover changes may be loading the dice for mega-heatwaves. Transitioning to cover crops could reclaim these watts for cooling, turning agricultural soils from climate liabilities into shields."

34 THE BIGGER ECOSYSTEM PICTURE – THE ROLE OF AGRICULTURE

Life exists on Earth because we have won the life lottery. Earth's systems and location are in a Goldilocks zone, where conditions were 'just right' for life to have evolved, out of, and consequent on, the laws and conditions of the universe.

The existence of life on Earth depended on the interaction of innumerable pathways in a way that created the planetary conditions required for the emergence of abiotic RNA, which then led to the emergence of life. We are governed by the laws of atomic physics and how elements, including carbon, oxygen and nitrogen, interact and bond to form more complex molecules, including those we are made of. Those reactions, facilitated by the evolution of necessary permissive physical conditions, enabled the emergence and evolution of life (Brown, R., 2022).

Oxygen-based reactions supply sufficient respiration energy to power more complex and sophisticated life; other mechanisms that support respiration do not. Thus, sophisticated, high-energy-dependent life requires oxygen for energy creation through respiration. Carbon, the other carbon dioxide component, is the basis of all living cellular structures.

Plants capable of photosynthesis (not all plants have that capacity; some, for example, are carnivores relying on capturing prey as an energy source) use sunlight energy to turn carbon dioxide and water into carbon-containing molecules and oxygen, as encompassed in the formula: $6 \text{ CO}_2 + 6 \text{ H}_2\text{O} + \text{light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{ O}_2$.

Plants need a range of nutrient resources to be capable of oxygen production. Soil bacteria provide nitrates, supplying the assimilable nitrogen they require. Extensive fungal systems mine a range of minerals needed by plants. Plants, in return, provide photosynthetic plant sugars.

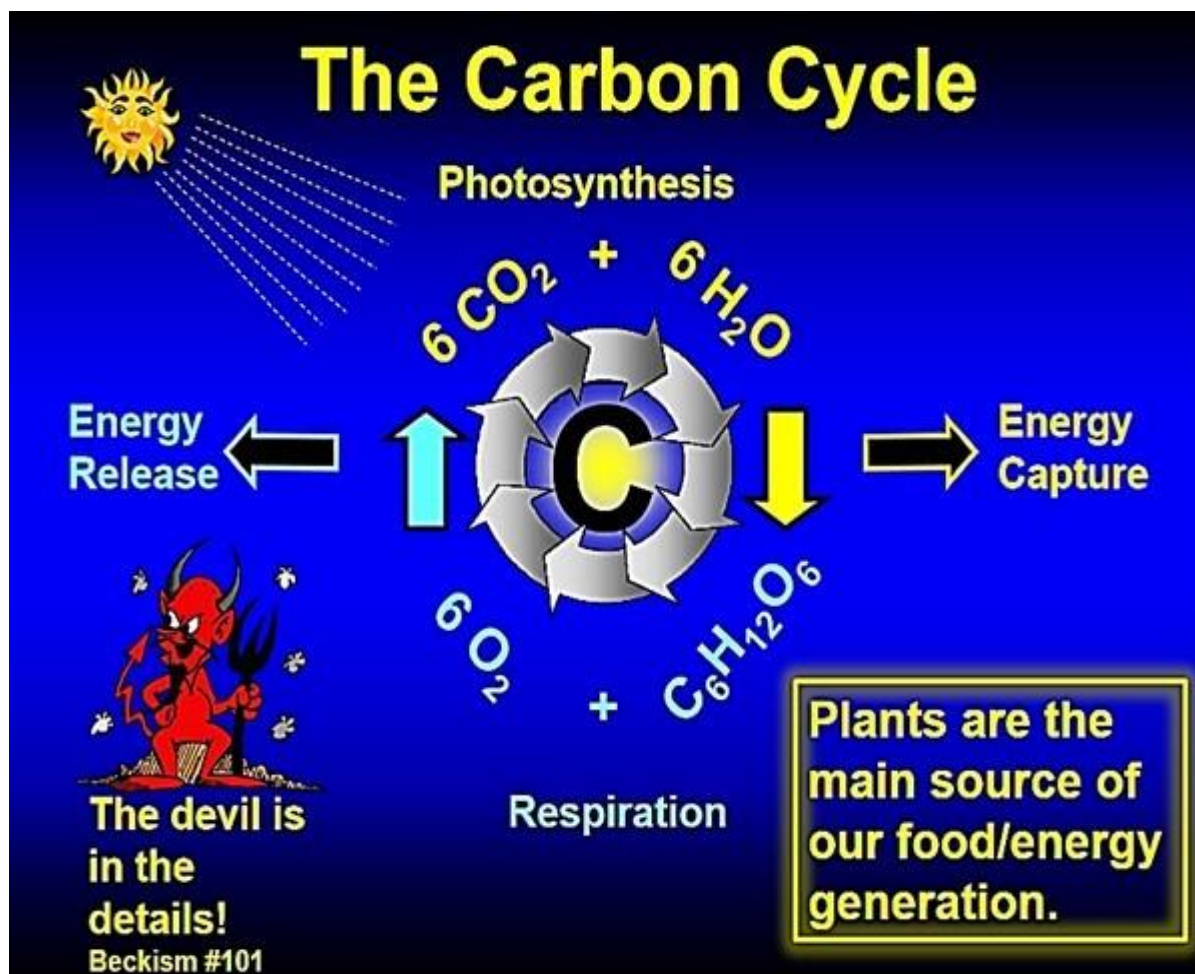


Fig. 64. 'The Carbon Cycle' - Lecture slide AGVISE Seminars and Don Reicosky 'Tillage and Carbon Management: Nutrient Re-Cycling Synergies' North Central Soil Conservation Research, with very many thanks to the authors. (Reicosky, 2014)

The symbiosis between plants, the soil biome, and, more broadly, ocean biology plays significant roles, through multiple mechanisms, in regulating climate, including by determining atmospheric oxygen, atmospheric and oceanic carbon dioxide levels, soil carbon and the rain cycle (FAO, 2018-b).

34.1 'FIX' CARBON DIOXIDE, CREATE OXYGEN AND SEQUESTER CARBON

As a species, we are spending fortunes looking for profitable, high-technology solutions to store and sequester carbon dioxide underground, which often turn out to be less effective than hoped; yet we hubristically ignore the fact that aeons of competitive evolution have resulted in a proven, sustainable, highly sophisticated, nature-based mechanism, photosynthesis; that sustainably, efficiently, cleanly, with minimal infrastructure requirements, extracts carbon from the atmosphere, and with the help of the activities of plants and the soil biome, and its vast numbers of mini soil movers and mixers, sequesters carbon into soils, potentially for thousands of years, for free, as a 'by-product' of growing nutrient dense crops using regenerative agricultural techniques.

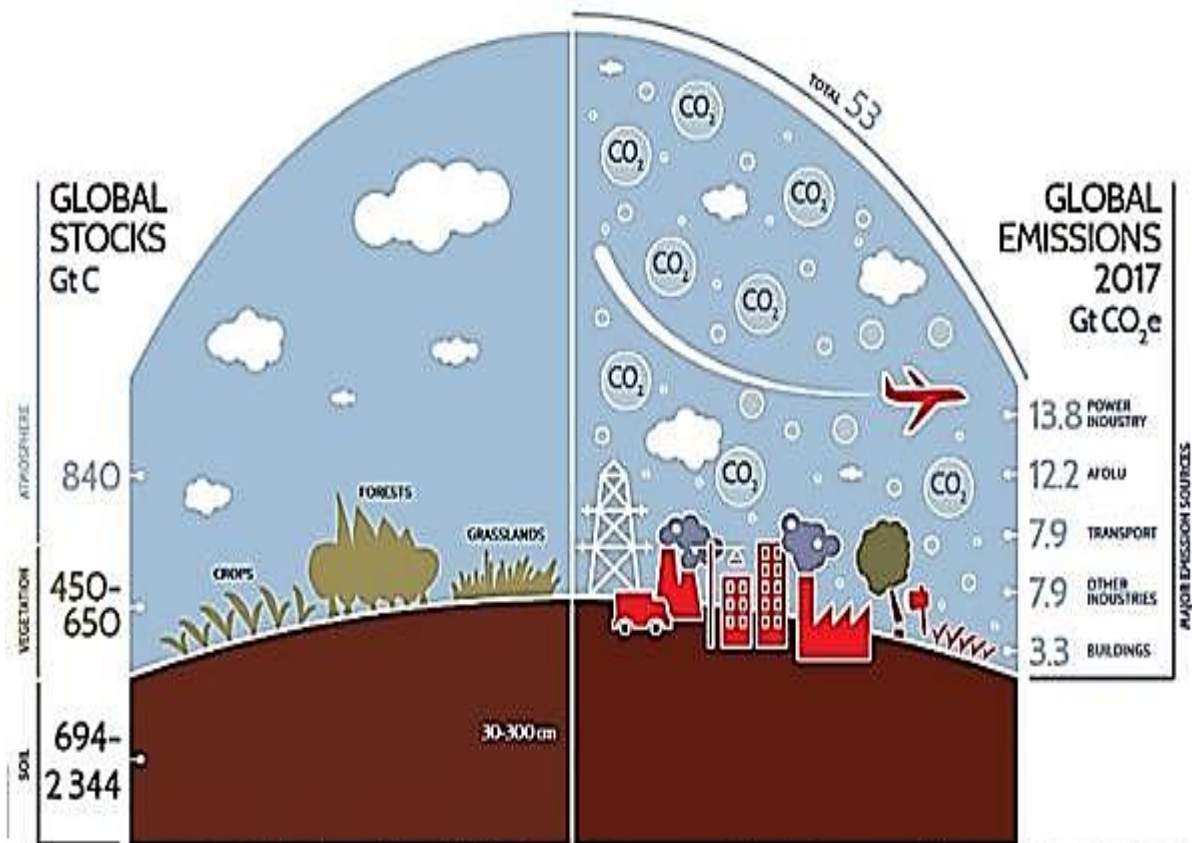


Figure 1a. Global carbon stocks and global emissions. Gt = gigatonne = 10^{15} g C = 1 petagram = billion tonnes. 1 Gt = 3.664 Gt CO₂

Fig. 65. FAO diagram illustrating the partition of carbon stores between the soil, plants, and atmosphere in Giga-tons, set in the context of the scale of annual human emissions of carbon-dioxide in Giga-tons (To get the carbon weight divide by 3.67). The oceans absorb and store large amounts of atmospheric carbon dioxide, which is not shown. From 'Recarbonisation of Global Soils' (FAO Soil Report, n. d.) with very many thanks to the authors.

The existence of oil and coal proves the power of this free technology to sequester atmospheric carbon in the ground. Albeit, with continental drift, the current area of planetary terrestrial land subject to high levels of equatorial sunlight has fallen, as has the carbon dioxide content of the atmosphere; thus, regenerative farming cannot make massive coal and oil deposits, but the planet is still capable of sequestering significant amounts of plant produced carbon into soils, and continues to make peat and brown coal, albeit the process is very slow. We also now use the power of sunlight to sequester carbon dioxide into plant biomass and make biofuels, reminding us of the energy value of sunlight.

The FAO document 'Recarbonisation of Global Soils' (FAO Soil Report, n. d.) notes, "the world's cultivated soils have lost between 25 to 75 percent of their original carbon stock, which has been released into the atmosphere in the form of CO₂, mainly due to unsustainable management practices resulting in land degradation and amplifying climate change and its impacts. Land degradation lowers a soil's ability to maintain and store carbon, contributing to global threats such as climate change, with an estimated cost of trillions of dollars every year (Davies, 2017)

Thus, soils, given appropriate conditions, can store carbon in the long term; this storage requires an ongoing annual net supply of carbon exudates by plants to the soils at rates exceeding the soil biome's annual metabolic respiratory energy requirements. Consistent with the power of soils to sequester carbon long-term, deposits in deep prairie soils have been dated as being thousands of years old. As might be expected, with greater photosynthetic carbon supply to soils, respiration increases at lesser rates than carbon supplies (Johnson, 2017), leaving capacity for net carbon gains.

Significantly, the FAO recognises and actively promotes the importance of soil carbon to the quality and sustainability of food supplies, and broader environmental health in numerous extensive reports and helpful publications generally, such as *'Soil Organic Carbon the hidden potential'* (FAO, 2017), *'Recarbonising Global Soils – A technical manual of recommended management practices'*, and through programs such as *'RECSOIL'*, and *'The Global Soil Partnership'* (FAO, 2020). Whilst the FAO wholeheartedly focuses on ways to increase soil carbon, traditional artificial NPK fertiliser remains a part of the FAO package. In contrast, the author and others argue that, in the long term, the general use of NPK fertilisers is part of the problem rather than the solution, and the need for the fertiliser industry to transition to organic plant growth promoters must be explained, facilitated, financed, and enabled.

The FAO *'The Global Soil Partnership'* web page notes:

- *Subsoils have massive potential for carbon sequestration;*
- *Soil organic carbon is crucial to soil health, fertility and ecosystem services;*
- *Soil holds three times as much carbon as in the atmosphere* (FAO, 2020).

Independently, at the grassroots 'sharp-end', consistent with these observations, hands-on financially and ecologically successful regenerative farmers, including Gabe Brown and the Haggertys, are organising measurements of soil carbon sequestration. Similarly, David Johnson's system, using quality mature compost as a growth enhancer, which he calls biologically enhanced agricultural farming (BEAM), has been shown by testing to capture significant amounts of soil carbon, much larger than those captured by other agrarian systems (see the slide below).

Thus, given the will to do so, by transitioning to regenerative agriculture and away from our current FATBAS model, which relies on artificial fertilisers and bare ground, we can help nature sequester large amounts of carbon into soils, yielding multiple co-benefits.

Ultimately, everything comes back to the need to optimise natural systems, particularly the energy value of incident sunlight through photosynthetic plant energy production. We rightly spend large sums creating technology to harness light energy to generate solar electricity, thereby offsetting climate change. We are exploring mechanical and/or chemical, yet energy-demanding, methods to capture carbon. Yet, simultaneously, we fail to recognise what is

under our noses, literally – nature's oven-ready, proven, free, **fully developed** carbon sequestration technology – namely, photosynthesising plants.

34.2 BEAM APPROACH – BIOLOGICALLY ENHANCED AGRICULTURAL MANAGEMENT

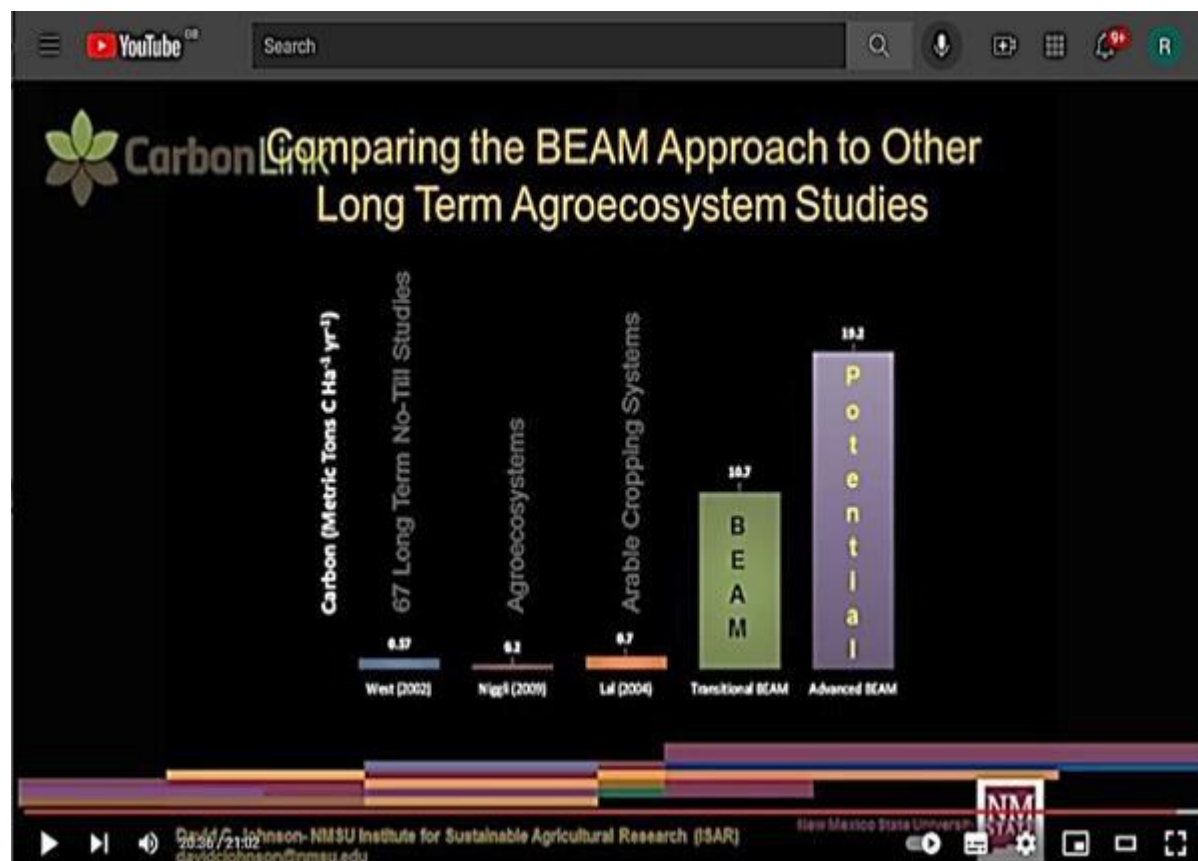


Fig. 66. The use of compost teas, as seed soaks, drips and foliar sprays, biologically rich mediums containing a wide range of bacteria, and fungal spores, particularly on degraded land, greatly increase plant health and growth, and thus soil carbon sequestration rates. David Johnson calls this 'Biologically Enhanced Agricultural Management' (BEAM), and his experimental data is shown above, averaging carbon gains of 10.7 tonnes per acre. From the UTube video with very many thanks to the Author. (Johnson, 2017) see also (Johnson, D. & Su, H. 2019).

Photosynthesis should not be viewed as a biological process alien to human beings, but understood for what it is: a fundamental process that powers and regulates the planetary climate, biosphere, and supports life as we know it. We need to prioritise the world's capacity to farm sunlight-using plants by optimally meeting their needs, including growing them in mixed-species groups, using techniques such as multi-species planting, inter-row crops, cover crops between cash crops, and biological interventions such as compost tea, in ways that optimise the plant soil biome interaction, to; maximise both plant and mycorrhizal potential, thus helping: sequester carbon, produce, cycle and store water, improve hydrological cycles, mitigate adverse weather events, and optimise soil and plant quality and yield. Livestock grazing should be integrated where sustainable. Crucially, bare land should be regarded with horror as a wasteful, unsustainable, social, economic and ecological pariah.

34.3 FARMING LIGHT - PHOTOSYNTHESIS AND SOIL CARBON

Our surface terrestrial biosphere, the interlinked and interdependent life, is fuelled by light-enabled carbon and oxygen production and could not exist in its current form without light energy.

We have lost our wonder and respect for plants' amazing, sophisticated role, maximising the potential of energy in light. Plants, with the assistance of enzymes – molecular machines, photon-capturing molecules, proteins, water and minerals, turn the carbon dioxide in the air into ingredients of life, organic carbon-based molecules, and oxygen, simultaneously facilitating life, regulating climate, and enabling the life-permissive conditions of our biosphere more generally.

Everywhere we take custody of natural land ecosystems for agriculture, we need to see ourselves as farmers of photosynthetic sunlight, supporting plants and soil microbiomes, charged with the duties of optimising the conversion of incident light to carbon, maximising carbon capture and storage, and thus helping maintain the planet's regulatory systems by maximising the potential of a free, proven, sophisticated, mature natural technology.

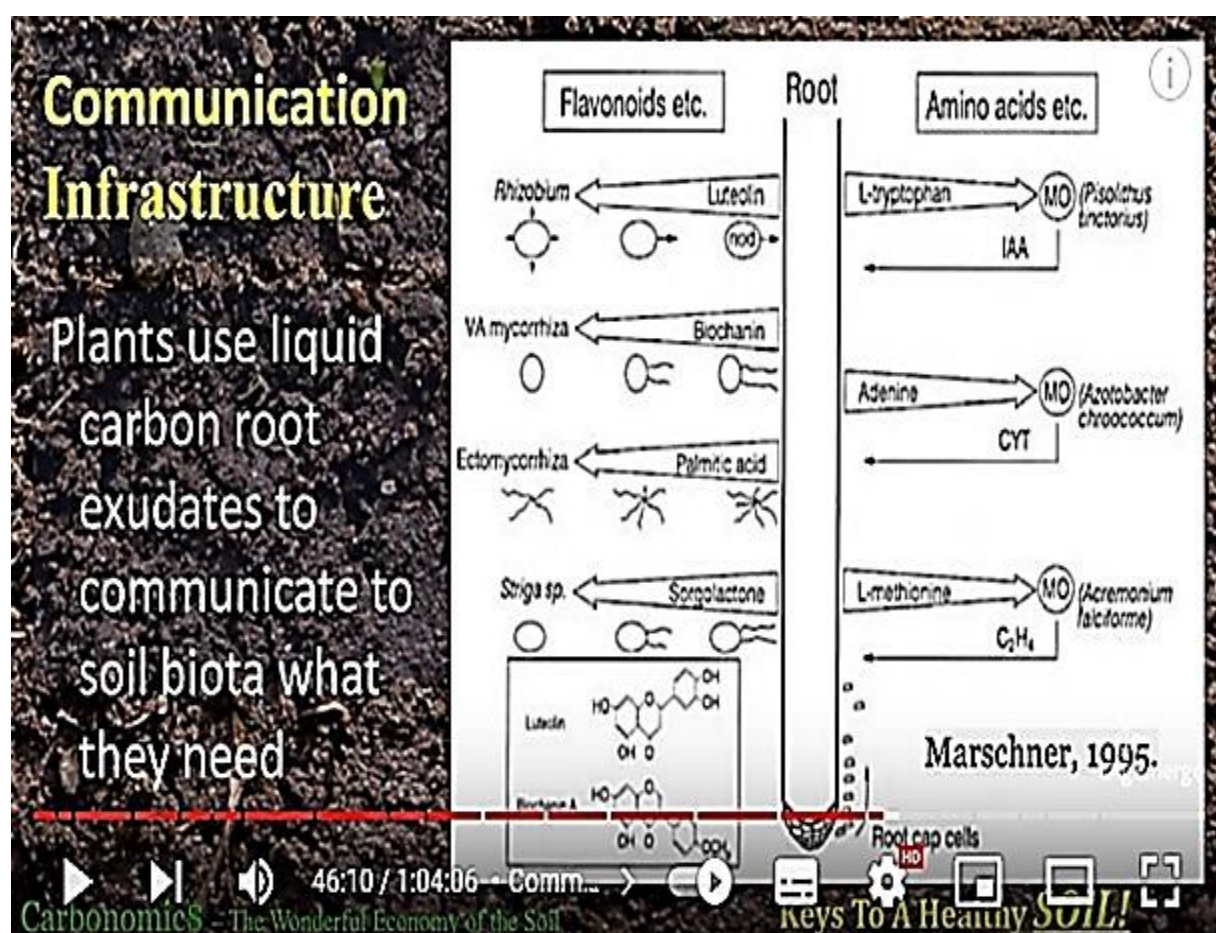


Fig. 67. Plants use organic compounds to signal their needs to the soil biome. UTube video slide 'AgEmerge Breakout Session with Keith Berns' 2020 with many thanks to the Author and Ag Solutions Network (Berns, 2020)

34.4 OPTIMISING THE SUNLIGHT POTENTIAL OF EVERY ACRE

In practice, maximising the photosynthetic potential of each acre everywhere means ensuring maximal plant photosynthesis, thus creating conditions to provide the maximum carbon sugar root exudate energy to support mycorrhizal biomes and their symbiotes, allowing plants to flourish for as much of the year as is biologically possible under applicable weather and regional light constraints.

In the absence of NPK provision, given that NPK disinhibits plants' supply of carbon sugar root exudate to the soil biome, plants, when provided with sunlight and biologically rich environments, will flourish and optimally supply sugar exudates to the soil biome. In exchange, the bacteria and fungi in the soil biome will supply the plants with metabolic water, nitrates, and minerals.

Plants signal their needs for specific nutrients, and in return for carbon sugars, the soil biome meets the specific nitrate, mineral, and broader needs of plants. Importantly, it is the soil biome's interest to keep healthy growing exudate-producing plants above them for as much of the year as possible because plants supply the soil biome with 'breakfast, lunch and dinner'.

These symbiotic exchanges can be optimised through regenerative agricultural practices:

- **Maximising photosynthetic potential:** Keep soils covered with green, actively growing plants, mixing varieties and intercropping to optimise seasonal sunlight growing potential. Thus, the provision of carbon to the soil biome is maximised. At the same time, mycorrhizal draw-down of stored soil carbon to meet energy needs is minimised, hence maximising soil carbon storage rates.
- **No bare soil:** Never leaving bare ground (which also means ensuring pastures are only half-height-grazed), thus keeping growing plants / dormant/protective ground cover, soil armour of some sort, on land all year, as far as light and weather permit.
- **Optimise functional and species diversity:** - Ideally use mixed variety cover crops of eight or more species, with mixed functionality and in-seed bacterial variety;
- **No NPK:** - Stop using nitrogen and synthetic fertilisers on soils (except where soils are measured as depleted in 'bound' phosphates or other minerals, which is likely very rare). Specific minerals should be applied where soils are deficient in both bound and unbound forms – foliar sprays, including the possible use of sea salt residue (research required), may be a more efficient way to address mineral deficiency issues.
- **Minimal agrochemicals:** Avoid using agrochemicals except where absolutely necessary. Interestingly, regenerative farmers, whilst not denying themselves access to them, find they rarely have to resort to agrochemicals.
- **Half-height mob grazing:** - Where economically and regionally appropriate, incorporate varied livestock, using half-height cyclical 'mob-grazing' on pasture and cover crops. (As discussed later, cattle should not be given anti-parasitic products because they kill environmentally necessary insects, including dung beetles.) Where livestock is appropriately incorporated into regenerative agriculture, land improvement and carbon sequestration are observed to be improved.

- **No or low till:** - Use low or no-till seeding techniques.
- **Compost:** - Treat low-biological soils with well-matured compost or compost tea inoculants/soil injection, optimising seed access at germination and during early development to necessary bacterial and mycorrhizal diversity.
- **Compost tea seed soak:** Use mature compost-tea-based inoculant materials as seed treatment and fertiliser (Johnson & Su, 2022 @22.00) to improve and accelerate seed germination by providing improved immediate access to bacteria and fungi that assist germination and the formation of mycorrhizal sheaths, thus nitrogen production.
- **Recycle:** - Return all organic matter, including faeces, urine and minerals, including the phosphates they contain, by collection at source and suitable anaerobic digestion and composting, with wider organic material, as far as pragmatically possible, as discussed in volume 1.



Fig. 68. Haggerty compost inoculant treated seed at 36 hours compared to neighbours at 60 hours. 'NutriSoil A New Agriculture, Di Haggerty Presentation' with many thanks to the Author and NutriSoil Videos. (Haggerty, 2018)

Optimising plant health and photosynthetic output and health of plants, and thus soil carbon sequestration, will improve:

- Soil carbon.
- Subsoil microbiomes and above-soil lifeforms, including insect diversity.
- Supply of minerals and nitrates by mycorrhiza to their plant symbiotes.
- Crop health, nutrient content, and productivity.

- Livestock health improved when fed on regenerative pastures and through better quality feed.
- Soil carbon retention to respiration rate ratios.
- Metabolic production of water.
- Soil carbon sequestration, which reduces atmospheric and oceanic carbon dioxide levels, thus moderates climate change.
- Oxygenation of the atmosphere and oceans.
- Reduction in; heating of bare soils, soil desiccation, crusting, re-emission of absorbed heat, related heat dissipating thermals, atmospheric drying, and consequent heat-dome production.
- Water retention in the soil, regional hydrology, transpiration rates, atmospheric moisture levels, drought resistance, and stomatal release of cloud-seeding bacteria.
- Improve regional microclimates by regulating water transpiration, improving soil water retention and local hydrology, reducing soil heating, and increasing regional air moisture. Thus, moderating climate change, including temperature rises, drought, heat domes, flooding, and related soil and nutrient loss, as well as erosion, and reducing the risk of extreme climate events.
- Energy efficiency of farming.
- Farming profits.
- Increased sustainability, including through reducing fertiliser-based eutrophication and agrichemical pollutants.

Happily, the food industry is recognising the potential of regenerative agriculture to improve crop quality, sustainability, and profitability of farmers, with wider environmental benefits. It is beginning to support the expansion of regenerative agriculture through multiple pathways, including significant financial support, training, and research funding.

35 ALL IN THE SOIL – Geology + Biology + Atmosphere = Soil

Soil = Geology + Biology + Atmosphere, where geology'- is a mixture of ground-up rocks: 'atmosphere' is the atmospheric derived air in soils: 'biology' is the bacteria, fungi and myriad of life forms, including plant roots and decaying matter, (aka the 'soil biome') that interact, change, exchange, excrete and die: and soil is the combination of them all.

Soil is made of minerals, biology, and air. Ultimately, there is no soil without the minerals that physically constitute 'geology', biology, and air between soil particles. Without minerals, there is no soil biome or its symbiont plants, which manufacture the photosynthetic carbon sugars that underlie most sophisticated life, that are key to regulating planetary atmospheric carbon dioxide, oxygen levels, rainfall, and climate, and including temperature.

Yes, plants can grow without soil in human-created hydroponic, all-essential-nutrient-providing media, including nitrates, but hydroponic solutions and delivery systems do not exist in nature.

In nature, soil biomes interact with root structures and mineral dust, binding and forming water-retentive structures that help prevent erosion, runoff, and flooding, while also improving drought resistance, local microclimates, regional hydrology, and weather patterns.

The soil biome's metabolic water production, decaying and dead matter, and layered living and dead plant growth on the soil surface create a microclimate and physical barrier that protects soils, including against excess heat, water loss, and crusting due to rain compaction.

Living plant material shades, shelters, and respire moisture, whilst dead plant matter absorbs and is degraded by light energy, consumed by parasitic bacteria, and transferred into soils by lifeforms of various sorts. The carbon and other nutrients are recycled. Thus, soil life forms assist in recycling, redistribution and breaking up soils, simultaneously creating passages for water, air, roots, and soil life.

Whilst dead plant material supplies some soil carbon, the soil's primary carbon source is plant-supplied photosynthetic sunlight-derived carbon, sugar, and plant root exudates. In healthy plant-soil systems, a portion of total plant root carbon exudate and carbon from dead plant matter is stored, allowing soil biomes to draw on stored carbon when plants are stressed, for example, in drought. Through continued soil biome respiration and consequent metabolic water production, soil-stored carbon symbiotically ensures that plants and their soil symbionts flourish as optimally as possible, even in challenging growing conditions.

Importantly and often not reflected on, absent human intervention with fertilisers, plants are, and always have been, totally dependent on nitrates supplied by soil bacteria, and the excretions of soil creatures whilst alive and in death, and in large part, on minerals mined, scavenged, and transported by fungal networks. The role of mycorrhiza in mineral transport is experimentally evidenced. For example, it was shown that plants receive very different amounts of radioactively labelled phosphates from a compartment outside the root zone, depending on the variety of fungi present. *"The hyphal uptake of ^{32}P (Radiolabelled phosphate) from the HC (lateral root-free compartment) increased as follows – *S. calospora* \geq *Glomus sp.* \geq *G. caledonium*. The uptake of ^{32}P from the HC was equivalent to 7, 21 and 109 % of the uptake of ^{33}P from the RHC (an identical lateral compartment with both roots and hyphae) in plants colonized by *S. calospora*, *Glomus sp.* and *G. caledonium*, respectively. This indicates that the relative contribution of the roots in total P uptake varied greatly between the three mycorrhizal treatments."* (Pearson, 1993)

Further, as evidenced by the experiment reported above, different fungal species have different capacities and symbiotic interests in mining minerals, including phosphates, to provide to plants. Such are the complexities and vastness of the diversity of soil life. We are only at the beginning of understanding how soils function. What is clear is that diversity significantly improves soil function and capacity to support plants.

Crucially, soil biology, including the bacterial/fungal balance, influences the species of plants that will grow in that soil. For example, many weeds prefer poor soils, and improvement of soils gives an advantage to other species with differing optimal nutrient needs, including those we rely on for food. Fungi and bacteria work in symbiosis, and both are essential for

healthy, optimal plant growth through overlapping but different ratios of fungal and bacterial soil services. Fungi require more carbon and bacteria more nitrogen, thus the fungal bacterial ratio changes, and so does the soil's capacity to support plants with different nutrient demands.

Thus, healthy plants require a healthy soil biome and vice versa. Furthermore, the wider soil life, including worms and dung beetles, provides a vast range of free eco-services, such as soil rotation, aeration, and fertilisation, often involving the movement of huge tonnages per hectare. Maintaining healthy agricultural plants and soils requires diversity, with human comprehension, understanding, and respect for the fundamental importance of nature's sophisticated biology.

The video player shows a slide titled "Typical Numbers of Soil Organisms in Healthy Ecosystems" with a subtitle "unlock the SECRETS of the SOIL". The slide features a table comparing organism counts in Crop Land, Prairie, and Forest. The table is divided into two sections: "Organisms per gram (teaspoon) of soil" and "Organisms per square foot".

	Crop Land	Prairie	Forest
Organisms per gram (teaspoon) of soil			
Bacteria	100 mil. -1 bil.	100 mil. -1 bil.	100 mil. -1 bil.
Fungi	Several yards	10s – 100's of yds	1-40 miles (in conifers)
Protozoa	1000's	1000's	100,000's
Nematodes	10-20	10's – 100's	100's
Organisms per square foot			
Arthropods	< 100	500-2000	10,000-25,000
Earthworms	5-30	10-50	10-50 (few in conifers)

Fig. 69. A slide from the UTube video '2021 AgEmerge Breakout Session with Ray Archuleta, with very many thanks to the authors. (Archuleta, 2021a)

36 SOIL CARBON

What do people mean by the term 'soil carbon': organic matter was defined by one review as the sum of *"the additions and losses of organic materials that have occurred over the years .*

... all three “types” of organic matter—the living, dead and very dead—serve critical roles, and the amount of each may be affected differently by natural factors and agricultural practices.” (Hills, 2021)

The review explains what determines the ‘Amount of Organic Matter in Soils’. *“The amount of organic matter in any particular soil is the result of a wide variety of environmental, soil and agronomic influences. . . tillage, crop rotation and manuring practices all can have profound effects on the amount of soil organic matter. (Hills, 2021)*

Organic matter can be added to the soil biome in several ways, including through:

- photosynthetic-derived, plant-produced carbon sugar root exudates, which constitute the primary source of organic matter in soils: it is carbon sugar root exudates that provide most of the substrate for energy and structure that is the essence of the very existence of the sub-soil ecosystem,
- decaying matter such as root systems and surface growth,
- recycling of soil life forms, animal, insect, bacterial, and fungal, including waste excretions and secretions by soil organisms,
- carbon char produced during fires that remains in the soil and,
- human, livestock, and wildlife application of organic matter and manure.

‘Soil carbon’, which includes plant, insect, bacterial, fungal and ‘animal’ material, is split into three categories, reflecting the average time they can be present in soils, and helpfully described by the FAO report ‘*Soil Organic Carbon, the hidden potential*’ (FAO, 2017) in the following terms:

SOM (Soil Organic Matter) contains roughly 55–60 percent C (Carbon) by mass. In many soils, this C comprises most or all of the C stock – SOC (Soil Organic Carbon) – except where inorganic forms of soil C occur. Similar to SOM, SOC is divided into different pools:

- *Fast pool (labile or active pool) - After addition of fresh organic carbon to the soil, decomposition results in a large proportion of the initial biomass being lost in 1–2 years.*
- *Intermediate pool - Comprises microbially processed organic carbon that is partially stabilized on mineral surfaces and/or protected within aggregates, with turnover times in the range 10-100 years.*
- *Slow pool (refractory or stable pool) - highly stabilized SOC, enters a period of very slow turnover of 100 to >1 000 years (including ‘biochar’) (FAO, 2017).*
- To which can be added the carbon in living soil entities, which are 70-90% water, and produce metabolic water, thus essential agents in the movement and metabolism of soil nutrients.

Indeed, the report also makes the point that the categories of soil carbon are not divisible but a complex continuum that will behave differently under alternative scenarios, thus the subject does not lend itself well to compartmentalisation, as explained in the terms *“The separation of SOC into different pools is largely more conceptual than measurable and is based on the ease of SOC oxidation or degree of physical stabilization within aggregates or through attachment to minerals determined through analytical protocols. Although SOC pools are often used to model carbon dynamics, ways to reconcile “measurable” and “modellable” pools have rarely been reported. SOC and SOM should therefore also be considered a continuum of organic material in all stages of transformation and decomposition or stabilization.”* (FAO, 2017).

Plant carbon sugar root exudates are existential to soil biome health because plant roots contribute much greater amounts of soil carbon than above-ground growth. The chapter ‘Amount of Organic Matter in Soils’ notes, *“One experiment with oats found that only one-third of the surface residue remained after one year, while 42% of the root organic matter remained in the soil and was the main contributor to particulate organic matter. In another experiment, five months after spring incorporation of hairy vetch, 13% of the aboveground carbon remained in the soil, while close to 50% of the root-derived carbon was still present. Both experiments found that the root residue contributed much more to particulate organic matter (active, or “dead”) than did aboveground residue.”* (Hills, 2021), which again brings us back to the fundamental role of carbon in plant sugar exudates to the creation of the soil biome structure, the provision of the energy substrates that support the soil biome, and the consequent capacity of in-soil carbon sources to contribute to soil carbon stocks, and related retained rainfall, and metabolic water, to a greater extent than above-ground biomass.

36.1 GLOBAL CARBON BUDGETS – DO THEY BALANCE - MAYBE NOT?

As with global soil carbon losses, there is enormous uncertainty about global carbon budgets and partitioning, including for soil carbon and above-ground biomass. Better data collection techniques are urgently needed. Greater emphasis is needed on the importance of accurately establishing global carbon flows. Without this knowledge, the effective planning and assessment of the rate of climate change and prospects are complex.

In effect, the uncertainties in the carbon cycle data and the necessity for estimation based on broad criteria allow considerable latitude to interpret the guestimate variables as we wish. Is the reality worse and more urgent? Perhaps we do not want to see that possible eventuality.

The only certainties are:

- We are burning quantifiably vast amounts of fossil fuels. *“Total carbon dioxide (CO₂) emissions are projected to be 41.6 billion tonnes in 2024. This includes fossil CO₂ emissions of 37.4 billion, and the rest from land-use change (deforestation), according to the Global Carbon Budget.”* (World Meteorological Organisation, 2024)
- Atmospheric carbon dioxide is rising at rapid rates; *“global average atmospheric carbon dioxide was 419.3 parts per million (“ppm” for short) in 2023”* (NOAA, 2024) and is higher than at any time in the last 800,000 years.

- The global figures for carbon sequestered in the atmosphere, oceans, soils, and biomass are massive and estimates of varying reliability.
 - Atmosphere – accurate - atmospheric carbon dioxide can be measured with relative accuracy,
 - Oceans – estimates with considerable scope for error - the exchange between atmosphere and ocean of carbon dioxide, and mechanisms for its transport and ‘storage’ in the ocean are highly complex, involving partial pressures, relative densities, wind and weather, temperature, currents, temperatures in the arctic, uptake by deep circulation currents, carbon sequestration in biology, ocean acidification, deposits on the ocean floor and subduction into the Earth’s’ mantle.
 - Above ground biomass – estimates demonstrate considerable scope for error – whilst the use of satellite data and A1 are beginning to offer overviews, the reality of ascertaining carbon in biomass is hugely complex and potentially very inexact; the paper, *‘Distribution of biomass and carbon content in estimation of carbon density for typical forests’* observes, “It is still difficult to meet the requirements for accurate and error-free estimation of regional forest carbon stocks due to the complexity of forest ecosystems, variations in research methods and heterogeneity of research sites” (Zhou, 2023).

An earlier highly cited paper titled *‘Importance of biomass in the global carbon cycle’*, comments, “Our knowledge of the distribution and amount of terrestrial biomass is based almost entirely on ground measurements over an extremely small, and possibly biased sample, with many regions still unmeasured. Our understanding of changes in terrestrial biomass is even more rudimentary, although changes in land use, largely tropical deforestation, are estimated to have reduced biomass, globally . . . At the same time, however, **the global carbon balance requires that terrestrial carbon storage has increased**, albeit the exact magnitude, location, and causes of this residual terrestrial sink are still not well quantified” (Houghton, 2009) (Author's emphasis).

Indeed, based on the need to ‘balance the books’, there is a widely adopted and deeply entrenched presumption that there has been a gain in global biomass simply because, otherwise, the global carbon budget does not balance. The uncomfortable possibility is that estimates of ocean uptake may be significantly understated, and diminution of soil carbon due to loss of bogs, tundra, and FATBAS may not have been adequately accounted for.

While there is evidence that increased atmospheric carbon dioxide may improve plant growth, that is subject to a wide range of variables and uncertainties.

- Soils, bogs, tundra—estimates with considerable scope for error. There is even less data on soil carbon than for above-ground biomass. Measurement is, in principle, more straightforward, but it is hugely resource-consuming to do accurately, given the vast differences in soil conditions and billions of hectares involved.

36.2 MEASUREMENT OF CARBON IN SOILS

The term soil carbon is central to the topic of regenerative agriculture. *“If you’re trying to manage something, then you need to measure it to know whether you’re making a difference - Cristine Morgan, chief scientific officer US Soil Health Institute.”* (Abram, 2020). Measuring carbon in soils on a comparable basis over time is difficult. Many factors complicate measurement.

The FAO report *‘Global Soil Organic Carbon Map’* (FAO, 2018b), the first global carbon map, gives an indication of the complexities and difficulty in putting together such a report, including the pragmatic need for and extent of data modelling (See section 5.4 of the report), which introduces its own potential uncertainties. The FAO report *‘Soil Organic Carbon, the hidden potential’* cites studies with global soil carbon figures varying between around 700 peta-grams (PgC)(1 petagram is equal to 1 gigatonne of carbon) at 0-30cm to 2,300 at a soil depth tranche of 0-300cm (FAO, 2017). The wide range of outcomes highlights the need to be mindful of uncertainties when considering reports and debates on soil carbon. Research is urgently needed to better understand and quantify the dynamics of historical and current soil carbon.

A key problem is the very loose use of the term soil carbon, and even where defined, soil carbon change over time is technically challenging to measure and further complicated by seasonal crop changes, crop variation, and a host of other extrinsic factors, as set out in *‘Methodological challenges in estimating soil organic matter: A review’* (Mir, 2023).

Further, soil carbon is also measured by reference to various soil depth profiles. As a result, soil surveys, even of the same regions, can produce very different figures depending on the criteria used. It is not easy even to establish regional baseline figures for soil carbon with certainty, and estimating global carbon stocks is even more challenging.

In addition to organic soil, soils contain inorganic carbon, including carbonates. Inorganic carbon can be extracted using acids. Organic carbon can be assayed by combustion. The percentage of carbon by soil weight will vary based on the soil's moisture content; therefore, to provide greater consistency of results, the soils are dried before testing for specific tests. Thus, acid and combustion (with or without soil desiccation) can be used to determine the amounts of inorganic and organic carbon in a soil test core sample, which test samples may range from 10 cm to a meter deep, with some extending even deeper.

Various proxy tests are being trialled and developed to provide more immediate indications of soil carbon health, such as *“Active C, 24-hour soil respiration and beta-glucosidase enzyme activity”* (Abram, 2020). Others are trying to develop soil carbon modelling, including the use of artificial intelligence to analyse relevant satellite image data, which aims to accelerate and simplify measurements. However, these are in early development stages and likely pose their own issues.

Issues in defining, measuring, and comparing soil carbon levels include:

- Differing soil core depths vary between ten centimetres and a meter, or more.
- Dates of sampling: soil carbon will vary by time of the year, seasonal weather, crops grown, and timing relative to agricultural cycles of planting, growth, harvest and fallow periods.
- Soil carbon will vary in different field locations.
- Measurement techniques vary. Dry soils contain different percentages to undried soils.
- The types of carbon included vary. Some include all undecomposed organic detritus, some are restricted according to size and type, and some include bound carbon, such as soil carbonates.
- Soil types and composition will vary, including the density, granularity, and size of particles present, such as gravel and rocks, altering the interstitial capacity to integrate organic matter.

In considering what soil carbon figures, tonnages per unit area, or percentages represent, it is helpful to know the amount of material in an acre or hectare of soil per 15cm (6 inches) tranche of vertical soil depth. Whilst weights vary due to structural composition and water content, a one-acre 15cm (6 inches) layer of soil weighs between 1,000 and 2,000 tons. Thus, an acre to the depth of 90cm (36 inches) contains between 6,000 and 12,000 tons of material.

A proportion of this will be water and soil organic matter. The water content will depend on the soil's water infiltration and carbon-related water retention capacity, the amount of rain received, and how recent it was.

Based on the above figures, an acre of soil to a depth of 90cm containing one per cent carbon will, therefore, contain between 60 and 120 tons of carbon. Soil carbon percentages vary greatly. Pre-FATBAS, some suggest agricultural lands may have included 10% carbon 600 – 1200 tons of carbon in the top 90cm - some contained more and some less. Unfortunately, data is limited, and we cannot go back in time. Unquestionably, soil carbon has declined, and a loss of just a percentage or two per acre globally represents a vast amount, equivalent to many gigatons. Accumulated total global soil carbon losses due to agriculture are estimated to be in the order of 115-154 giga-tons – *“the world’s cultivated soils have lost between 25 to 75 percent of their original carbon stock”* (FAO Soil Report, n. d.), but could realistically be considerably more given all the uncertainties in the calculation of those estimates.

Thus, there is a significant opportunity to sequester carbon using regenerative agriculture techniques, therefore optimising the photosynthetic potential of every acre of land. A successful crop can generate several tons of organic matter per acre when the roots, stems, leaves and crop seeds are considered. In addition, during the crop's growth, the subsoil biome likely and logically increases its mass significantly. By growing more than one crop, particularly cover crops, the carbon returned to the soil significantly increases compared to monocrops and bare ground.

Hence, it would appear entirely feasible to sequester a ton or more of soil carbon per acre per year. If one ton an acre was achieved globally over the 5bn hectares (1 acre is

approximately 0.4 hectares) under human management, very approximately 10bn tons of carbon would be sequestered, significantly contributing to mitigating annual atmospheric carbon dioxide increase due to fossil fuels combustion, around 10GT annually of carbon, representing about 37GT of carbon dioxide (oxygen is heavier than carbon, and each carbon dioxide molecule contains two oxygen).

Given that it appears we have lost several percent of soil carbon from soils, and one percent represents between 60 and 120 tons, the potential of regenerative agriculture to draw down carbon dioxide is considerable and, with good management, could continue for many years; yes, the data needs refining and confirming, but it is clear the potential to help stabilise atmospheric carbon dioxide levels is considerable and will buy time for the development of genuinely green energy sources.

36.3 TEMPERATURE – IMPACT ON SOIL LIFE AND CARBON

Levels of soil carbon depend in part on the metabolic rate of soil residents, which in turn depends in part on soil temperatures. Temperature impacts growth rates and subsoil activity rates, including of fungi, bacteria, and life forms dependent on them. *“Most soil micro-organisms require temperatures between 10°C-35.6°C for their activities. At a soil temperature range of 10°C-24°C, soil macro-organisms have increased rate of metabolism requiring them to either feed more or burn their own fat stores. At extreme high temperatures of 58°C, soil macro-organisms die.”* (Onwuka, 2018)

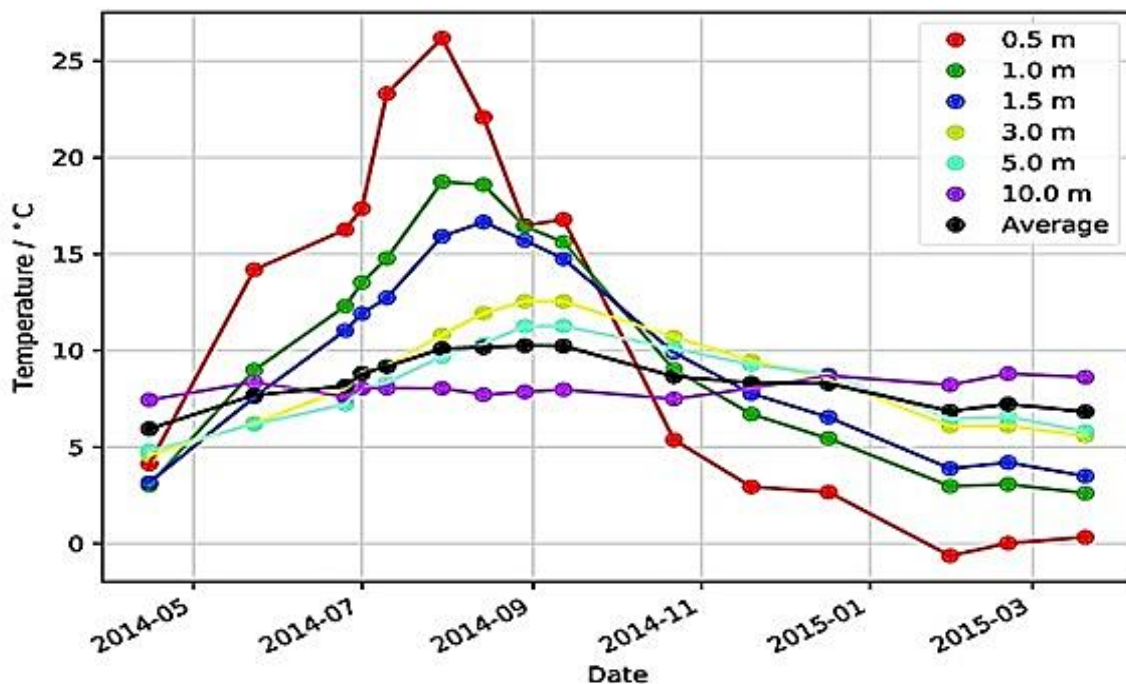
The optimal growth temperature levels will vary as community species balances change. Arctic research suggested optimal temperatures for bacterial activity were between *“23.4 ± 0.5 and 34.1 ± 3.7 °C”* (Rijkers, 2022). Temperature also indirectly impacts pH and soil structure (Barros, 2021). More broadly, a range of factors, including nutrient availability, will also influence the relative abundance of specific bacterial communities.

Interestingly, *“Bacterial communities in Arctic soils have a structure similar to those found in soil environments elsewhere”* (Schostag, 2015). In arctic soils and related scenarios, it is suggested that bacteria can remain active well below freezing (Gadkari, 2020). Observations have shown that the relative abundance of species changes over the season, and temperature, both directly and indirectly, will undoubtedly be a factor in this change. Bacterial function at low temperatures would add to the complexities and potential for bio-optimisation of agricultural soils.

Further, due to more stable lower temperatures at deeper levels in soils, carbon of all sorts that is sequestered by deep roots, both through their structural carbon content and carbon sugar exudates, as well as the movement of soil life deeper into soils, will remain unoxidised by bacteria for metabolic respiratory purposes for longer on average, than in shallower soils subject to higher seasonal temperatures.

In addition, higher water retention by soils containing more carbon will result in soil cooling due to surface respiration. Retention of living or dead plant soil cover will further reduce surface soil temperatures, thereby reducing bacterial respiration and supporting the growth of carbon-rich soil stocks. Hence, the presence of carbon in soil life and plant material, in

addition to above-ground growth and detritus, creates an environment that positively supports further soil carbon sequestration.



Soil temperatures measured at different depths (0.5 m, 1.0 m, ..., 10 m) and the weighted average temperature of the whole 10 m deep layer.

Fig. 70. From the paper, based on Scandinavian derived data, titled 'Temperature Measurements on a Solar and Low Enthalpy Geothermal Open-Air Asphalt Surface Platform in a Cold Climate Region', showing even with a heat absorbent surface and limited water infiltration through rain, that soil temperatures at depth, are much reduced in summer, and more stable at depth, with many thanks to the authors. (Çuhac et al., 2020)

This makes carbon sequestration strategies such as cover crops and perennial grasses (Tessema, 2021), including particularly deep-rooting plants, even more critical in the quest to sequester carbon into soils for extended time frames. This may help explain why ancient carbon is found in prairies, where native plants and grasses can reach down several meters.

36.4 FATBAS - SOIL CARBON LEVELS HAVE FALLEN – ATMOSPHERIC CARBON DIOXIDE HAS RISEN AS A RESULT

The FATBAS farming paradigms adopted in the 20th century resulted in soil carbon loss. It is suggested that "In general, cultivated soils normally contain 50-75 percent of the original SOC (Soil Organic Carbon)". Numerous sources point to the loss of significant organic matter in soils. For example, 'Carbon Brief' suggests "The world's soils have lost a total of 133bn tonnes of carbon since humans first started farming the land around 12,000 years ago". 'Importance of regenerative agriculture: climate, soil health, biodiversity and its socioecological impact' notes, "In the Midwest, many soils lost 50% of their organic matter within 40 years of the onset of cropping." (USDA Magdof (2021).

The paper 'North American Soil Degradation: Processes, Practices, and Mitigating Strategies' comments, "*The SOM (soil organic material) content of many soils in North America is **only about 50%** of the level present at the time they were converted from forests or prairies to farm lands.*" (Baumhardt, Stewart & Sainju, 2015) (Authors' bold emphasis).

In a spring wheat-fallow system, the practice of leaving land fallow between crops, combined with limited replacement of soil organic matter, reduced SOM in the upper 7.5 cm by 25 to 30% compared to non-fallow systems using conventional tillage or no tillage (Baumhardt, Stewart & Sainju, 2015).

A review titled, '*Composting and Climate Change; Opportunity in a Carbon Conscious World*', observes that in the USA, in upper soil, organic matter has, on average, approximately fallen from 8% to 3% in around 100 years; "*we calculate that the first metre of depth in the above farmland (In the USA) contained 1.225 trillion tonnes of soil. When this soil contained eight percent organic matter, the total organic matter equalled 98 billion tonnes. At a level of three percent, the organic content equals only thirty-seven billion tonnes. That means that 51 billion tonnes of carbon rich compounds have been stripped from the soil and added to the carbon cycle since 1900 **just from the croplands of the USA.***" (Hill, D. 2008) The early carbon data was based on the paper 'Nitrogen and Carbon Changes in Great Plains Soils. USDA Bulletin 1164' (Haas, Evans & Miles, 1957). (Authors' bold)

The review '*The potential of agricultural land management to contribute to lower global surface temperatures*' observes, "*Land-use change and poor management practices have resulted in the loss of more than 130 peta-grams carbon (130 peta-grams = 130 billion tonnes=130 gigatons) from agricultural soil, leaving >1 billion hectares (10 million sq. km.) of degraded soil worldwide*" (Mayer, 2018).

The review '*Global Sequestration Potential of Increased Organic Carbon in Cropland Soils*' (Zomer, 2017) suggests a similar loss, "*This land-use change and soil cultivation have contributed 136 ± 55 petagrams of carbon (Pg C) to the atmosphere from change in biomass carbon since the beginning of the Industrial Revolution, with depletion of soil organic carbon (SOC) accounting for a further contribution of 78 ± 12 Pg C.*" (Zomer, 2017)

The review '*Greenhouse gas mitigation in agriculture*' (Smith, 2008) suggests a lower but still large figure; "*Agricultural ecosystems hold large reserves of C (IPCC, 2001), mostly in soil organic matter. Historically, these systems have lost more than 50 Pg C*" (Smith, 2008).

Such trends appear global. Dr Christine Jones in '*Within Environmental Limits*' notes, "*Professor Louis Schipper and five colleagues recorded soil carbon **losses averaging 21 tonnes per hectare (21 tC/ha) in the top one metre of soil at 31 sites on flat to rolling pastoral land in New Zealand.** In their paper entitled '**Large losses of soil C and N from soil profiles under pasture in New Zealand during the past 20 years**', the authors noted that their findings confirmed studies in other temperate parts of the world where similar soil carbon losses had been recorded. These losses were associated with an intensification of land use and commonly extended to depths of one metre or more*" (Jones, 2017).

Modelled estimates of annual carbon loss from soils vary. (2006) (*“Global Carbon Emissions,”* n.d.) Thus, significant uncertainties exist, and more so given the report above of New Zealand grasslands losing approximately a ton per hectare per year, which, if representative, could suggest global soil carbon losses on 5bn hectares of possibly 5 giga-tons a year, or more – whatever the figure it is logically inevitably large.

Thus, it is clear that large amounts of soil carbon have been lost; however, given the lack of robust historical data and practical difficulties in measuring soil carbon, there is significant variance in estimates, and the figures could, in reality, be higher.

Clearly, such estimates differ and are open to debate, but the New Zealand soil carbon losses of over a tonne a year from pastoral land are nonetheless thought-provoking. If such figures are representative globally, even at the lowest estimates, they would represent the equivalent of many years of carbon emissions from fossil fuels. The only relative certainty is that soils are losing carbon, and reversing this loss could significantly contribute to mitigating climate change.



With thanks to Adobe Stock

In conclusion, biology, strong observational evidence, and limited research data suggest soils farmed with artificial fertiliser will experience falling stored soil carbon levels. Consequently, soils farmed under FATBAS protocols using significant amounts of agrochemicals and regular fertiliser application are likely to be a substantial net atmospheric carbon source rather than a sink.

36.5 FACTORS CONTRIBUTING TO SOIL CARBON LOSS

Factors contributing to soil carbon loss are dealt with in greater detail in other sections, but in summary, include:

- Artificial fertiliser use – reduces the provision of carbon sugar exudate to soils by plants and speeds the soil metabolism of soil carbon.
- Agrochemical use – kills soil life.
- Tillage – kills soil life, destroys water and air channels, and creates soil pans.
- Failure to return organic matter reduces soil organic matter.
- Bare soils – fail to maximise the photosynthetic potential of land, cause crusting, inhibit water penetration, and increase soil heating.
- Erosion – carbon and other resources are washed away.
- Temperature rises – increases soil metabolism of stored carbon, and at higher levels kills biology.

36.6 SOIL CARBON DATA – CONSIDERABLE MEASUREMENT UNCERTAINTIES

As discussed previously, there is a lack of accurate, cheap, practical technologies and protocols for measuring soil carbon levels, particularly at greater depths (measurement techniques and protocols are still being developed—an industry in its infancy). The urgency of this deficit is compounded by an insufficient understanding of the role of soil carbon in regulating atmospheric carbon dioxide levels.

Estimates of global soil carbon and related data vary significantly for the reasons outlined earlier, including the limited variety of data and the difficulties, differences, and complexities associated with assay and computation.

The paper ‘Soil Carbon Storage’ observes, “*The amount of C (carbon) in soil represents a substantial portion of the carbon found in terrestrial ecosystems of the planet. Total C in terrestrial ecosystems is approximately 3170 gigatons (GT; 1 GT = 1 petagram = 1 billion metric tons). Of this amount, nearly 80% (2500 GT) is found in soil (Lal, 2008). Soil carbon can be either organic (1550 GT) or inorganic carbon (950 GT). The latter consists of elemental carbon and carbonate materials such as calcite, dolomite, and gypsum*” (Lal, 2004). . . . “*The soil carbon pool is approximately 3.1 times larger than the atmospheric pool of 800 GT. Only the ocean has a larger carbon pool, at about 38,400 GT of C, mostly in inorganic forms.*” (Ontl, & Schulte, 2012)

In contrast, the 2007 FAO report concluded that total soil carbon in the 0 - 30cm range, with some reporting to 1 metre, is significantly lower, 504 -1267 peta-grams. (FAO, 2018b) As discussed, estimates vary, making it difficult to draw conclusions about measured outcomes.

36.7 GLOBAL SOIL CARBON STOCKS – LIMITED DATA – BEST ESTIMATES

Global Carbon Budget, 1959-2018

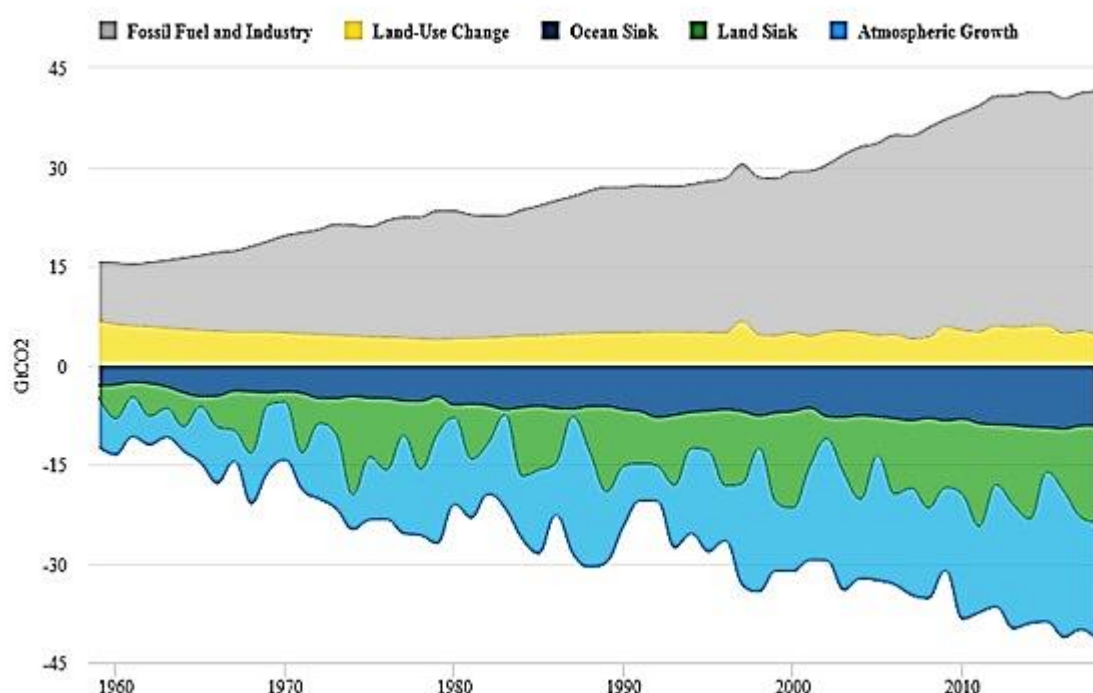


Fig. 71. “Annual global carbon budget of sources and sinks from 1959-2018. Note that the budget does not fully balance every year due to remaining uncertainties, particularly in sinks. 2018 numbers are preliminary estimates. Data from the [Global Carbon Project](#); chart by Carbon Brief using [Highcharts](#).” From ‘GLOBAL EMISSIONS 5 December 2018 18:00 Analysis: Fossil-fuel emissions in 2018 increasing at fastest rate for seven years’ – ‘Carbon Brief Clear on Climate’ by Zeke Hausfather (Hausfather, 2018)

36.8 ATMOSPHERIC CARBON DIOXIDE – CONTRIBUTION OF SOIL CARBON

The standard position is that the increase in carbon dioxide in the atmosphere is predominantly due to fossil fuel combustion, as moderated by the absorption of carbon dioxide by the oceans. Limited consideration is given to the contribution to atmospheric carbon dioxide of the historic and ongoing loss of soil carbon, which is likely to be significant. Similarly, beyond fossil fuel consumption and climate gas production, scant attention is given to the impact of modern farming on climate change. Hence, many carbon models may be inaccurate, especially given that core assumptions are based on the need to get the carbon cycle figures to ‘balance’, as discussed above.

The FAO estimates that “*land-use conversion and soil cultivation are still responsible for about one-third of GHG [greenhouse gas] emissions*” (*‘What is Soil Carbon Sequestration? FAO SOILS PORTAL’*, n.d.), which is at odds with the figures cited earlier

For example, a ‘Carbon Brief Clear on Climate’ report suggests “*Land-use changes, such as deforestation and fires, comprised 10.6% of total CO2 emissions in 2018, down a bit from 12.6% in 2017. The remaining 89% of emissions came from fossil fuels and industry. Total CO2*

emissions increased by about 0.7% between 2017 and 2018, driven by higher fossil-fuel emissions but lower land-use emissions” (Hausfather, 2018) – concerningly and surprisingly, there is no mention of soil carbon.

According to the GCP estimates, about 43% of CO₂ emitted in 2018 accumulated in the atmosphere. The remainder was taken up by carbon sinks – 35% by the land and 23% by the ocean. Land uptake was unusually high in 2018 and one of the highest levels in the past few decades, though the cause of this is currently unclear, the authors tell Carbon Brief.” These are estimates, and it is hard to understand how they come to those conclusions as to take up by the land. The FAO, conversely, suggests that agriculture may contribute a third of greenhouse gases overall.

The above analysis does not account for agriculture-related losses of soil carbon. The explanation for this likely discrepancy in the carbon budget is that oceans may have a much higher carbon dioxide absorption rate than estimated, masking the release of carbon dioxide from agricultural soils, the thawing of Arctic tundra, and the drying of peat bogs.

We know agricultural soils and soil hydrology are unquestionably degrading, which points to net carbon loss, rather than net sequestration, of carbon in soils. Raised carbon dioxide increases plant metabolism, but conversely, raised soil temperatures increase soil metabolic rates. The limited data available, combined with widespread observations of degrading soils, suggest that FATBAS-managed soils are losing, rather than gaining, carbon.

On the positive side, soils have the potential to store vast amounts of carbon. Exact agricultural soil losses are unknown, but some estimates place them at 1 billion gigatons per year. The FAO observes, *“improved land management will result in economic gains and environmental benefits, a greater agro-biodiversity, and improved conservation and environmental management and increased carbon sequestration.”* (*“What is Soil Carbon Sequestration? FAO SOILS PORTAL,”* n.d.)

36.9 INCREASED CO₂ = INCREASES PLANT GROWTH – TO A POINT

Anecdotally, observation, and limited studies suggest that plant growth, and related photosynthetic supply of carbon sugar exudate to the soil biome, as expected, is increased by additional atmospheric CO₂. This would be a logical evolutionary mechanism for a self-regulating Gaian system that has evolved to maintain atmospheric carbon dioxide within habitable limits. Additional plant growth would reduce atmospheric carbon dioxide and increase soil carbon sequestration, thus bringing the system back into balance.

However, and soberingly, given the predicted rises in atmospheric carbon dioxide, the Gaian environmental regulatory system logically has operating limits, and there is possibly an upper ceiling for increased atmospheric carbon dioxide, above which plant growth is negatively affected. A paper titled *‘The optimal CO₂ concentrations for the growth of three perennial grass species’*, concluded, *“All three perennial grasses featured an apparent optimal CO₂ concentration for growth. Initial increases in atmospheric CO₂ concentration substantially enhanced the plant biomass of the three perennial grasses through the CO₂ fertilization effect,*

but this CO₂ fertilization effect was dramatically compromised with further rising atmospheric CO₂ concentration beyond the optimum.” (Zheng, 2018)

Thus, if action is not taken to use regenerative practices to restore soil carbon with some degree of urgency, the task of returning carbon to the soil may become more difficult as atmospheric carbon dioxide levels rise above the threshold at which photosynthesis becomes less efficient.

In the meantime, unless any additional CO₂-promoted plant growth is linked to the long-term return of additional plant carbon to the soil through changed farming practices, increased atmospheric CO₂ above the threshold is unlikely to result in increased sequestration of significant amounts of carbon. Furthermore, continued application of artificial nitrogen to increase plant growth may well negate sequestration, as discussed, thereby accelerating soil carbon respiration.

37 SOILS AS AN AGRICULTURAL CARBON SINK

At a global level, regenerative agriculture, through plants, has massive potential to capture atmospheric carbon dioxide, convert it into carbon and oxygen, and provide carbon to the soil biome, which will sequester any carbon surplus into the soil. The areas of agricultural land under human management are vast, 5bn hectares. Due to suboptimal farming, large amounts of soil carbon have been lost from soils globally. Additionally, regenerative agriculture is relatively easy to implement, and nature's carbon capture technology, photosynthesis, and soil biome carbon storage are proven and free. The carbon dioxide reduction potential of regenerative agriculture exceeds that of all current human-constructed technologies.

Regenerative agriculture cannot replace, but it complements emerging carbon-saving technologies such as photovoltaic cells or carbon capture. The development of alternative energy sources remains essential, but regenerative agriculture could buy time for the development of genuinely green energy systems.

Regeneratively grown plants are significantly easier, cheaper, and greener than industrial carbon capture installations, offering a host of additional benefits, including providing food and cooling the planet. However, we do need to pursue and optimise all options.

Soils, in comparison to forest timber, which is recycled by humans or forest fires, could potentially provide a comparatively more stable carbon sink capacity, as evidenced by historic, pre-industrial, long-standing, 3-5-meter-deep carbon-rich soils on prairies, which carbon at depth can be many thousands of years old.

The potential to sequester carbon in soils has been implicitly accepted by some at the Government level. *“There is general agreement that the technical potential for sequestration of carbon in soil is significant,” “An implicit basic assumption is that in general, 50 to 70% of soil carbon stocks have been lost in cultivated soils, such that the SOC status of almost all cultivated soils can be increased.” (Zomer, 2017) “It is estimated that soils can sequester*

around 20 Pg (20 billion tons) carbon in 25 years, more than 10 % of the anthropogenic emissions” (“What is Soil Carbon Sequestration? FAO SOILS PORTAL,” n.d.).

The ‘IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems



Fig. 72. Adapted from the UNFAO document ‘Global Soil Organic Carbon Map’ V1 (“Global Soil Organic Carbon Map, Version 1.0,” 2017).

Summary for Policymakers Approved Draft’ observes, “The global sequestration potential of cover crops would be about 0.44 +/- 0.11 GtCO₂ yr⁻¹ if applied to 25% of global cropland (high confidence).” (Arneth, 2018), Other sources suggest at least one ton a year per acre is feasible. Some have achieved much greater soil carbon gains.

Several European Governments, including Spain, Germany, and France, have supported the CIGAR soil carbon sequestration ‘4per1000’ project, which was launched in 2015. “The International ‘4 per 1000’ Initiative encourages stakeholders to engage in a transition towards a regenerative, productive, highly resilient agriculture, based on appropriate land and soil management, which creates jobs and income and thus leads to sustainable development.” (“The international ‘4 per 1000’ Initiative. Soils for Food Security and Climate”, n.d.).

37.1 SOIL CARBON ACCRETION RATES

Farmers worldwide who use regenerative agricultural practices are reporting increased carbon sequestration in their soils. For example, New Mexico State University data suggest that farmers eschewing artificial fertilisers and using low-till multispecies cover crops are seeing remarkably significant increases in soil carbon, in the order of 6-7 per cent over 20 years.

More optimistic estimates than those of CGIAR suggest that even higher rates of carbon could be sequestered into soils. In his YouTube presentation ‘The BEAM Approach,’ Dr David

Johnson states that his research has generated soil carbon accretion rates of between 10.7 and 19.2 metric tons per hectare per annum (Johnson, 2017). Gabe Brown has also produced good results. Dr Jehne suggests, based on current research and historical data, that figures of this order are feasible (Jehne, 2017a; Jehne, 2017b).

An article in 'Science Daily' observed "Compost Can Turn Agricultural Soils Into A Carbon Sink, Thus Protecting Against Climate Change" ("Compost Can Turn Agricultural Soils Into A Carbon Sink Thus Protecting Against Climate Change," 2008). The Rodale Institute paper, "Regenerative Organic Agriculture and Climate Change" (Smallwood, n.d.), also supports the contention that carbon can be sequestered into soils (Paredes, 1996), as do reports by Gabe Brown, Dr Christine Jones, Dr David Johnson and others.

As a carbon sink, soils logically have a maximum capacity, which varies with their depth and type, so it is unclear how long regenerative agriculture's soil carbon accumulation will continue to increase - only time will tell. Whilst the capacity for storage of soil carbon may, over time, flatten, it is arguably a 'no-brainer' for us as a species to optimise the utilisation of photosynthesis by plants, a free existing proven and working technology, to capture carbon.

Dr David Johnson reports details of soil carbon respiration and capture rates using Biologically Enhanced Agricultural Management (BEAM), which involves compost priming, in the videos referenced in the slides below. This suggests that significant net annual soil carbon capture of several tons per hectare is possible.

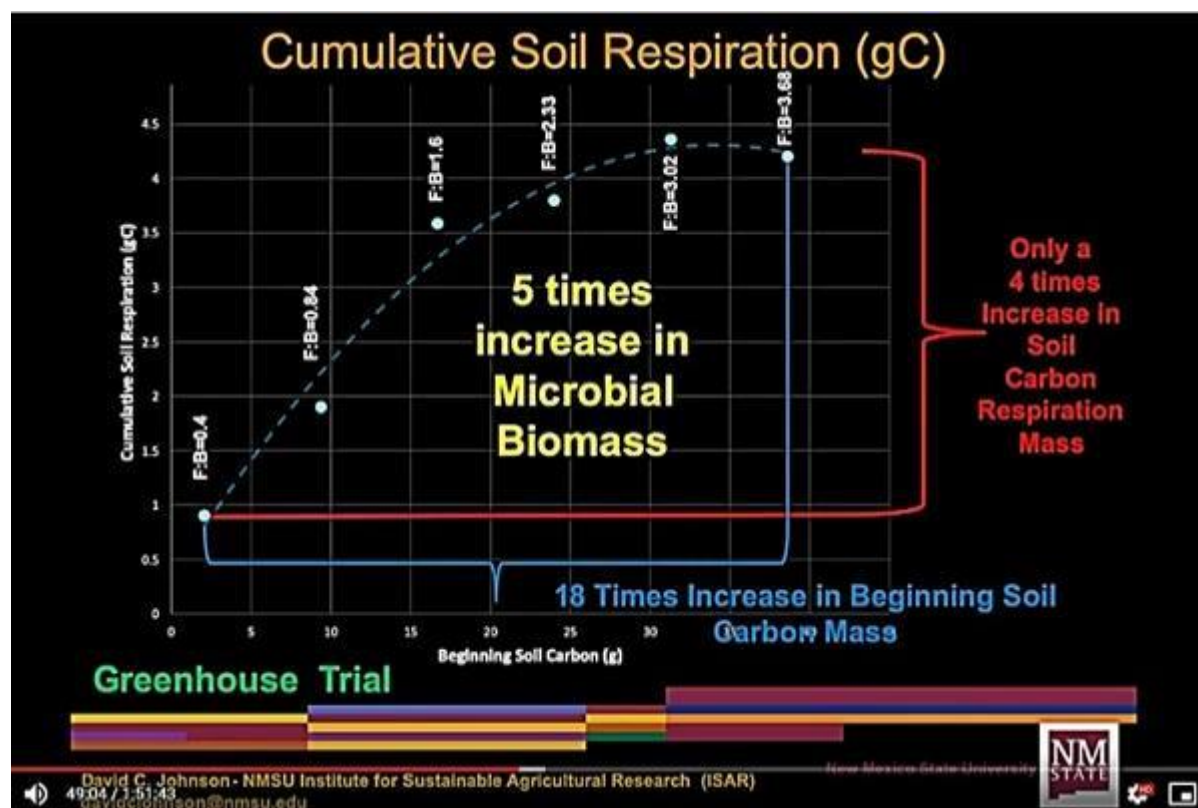


Fig. 73. In optimal circumstances, the rate of soil carbon sequestration exceeds that consumed by increased soil respiration rates, from the YouTube lecture 'Dr David and Hui Chun Su Composting', with many thanks to the authors. (Johnson & Su, 2019)

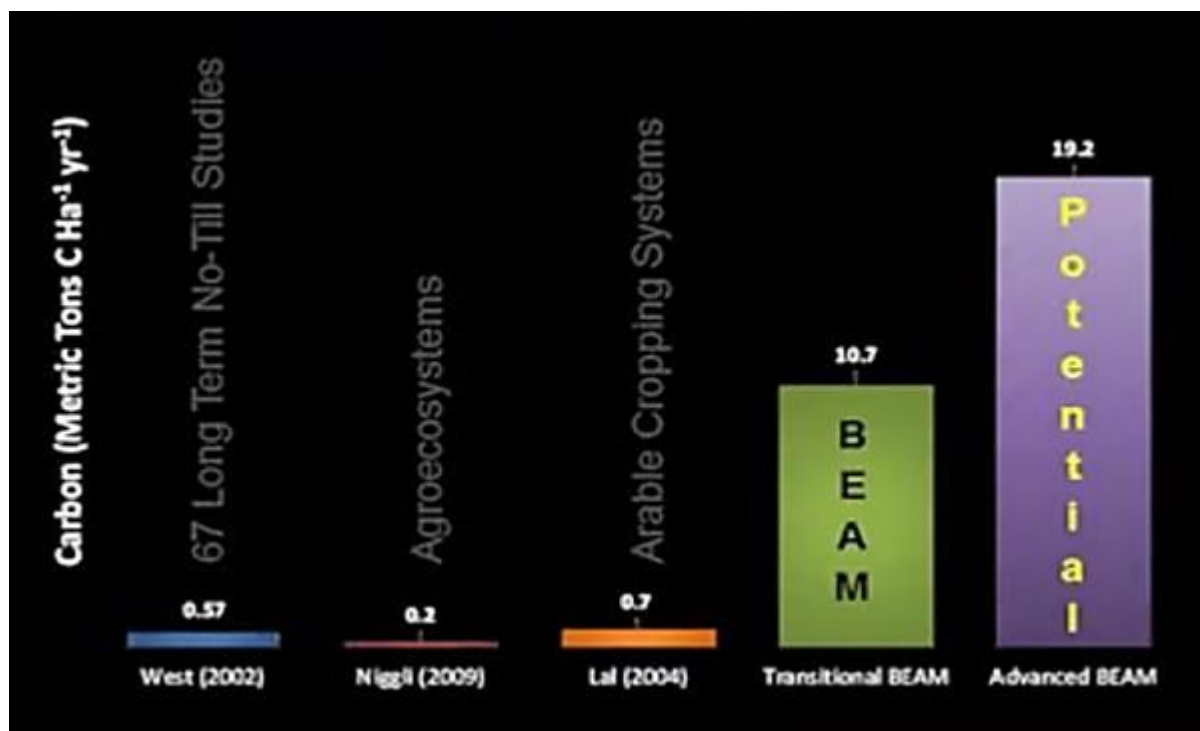


Fig. 74 The rate of soil carbon sequestration was much higher when mature compost was used as an inoculant, from the YouTube lecture ‘Dr David and Hui Chun Su Composting’, with many thanks to the authors. (Johnson & Su, 2019)

Soil carbon capture will not mitigate our use of fossil fuels, but it will help meaningfully by buying us time. At the same time, it will enhance soil quality, improve water retention, and increase crop nutrient density. It will likely mitigate climate effects, including heatwaves, heat domes, droughts, and fires, reduce flooding, and improve hydrology and regional weather patterns, for the reasons given previously. Thus, it warrants serious consideration and research.

37.2 CARBON STORAGE IN PRAIRIES AT DEPTH 1,000-13,000 YEARS

Carbon can be stored in soils for very long timeframes. The subject is discussed further in a later section; however, the figures below confirm that agricultural land has long-term carbon storage potential, provided it is appropriately managed and plant carbon sugar exudate supply to soil biomes is maximised.

Radiolabelled studies of old grasslands, such as the Great Plains in central US and western Canada, show that the element can remain in the earth for up to several thousand years, especially at greater depths. *“¹⁴C carbon dating of soil carbon indicates that the one-half of the SOC that is sequestered below 20 cm has mean residence times (MRT) that are greater than 1,000 to 2,000 years. Soil carbon at depths of about 2 m has MRT of 9,000 to 13,000 years, but accounts for only about five per cent of the total. **Thus, once sequestered, immense amounts of SOC have remained in soil profiles for a very long time**”* (Follet, n.d.) [this author’s bold and underline].

37.3 GLOBAL AREA UNDER AGRICULTURAL PRODUCTION

The FAO estimated the amounts of land under agricultural management in 2023:

- ***“Total of land used to produce food: 49,116,227 square kilometers or 18,963,881 square miles (100 hectares =1 square kilometre) ≈ 4.9 bn hectares***
- *Arable land: 13,963,743 square kilometers or 5,391,431 square miles*
- *Permanent pastures: 33,585,676 square kilometers or 12,967,502 square miles*
- *Permanent crops: 1,537,338 square kilometers or 593,570 square miles (FAO, 2024; FAO, 2023; Wikipedia, 2024)*

These are not easy figures to calculate precisely. Whatever the exact figure, the point is that extensive areas are involved. Realistically, it would take years, even in the best scenario, for the entire world to adopt regenerative agriculture globally. However, sequestering a ton or two of carbon per annum per hectare globally would amount to five to ten gigatons per annum, in the same order as the global Anthropocene carbon combustion rates.

Agricultural area over the long-term

Total areal land use for agriculture, measured as the combination of land for arable farming (cropland) and grazing in hectares.

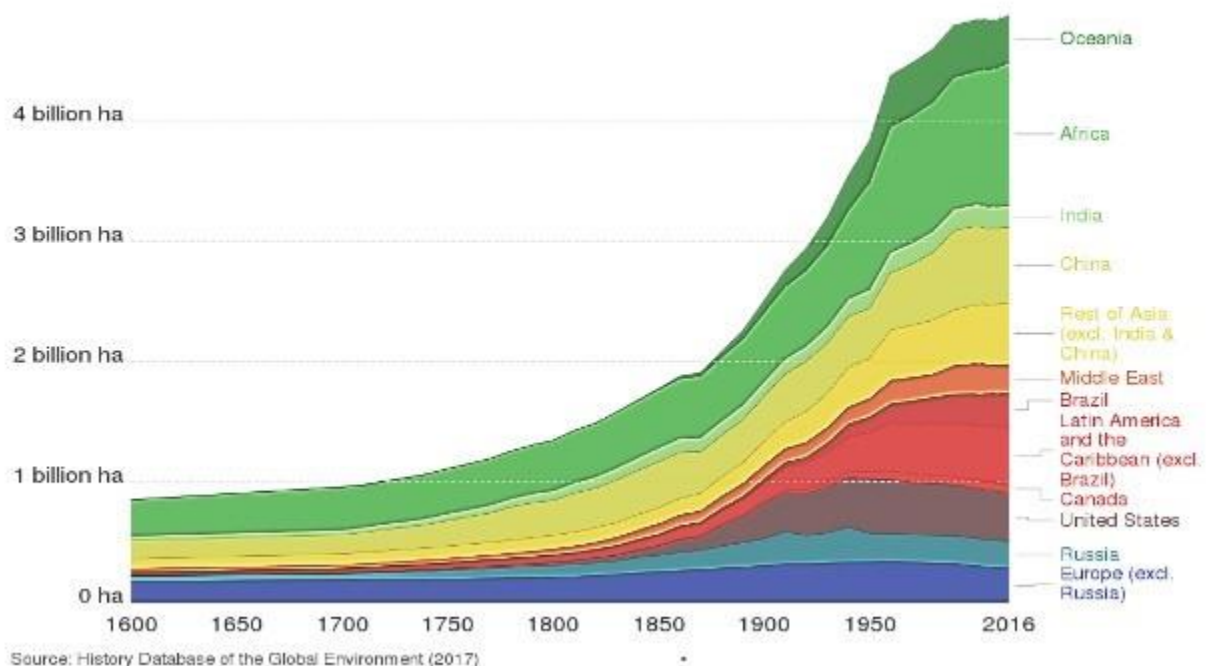


Fig. 75. With thanks to Wikipedia and Our World in Data for the figure (Wikipedia, 2021)

With sufficient will, motivation, and energy, such changes could be achieved in a short time span—a few years. Thus, they arguably represent the only meaningful, immediate ‘oven-ready’ substantially impactful action humanity can take to mitigate climate change while improving and finding new options for truly green energy production. No other current options offer anything near these potential benefits.

37.4 TREES A CARBON SINK – AGRICULTURAL SOIL OFFERS BETTER POTENTIAL.

It is often suggested that carbon sequestered by trees mitigates climate change. Clearly, forestry is infinitely preferable to bare degraded soils, and particularly so in arid landscapes. Mixed tree plantations provide a range of much-valued eco-services, including firewood, shade, cooling and food, to small communities living on marginal land.

However, the contribution of trees, including mono-crop plantations, to carbon sequestration is complex. When determining the level of carbon sequestration by trees, it is also necessary to consider their broader environmental impact, including its effect on soil carbon levels. For example, in some instances, trees planted on carbon-rich soils may significantly fuel growth by drawing on soil resources, including the carbon beneath them, resulting in a limited net carbon sequestration gain for the climate.

For example, a study looked at the spread of junipers onto Great Plains grassland soils and found, *“In spite of fast dynamics of soil C turnover, there was no net change in SOC amounts over 40–60 years (cumulative mineral and organic SOC in forest, 8782 g C/m² ± 810; in grassland, 7699 ± 1004). Thus, as junipers expand into mesic areas of the Great Plains, juniper forests will provide little additional soil C storage.”* (Smith & Johnson, 2003). More research is required, but other studies have also observed limited net carbon uptake in some new tree plantations

Numerous variables will come into play, including the species and age of the woodland, the destiny of the timber produced, and the net calculation of changes in soil and tree growth-related carbon. Forest soils vary in depth but are often not very deep, though ancient and established mixed broadleaf forests tend to be exceptions. Surprisingly, soil carbon levels of tree plantations can be below those of agricultural land.

Additionally, the speed at which carbon can be sequestered in agricultural soils may be faster than sequestering carbon in trees. However, there are good reasons to do both as part of creating sustainable landscapes. *‘Global Sequestration Potential of Increased Organic Carbon in Cropland Soils’* (Zomer, 2017) observes, *“Increasing soil organic carbon on the vast areas of cropland globally which are already intensively managed is more immediately practical and likely than on the other available landuse types, e.g. forestry or grazing land. On these croplands adoption of improved management practices offers the opportunity to sequester significant amounts of carbon in the near term, and potentially to make an important contribution to global mitigation efforts.”* (Zomer, 2017)

Further, the carbon in the structure of trees will also be released when they die and degrade in situ, are used as fuel, or for other ultimately disposable purposes. Whereas agricultural soil carbon can be sequestered at depth for extended time frames with greater certainty, providing that stores are not drawn down on and that positive input flows are maintained. However, trees clearly still play a very significant role in the long-term management of cropland and other landscapes by maximising soil retention through the use of shelter belts when planted on steep slopes as part of water catchment systems and by providing climate mitigation, including through shade, cooling through respiration of water; as well as providing sources of; beneficial seed crops, organic leaf matter, firewood, feedstock for enclosed

livestock; as well as supporting wildlife and diversity. Appropriate use of trees unquestionably offers multiple environmental benefits.

Careful consideration needs to be given, though, to determine the actual value of simply planting mono-crop trees en masse on agricultural soils for carbon credit-related sequestration rather than sequestering carbon into continuously productive cropping agricultural soils through environmentally sensitive, regenerative approaches to farming, with the use of trees as an integrated part of that strategy.

37.5 RECYCLING OF STORED SOIL CARBON

High carbon demand by above-ground growth and below-ground roots, by nutrient resource demanding crops such as maize at peak growth, as well as using photosynthetically fixed carbon from carbon dioxide, likely draws down on previously stored carbon from soil biome reserves to build root and broader structure, which would make extensive soil carbon essential to high yields.

Where plants draw soil carbon for root and wider growth, are long-lived or grown repeatedly in succession, this process reduces available soil carbon, helping to explain the loss of soil carbon. Bacteria produce carbon dioxide when they respire, and some of that carbon dioxide may be taken up by plants and recycled, however the amount retained or exhaled into the atmosphere will depend on whether the soil biome is increasing or shrinking.

The study *'Uptake of Soil-Derived Carbon into Plants: Implications for Disposal of Nuclear Waste'* noted, *"Our results indicated that although the majority of plant C was obtained from atmosphere by photosynthesis, a significant portion (up to 3–5%) of C in plant roots was derived from old soil."* (Majlesi, 2019).

In another labelling study (Yamamuro, 2002) in poor soil, using labelled manure on corn, *"The final uptake rates (by the plants of stored carbon from the soil biome) of ¹³C and ¹⁵N reached about 13 and 10% of C and N applied, respectively"*, again evidencing that the dynamics of plant growth is complex, and may include direct or indirect extraction of carbon from the soil. The figures for rice were much lower. In rice, most of the carbon uptake was present in the roots. Further research is needed to better understand the dynamics of soil carbon in the growth of fast-growing plants.

37.6 ARTIFICIAL FERTILISERS 'FRUSTRATE' CARBON SEQUESTRATION BY SOILS

The observation that artificial nitrogen leads to the depletion of soil carbon was first noted by agronomists as long ago as the early 1900s. Based on soil trials, it was further reported that depletion was observed to occur where nitrogen was applied, even where large amounts of organic matter were annually incorporated into soils.

Nitrogen addition changes bacterial and fungal metabolism and balance and, in the absence of adequate available soil carbon, results in a drawdown of stored soil carbon. The science is very complex, and these changes are likely at least partly due to the disincentivisation of plants to supply root carbon sugar exudates to the soil biome. Several more recent papers

also point in this direction (Weng, 2022), but as noted above, the suggestion that fertilisers damage soils has been around for over one hundred years.

A miller, Hensel, writing about *'Stone Meal as a Fertilizer'* (Hensel, 1894), in the book *'Bread From Stones'* (Hensel, 1894) (see the section on the use of rock dust below) claimed artificial fertiliser (probably Chilean rock nitrate – which may have contained other deleterious substances) damaged soils and crops. He presciently said of early 'artificial' rock-based fertiliser:

- (1) *"It poisons the soil, destroying beneficial soil bacteria, earthworks and humus,*
- (2) *It creates unhealthy, unbalanced, mineral-deficient plants, lacking resistance to disease and insect pests, thus leading to the spraying menace in an effort to preserve these defective specimens.*
- (3) *It leads to diseases among animals and men who feed on these abnormal plants and their products,*
- (4) *It leads to a tremendous expense to the farmer, because chemical fertilizers, being extremely soluble, are quickly washed from the soil by rainfall and needs constant replacement."*

Yes, 'only' Hensel's observations as a miller, but respected highly experienced then leading agronomists, Albrecht, Howard and others, in the 1920s-40s also had observed 'artificial' were damaging soil fertility and crop quality. Sir Albert Howard, *'the father of organic farming'*, respected author, founder and head of an agricultural research station in India, later observed in his book *'Soil and Health'* (1947), *"The use of artificial manure, particularly [synthetic nitrogen] . . . does untold harm . . . in the search for organic matter (Soil carbon) needed for energy and for building up microbial tissue, (bacteria) use up first the reserve of soil humus and then the more resistant organic matter which cements soil particles."* He had observed that nitrates and or phosphates accelerated mycorrhizal respiration and reduced carbon, but presumably did not fully understand the mechanism.

A few brave current researchers, more recently, revisited old research and again highlighted that artificial nitrates and phosphates are causing soil carbon depletion. Philpott records, *"Mulvaney told me that in his academic training — he holds a PhD in soil fertility and chemistry from the University of Illinois, where he is now a professor in the Department of Natural Resources and Environmental Sciences — he was never exposed to the idea that synthetic nitrogen degrades soil. "It was completely overlooked," he says. "I had never heard of it, personally, until we dug into the literature."* (Philpott, 2010)

The article *'New research: synthetic nitrogen destroys soil carbon, undermines soil health'* by Tim Philpott observes, *"In their latest paper, "Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production," which appeared last year in the Journal of Environmental Quality, the researchers point to two pre-war academic papers that, according to Mulvaney, "state clearly and simply that synthetic nitrogen fertilizers were promoting the loss of soil carbon and organic nitrogen."* (Philpott, 2010)

The paper ‘*Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production*’ also observes, “The assertion has often been made that synthetic N fertilization maintains or increases soil organic C (SOC) by enhancing the production of crop residues (e.g., Melsted, 1954; Odell et al., 1984; Mitchell et al., 1991; Havlin et al., 2005). Yet the opposite effect was reported long before the modern era of chemical-based N management (White, 1927; Albrecht, 1938), which is fully consistent with evidence that mineral N enhances microbial decomposition of plant residues (e.g., Starkey, 1924; Waksman and Tenney, 1928; Tóth, 1977; Reinertsen et al., 1984; Schnürer et al., 1985; Green et al., 1995; Recous et al., 1995; Neff et al., 2002; Mack et al., 2004; Conde et al., 2005; Pikul et al., 2008; Poirier et al., 2009). Such evidence is likewise consistent with the decline of SOC we previously reported in a paper by Khan et al. (2007) that documented this trend for numerous baseline data sets involving nitrogen–phosphorus–potassium (NPK) fertilization and a wide variety of geographic regions, cropping systems, and tillage practices.” (Mulvaney, 2009). (References in italics are available in the original, but not herein, and have been left in the text body on this occasion, given the importance and contentious nature of the subject).

Additional research is set out in the paper titled “*The Myth of Nitrogen Fertilization for Soil Carbon Sequestration*”, which looks at the general loss of soil carbon, particularly at depth, since 1967 in the Morrow Plot studies. Despite the addition of significant compost over many years, soil carbon levels had still fallen where artificial nitrogen fertiliser had been applied. Synthetic nitrogen, as well as depriving mycorrhiza of carbon supplies by reducing plant-produced sugar exudate, likely drives reduced soil carbon by increasing respiration rates of mycorrhizal/bacterial systems.

Science Daily, reporting the paper in the article titled ‘*Nitrogen Fertilizers Deplete Soil Organic Carbon*’ comments, “To understand why yields were lower for plots that received the most nitrogen, Khan and his colleagues analyzed samples for organic carbon in the soil to identify changes that have occurred since the onset of synthetic nitrogen fertilization in 1955. “What we learned is that after five decades of massive inputs of residue carbon ranging from 90 to 124 tons per acre, all of the residue carbon had disappeared, and there had been a net decrease in soil organic carbon that averaged 4.9 tons per acre. Regardless of the crop rotation, the decline became much greater with the higher nitrogen rate,” said Khan.” (University of Illinois at Urbana-Champaign, 2007) Author’s underline.

Whilst some studies do record increased soil carbon in topsoil layers with nitrate use, broader general observations, degradation of land globally, and biology jointly suggest that the industrial high fertiliser agrochemical farming model FATBAS is a significant factor in soil, and hence land, degradation, including soil carbon loss (Khan, 2007), biology, including the negative impact of agrochemicals on the soil biome and the impact of artificial nitrogen on plant sugar exudate production, adds further evidence to this hypothesis.

Carbon and nitrogen are essential components of the organic matter comprising the carbon-based soil biome. Thus, falling soil carbon would be accompanied by falling nitrogen in soils. The paper ‘*Synthetic Nitrogen Fertilizers Deplete Soil Nitrogen: A Global Dilemma for Sustainable Cereal Production*’ lists several studies showing decreasing stored soil nitrogen co-occurring with long-term usage of artificial fertiliser, which is not what might be intuitively expected, but maybe a consequence of reduced organic matter availability.

Deeper soils were more affected: *“In each case, the decline in potentially mineralizable N was more extensive for the subsoil than the plow layer and was also more extensive than the corresponding decline in total N”*.

From a biological mechanism perspective, it is increasingly evident and evidenced that artificial nitrogen and or phosphate application reduces the need of plants to obtain nitrogen and or phosphates from the soil mycorrhizae, thus disincentivises plants from symbiotically interacting with their mycorrhizal and bacterial symbiotes, including inhibiting supply and production by plants of photosynthetic carbon sugar root exudates, *“organic acid anions, enzymes, secondary metabolites and sugars”*, to mycorrhiza (Campos, 2018).

As might be expected, there is significant opposition to the idea that artificial fertilisers inhibit soil carbon supply and sequestration from the agro-fertiliser industry and many agricultural advisers who have promoted fertiliser-intensive farming for decades. Whilst the direction of travel is arguably evident, more research into the field is urgently required. However, on a pragmatic here and now, climate change-centred, available evidence, supportive biology, risk-reward basis, promoting rapid adoption of regenerative agriculture, discontinuance of NPK, and reclamation of degraded land globally makes sense.

NPK agrochemical bare-ground annual-tillage farming, FATBAS, by killing soil life, destroying soil structure, severing and overturning air and water channels, reducing organic carbon, related soil water retention, and results in soil compaction and crusting. It also reduces interstitial space air volumes and connection spaces, water penetration, infiltration and storage; creates soil pans below the plough-layer, slows and reduces downward root growth, inhibits movement and gas exchange including of the nitrogen necessary for nitrate formation, encourages waterlogging and disease, and more widely makes the plant soil biome interactions necessary to live, very difficult.

37.7 BARE LAND DOES NOT CAPTURE CARBON

“Green is good - and yearlong green is even better.”

(Jones, 2018a).

The advent of artificial fertilisers led us to naively believe that the then power and sophistication of our science were greater than that of nature, and that we could afford to go to war with nature, ignoring the aeons of evolved symbioses, which had allowed life to self-perpetuate and prosper. As discussed, verdant landscapes cool and capture carbon, whereas bare land destroys soil carbon, hobbles the water cycle and causes climate change, including heating and drying.



Fig. 76. *“Voices from the field | Awash Basin, November 2018”* bare fields in water stressed Ethiopia, with many thanks to the authors. (*“Voices from the field | Awash Basin, November 2018. REACH: Improving water security for the poor,”* 2018)

By leaving our farming land bare between crops, and allowing degradation of land through poor agricultural practices, including overgrazing, we ignore a vast free carbon-capture light-energy-driven production system. We also forget the importance of photosynthesised plant carbon to the soil biome, wider environment, water availability, hydrology, Gaian regional climate regulation, and carbon dioxide and oxygen partition between the earth’s crust, soils, atmosphere, oceans and living things.

38 KEEP IT GREEN LONGER

Green-growing plants are, of necessity, photosynthesising. The longer the growing season of single or multiple crops, the more carbon sugar exudate will be supplied to soils, increasing fertility and water retention; the more solar energy will be used to moderate the climate rather than being absorbed by bare land and causing climate degradation by a variety of mechanisms.

Using cattle at appropriate times of the year on grazing land will encourage new and more growth through several mechanisms. Cattle spread bacterial and fungal biology in saliva, urine and dung, and nutrients, including nitrates and minerals in manure and urine.

On arable land, most crops are optimally photosynthetically active for around 70 days, with a longer time for the subsequent ripening of grains. It may take between 90 and 120 days for mature seeds to be produced. Inter-row crops can help optimise the photosynthetic capacity of arable land throughout the growing season.



Fig. 77. A slide showing greening following grazing (right hand side of field) compared to an un-grazed adjacent area, from an interesting UTube lecture Adaptive Grazing Webinar: by Blain Hjertaas with thanks to the authors. (Hjertaas 2022)

38.1 POWER OF PHOTOSYNTHESIS TO SEQUESTER CARBON

Whilst the amount of energy from sunlight used from photo synthesis is proportionately small, the amount of carbon it can sequester from carbon dioxide per hectare per year, possibly 8-30 or more tonnes of carbon, is significant, as illustrated by the figures below produced by a request to DeepSeek.

*"Biomass Yields & Carbon Allocation
(Based on USDA/FAO Data):*

- **Above-ground biomass:**
 - Cereals (wheat, corn, rice): 5–12 t/ha/year (dry weight).
 - Roots: ~20–30% of above-ground biomass (root-to-shoot ratio = 0.2–0.3).
 - Exudates: 10–20% of total plant carbon (rhizodeposition to soil).
- **Carbon content:** Plant biomass is ~40–50% carbon (avg. **45%**).

Example Calculation (Per Hectare):

Component	Biomass (t/ha)	Carbon (t C/ha)
Above-ground (crop)	10 t	4.5 t C
Roots	2.5 t	1.1 t C
Exudates	1.2 t	0.5 t C
Total	13.7 t	6.1 t C/ha

Photosynthetic Power of High-Biomass Crops

Key Examples:

- **Sugarcane (C4 plant):**
 - Biomass yield: 100–150 t/ha/year (fresh weight) → ~30–50 t/ha/year dry biomass.
 - Carbon fixed: ~15–25 t C/ha/year (45–50% carbon content).
 - Growing season: 9–15 months (tropical/subtropical regions).
- **Cereals (C3 plants):**
 - Wheat/Rice/Maize: 5–12 t/ha/year dry biomass → ~2–5 t C/ha/year.
 - Global dominance: 80% of agricultural biomass production.”

When such figures are considered in relation to the capacity of regenerative agriculture to improve plant growth and health on the 39% of the ice-free ocean land surface managed by humans, 5 billion hectares, nature is a potential free powerhouse capable of sequestering huge amounts of carbon and greatly improving water retention and hydrological flows, including reducing global drying and moderating the risk of extreme climate events.



Fig. 78. A slide making the point the growing phase of many seeding crops is limited, variable but about 70 days, and that bare land does not feed carbon sugar exudate to soils, from an interesting UTube lecture Adaptive Grazing Webinar: by Blain Hjertaas with thanks to the authors. (Hjertaas, 2022)

38.2 IMPROVED PLANT HEALTH, GROWTH, AND MINERAL AVAILABILITY THROUGH PROVISION OF ASSISTIVE, BIOLOGY-RICH COMPOST EXTRACT

Notably, both soil carbon and atmospheric oxygen originate from the photosynthetic metabolism of carbon dioxide. Thus, whilst the Earth's Gaian biosphere is intact and

functioning, carbon dioxide, oxygen, and molecular carbon in plants, bacteria, fungi, and related life forms will continue to be cycled, supporting and enabling the essential Gaian life-sustaining ecosystem.

The use of regenerative agricultural techniques, including no-fertiliser, seed inoculants, and plant diversity, in this case, BEAM, '*Biologically Enhanced Agricultural Management*', provides immediate access to the necessary bacteria and fungi for optimal soil biome function, ensuring adequate mineral and nitrate supply by the soil biome, to plants, thus improved germination, growth health and yield, as discussed in more detail later. BEAM "Biologically Enhanced Agricultural Management" is one such approach, an adaptation of the approach of Sir Albert Howard in the 1930s, who found that applying modest amounts of quality compost (The Indore Process) greatly improved plant health and yields.

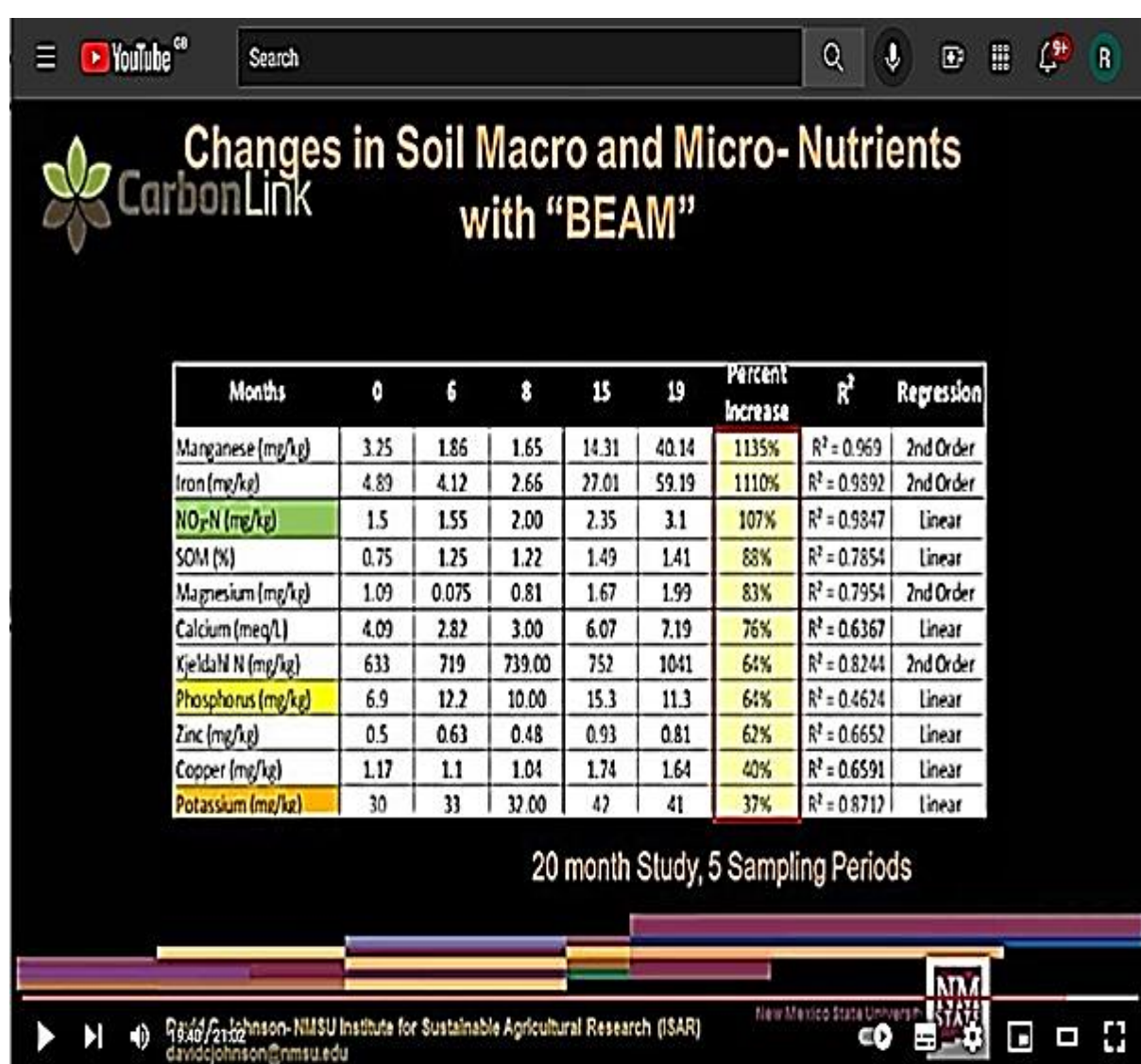


Fig. 79. From video lecture by Dr David Johnson explaining the changes in soil parameters with the use of '*The BEAM (Biologically Enhanced Agricultural Management)*' Approach" (Johnson, 2017).

38.3 EROSION AND SOIL DEGRADATION

Bare carbon-depleted soils are, and always have been, very prone to erosion. Humans, through need, have first agriculturalised and then, through ignorance and greed, degraded productive natural ecosystems throughout history. *“Dirt, The Erosion of Civilisation”* (Montgomery, 2007) provides a highly impactful history of man’s degradation of agricultural lands over human history, references prior earlier sages with the same message, and notes the consequence over long time scales of poor land management was, hugely degraded landscapes, loss of capacity to feed citizens, often ultimately leading to the failure of civilisations, as seen on multiple occasions over millennia, in the southern and eastern Mediterranean regions, as discussed later.

We now understand the causes and consequences of erosion, yet we have not learnt the lessons; we continue leaving soils bare to the elements and the destructive combinations of sun, rain and wind. Montgomery observes, *“In exploring the fundamental role of soil in human history, the key lesson is as simple as it is clear: modern society risks repeating mistakes that hastened the demise of past civilizations. Mortgaging our grandchildren's future by consuming soil faster than it forms, we face the dilemma that sometimes the slowest changes prove most difficult to stop.”* (Montgomery, 2007)

38.4 RECLAIMING DESERTS



Fig. 80. From video lecture by Dr David Johnson, growing winter / spring crops on desert soil using multi species cover crops, and compost inoculants, with no fertiliser ‘*The BEAM (Biologically Enhanced Agricultural Management’) Approach*’ (Johnson, 2017).

As discussed in greater detail in later sections, tremendous opportunities exist to reclaim degraded farmlands, including deserts, by adding the use of suitable microbiome inoculants to basic water capture and retention techniques, with, in addition, the inclusion of livestock where appropriate, managed using short-term mob-grazing techniques.

38.5 POLLUTION

Industrial agrochemical-based farming results in pollution and environmental damage at many levels, as discussed in more detail in the first and last sections. Runoff of nitrates and phosphates results in eutrophication and, in addition, is wasteful of resources, including the carbon energy needed for fertiliser and agrochemical manufacture. Further, the application of fertiliser produced from rock phosphates results in the pollution of soils with varying amounts of heavy metals, including at a low level, radioactive substances (Khater, 2015; Khater & AL-Sewaidan, 2008) and other pollutants such as perchlorates (Urbansky *et al.*, 2001). Heavy metals can end up in the food chain. Perchlorate is found in breast milk. Soil salinization is another consequence of bare land fertiliser-dependent farming.



Fig. 81. From a video lecture by Dr David Johnson, grown without fertiliser, using 'The Beam Biologically Enhanced Agricultural Management approach with very many thanks to the authors. (Johnson 2017)

Further, under the current agricultural model, chemical use is widespread. Some of the applied agrochemicals, including pesticides and herbicides, remain in soils, and some end up in runoff, thus waterways, aquifers and oceans. In the short term, agrochemicals kill and damage the soil biome to varying extents. They are a part of the processes degrading soil

biology, sustainability, and carbon levels, and they can inhibit plant growth, nutrient creation and uptake. They also reduce biodiversity, including pollinators, soil biome cultivators and conditioners, beneficial prey species, and food sources for animals up the food chain, thus threatening the long-term stability of the ecosystem.

The broader, longer-term implications of agrochemical pollution of the land environment, oceans, and living creatures, including humans, are not yet understood but are clearly not beneficial. The good news is that regenerative farmers are achieving equivalent average yields, better profits, improved biodiversity, reduced pollution, and finding they rarely need to use agrochemicals.

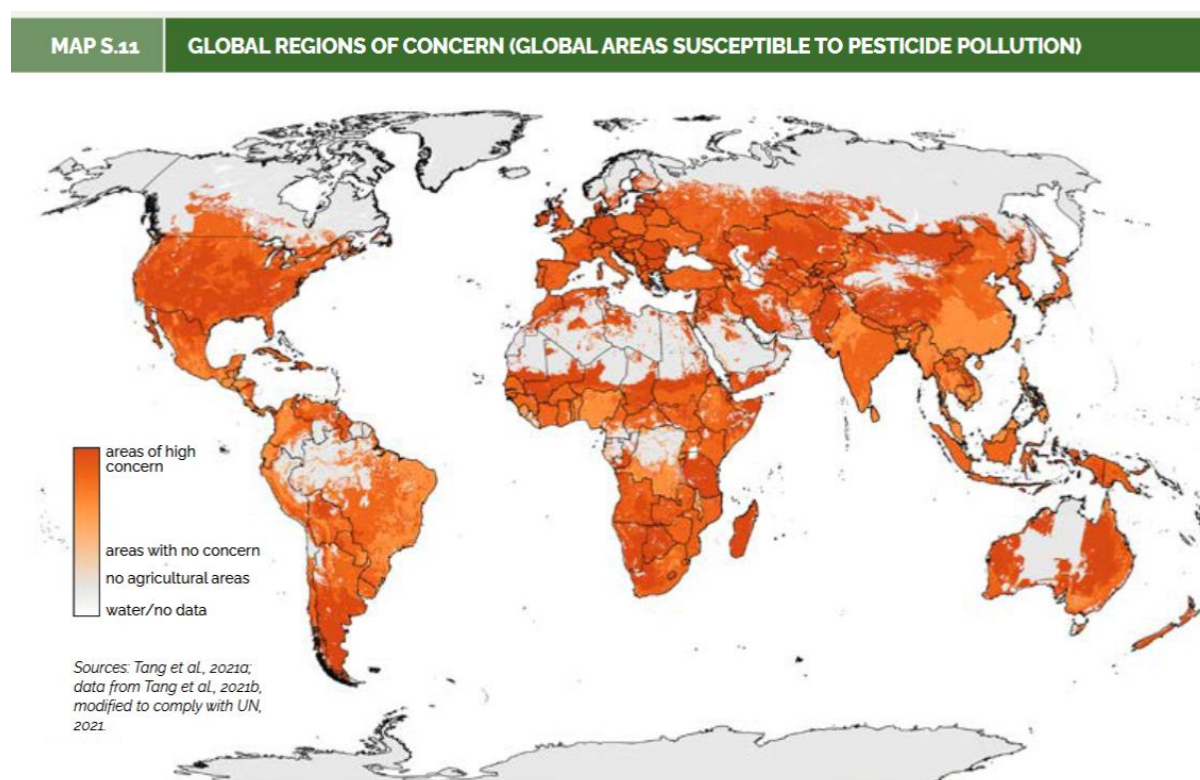


Fig. 82. From FAO 'The State of the World's Land and Water Resources for Food and Agriculture, Systems at Breaking Point' with many thanks to the Authors (FAO 2021a)

38.6 DRAWDOWN OF AQUIFERS

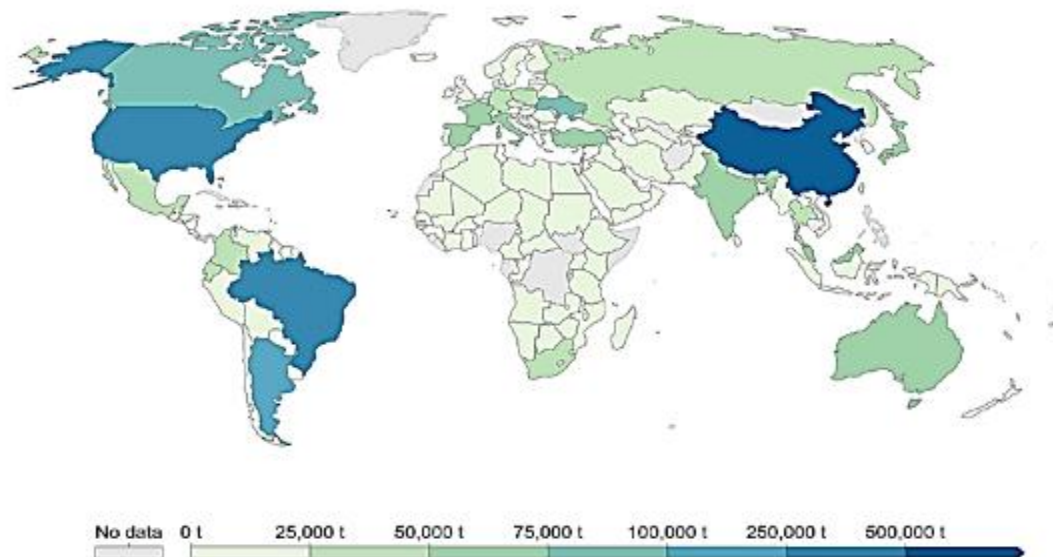
The world is witnessing rising temperatures and reduced rainfall, part of which must logically be a consequence of FATBAS fertiliser-dependent / bare-land farming. As discussed, such practices, including overgrazing, result in atmospheric heating, desiccation and crusting, so inhibition of water infiltration-penetration of bare soils, creation of heat domes, diversion of moist ocean air away from land, loss of metabolic plant water production and transpiration, reduction of plant release of cloud seeding bacteria, reduced capacity of soils to hold water, flooding and erosion, soil carbon organic matter reduction, and ultimately desertification due floods.

Much of agriculture is reliant on historically stored water in aquifers. The drawdown of ancient aquifers is a global problem. Many of these deep, ancient water sources are not significantly replenished by natural systems and can be used only once. Thus, it makes great

sense to optimise natural water cycles, including metabolic water production, by growing plants, working with, as opposed to, nature, and adopting soil health-centric regenerative agriculture.

Pesticide use, 2017

Total pesticide use measured in tonnes of pesticide consumption per year.



Source: UN Food and Agricultural Organization (FAO)

OurWorldInData.org/fertilizer-and-pesticides/ • CC BY

Fig. 83 FAOSTAT ANALYTICAL BRIEF 16, Pesticides use Global, regional and country trends 1990–2018, with many thanks to the authors. (FAO, 2021)

38.7 FOOD PRODUCTION ENERGY EFFICIENCY IS NEGATIVE

Whilst estimates vary greatly, the calorie input required to farm and process one calorie of food is between 3 and 10 times greater than the actual calorie value. Meat will have an even higher input ratio. Transport and processing add further significant calorie costs. Thus, it takes many external energy calories to produce one calorie on the plate, part of which calories are attributable to farming inputs, including fertilisers, chemicals and fuels, and part to post-farm-gate transport, processing, packaging, and marketing.

Thought-provokingly, farming only represents about 1.6 of those seven calories (Heinberg, 2009); thus, farming is a minor but not insignificant portion of the calorie input into food. Sustainable, regenerative agriculture significantly reduces farming energy input and related costs, including fuel, nitrogen, and rock phosphate-based fertiliser production costs.

A broader reduction of food energy inputs, including for livestock-related products, will require social debate and significant change. The energy and environmental implications of livestock raised on marginal land and integrated into regenerative agriculture are more favourable, complex, and nuanced than those raised in industrial facilities. Nutrient value also needs to be factored into environmental-related food debates, including for those with particular diets, such as vegetarians and vegans.



Fig. 84. Transportation of pipe segments in the 1980s for the Great Manmade River in the Sahara Desert, Libya. This network of pipes supplies water from the Nubian Sandstone Aquifer System, a fossil aquifer in the region. The Great Manmade River is the world's largest irrigation project with abstraction estimated at 2.4 km³ per year. With many thanks to Jaap Berk.

On a broad, varied, nutrient-rich, minimally processed diet, Vegans grown on healthy soils, such as those available to historic Jains, were a healthy and greatly respected civil group. Artificial, highly processed modern diets derived from FATBAS-grown foods with restricted diversity are unlikely to provide the nutrients required for optimal health. Consistent with this, and sadly, there are frequent reports of vegetarians and vegans and their children suffering from insufficiencies or deficiencies of one or a range of essential nutrients.

The issue of nutrient value extends to meat substitutes, which are not nutritionally equivalent to the dietary choices of the Jains; there is a lack of research into meat and other substitutes; more research is urgently required. For example, *“Future studies are needed to better understand how the presence and absence of metabolites and nutrients in plant-based meat alternatives and meat impacts short- and long-term consumer health. Studies performed in various populations (children, elderly, those with metabolic disease etc.), and in response to various types and amounts of plant-based meat alternatives are required to evaluate their healthfulness and appropriateness within the human diet.”* (van Vliet, 2021).

38.8 RURAL POPULATIONS, SOCIETAL IMPACTS AND URBANISATION

Partly as a result of FATBAS, rural communities have seen and faced a real danger of further decline (Parton, 2007). Regenerative agriculture, as a greener, more profitable prospect, can encourage and support the retention of small farms, adaptation and localisation of food

chains, the passing of farms between generations, a better perspective of farming as an occupation, a greener perception of country living, more localised production and distribution, job diversity and satisfaction, and thus the longevity, economic and social health, and survival of rural communities, which is arguably vital for a host of reasons.

38.9 A COMPLEX EVOLUTIONARY SELF-REGULATING WEB

In summary, we humans, whilst on a wobbly technical development 'AI' and 'human genetic manipulation' based fulcrum that could allow us to determine our own evolutionary, including cyborg future, remain unavoidably part of and currently ultimately totally dependent on an enormously complex natural Gaian eco-regulatory web that facilitates a life-supporting biosphere. However, we rarely sufficiently consider the impact of our actions on the broader, interlinked Gaian climate regulatory biosphere systems that support us.

There is sophistication, elegance, and beauty in the evolved and inevitably evolving self-regulating systems that make life on Earth possible. They interlink atmospheric gaseous carbon dioxide and oxygen content to climate, including rain and temperature regulation, rainfall, soil water retention, wider regional hydrology, plant growth, soil health, and, importantly, carbon sequestration into soils and oceans, which are interlinked processes, are all fundamental to the maintenance of the capacity of the biosphere to support life.

Frail humans, in the pursuit of the short-term gain demanded by investors and markets, fail to look at or factor in the bigger picture. Past generations of humans can be forgiven, as they did not sufficiently understand how our planetary ecosystems function, but we no longer have that excuse.

More broadly, the adoption of better farming methods is central to the long-term sustainability of commercial agriculture. It also improves the nutrient density and quality of foods and, thus, ultimately, the neurological and broader health of those who depend on those food nutrients. Cells have evolved to the presence and availability of a basket of essential nutrients; thus, the insufficiency of any of those nutrients inevitably compromises cellular and human function.

Given that we now better understand how the biosphere works, future generations will consider it inexcusable if we do not rationally act on this knowledge. It needs to be widely understood that the fertiliser-agrochemical-bare-soil dependent farming techniques we use and our lack of care for the biology of our soils have fundamental implications for our biosphere, including, and crucially, factoring in the regulation of biodiversity, climate change, including warming, drought, and extreme weather events. We ignore the fact that the functional parameters of the earth's natural Gaian regulatory systems are required to maintain a healthy biosphere at our peril.

38.10 ESSENTIAL TO MITIGATING CLIMATE CHANGE

Without the adoption of a regenerative agriculture approach to soils as an integral part of the climate package, it is doubtful we will be able to halt climate change. Human hubris, reluctance to keep an open mind, 'corruptibility', sometimes lemming-like tendencies, our

need to belong, so the tendency to follow the current 'group' think, our understandable individual needs to make ends meet, and societal structures often predicated on short term profit, lack of education and broader understanding, absent change, risks at best heralding severe environmental degradation, at worst our demise as a species, and as a minimum places us at risk of a period of violent chaos, driven by degraded ecosystems, and consequent, likely violent, competition for essential resources including food and water.

Realistically, considerable economic capital, employment, income generation potential, and human 'pride' are tied up in the current fertiliser and agrochemical-based FATBAS agricultural model. Thus, commercial pressures, ever-present human frailty, and tendencies to short-termism may mitigate against the change to regenerative agriculture. However, moving to regenerative agriculture is essential for us to have a realistic hope of addressing the climate change issues we face.

There is an alternative to possible extinction: a global move to regenerative agriculture. However, it will take considerable leadership, wisdom, and corporate foresight to drive the necessary, not always straightforward, but relatively simple and painless change to regenerative agriculture, with its multiple planetary ecosystems and human health benefits.

39 SOIL WATER RETENTION IS PROPORTIONAL TO SOIL CARBON

"Each 1 percent increase in soil organic matter helps soil hold 20,000 gallons more water per acre." (Bryant, 2015)

This section examines the relationship between soil carbon and water retention. As discussed, when living creatures, including mycorrhizal and bacterial systems, respire, dependent on respiration and water reuse rates and their broader biology, they can produce and contain significant quantities of metabolic water.

Further, soil biomes in association with plant root systems, produce gels that bind soil material into water-retaining aggregates, providing homes for burrowing creatures which create networks of mini-tunnels, often utilising and clearing channels created by dead plant roots, the whole process allowing soils to better absorb, transport, including to deeper soils, and retain rain, dews, and metabolic water, as well as facilitating gas exchange.

The capacity of soils to retain water is strongly related, indeed proportional to, the amount of life in soils, which in turn, by its very nature, is a reflection of soil carbon content (aka soil biome systems) *"Organic carbon holds between four and twenty times its own weight in water. In many environments, moisture availability (rather than nutrient availability) is the most limiting factor for production."* (Jones, 2018a) Thus, by improving the amount of life in the soil biome, and hence the soil carbon content, the opportunity exists to significantly improve soil water retention, soil moisture content, plant water use efficiency, and crop productivity.

Conversely, a reduction in soil biotic life, thus soil carbon, will result in a significant reduction in the water retention capacity of soils. The review 'North American Soil Degradation: Processes, Practices, and Mitigating Strategies' observes, "Degradation of soil physical properties is closely linked to the loss of SOM because it serves as the glue to hold soil particles together to form aggregates. Aggregates provide structure that makes soils more resistant to erosion and compaction and increases the amount of plant available water they can hold."

*"Hudson showed **that the volume of water held at field capacity decreased 3.6% (v/v) for each 1% decline in SOM.** In all texture groups, **decreasing the SOM content from 3.0% to 0.5% subsequently decreased the plant available water capacity by more than 50%.** For example, a reduction of SOM content "from 3.0 per cent to 0.5 per cent subsequently decreased the plant available water capacity by more than 50 per cent (Baumhardt, 2015). "The loss of SOM also decreased the infiltration rate so that run-off increased, particularly during high-intensity precipitation events. This resulted in water erosion as well as storing less water in the soil profile for plant use" (Baumhardt, 2015)*

Whilst exact results regarding the impact of soil carbon on water retention differ significantly, data, including that provided by Dr Johnson, and the observational experience of regenerative farmers consistently support the importance of soil carbon in water retention and infiltration.

Loss of soil carbon proportionately reduces soil water retention capacity, thus reducing soil and plant health, soil cover, and, as discussed, evapotranspiration capacity, thus regional moisture, due to,

- less stored soil water available for plant and soil evapotranspiration in the dry season,
- reduced microbiome populations result in lower metabolic water production,
- reduced soil biomes and water result in lower plant growth, thus lower evapotranspiration, and reduced mycorrhizal supply of nutrients to plants,
- reduced plant growth reduces the supply of sugar exudates to the mycorrhizal biome,
- agricultural soils containing no growing plants further reduce transpiration,
- bare soils speed initial water evaporation of rain and metabolic water stored in soils, adding to the impact of dry season droughts,
- bare soil facilitates water runoff and erosion rather than soil penetration, and through absorption of UV and visible light, and their reemission as mid/long-infrared, leads to soil heating, thus high-pressure regions, and heat domes, which in turn inhibit circulation of ocean moisture inland, and thus reduce rainfall,
- greater plant cover, dead or alive, of soil, protects the surface of the soil from rain drop impact compaction, heating of soil, reduces evaporation, and as an extension of life in the soil, facilitates rapid infiltration of water from the surface to within the soil structure,
- absence of transpiration by plants, increased soil temperatures due to bare soil, related heat domes, and loss of plant stomata released cloud seeding bacteria,

negatively affecting weather, including rainfall (Hardy, n.d.; Jehne, 2015; Jehne, 2017a; Jehne, 2017b; Ogden, 2014),

- agrochemicals, including, for example, fungicides, by killing life in the soil biome, will ultimately reduce soil water content and negatively impact local hydrology. For example, studies have reported that approximately 50% of natural microorganisms can be adversely affected via practices such as the use of fungicide for seed coating (Wang, 2020).

Further, and thinking more widely, the use of biocides may kill or alter populations of rain-seeding bacteria, *Pseudomonas syringae*, emitted by plants, which could potentially influence cloud seeding and, consequently, rainfall (more research required). This reminds us of the interconnectedness of natural systems and the potential for our actions to have unforeseen consequences.

Loss of soil carbon also increases the risk of erosion; *“The loss of SOM also makes the soils more vulnerable to wind erosion because individual soil particles are smaller and much more subject to erosion than aggregates.”* (Baumhardt, 2015) In contrast, plant ground cover, combined with good levels of soil carbon, massively increases the capacity of water to infiltrate soils, from an inch an hour in FATBAS soils to 8 to 11 inches an hour in regenerative soils, which in turn prevents downstream flooding, and erosion and eutrophication, due to soil washout.

Soil carbon and related diverse fungal, bacterial, and broader life also improve biological remediation, filtration, and aeration, enhancing emergent water quality. Water that infiltrates will replenish local hydrology, resulting in stream flow returning for longer periods of the year, greater plant respiration, and cooler temperatures, positively influencing local microclimates.

39.1 SOIL STRUCTURE, WATER PENETRATION, INFILTRATION, RETENTION, INCREASED FLOODING AND EROSION RISK

The video *'Magic of Soil'* refers to simple but visually powerful demonstrations by Ray Archuleta of the loss of water infiltration-penetrability of degraded compared to regenerative soils. As can be seen from the slides above, the water rapidly penetrates and infiltrates the undisturbed soil. However, it sits on and is unable to infiltrate or penetrate the industrially farmed soils rapidly.

The second experiment demonstrates how, when industrially farmed soil and biologically rich undisturbed soil are each placed in a porous container, and the container is immersed in a tube of water, the industrially farmed soil rapidly dissolves and disintegrates because it is not held together by exudates from bacteria and fungi, strands of living material, and incorporated dead organic matter. In contrast, biologically rich soil remains largely intact.

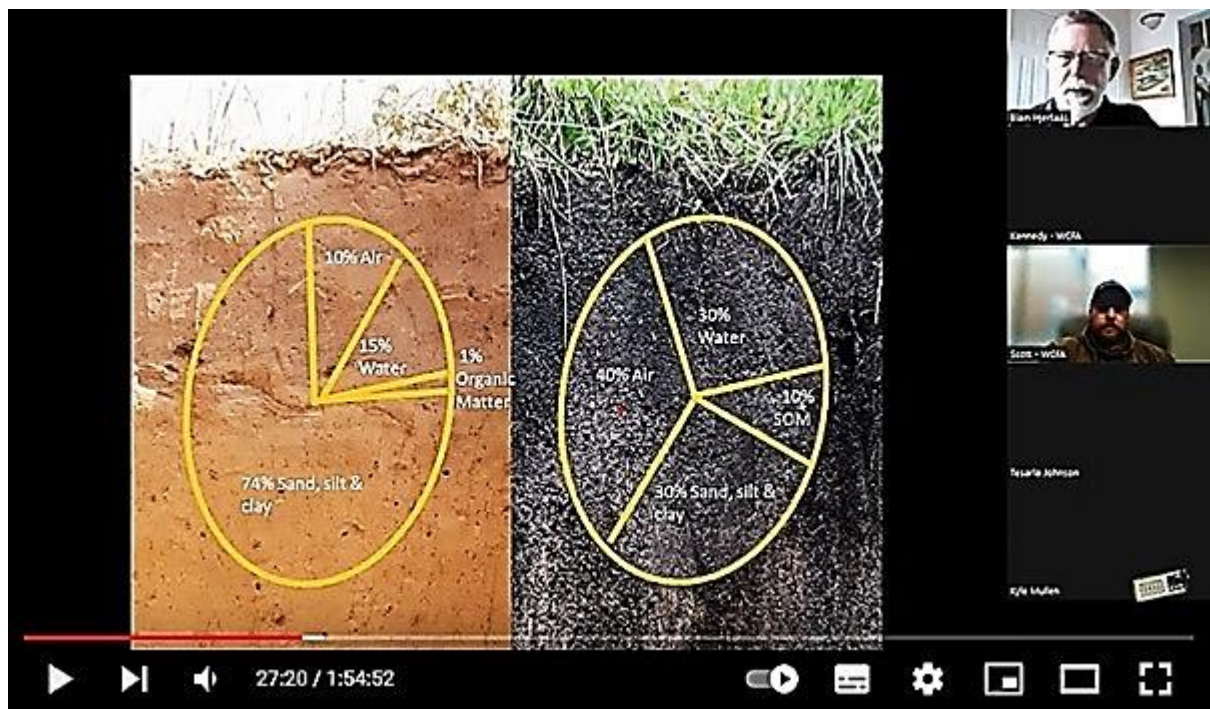
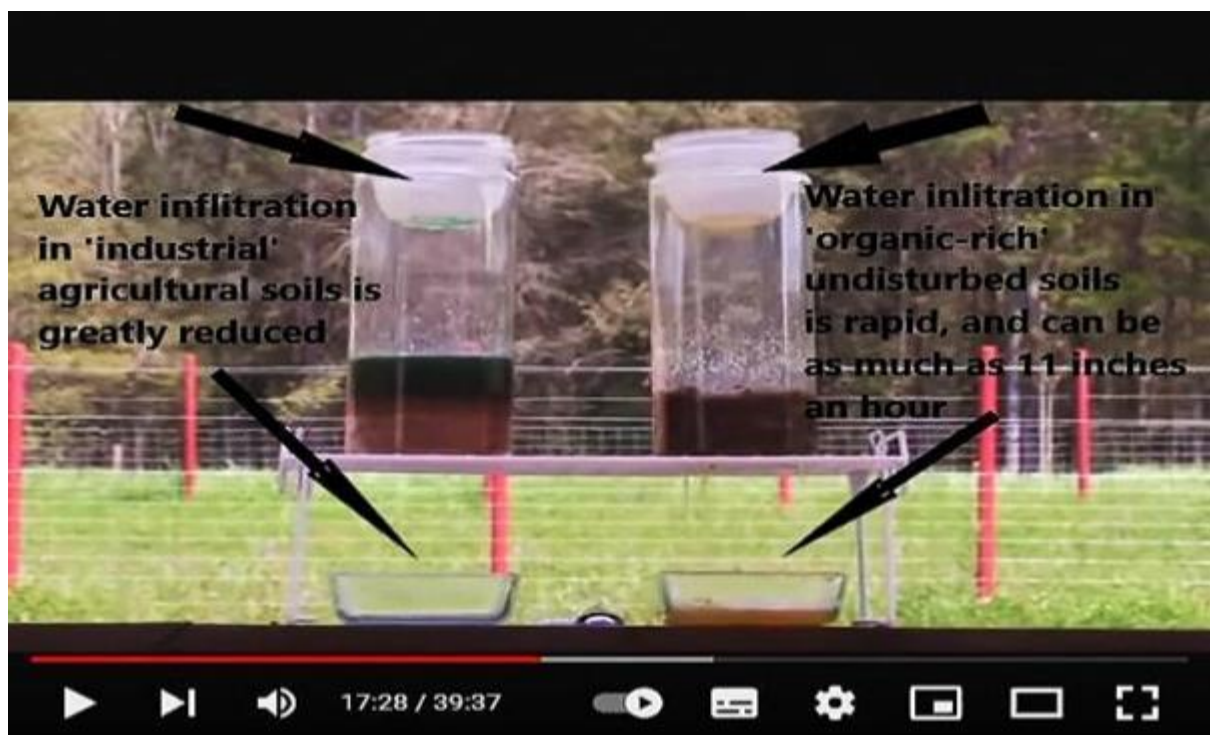


Fig. 86. A slide showing soil compaction from the interesting UTube lecture Adaptive Grazing Webinar: by Blain Hjertaas with very many thanks to the authors (Hjertaas 2022)



The Magic of Soil

Fig. 856. Annotated and with very many thanks to 'Magic of Soil' and 'Soil health lessons in a minute: soil stability test' - NRCS Agronomist Ray Archuleta (Archuleta, 2012b; Gregory, 2017).



Fig. 88 Lack of structural stability of 'industrially' farmed soils. The ploughed soil on the right rapidly breaks down when placed in a porous container in water, whereas the non-ploughed non-treated does not. A slide from the UTube lecture "*The long term effect of chemical fertilizers on soil health*" from 'Plant Health Cure BV'. ('Plant Health Cure', 2019)



Fig. 87. A similar effect is illustrated by Ray Archuleta in '*Soil health lessons in a minute: soil stability test*'. Annotated and with very many thanks to 'Magic of Soil' and '*Soil health lessons in a minute: soil stability test*' - NRCS Agronomist Ray Archuleta (Archuleta, 2012b; Gregory, 2017)

39.2 ROTATIONAL GRAZING WATER INFILTRATION INTO SOILS

Rotational grazing improves water penetration rates into soil, as illustrated by the slide from a lecture by Ray Archuleta.

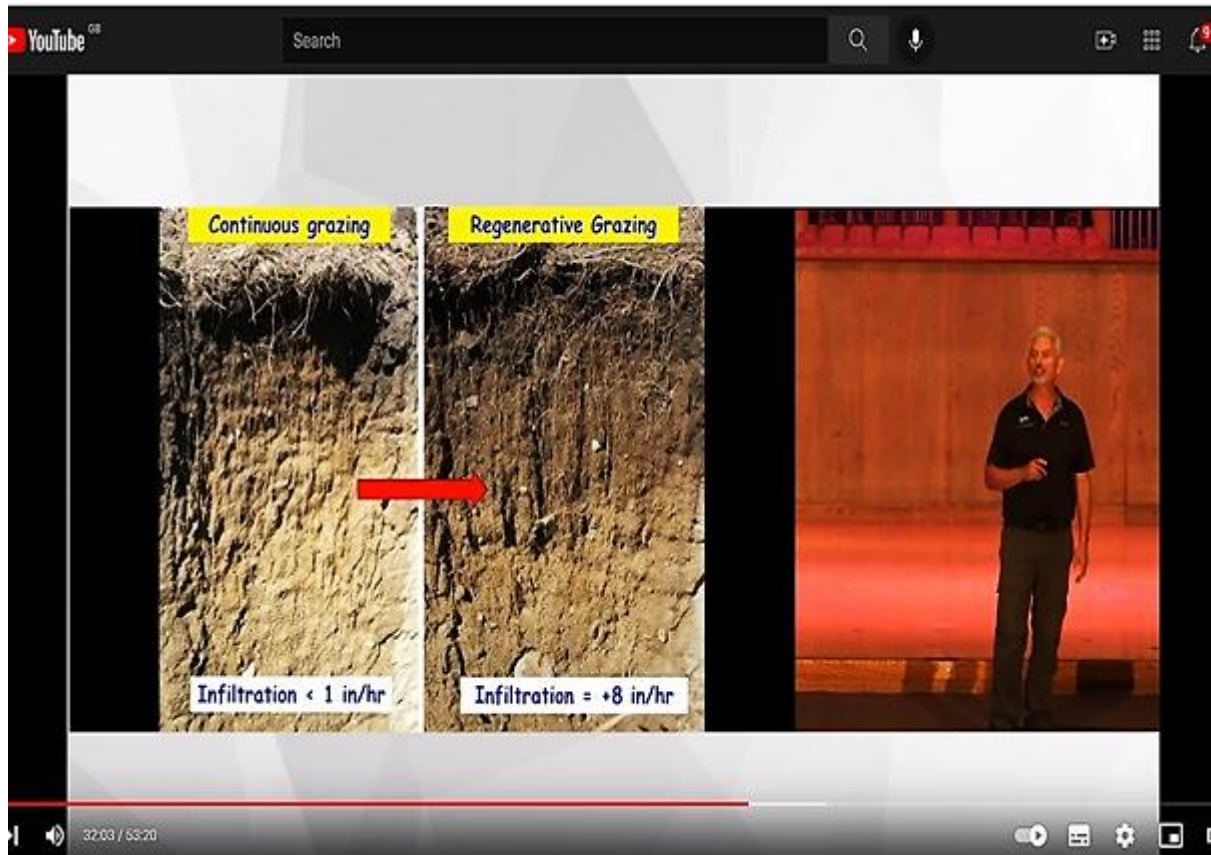


Fig. 89 . 'Regenerative Agriculture Healing the World - By Ray Archuleta @ Carbon Summit' – Capacity of farming techniques to improve water penetration. Elsewhere, Gabe Brown reports measure rates of 11 inches and more per hour in his farm, a vast improvement from the original rate of 1 inch per year. (Archuleta, 2021b)

39.3 SOIL CARBON -WATER RETENTION REGIONAL AND WIDER HYDROLOGY

It is easy to write off arid or semi-arid land as irredeemably unproductive and beyond practical cultivation. However, multiple real-life examples at scale, provide evidence of the capacity to return severely degraded lands to productive farmland and ecosystems.

The common problem is not just water scarcity, but degraded, often bare, atmosphere heating, solar energy absorbing, soils, with depleted carbon, soil biome biology, water retention capacity and plant cover. The loss of soil plant cover increases erosion, raises soil temperature, speeds up soil water evaporation, and precludes any photosynthesis of carbon dioxide into the carbon organic molecules, which ultimately 'fuel' the subsoil system. Loss of surface plants and soil organic life, including root systems and burrowing life forms, limits water penetration and retention, diminishes metabolic water production through soil biome respiration, and prevents cooling evapotranspiration from occurring.

Water scarcity issues are global, and growing even in areas where they would not be expected, such as central Europe. Science Daily reports, *“Europe has been experiencing a severe drought for years. Across the continent, groundwater levels have been consistently low since 2018, even if extreme weather events with flooding temporarily give a different picture.”* The article continues, *“The effects of this prolonged drought were evident in Europe in the summer of 2022. Dry riverbeds, stagnant waters that slowly disappeared and with them numerous impacts on nature and people. Not only did numerous aquatic species lose their habitat and dry soils cause many problems for agriculture, but the energy shortage in Europe also worsened as a result. Nuclear power plants in France lacked the cooling water to generate enough electricity and hydroelectric power plants could not fulfil their function without sufficient water either.”*

Logically, for the reasons discussed, these drought events are likely in significant part connected to FATBAS bare-ground farming, the impacts of which are exacerbated in areas of the world with less moderate climates. (Graz University of Technology. 2023).

Even in relatively extreme climates, soil improvement makes degraded land recovery possible. For example, even in Africa’s Sahel – the belt of semi-arid savannah immediately south of the Sahara Desert, stretching from the Atlantic Ocean to the Red Sea - much better yields should be possible, even with the meagre rainfall received, according to Professor Malin Falkenmark of Sweden’s Stockholm International Water Institute. In her 2013 paper *‘Growing water scarcity in agriculture: future challenge to global water security’*, she explains that the problem lies with suboptimal amounts of water being retained by the soil and made available to the plants. *“Only a very limited part of the incoming rain is taken up and transformed into biomass, typically resulting in crop yields in the 1 ton ha⁻¹ level only, far below the potential yield level for that particular hydroclimate.* (Author’s underline)

“There is however enough water available for considerably higher yields, but not accessible to the plant because of low infiltration, disturbed water-holding capacity of the soil, and low uptake capacity of the drought-damaged roots. By reducing these disturbances, yields could be considerably increased. Such agriculture is referred to as ‘triply green’ (green for productivity increase, sustainability and rain-fed agriculture).

“From an agro-hydrological perspective there is enough rainfall even in semi-arid and dry-subhumid savanna agro-ecosystems to allow significantly increased yield levels. Field observations indicate a yield gap of a factor 2 - 4 between current farmers’ yields and achievable yields in developing countries.

“At a generic level, if all water accessible in the root zone could be used productively - ie without non-productive vapour losses and nutrient deficiency - the potential yield in the illustrated case would reach 3 t.ha⁻¹. If there also was no deep percolation, the potential yield would reach 5 t.ha⁻¹. If, finally, all local rain could be put to use without any farm-level water losses, the potential yield would rise to 7.5 t.ha⁻¹. “Field observations [show] that yields in small-holder tropical farming systems can be raised on average by 100 per cent, and often by several hundred per cent” (Rockstrom, 2007)

No bare ground, controlled grazing, cover crop use, seed soil biology inoculation, regenerative agriculture approaches, when used, increase metabolic water production, rain penetration, and retention. Permanent ground cover, including though use of multispecies cover crops and underplanting, combined with more productive mycorrhizal systems, thus soil carbon increases, would improve; water availability, drought resistance, ground cover and protection, and crop nutrient access, which would all add further resilience and cropping capacity, and assist recovery of degraded lands, as discussed in the section on desertification.

39.4 RUN-OFF FROM OVERGRAZED UNRESTED PASTURES

Poor infiltration and high runoff, as well as being an issue of 'industrially' NPK, high-tillage, bare-ground, farmed arable land in overgrazed unrested annual pastures, compaction and loss of soil biology, also results in high levels of runoff and more significant erosion, when compared to moderately grazed rested pastures with rich undisturbed soils of high organic content, as illustrated by the experiment in the slide below, comparing water penetration-infiltration of such soils.

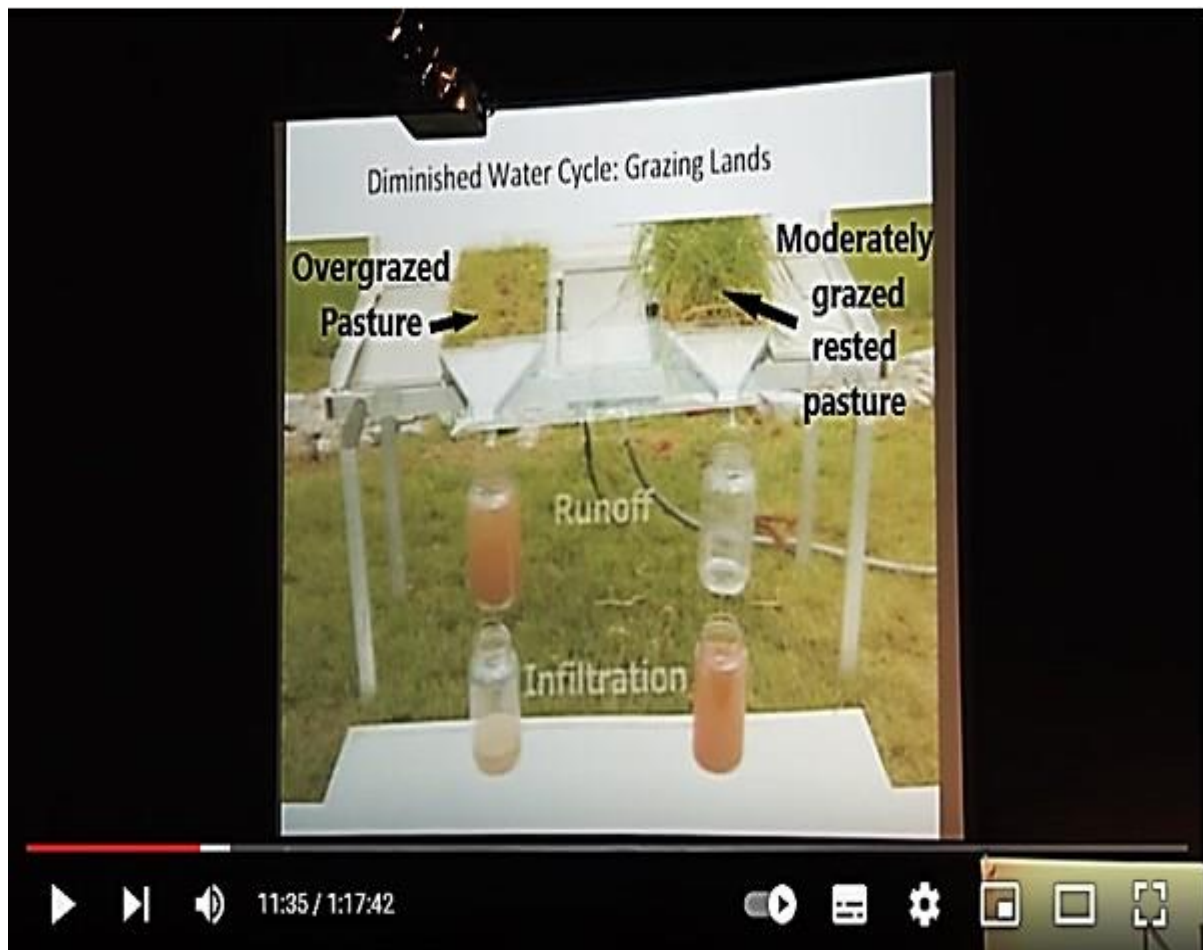


Fig. 90 Annotated slides with very many thanks to Ray Archuleta from his UTube lecture 'No-till on the Plains' (Archuleta, 2016).

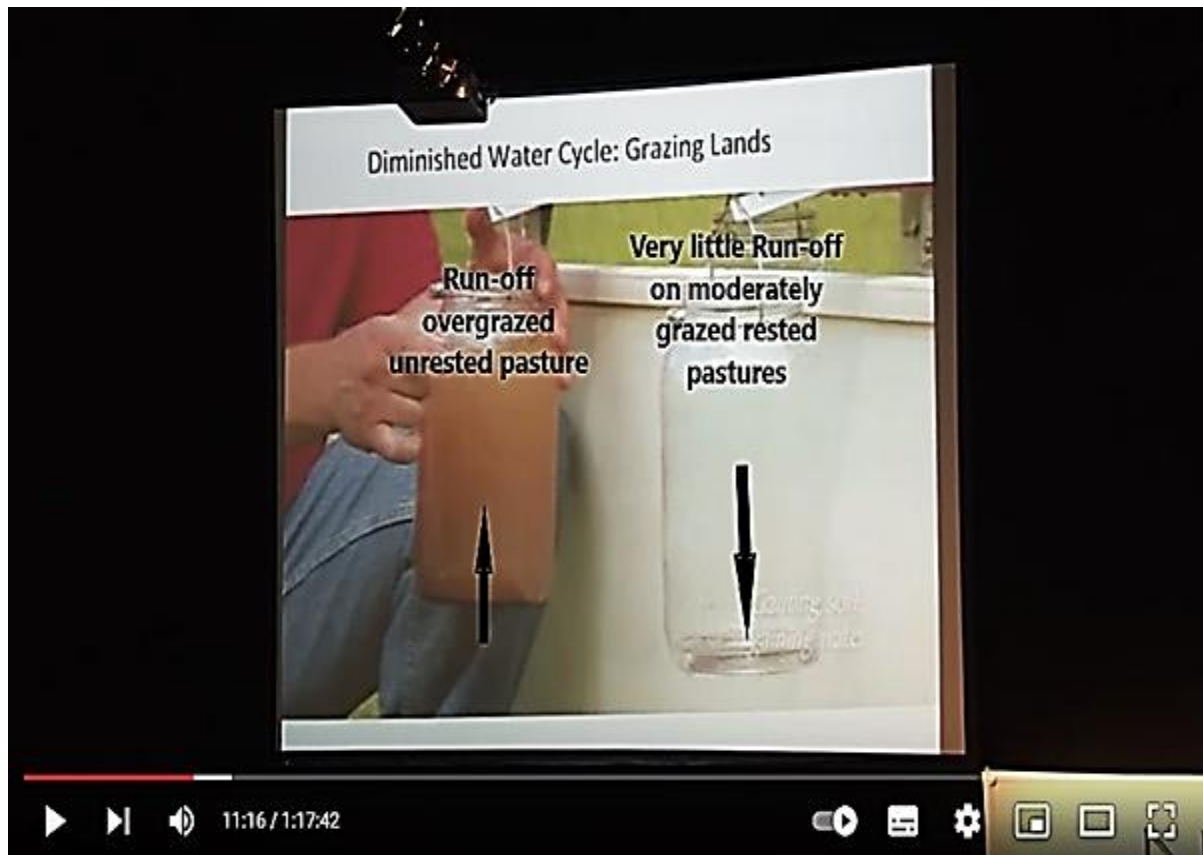


Fig. 91 Annotated slides with very many thanks to Ray Archuleta from his UTube lecture 'No-till on the Plains' (Archuleta, 2016).

39.5 FLOODING, EROSION AND DROUGHT

Farmers, as they switch to regenerative agriculture, report massive increases in measured infiltration rates of rain into soil, from **less than one inch per hour to many inches per hour**. Gabe Brown reported 11 inches per hour infiltration. As a result, the fields of established regenerative farmers are free of lying water or soil run-off after rain events of several inches per hour.

In contrast, their immediate neighbours with adjacent land with similar soil, using bare soil/fertiliser/agrochemical farming techniques, suffer drowned soils not accessible to farm equipment, the water often lying for significant periods, as well as soil erosion including loss of nutrients, related carbon, nitrate and mineral loss, and consequent pollution of water courses.

As the slide above illustrates, soils damaged by FATBAS significantly reduce soil water infiltration. Arguably, if every farm had optimal rain percolation into soils, eleven inches rather than one-inch penetration per hour, water would be retained in the regional hydrological system and released over a long-time frame into streams and rivers. Consequently, flood events would be significantly reduced.



Soil health lessons in a minute: benefits of no-till farming

Fig. 92 Water in a porous bottomed container, sitting above and failing to drain through a handful of cultivated soil, illustrating the lack of porosity of such soils (See also section on compaction and destruction of soil). With thanks to '*Magic of Soil*' (Gregory, 2017), and '*Soil health lessons in a minute: benefits of no-till farming*' - With very many thanks to the authors. (Archuleta, 2012a)

The negative impact of FATBAS on soil infiltration, penetration, and water retention capacity raises the question of the extent to which the global rise in severe flooding events is primarily due to FATBAS-damaged, reduced-infiltration-rate soils, consequent on fertiliser/agrochemical and bare-ground farming, rather than increased rainfall.

As is self-evident, flooding, as well as causing infrastructure damage, economic loss and general disruption, has a whole host of other negative consequences, including for soil, nutrient runoff, erosion, loss of soil carbon, dispersion of contaminants in fertiliser and sewage sludge, (Bashagaluke, 2018) with consequent downstream eutrophication, silting, and increased opacity and pollution generally, of otherwise clear water in rivers and ocean deltas.



With thanks to Adobe Stock

39.6 OVERCOMING SALINITY

The Haggertys and other farmers in Western Australia have observed that regenerative agriculture helps reverse the impact of soil salinisation. The processes are not entirely clear; however, soil biomes, as well as assisting moderate plants' mineral intake, logically engineer the soil they occupy to optimise their survival, including by likely expelling salts into lower, non-colonised soil layers.

Sir Albert Howard also noted that, as far back as the 1930s, quality compost application allowed non-productive saline land to be brought back into use. He cites observations of one of the groups he assisted, *"Indore compost is one of the material blessings of this life, like steam, electricity and wireless. We simply could not do without it here. It has transformed all our agricultural interests. We have 43 acres under wet cultivation, and most of the land three years ago was of the poorest nature, large patches of it so salty that a white alum-like powder lay on the surface. We have now recovered 28 acres, and on these we are having a bumper crop of rice this year. There have never been such crops grown on the land, at least not for many years".* The observations are set out in more detail in the Sir Albert Howard section below. (Howard, A. 1943)

There is also considerable evidence that mycorrhizal organisms may help increase plants' tolerance to saline conditions. *"Sodium concentrations in non-mycorrhizal citrus were... 150 per cent greater than in mycorrhizal citrus. [Research] found that mycorrhizal fungus increased bell peppers' tolerance to salinity"* (United States Congress 1985).

"Considerable evidence exists to suggest that mycorrhizal plants may be better equipped to withstand the toxic effects of salt (likely by moderating plant uptake). Calcium, magnesium, and sodium concentrations in non-mycorrhizal citrus were 41 percent, 36 per-cent, and 150

percent greater than in mycorrhizal citrus. Hirrel and Gerdemann found that mycorrhizal fungus increased bell peppers tolerance to salinity (United States Congress 1985).

The slide from the video lecture *Adaptive Grazing Webinar* by Blain Hjertaas provides a striking comparative example on immediately adjacent land areas of the capacity of regenerative agriculture to mitigate salinity.



Fig. 93 A slide showing adjacent farms, one adopting regenerative principles, the other not, and the positive impact of regenerative agriculture on salinity of land, from the interesting UTube lecture *'Adaptive Grazing Webinar'* by Blain Hjertaas, with very many thanks to the authors. (Hjertaas, 2022)

39.7 SELECTIVE UPTAKE OF MINERALS – EXCLUSION OF HEAVY METALS

The soil biome selectively supplies minerals to its plant hosts, increasing supplies of those needed for growth and excluding damaging heavy metals. At an evolutionary level, it makes sense for the soil biome to protect plants, given their symbiotic relationship, and the essentiality of plants to the soil biome. *"There are convincing evidences that mycorrhizal associations can be of major importance to reduce metal transfer to plants or serving as an effective exclusion barrier for the transport of these elements from roots to shoots."* (Cabral, 2015)

For example, Trappe, et al., indicated that VA mycorrhizal fungi provided resistance to the toxic effects of arsenic. Mycorrhizae may also provide tolerance to excessive soil manganese and aluminium" (Menge, 1985) (Please see the original for references supporting the above, which are extensive) *"The cell wall of fungi contains free amino acids, hydroxyl, carboxyl and*

other groups that represent binding sites for the adsorption of certain trace elements”, particularly copper and zinc (Cabral, 2015), “retention of trace elements in tissues of mycorrhizal fungi happened quickly, and the retention capacity was higher for Cu and Zn, while the retention of Cd and Pb were lower in tissues of AMF. Regardless of the fungal isolates, the retention rates decreased in the following order: Cu > Zn >> Cd > Pb.” . . . “AMF can mitigate the harmful effects of trace elements to plants, mainly by mechanisms taking place in the roots.” (Cabral, 2015)

The review ‘*Arbuscular mycorrhizal fungi (AMF) in phytoremediation of contaminated areas by trace elements: mechanisms and major benefits of their applications*’ (Cabral, 2015) notes, “There are convincing evidences that mycorrhizal associations can be of major importance to reduce metal transfer to plants or serving as an effective exclusion barrier for the transport of these elements from roots to shoots”. Thus, the soil biome likely helps protect our food and livestock from heavy metal pollution of foods as a free service.

40 NPK FERTILISER - PLANT MYCORRHIZAL CARBON EXCHANGE

The discovery of industrial processes to make nitrate and extract phosphate, thus producing fertilisers, was perceived as a new miraculous agricultural revolution. It offered a brighter, better future and helped farmers cost-effectively bring ‘worn-out’ land back into production.

Despite encouraging early results, longer-term NPK application damages soil sustainability, carbon levels, and plant productivity and health, requiring ever greater inputs, including agrochemicals and improved breeds, to maintain outputs.

At the outset of NPK use, the underlying negative biological consequences of the supply of plant-available ‘artificial’ phosphates and nitrates on mycorrhizal systems/soil carbon/root biology were not generally understood. In the hubristic excitement of technological discovery and commercial rush for profitable new industries, those agronomists who expressed reservations or raised concerns as to the long-term implications of NPK use on plant and soil biome health remained unheard.

We now have a much better understanding of plant biology, which is slowly becoming more widely understood and accepted. The problem is that provision to plants of ‘plant-available’ easily soluble phosphates and nitrates in artificial fertilisers will result in the reduced supply to the soil biome by plants of the photosynthetic carbon sugar exudates that are used by mycorrhiza as fuel. A reduced supply of carbon sugar exudates leads to the degradation of soil biome systems, loss of interaction with plants, and a reduced supply of nitrates, minerals, stored and metabolic water, and broader plant bio-support systems by the soil biome to the plant biome. Ploughing, bare soil, and the use of agrochemicals accelerate soil biome destruction.

Dr Christine Jones observes: “*The application of high rates of inorganic nitrogen in agricultural systems has had many unintended negative consequences for soil function and environmental health*” (Jones, n.d.-b). “*Data from North America’s longest-running field experiment on the impacts of farm production methods on soil quality have revealed that high nitrogen inputs deplete soil carbon, impair soil water-holding capacity - and ironically, also deplete soil*

nitrogen. Taken together, these factors have been implicated as the underlying cause of widespread reports of yield stagnation around the world” (ibid).



Fig. 94. Testing crops in 1940s Tennessee. Franklin D. Roosevelt Presidential Library and Museum from a *'The Conversation'* article February 2011, titled *'How the great phosphorus shortage could leave us all hungry'* with very many thanks to the Presidential Library. An experiment based on a flawed premise and lack of understanding of soil functions and plant soil biome interactions (Faradji & de Boer, 2016).

There is no question that phosphates and nitrates are essential to plant growth. The ground-up rocks in soils and subsoils contain a range of minerals, including phosphates in varying mixes and amounts. Most soils contain adequate mineral phosphate to last hundreds or more years. Indeed, healthy biomes have evolved over aeons to supply plants with adequate plant accessible nitrates and phosphates in return for plant sugars, and have been doing so for aeons without human intervention.

40.1 NITRATE FIXATION BY MYCORRHIZAL SYSTEMS

Nitrogen is an essential building block of many organic molecules needed by plants. Hence, plants must acquire nitrogen in an available soluble form to exist, but they cannot themselves make such products from the nitrogen in the air.

Dr Christine Jones, in her video lecture “*Nitrogen: The double-edged sword*” (Jones, n.d.-b; Jones, 2018b) (highly recommended viewing) and accompanying opinion piece, observes that nitrogen is essential to life.

Assimilable nitrogen is available from):

- Conversion of atmospheric nitrogen by lightning (limited source).
- Conversion by organisms (prokaryotes), including soil bacteria that possess the enzymes to process atmospheric-derived nitrogen to ammonia and derivatives.
- Degradation of organic matter, including urine, plant detritus, and dead organisms, including soil microbial and broader life.
- Human supply of industrially supplied ‘artificial’ nitrogen fertilisers. (Wagner, 2011)

For the avoidance of doubt, contrary to often cited ‘wisdom’, it is not only brassicas that can fix nitrogen, given a low oxygen home in the mycorrhizal sheath, and a plant produced energy source of fats and sugars, “*Many heterotrophic bacteria live in the soil and fix significant levels of nitrogen without the direct interaction with other organisms.*” (Wagner, S. 2011)

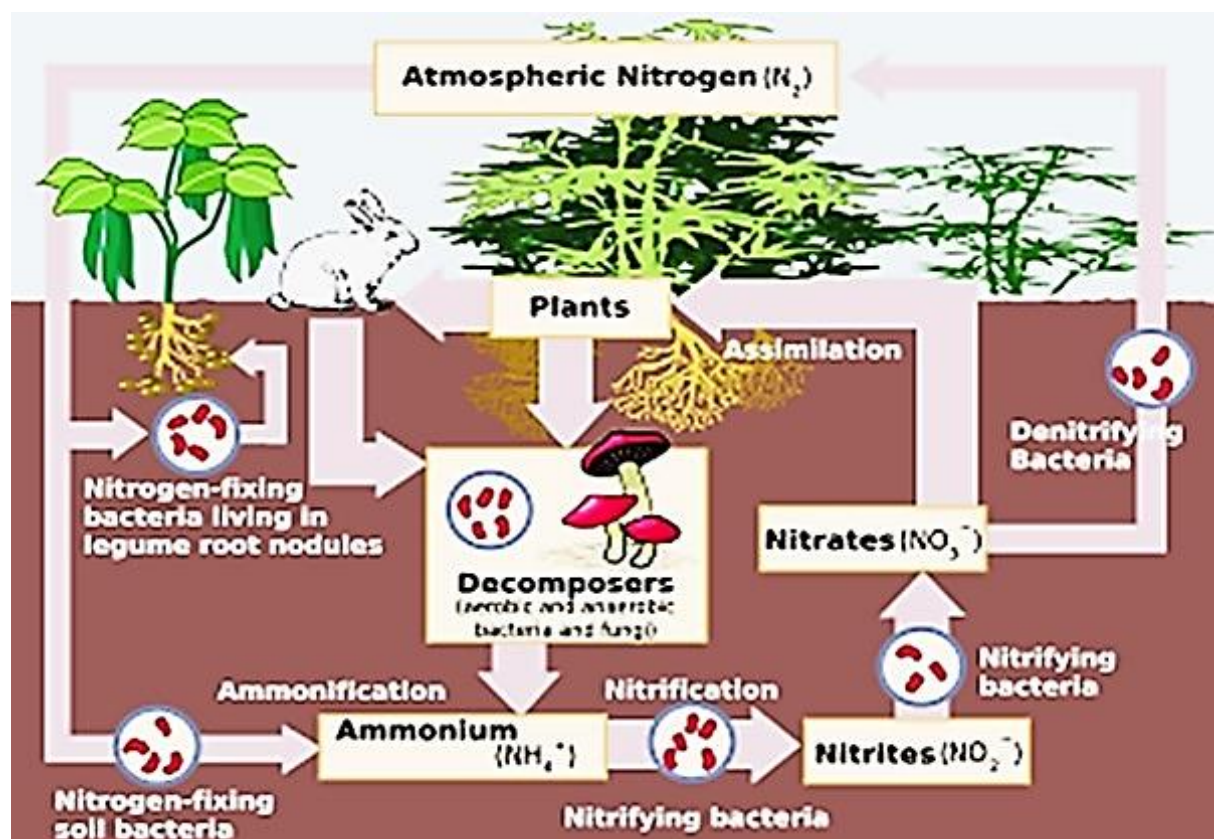


Fig. 955. Schematic representation of the nitrogen cycle. Abiotic nitrogen fixation has been omitted. With very many thanks to Wikipedia and image author Dreoj J. (Wikipedia, 2022a)

Importantly, bacteria can only naturally create nitrogen products in a low-oxygen atmosphere enclosure, which requires mini-compartments, such as root nodules on brassicas or, more widely, low-oxygen ‘compartments’ formed by bacteria and fungi with exudates within plant root rhizosheaths.

Plant functional and species diversity, which contributes to the formation of healthy soil biomes, increases nitrogen fixation of nitrates. The Jena study reported that nitrogen availability increased as the numbers of cover plant species rose. One species made little difference, but 16 species, when combined, significantly increased nitrate productivity.

Sixteen species with no nitrogen addition, in terms of growth, outperformed the addition of 0kg, 100kg or 200kg nitrogen per hectare per year with 0, 1 or 2 plant species. In her lecture video, Dr Christine Jones stresses, “**Species richness was the most important factor for soil carbon sequestration**” (Author's bold).



Fig. 96. Jones, PhD, Founder of ‘Amazing Carbon’ (Australia) and soil ecologist – ‘Nitrogen: The double-edged sword’ – With many thanks. (Jones, n.d.-b, Jones, 2018b)

As might be expected from the relevance of a healthy soil biome, soil carbon levels are also crucial to nitrogen management, production and uptake. The importance of soil carbon, as a limiting factor in soluble nitrogen uptake, is helpfully discussed in the review, ‘Organic nitrogen storage in mineral soil: Implications for policy and management’ (Bingham & Cotrufo, 2016) which observes, “As we discuss below, the first step in the retention of added N is microbial processing driven by C availability, a driver of kinetic saturation.” (Bingham & Cotrufo, 2016) (Authors underline) As might be expected, in nature, when soil carbon is increased, it is accompanied by increased nitrogen processing capacity; both are symbiotically interlinked.

Conversely, as discussed, the supply of artificial nitrogen to low-carbon soils may exacerbate issues. *“The capacity of a soil to process N is increasingly being recognized as the bottleneck that leads to N saturation; this kinetic saturation appears to be driven by an imbalance of N inputs over C inputs, but factors that influence long-term N storage may play a role as well”* (Bingham, 2016)

The paper further notes, *“forest soils with greater C content (such as old growth forests) rapidly integrate greater amounts of N into long-term storage than forest soils with lower C contents.”* (Bingham, 2016)



Fig. 977. Jones, PhD, Founder of 'Amazing Carbon' (Australia) and soil ecologist Dr Christine Jones – 'Nitrogen: The double-edged sword'– With many thanks to the author. (Jones, n.d.-b; Jones, 2018b)

40.2 EXCHANGE AND REGULATION MECHANISMS - PLANT SUGARS TRADED FOR PHOSPHATES AND NITRATES - PLANT / SOIL BIOME INTERDEPENDENCE

Phosphates, nitrates and magnesium are arguably used jointly by plants and mycorrhiza as the master regulatory sensing systems, the key control gauges, or predominant trading currencies, if you like, between the mycorrhiza and plants. Phosphates, nitrates, magnesium, and other minerals are exchanged for plant photosynthetically produced carbon-based sugars and fats.

Nature tends to optimise resources by simplifying core systems. Until humans intervened with artificial fertilisers, the apparent key evolutionary selected regulatory exchange currency mechanisms, sugars for phosphates and nitrates, worked well.

However, when we befriended plants and well-meaningly provided them with plant-available chemically derived soluble phosphates and nitrates, we disturbed those carefully balanced exchange mechanisms because the plants, based on nitrate and phosphate availability, thinking they have all the nutrients they need, no longer feel obliged to provide the mycorrhiza with all the carbon sugars they need. Equally, the mycorrhiza, deprived of plant sugars, are less motivated to supply nitrates, phosphates, and other minerals, as well as wider factors that support plant health.



Fig. 98. A slide from the UTube lecture '*Regenerative Agriculture Healing the World*' - By Ray Archuleta @ Carbon Summit, with many thanks to the author. (Archuleta, 2021b)

Mechanisms regulating these exchange currency/petrol gauge interactions have begun to be putatively identified, but are immensely complex. Dr Christine Jones, in a video lecture titled '*Summer 2018 Field Day | Dr Christine Jones | 6.5.18 @1.14*' (Jones, n.d.-c), demonstrates the simple action of supplying one of two identically pot-maintained and lit plants with nitrogen by foliar spray, will result in a measurable comparable loss in photosynthetic production of plant root exudates, within a short time frame 30 minutes or less, as evidenced by a reduced Brix reading.

Other studies have also observed these phosphate/ nitrate regulatory exchange systems "*AM fungi increase the uptake of P_i and N by plant hosts from soil. In turn, P_i and N regulate AM symbiosis.*" (Wang, 2017) Interestingly, when phosphate starvation occurs, carbon sugar resources are allocated to the roots.

Consistent with this, the paper *'Compost Addition Enhanced Hyphal Growth and Sporulation of Arbuscular Mycorrhizal (AM) Fungi without Affecting Their Community Composition in the Soil'* observes, "It was well demonstrated that use of inorganic fertilizer (e.g., N and P fertilizer) negatively affect AM abundance and diversity" (Yang, 2018).

Interestingly, the application of fertilisers to longstanding natural pastures that have achieved a natural ecological balance of species may upset the natural plant species balance, reducing the number of plant varieties and impacting the soil biome. Conversely, the application of solutions containing a broad mix of fungal spores and bacteria, as well as increasing fertility, has been observed to result in the reappearance of native species in 'natural' grasslands.

The paper *'Direct and indirect influences of 8 yr of nitrogen and phosphorus fertilization on Glomeromycota in an alpine meadow ecosystem'* (Liu, 2012) observes, "As predicted, fertilization reduced the abundance of Glomeromycota (Fungi that forms arbuscular mycorrhiza – authors' note) as well as the species richness of plants and AM fungi." . . . "The functional equilibrium model predicts that the enrichment of soil resources by fertilization will reduce plant allocation to roots and mycorrhizas because, once soil resource limitation is eliminated, plant competition for above-ground resources (i.e. light) will become stronger, so that plants should allocate more biomass to shoots and leaves rather than below ground. Empirical field studies support these predictions by showing that fertilization reduces significantly the biomass of plant roots and AM fungi. Furthermore, fertilization has been shown to influence the species composition and reduce the species richness of plants and AM."

. . . "Fertilization with both nitrogen (N) and phosphorus (P) often reduces AM fungal abundance" . . . "It is well established that fertilization reduces soluble carbon in the apoplast of plant roots" . . . "In our experiment, the highest level of fertilization caused the number of plant species to decline by more than six-fold (Table 2), and reduced the number of AM fungal phylotypes by one-half" (Liu, 2012)

Whilst not yet widely accepted, there is arguably a sufficient basket of evidence and biology that the use of artificial phosphate and nitrate fertiliser reduces the supply of carbon sugar exudates by plants to the soil biome.

40.3 MYCORRHIZA SHEATH CENTRAL TO EFFICIENT NUTRIENT EXCHANGE

The soil volume accessible by roots through which to take up soluble phosphorus is limited; thus, without mycorrhizal assistance, plants rapidly deplete the area accessible to their roots of soluble phosphorus. Further, the surface supply of plant-available 'artificial' phosphates and nitrates, both before seeding and during growth, encourages shallow surface root formation to optimise uptake. Shallow roots increase plant reliance on the external supply of nitrates and phosphates throughout the growing season. As a result, access to the deeper soil biome to root-supplied sugar exudates is reduced, as is plant drought tolerance; the effect of shallow roots will be magnified due to reduced carbon supply to the soil biome, resulting in lower soil metabolic water production and reduced soil carbon-related rainfall retention.

Efficient abstraction and supply of phosphorus to plants from more expansive areas of soil by mycorrhizal systems is important. Whilst it is a 'relatively' 'scarce' mineral in the earth's crust,

“When compared to other essential macronutrients, P (Phosphorus) is one of the less-abundant elements in the lithosphere (0.1% of the total). (Campos, 2018) (Authors’ underline). The relative amount of phosphorus in the earth’s crust and its crucial metabolic importance are usefully explained in the review, ‘Phosphorus Acquisition Efficiency Related to Root Traits: Is Mycorrhizal Symbiosis a Key Factor to Wheat and Barley Cropping?’ (Campos, 2018).

The extensive reach of healthy mycorrhizal systems, and their capacity to mine and turn insoluble phosphates into soluble phosphates mean that biome-rich soils can generally supply plant phosphorus and other mineral needs – albeit within a modern farming degraded soil carbon context, pending development of mature diverse soils, plants may grow better when provided with a broad-based foliar mineral spray (including for example seaweed extract or possibly sea salt extraction residue).

Table 7 *Approximate minerals composition of the earth’s crust – with thanks to the authors and Wikipedia. (Wikipedia, 2022)*

Most Elements Crust	Abundant of Earth's	Approximate % by weight	Oxide	Approximate % oxide by weight
O		46.6		
Si		27.7	<u>SiO₂</u>	60.6
Al		8.1	<u>Al₂O₃</u>	15.9
Fe		5.0	<u>Fe as FeO</u>	6.7
Ca		3.7	<u>CaO</u>	6.4
Na		2.7	<u>Na₂O</u>	3.1
K		2.6	<u>K₂O</u>	1.8
Mg		1.5	<u>MgO</u>	4.7
Ti		0.44	<u>TiO₂</u>	0.7
P		0.10	<u>P₂O₅</u>	0.1

Phosphate availability to plant roots depends if they are in solution, or when not in solution, how they are bound to soil components; the paper ‘*Efficiency of soil and fertilizer phosphorus use - Reconciling changing concepts of soil phosphorus behaviour with agronomic information*’ (Syers, 2008) observes:

- *“In the soil solution P is immediately available for uptake by plant roots (as it is in hydroponic systems).*
- *The second pool represents readily-extractable P (soluble phosphates) held on sites on the surface of soil components. This P is considered to be in equilibrium with P in the soil solution, and it can be transferred readily to the soil solution as the concentration of P in the latter is lowered by P uptake by plant roots.*

- *The P in the third pool is less readily extractable and is the P that is more strongly bonded to soil components or is present within the matrices of soil components as absorbed P (i.e. P adsorbed on internal surfaces) (including minerals) but can become plant-available over time.” (Syers, Johnston & Curtin., 2008)*

The first pool is easily accessible by plants, the second less so, and the third requires the presence of mycorrhizal extraction and transport to plant roots. When phosphates are applied in water-soluble form in fertilisers, as much as 90% of the application is not subject to run-off and binds with relatively insoluble minerals, which mycorrhizal systems can abstract but plants cannot. Thus, soils heavily fertilised over years contain large amounts of bound phosphates, which mycorrhizal systems can efficiently access and solubilise.

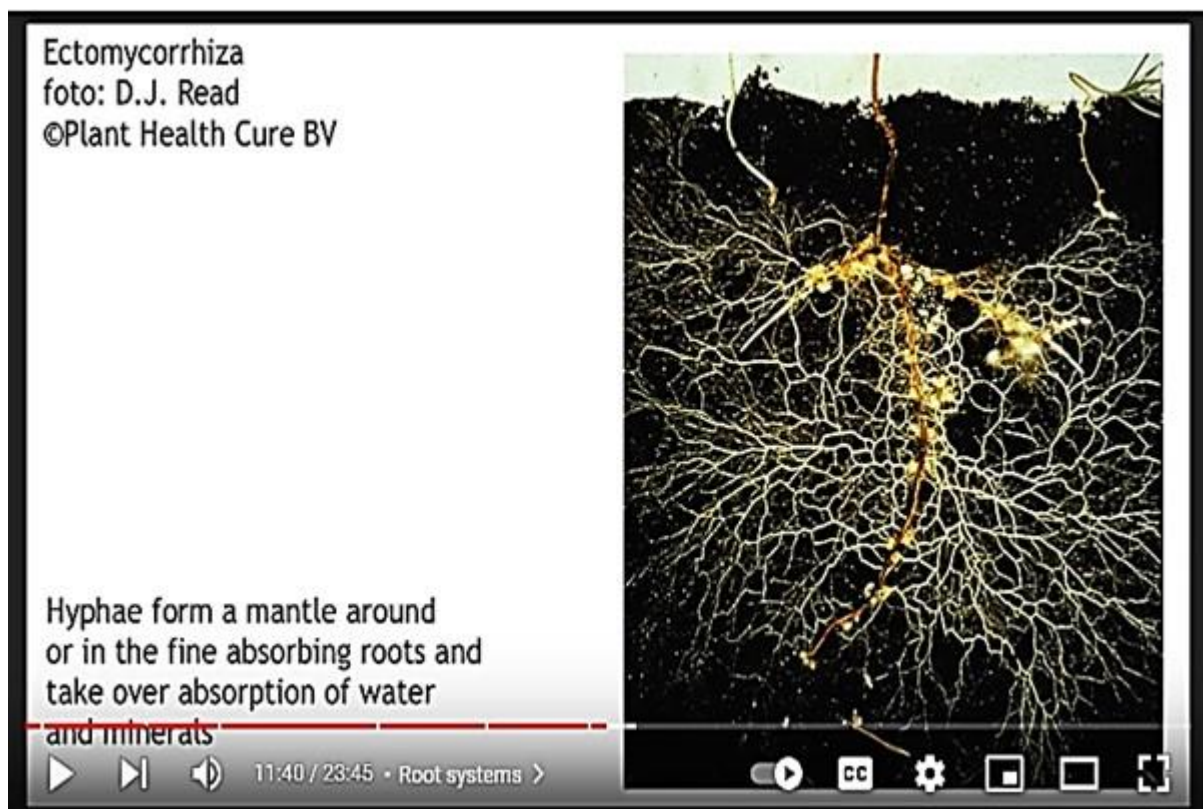


Fig. 99. Young seedling plant roots (dark brown) quickly develop mycorrhizal symbiotes (light brown) to optimise nutrient supply, helping explain why compost tea seed treatments and drip, and foliar sprays, optimise plant germination, health, and subsequent growth in poor soils. With very many thanks to the authors – UTube lecture “*The long term effect of chemical fertilizers on soil health*” (‘Plant Health Cure’, 2019)

The bottom line is that mycorrhiza are experts in phosphorus extraction and transport, with the capacity to create extensive underground networks that mine, move, and make phosphorus available to plants in exchange for payment in sugars and fats. Importantly, plants can only take up solubilised phosphorus that is positioned close to their roots, so, in the absence of human-applied soluble fertiliser, they are usually forced to trade sugars for mycorrhizal/bacterial delivery of soluble phosphates. “*Although plants can utilize a variety of*

mechanisms to increase P uptake, the most efficient and widely utilized method is mycorrhizal colonization” (Kluber, 2012).

“Between 1-50% of soil bacteria and about 0.5-0.1% of soil fungi can be classified as P-solubilizing microorganisms” (Campos, 2018). Mycorrhiza and accompanying bacteria improve the efficiency of phosphorous abstraction, usage, and uptake by plants from soils through several mechanisms, such as hormonal regulation of plant root architecture; more efficient phosphorous abstraction by small diameter phylae able to access soil compartments closed to plant roots; and wider interlinked mycorrhizal and bacterial networks span much greater soil volumes than plants roots.

Phosphorus also symbiotically helps regulate mycorrhizal root colonisation, so transport and broader interaction. Phosphorous, a requirement for plant growth, is similarly required by the mycorrhizal fungi and the bacteria that form the soil biome. Thus, when plants are thriving and supply sugars to mycorrhizal systems, more phosphate is mined, which both increases mycorrhizal activity and plant supply in a positive synergistic feed-forward cycle.



Fig. 100. *Mycorrhizal sheath on wheat seedlings. Image from ‘Quorum Sensing In The Soil Microbiome (Understanding The Role Of Soil Microbial Interactions For Soil Health)’ - Dr Christine Jones, Soil Ecologist, Australia, 2019 Conservation Tillage and Technology Conference, March 5 - 6, 2019, Ada, OH, USA. With thanks to the authors. (Jones, 2019b)*

The processes between plants and mycorrhiza are symbiotic, with both parties seeking to enhance their existence by promoting and optimising the growth of the other to best suit their needs. For example, plants can, in some circumstances, symbiotically *“increase or decrease rhizospheric pH up to 2–3 pH units, mainly by absorption or release of protons”* (pH impacts mineral including phosphate solubility thus availability.) and *“plants can also modulate the symbiosis, by stimulating fungal metabolic activity and hyphal branching among other effects”* (Campos, 2018).

Healthy plants work with mycorrhizal systems to create a mycorrhizal sheath of soil particles, fungi, bacteria, root exudates, and bacterial films that create microenvironments, or mini-factories, for specialised biology to take place, including low-oxygen spaces that allow the creation of nitrates. The mycorrhizal sheath area is also called the rhizosphere, “*The rhizosphere encompasses the first millimeters of the soil surrounding plant roots, where biological and ecological complex processes occur. This is the critical zone for P dynamics as plants roots are capable of modifying this environment through their physiological activities, especially by exudation of organic acid anions, enzymes, secondary metabolites and sugars. These processes not only determine solubilization/mineralization, acquisition of soil nutrients and microbial dynamics, but also control the efficiency of nutrient use by plants and crops, therefore influencing productivity and sustainability of the agroecosystems.*” (Campos, 2018)

Mycorrhiza can extract and transport phosphates from a much wider soil area than plant roots and concentrate dilute amounts of phosphates in soils, overcoming phosphate depletion zones caused by plant root activity.

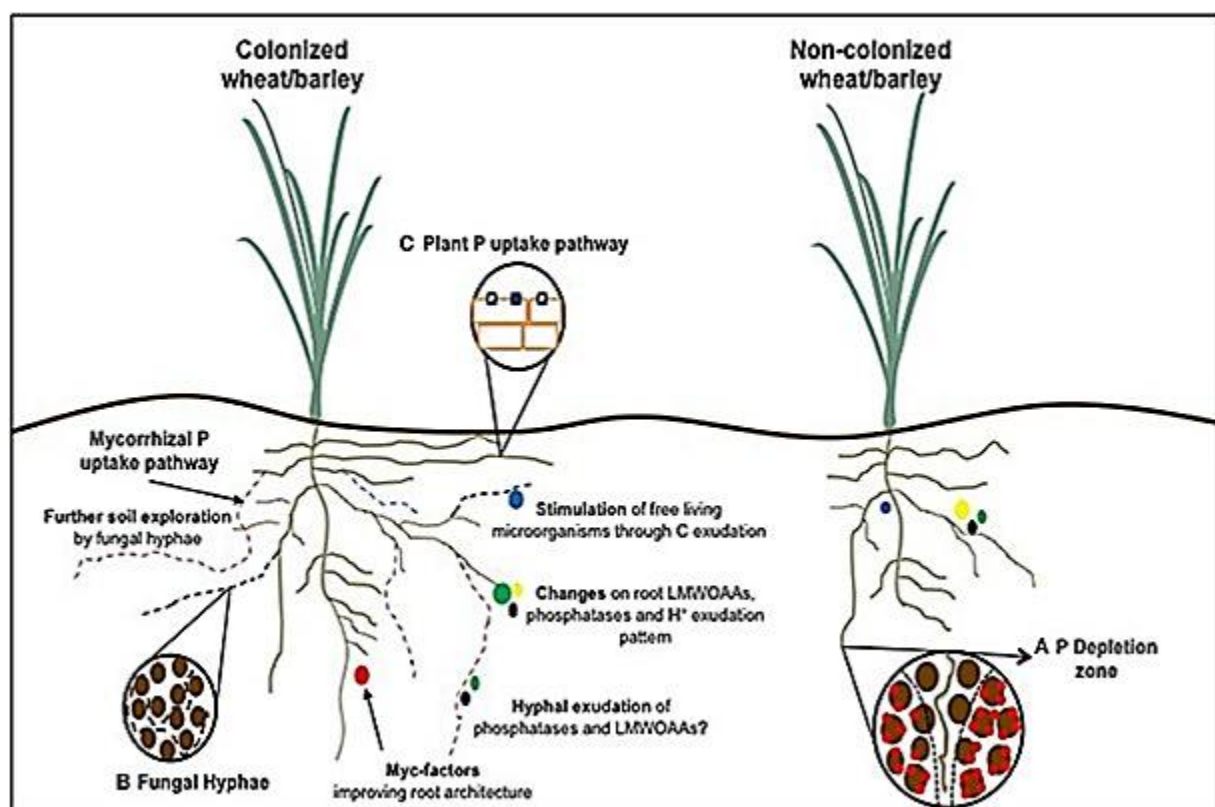


Fig. 1011. From ‘Phosphorus Acquisition Efficiency Related to Root Traits: Is Mycorrhizal Symbiosis a Key Factor to Wheat and Barley Cropping?’ (Campos et al., 2018) “Phosphorus acquisition efficiency related traits of wheat and barley roots affected by arbuscular mycorrhizal symbiosis in comparison to a non-colonized counterpart. (A) Representation of P depletion zone around the rhizosphere; (B) Access to smaller soil pores by AM fungal hyphae; and (C) Modulation of plant P transporters following colonization.”, with very many thanks to the authors. (Campos et al., 2018)

Phosphorus has particular and crucial roles in enzymes; *“P is an important component of organic molecules such as nucleic acids, ATP and phospholipids; thus, playing a crucial role in energy metabolism of both plants and animals. Phosphate is also involved in signal-transduction pathways via phosphorylation/dephosphorylation, hence regulating key enzyme reactions in general cellular metabolism, including N (Nitrogen) fixation on N-fixing plants”* (Campos, 2018)

As well as phosphorus, a range of minerals are crucial to cellular function because one or more of them are selectively incorporated into most enzymes, where they act as electron donors and acceptors. Plants accumulate “essential” metals from soil, including Ca, Co, K, Mo, Na, Mg, Mn, Ni, Se, Cu, Fe, V and Zn. Plants require different amounts of these for their growth and development. *“Minerals, such as Co, Cu, Fe, I, Mn, Mo, Se, and Zn, (also Ni Cr) are part of the numerous enzymes that coordinate many biological processes, and consequently are essential to maintain animal health and productivity. Essential metals perform four important types of function: structural, physiological, catalytic and regulatory.”* (Hejna, 2018)

In summary, mycorrhizal/bacterial systems extract phosphorus and other minerals from soil much more efficiently than plants and are happy to trade it for photosynthetically produced sugars and fats. Phosphorus (the total phosphorus pool) is limited in soils, and soils might, over the very long term, become depleted of phosphorus. Hence, it makes sense to develop systems, including through greater use of composting of faeces and urine collected at source, to close the phosphorus cycle by returning the phosphates mined in crops, which are exported in food, including grain, to city conurbations and livestock facilities, to the land.

40.4 MAGNESIUM SUPPLY REGULATION

Mycorrhiza also provides plants with magnesium and other minerals (Zare-Maivan, 2017), creating a further feedback regulation pathway. Magnesium is also necessary for the function of phloem (Wikipedia, 2019c), the living tissue that transports plant sugars to where they are needed.

Consistent with this, reduced magnesium uptake results in a build-up of carbon sugars in leaves, *‘Effects of magnesium deficiency on photosynthesis and carbohydrate partitioning’* notes, *“sugar accumulation in leaves that results from the impairment of their transport in phloem is considered as an early response to Mg deficiency. The most visible effect is often recorded in root growth, resulting in a significant reduction of root/shoot ratio. Mg is involved in the source-to-sink transport of carbohydrates. Hence, an inverse relationship between Mg shortage and sugar accumulation in leaves is often observed.”* (Farhat, 2016)

Thus, it is in the interest of mycorrhiza to supply plants with magnesium as part of a basket of mineral supply; likely, on an evolutionary basis, plants have come to rely on this substrate exchange pathway for the optimal provision of magnesium.

41 PLOUGHING, SOIL CARBON LOSS

Ploughing both increases the bare surface soil area and further exposes soil biology to light and heat, which kills many fungal and bacterial elements and impairs the function of others. Ploughing also severs root and burrow-based air and water channels, mycorrhizal and rhizosheath soil structures, and cuts off any remaining exchange of photosynthetic root exudates for soil life biome-supplied nitrates, minerals, and metabolic water. It also creates a semi-impermeable thatch layer of dead organic surface material at the plough cut plane, further impeding gas and water flows.

Further, logically, ploughing also severs the soil's gaseous pore nitrogen and oxygen transport channels, which are cut, directionally disturbed and overlaid with the turned surface soil and biology.

Once the mycorrhiza below the plough-cut plane become socially isolated, disconnected from live photosynthesising plant roots, they can no longer cycle metabolic soil biome water above the cut point. Gravity will drain retained water downwards, drying the soil above the plough-cut layer. Consistent with this, farmers historically observed and recorded that shallow ploughing restricted soil moisture to the upper layer.

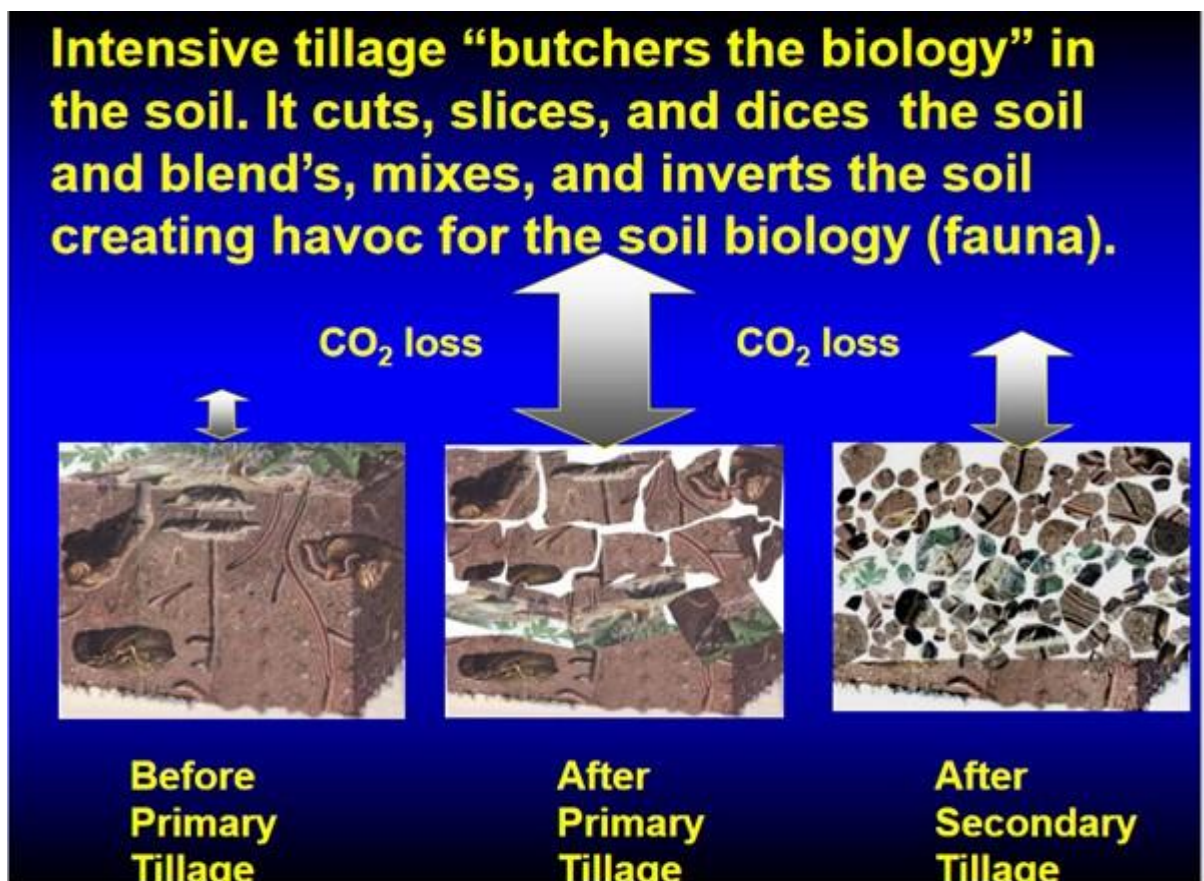


Fig. 102. Lecture slide AGVISE Seminars and Don Reicosky 'Tillage and Carbon Management: Nutrient Re-Cycling Synergies' North Central Soil Conservation Research, with very many thanks to the authors. (Reicosky, 2014)

Hence, the horizontal cut layer, will impair the downward penetration of; plant sugars, rain, as well as dew, oxygen and nitrogen; thus, below the cut layer inhibiting; mycorrhizal, bacterial, and broader soil-life function, ultimately killing the denizens of the soil biome, and in turn switching off the soil biome supply of phosphates, nitrates, other nutrients, and metabolic water, to the ploughed layer above the cut line, so inhibiting plant growth.



Fig. 103. *'Magic of Soil'* Philip Gregory, equipment used by Dr Don Reicosky for measure carbon dioxide loss following tillage. With many thanks to the Author. (Gregory, 2017)

In addition, seeds (absent pre-treatment with soil biology) newly planted, in the UV-exposed, wind and light desiccated upper soil layer, will have reduced access to the soil biology they need to form the early mycorrhizal root sheaths that help provide nutrients and water, required to establish efficient early growth.

Indeed, tillage has been experimentally shown to result in the death and destruction of soil life, which is then respired in an ever-diminishing annual downward spiral, each year diminishing the remaining soil life, leading to the loss of soil carbon that exits the soil as carbon dioxide. The stored carbon from dying soil biome life forms is metabolised because, consequent on tillage and bare ground, in the absence of supply of plant-based photosynthetic carbon sugar exudate, it becomes the only available below-ground source of an energy substrate.

An experiment using equipment to measure carbon dioxide loss following tillage showed increased carbon dioxide emission from recently tilled soils, which equated to soil carbon loss. The increased emission from soil following tillage was *"0.197 tons of carbon/ acre lost from the soil in the 24 hrs following plowing compared to only 0.013 tons of carbon/acre for the unplowed soil.* Clearly, similar losses will continue over many days, thought-provokingly equating over time to a ton or more of carbon lost per acre.

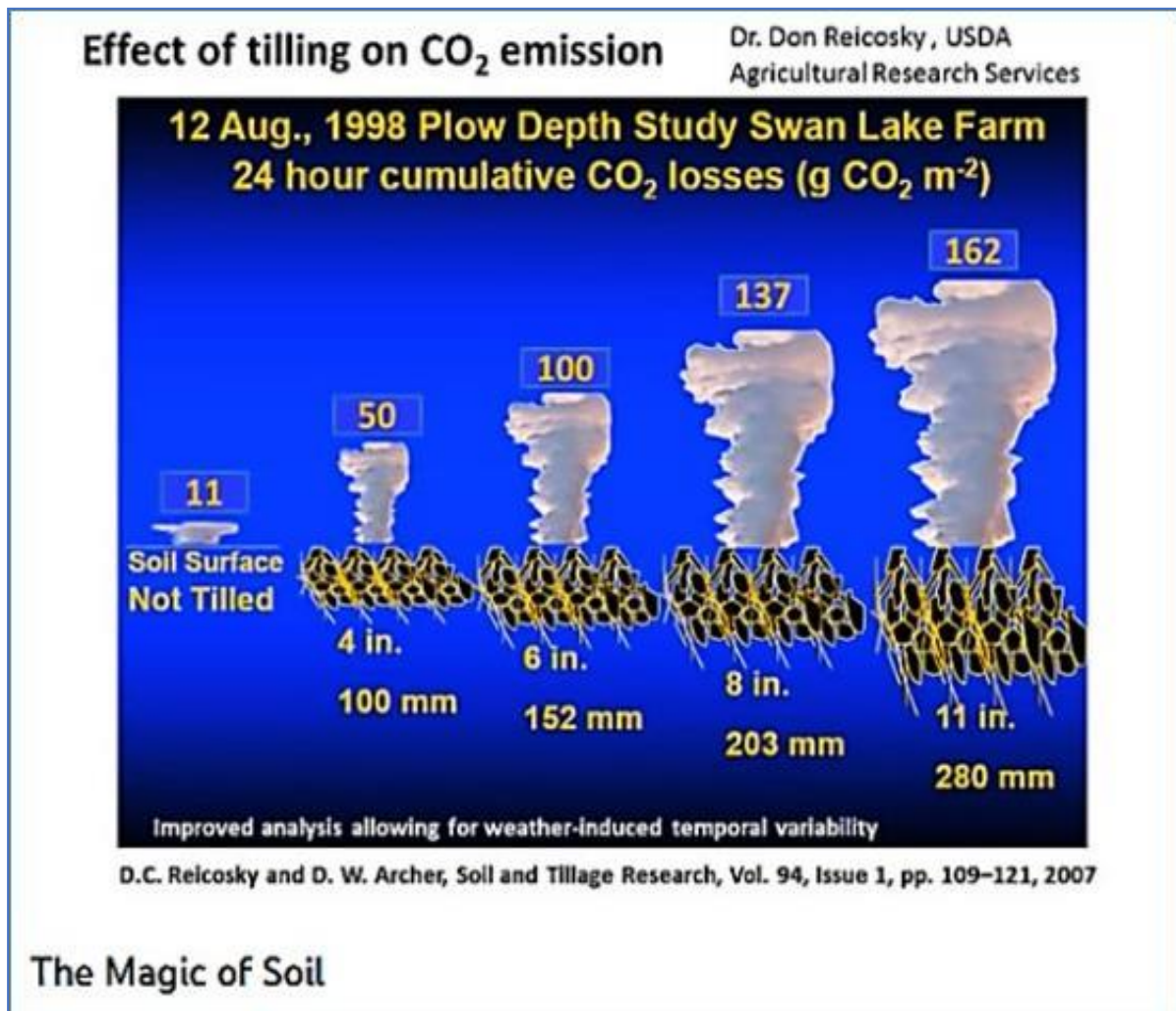


Fig. 104. 'Magic of Soil' Philip Gregory, "Now one acre is 4047 sq. meters which means $162 \times 4047 = 655,614$ grams or 656 kg of CO₂ released from one acre which translates to 0.657 tonnes per acre or 0.723 U.S. tons of CO₂/acre. To convert tons of CO₂ to tons of carbon divide by 3.67 which yields finally 0.197 tons of carbon/ acre lost from the soil in the 24 hrs following plowing compared to only 0.013 tons of carbon/acre for the unplowed soil." With very many thanks to the author. (Gregory, 2017)

Of course, once new seeds are planted and start to grow, plant sugar exudates will again be supplied to soils, but the combination of tillage, bare ground, agrochemicals, and NPK usage, clearly results in a downward spiral of soil carbon, which is being seen in the many facets of soil and land degradation.

Interestingly, whilst the recorded global overall long-term seasonal trends of carbon dioxide, as measured in the Pacific away from major land masses, at Mona Loa by NOAA, remain steadily upward, regional and annual seasonal atmospheric carbon dioxide change as

measured from satellites is large, which is intriguing and thought-provoking, as discussed in the following section.

41.1 TILLAGE - SEASONAL ATMOSPHERIC CARBON DIOXIDE CHANGE IMPACT

In the spring tillage season, Ray Archuleta (see annotated slides below) observed that in the northern hemisphere, in spring, as plants again start to grow, the atmospheric carbon dioxide increases to levels above those seen in mid-winter when fossil fuel combustion for home heating is increased. This is a wake-up call as to the amount of carbon dioxide likely released from spring tillage of soils; there are no other obvious explanations for this phenomenon. Then, as might be expected, atmospheric carbon dioxide is reduced in the growing season due to uptake by photosynthesising plants.

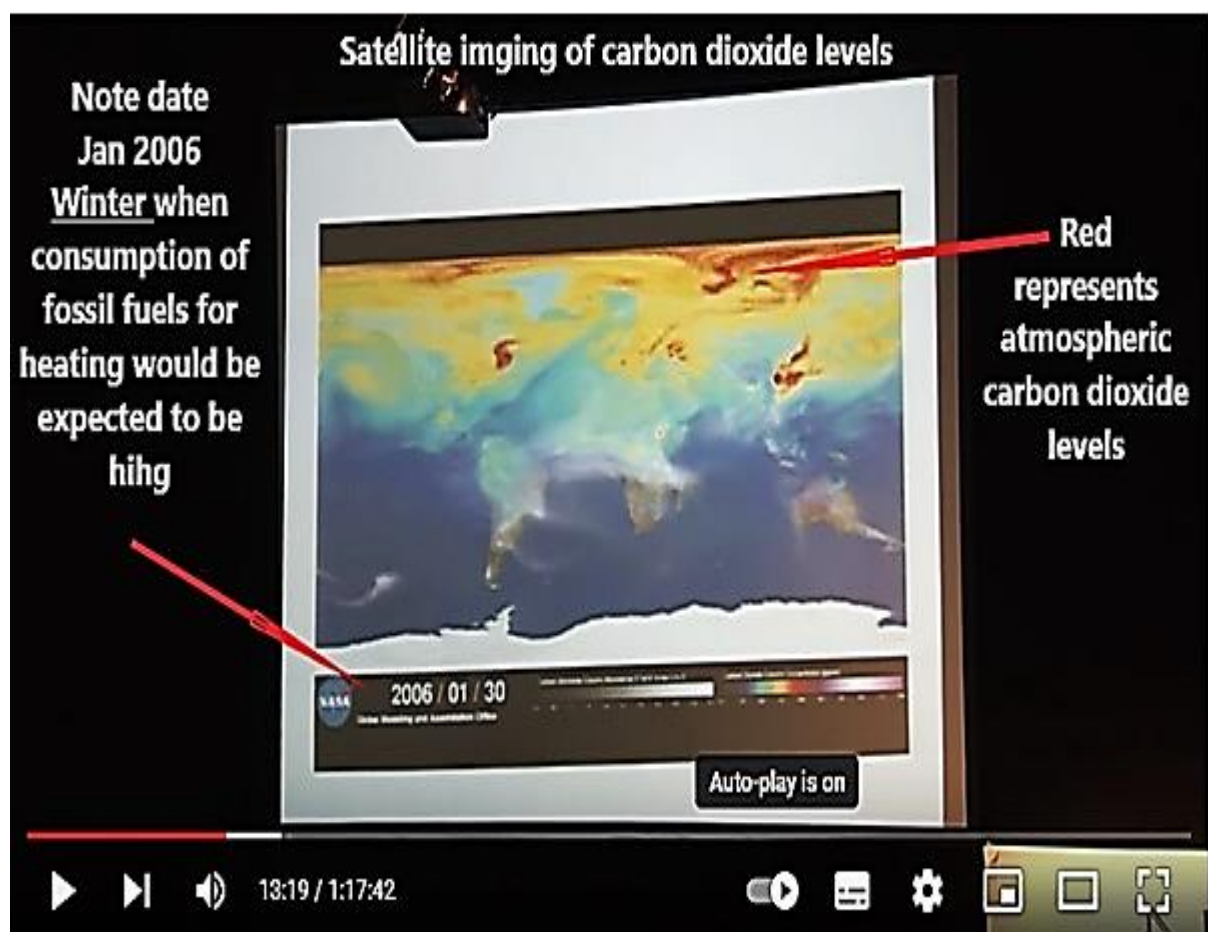


Fig. 105 Annotated and with very many thanks to 'No-till on the Plains' by Ray Archuleta and NASA, taken from a video representation of changing annual atmospheric carbon dioxide levels (Archuleta, 2016).

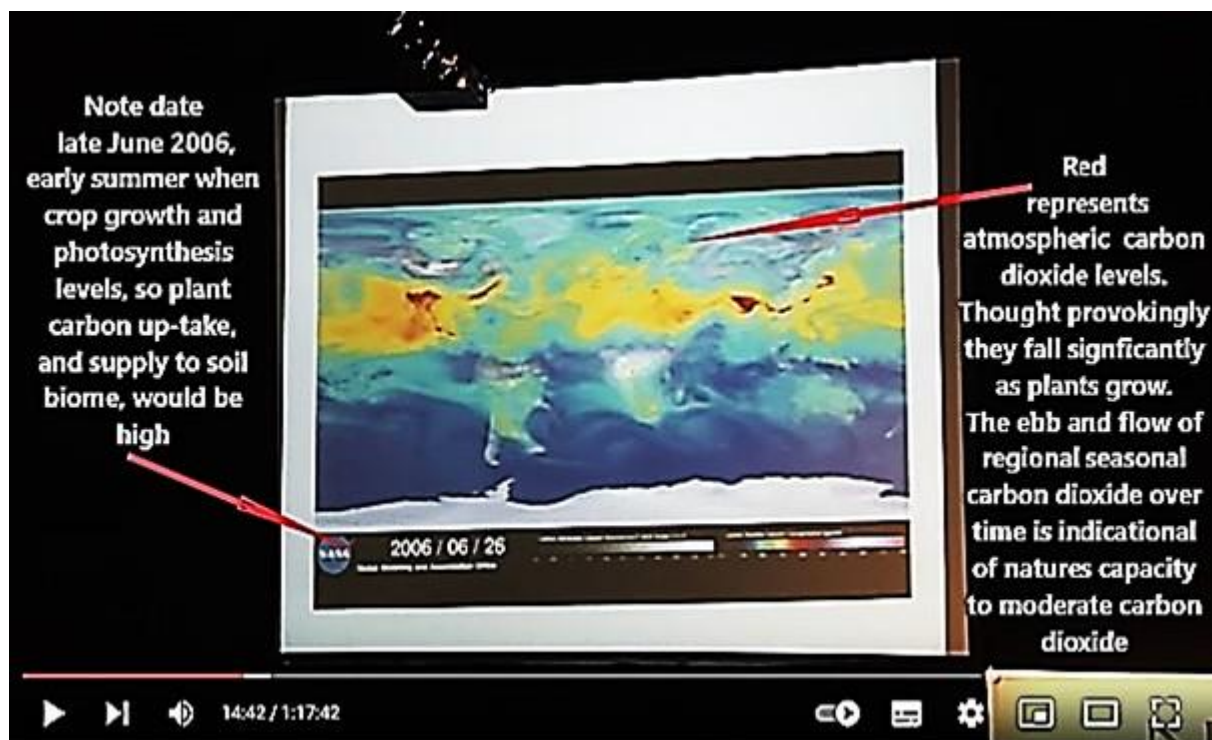
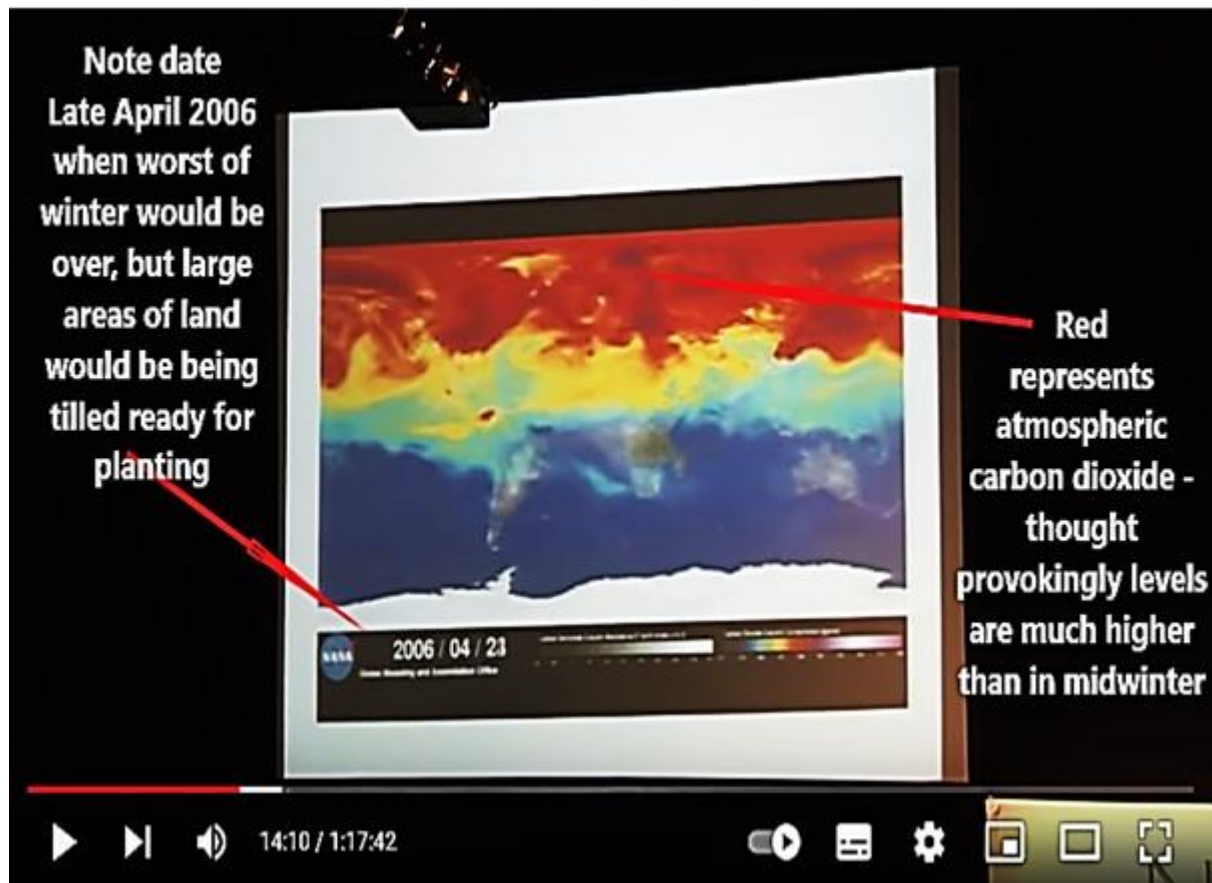


Fig. 106. Annotated and with very many thanks to 'No-till on the Plains' by Ray Archuleta and NASA, taken from a video representation of changing annual atmospheric carbon dioxide levels. (Archuleta, 2016).

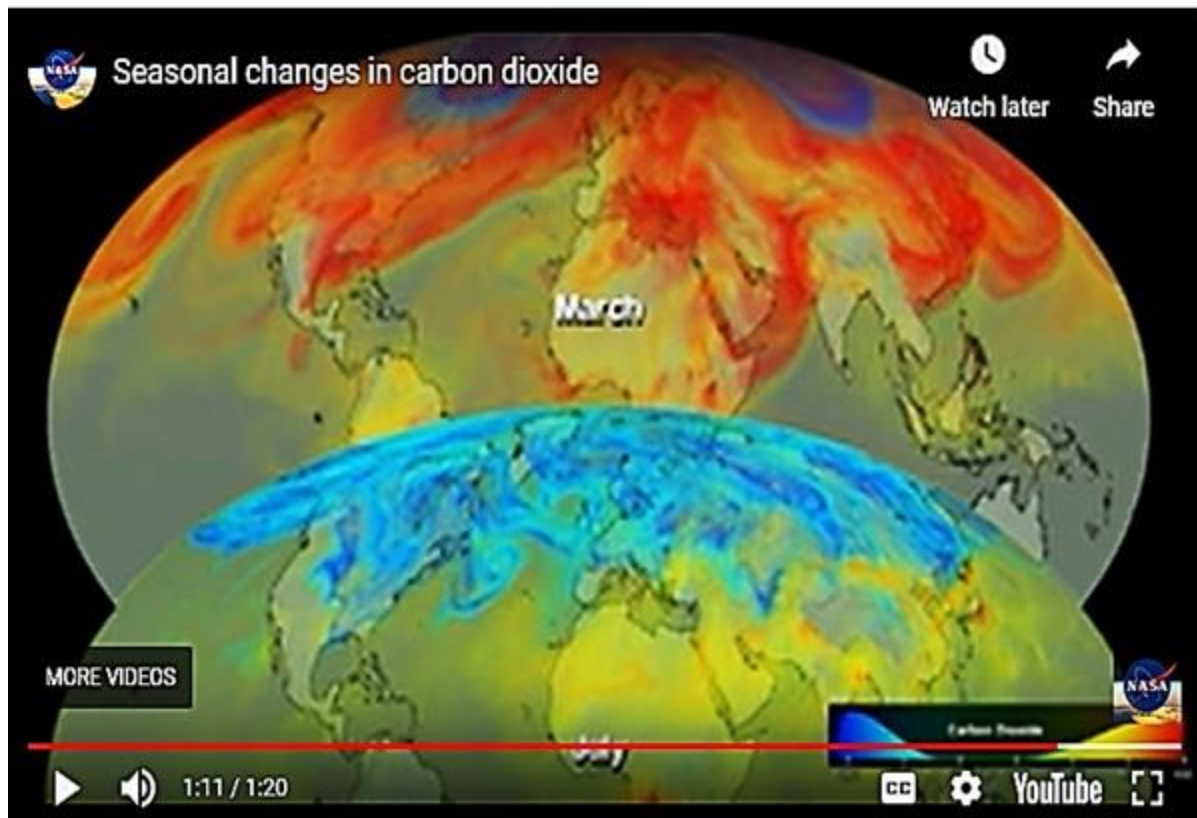


Fig. 107 With many thanks to NASA - *“This visualization provides a high-resolution, three-dimensional view of global atmospheric carbon dioxide concentrations from September 1, 2014 to August 31, 2015. The visualization was created using output from the GEOS modelling system, developed and maintained by scientists at NASA.”* (*‘Video: Seasonal changes in carbon dioxide’*, 2015)

The satellite images above suggest that our agricultural practices have a much more significant potential impact on carbon dioxide levels than generally realised. If emissions due to tillage could be minimised, and annual photosynthetic productive capacity, thus soil carbon sequestration and related soil biology increase, maximised, as discussed, that would logically help mitigate climate change and, at least for a few years, reduce the net rate of atmospheric carbon dioxide increase, ocean acidification and deoxygenation, despite rising fossil fuel usage, buying us precious time. It would also logically reduce the occurrence of climate-related events, including droughts, heat waves, heat domes, flooding, eutrophication, and extreme climate events.

41.2 INCREASED CO₂ = REDUCED PLANT NUTRIENT CONTENT

Worryingly, whilst increased atmospheric carbon dioxide speeds plant growth, it decreases the nutrient density of crops. *“Plants are growing faster, but they have on average more starch, less protein and fewer key vitamins in them”* (*‘Higher carbon dioxide levels increase plant growth, not nutritional value - Farm and Dairy’*) (Reints, 2018).

Most humans meet their protein and mineral requirements primarily through plant-based foods. *“In general, humans tend to get a majority of key nutrients from plants: 63% of dietary*

protein comes from vegetal sources, as well as 81% of iron and 68% of zinc.” ('As CO₂ levels climb, millions at risk of nutritional deficiencies,' 2018).

Thus, it is of considerable concern that “*rising CO₂ levels from human activity could result in 175 million people worldwide becoming zinc deficient and 122 million people becoming protein deficient by 2050.*” (“*Millions in India may face nutritional deficiencies due to CO₂ rise: Study - The Hindu BusinessLine,*” 2018). One example of many, iron deficiency is a significant concern that affects future generations (Reints, 2018).

Self-evidently, but of enormous importance, plants are essential for human and livestock nutrient provision. The reduction in proteins and vitamins in staple crops, such as rice and wheat, due to both NPK use and increased carbon dioxide (Weyant, 2018), exacerbated by nutrient removal and damage during excessive food processing, increases the risk of nutritional deficiency in populations worldwide.

Yes, these are just estimates, and much is unknown. However, the downward trend in nutrient availability in food, due to FATBAS, rising atmospheric carbon dioxide, and overprocessing of foods, and the consequences for human health, including impaired neurological development and function, increased adverse behavioural outcomes, and a raised risk of conditions such as dementias, is crystal clear.

Thus, optimising the nutrient density of plants, and minimising the pollutant content, including through ‘soil carbon centric’ regenerative agriculture and nutrient density-centred breed selection, is crucial to the well-being of many species, including humans. While biology and early results suggest that regenerative agriculture techniques would mitigate the observed depletion of crop nutrient density, unfortunately, the negative effects of nutrient density reduction due to increasing atmospheric carbon dioxide and over-processing of foods may negate some of that benefit. More research is required.

42 ATMOSPHERIC OXYGEN ALSO MATTERS

Atmospheric oxygen depletion, through its conversion to carbon dioxide, via the burning of fossil fuels, and net biome respiration of carbon from soils and tundra to carbon dioxide, is not given the same attention as increased atmospheric carbon dioxide. This is because oxygen forms a relatively large portion of gases in the atmosphere above 20% - totalling around 1.2 million gigatons - thus the anthropogenic removal of a ‘few gigatons’, maybe 40GT on an annual basis, but could be more, is not seen by atmospheric scientists or climatologists as a determinant issue, for climate change, or wider short-term human survival.

However, it is unquestionable that, as part of the planetary self-equilibrating ecosystem, gasses are exchanged between oceans, soils, and the atmosphere. Carbon dioxide and oxygen exchange between the atmosphere and oceans is governed by the physical laws of the universe, including Henry’s Law as to the exchange of gas between liquids and gaseous environments. The amount of oxygen in the atmosphere and oceans is also moderated by the production of oxygen by plants and oceanic oxygen-producing photosynthetic organisms, and conversely, through consumption of oxygen through conversion to carbon dioxide through combustion and respiration.

Clearly, oceanic atmospheric interchange will also be affected by surface mixing conditions, temperature, delivery of oxygen from the deep ocean, eutrophication, and population health of ocean oxygenators. However, no matter the complexities, the atmosphere and oceans are two systems trying to maintain an interdependent, long-standing gas exchange equilibrium governed by the laws of matter at a complex air-water interface.

Despite its complexities, this is a long-standing self-regulatory planetary ecosystem, and the anthropogenic removal of oxygen from the atmosphere represents a destabilisation of that equilibrium, which the system will seek to re-equilibrate back to the status quo. This requires the movement of oxygen from the ocean into the atmosphere. Oceanic oxygen will move upward in the ocean layers to restore the surface oxygen partial pressure. Whilst not currently on the agenda of the climate change community, it is suggested that this will likely prove to be a significant contributing factor to oceanic oxygen depletion.

This effect is logically very important, and the impact is underappreciated because whilst there are about 1,200,000 gigatons of oxygen in the atmosphere, it is estimated there are only about 8,000 gigatons in the oceans, of which, say, 4,000 gigatons are in the upper ocean layers, and 4000 gigatons in the deep ocean.

Thus, a net anthropogenic annual reduction of maybe 40 gigatons of atmospheric oxygen due to a combination of fossil fuel combustion and respiration of soil carbon, if replenished by the release of oceanic oxygen, to maintain partial pressure equilibrium, could represent up to 1% of the oxygen in the upper ocean layers. Even if half that amount or less moved from the ocean to the atmosphere annually, the increase in ocean deoxygenation would still be significant and may account for a portion of the important, yet not fully explained, observed oxygen loss from oceans (Brown R, 2021e).

We understand the broad principles but cannot precisely explain why the gaseous distribution ratios between the Earth's crust, atmosphere, ocean, soil, and living matter are what they are. However, natural systems, throughout aeons of evolution, have determined that it is so. The partition of resources is the consequence of the laws of physics and the presence of evolutionary pathways. Biosystems are obliged to conform to those laws, even if that does not accord with human aspirations.

The author posits, that the logical consequence of Henry's 'Law', and the consequent inherent self-regulating quality of biosphere systems, is that the limited stores of oxygen in the upper ocean layer, will nonetheless seek to recharge depleted atmospheric oxygen, and thereby maintain the stable system status quo.

In liquids in motion, gases tend to move over time to the surface due to pressure changes caused by upward movements of gas-containing water and reduction of gaseous solubility. Further, oxygen in some forms, including as microbubbles, is less dense than water, so it is more buoyant. Thus, logically, the ocean will move oxygen to the surface layers, even though oxygen at depth is falling.

Loss of ocean oxygen will be further exacerbated by damage to oxygen-producing marine organisms, eutrophication, warming of the poles, ocean warming, particularly in the arctic zones, which reduces dissolved oxygen per unit volume of water, and consequent reduction in the Gulf Stream and related global current system oxygen subduction and transport. Oxygen levels will likely be further negatively impacted by pollution, acidification, stratification, rising minimum oxygen boundaries, and other damage to ocean biology.

The key issue is that, although there are comparatively large amounts of oxygen in the atmosphere, there are significantly smaller amounts in the ocean, which tend to concentrate in the upper oceanic layers. Thus, oxygen equilibration, in effect, repletion of the atmosphere by oceanic oxygen, through a system tied to the laws of gas exchange, which attempts to maintain steady partial pressures over time, will greatly increase the risk of the ocean regionally suffering significant anoxic episodes.

The risk of oceans becoming anoxic has massive environmental implications. Concerningly, we are already seeing significant and partly unexplained declines in ocean oxygen levels. Seas in vulnerable areas have already turned anoxic occasionally, for example, off the Namibian Coast.

Anoxic oceans, where the biology becomes sulphidic, can emit hydrogen sulphide, a very toxic gas that is fatal even at low concentrations. Hydrogen sulphide kills ocean life forms, and if emitted as gas in quantity, and moved onshore, it could cause mass fatality to all species in the relevant toxic gas concentration zone. We are not at that stage yet, but it would be a logical consequence of the long-term loss of oceanic oxygen in susceptible regions.

Looking more widely and in the long term, if ocean deoxygenation continues, significant oceanic emissions of hydrogen sulphide into the atmosphere could ultimately damage the ozone layer, resulting in increased surface UVC incidence and harming all forms of surface life, including plants. Indeed, as discussed and referenced earlier, research suggests that ocean anoxia was a factor in many global extinction events, and emissions could be a plausible causative factor in such events. Atmospheric hydrogen sulphide would further lead to extremely damaging acid rain. Thus atmospheric oxygen loss, including through, the combustion of fossil fuels, loss of soil carbon, and degradation of the photosynthetic potential of; land through bare soil farming, and due to ocean damage, may well, through the acceleration of ocean deoxygenation, be a much bigger 'climate' risk issue than as yet appreciated.

Other factors likely to impact oceanic oxygen levels are acidification and eutrophication, including those caused by anthropogenic increases in marine phosphates, runoff from fertiliser applied to agricultural land, and more broadly, soil erosion. These factors would lead to increased growth and activity of marine net oxygen-consuming organisms (Watson, Lenton & Mills, 2017), including bacterial blooms, through the mass increase in respiration, which decreases regional oceanic oxygen. Over time, this combination would lead to anoxic events and mass die-offs.

Thus, when considering the effects and impacts of strategies to mitigate the impact of climate change, it is also arguably necessary to consider their rarely discussed implications for atmospheric oxygen levels, as this will ultimately impact the rate of ocean deoxygenation.

Importantly, ocean warming and related effects alone cannot explain the observed level of oceanic oxygen depletion. Reabsorption of oceanic oxygen into the atmosphere is entirely logical and inevitable, based on the laws of physics, and would help explain unaccounted-for oceanic oxygen depletion. More worryingly, it suggests that the rate of oceanic oxygen loss, current or built into the system, might be more significant than realised. This is possible given that data on oxygen levels in oceans is, in relative terms, very limited, and there is insufficient information to accurately determine how fast marine oxygen is being depleted.

In terms of mitigation, carbon capture may address issues of carbon dioxide emissions, but it will not address the reduction of atmospheric oxygen, which could lead to consequent ocean damage. In the face of continued use of combustion, including the combustion of hydrogen to create energy or electricity, the replacement of atmospheric oxygen used, will require the use of atomic or other green energy to split water into hydrogen and water, with a net release of oxygen into the atmosphere, at the same time producing hydrogen for fuel. Plants also produce net oxygen when carbon is stored long-term in soils.

Yes, the logical possibility of oxygen movement from oceans that are otherwise at risk of oxygen depletion into the atmosphere, with large oxygen reserves, is inconvenient in terms of climate change. However, nature is governed by the laws of the universe, not the wishes or needs of humans.

42.1 URINE AND FAECES AND CLIMATE CHANGE

Industrial livestock raising, transport, feedstock requirements, medication, and dealing with urine and faeces have significant environmental consequences. Livestock animals, particularly cattle, inevitably produce large amounts of faeces and urine, a considerable issue when animals are raised in yards. Human faeces and urine add to the problem.

As evidenced by the review *'Global Farm Animal Production and Global Warming: Impacting and Mitigating Climate Change'* (Koneswaran & Nierenberg, 2008), determining the impact of faeces and urine on climate change is complex; factors include;

- Release during processing or storage of slurry, of 'climate warming' gases such as ammonia, methane, carbon dioxide, etc..
- Release from treatment plants, runoff from un-composted sewage sludge and untreated sewage and manure,
- Application slurry resulting in the release of soluble nitrates and phosphates into rivers and oceans, causing pollution and eutrophication.
- Potential damage to the soil microbiome and aquatic systems by pharmaceuticals and antibiotics, in cattle slurry, and sewage sludge applied to land.

Volumes 1 and 3 consider the options for disposing of urine, faeces, and related sewage sludge, and consequences of wastewater discharge, and direct discharge into the

environment in greater detail, so they are not repeated here. They also propose alternative protocols for the collection, processing and treatment of sewage and slurry.

43 SOIL DEGRADATION LESSONS OF HISTORY

Many soils are depleted of nutrients to such an extent that they are only viable with near saturation with artificial fertilisers; these soils are in danger of becoming 'hydroponic-like' dust media to hold up plants, growing media devoid of carbon and related soil biome systems utterly dependent on 'artificial' inputs of fertiliser and agrochemicals.

In the middle of the last century, books on agriculture and soils were written that were prescient in their predictions and remain relevant. These include books by Rodale, Howard, Albrecht, and King (Albrecht, W. A. 1958; King, F. H. 1911; Howard, "The Soil and Health," n.d.). Their messages about the importance of nutrient-dense food to all civilisations and the need to maintain productive soils remain enduring and fundamental truths.

Historically, agricultural soils have been repeatedly exploited for short-term food yields and profits, including by absentee landlords, whose primary concern was short-term profitability, as seen in the Roman era. The result is that many civilisations, including the Romans, ultimately destroyed large areas of fertile land. Human nature and behaviour seem to remain stubbornly consistent. Yet, they need to change, with a greater emphasis on the greater good and the long term, as well as the last quarter's profits, if we are to prosper as a species.



Fig. 108. Spoil tip covered in rills and gullies due to erosion processes caused by rainfall with very many thanks to Wikipedia and the author Ivar Leidus (Wikipedia, 2019a).

Dr W. C. Lowdermilk was commissioned by the U.S. Soil Conservation Service in the late 1930s to tour Europe and the Middle East, examining the history of soil erosion. He summarised his observations in the very thought-provoking and sobering book *'Conquest of the Land Through Seven Thousand Years'* (Lowdermilk, 1939), which, in text and photos, records the many agricultural empires, which consequent on land degradation, including soil erosion, literally crumbled, disappearing with the dust erosion they had created.

He observes that the Mediterranean basin contains many *"Graveyards of Empires"*—examples of Peoples and Nation States that failed to both look after and, at the same time, overexploited the soil's stored resources to meet commercial demand for the export of food to the cities, often in other lands, such as North Africa supplying Rome. The consequent Mediterranean agricultural 'graveyards' include areas of the Middle East, North Africa, and the forests of Lebanon and Mesopotamia.

'Rape of The Earth – A World Survey of Soil Erosion for the Chilean Nitrate Agricultural Service', also published in 1939, echoes similar concerns as to levels of soil erosion globally in the 1900s and looks at some of the then agricultural practices to reduce it (Jacks & Whyte, 1939).



Figure 109 *"Buried machinery in barn lots, Dallas, South Dakota, USA. May 13, 1936 (USDA image No:oodi097I CD8151-97I)" with thanks to Dirt by D Montgomery, the author, and USDA. (Montgomery, 2007)*

Historically, in the mid-1930s, vast amounts of soil were lost in the USA. *“The National Resources Board reported that by the end of 1934, dust storms had destroyed an area larger than the State of Virginia. Another hundred million acres were severely degraded.”* (Montgomery, 2007) The effect of the combination of poor agricultural practice and importune weather is recorded in poignant and shocking images of ploughed prairies and farmsteads that, after exposure to drought and wind, had become dust bowls.

The Europeans similarly mined the soils for nutrients, including carbon. However, the climate historically has been kinder, and a lack of new available agricultural land long ago forced central Europeans to take somewhat better care of their soils in many regions; thus, the soils have larger nutrient reserves, so the problems are less immediately evident but real.

For example, the paper *‘Sewage sludge composting and fate of pharmaceutical residues – recent studies in Estonia’* observes, *“Inventories of soil productive capacity indicate human-induced soil degradation on nearly 40% of the world’s arable land; this warns us of the ecological collapse of the world’s productive soils”* (Haiba, 2016).

Whilst Europe is less immediately susceptible, it is not immune to the long-term failure to return organic matter and minerals to the land and optimise photosynthetic resource opportunities per unit area of agricultural land to maximise soil carbon sequestration potential. It would arguably benefit economically and environmentally from doing so. As discussed below, parts of Estonia are no longer financially viable for FATBAS farming due to soil quality degradation and the high cost of artificial fertilisers.

The economic cost of fertilisers has diminished the capacity to use artificial fertiliser-dependent, available agricultural land; for example, *“In Estonia the highly industrialised and centralised agricultural production system collapsed in the late 1980s and early 1990s.”* The paper notes that due to the lower affordability of artificial fertilisers, arable land under usage dropped from 1 to 0.6 million hectares, observing, *“Currently crop production in Estonia largely takes place at the expense of soil phosphorous resources”* (Haiba, 2016). The implication is that land is not economically productive if the artificial fertiliser agrochemical FATBAS farming model is considered. However, regenerative agriculture would logically allow this land to be brought back into economic production.

Less economically well-off countries, located in warmer areas with less predictable rainfall, are significantly more susceptible to land degradation. Vast areas, possibly one-third of global formerly arable land, have been lost in the last 40 years (Milman, 2015) in geographical locations with soils at greater risk, such as in Sudan and Ethiopia, where after the productive use of agro-fertiliser and chemicals for several years, with unsustainable bare ground farming practices, the soils eventually became incapable of supporting crops. Ethiopia's annual cost of land and broader degradation is estimated at \$4.3 billion (Gashaw, 2014; Gebreselassie, 2015).

We are becoming more aware of soil erosion. However, it continues, including windborne erosion of friable soils that lack the organic matter traditionally binding them, and water-

based erosion due to the lower permeability and absorbency of damaged soils, resulting in runoff of fine particulates.

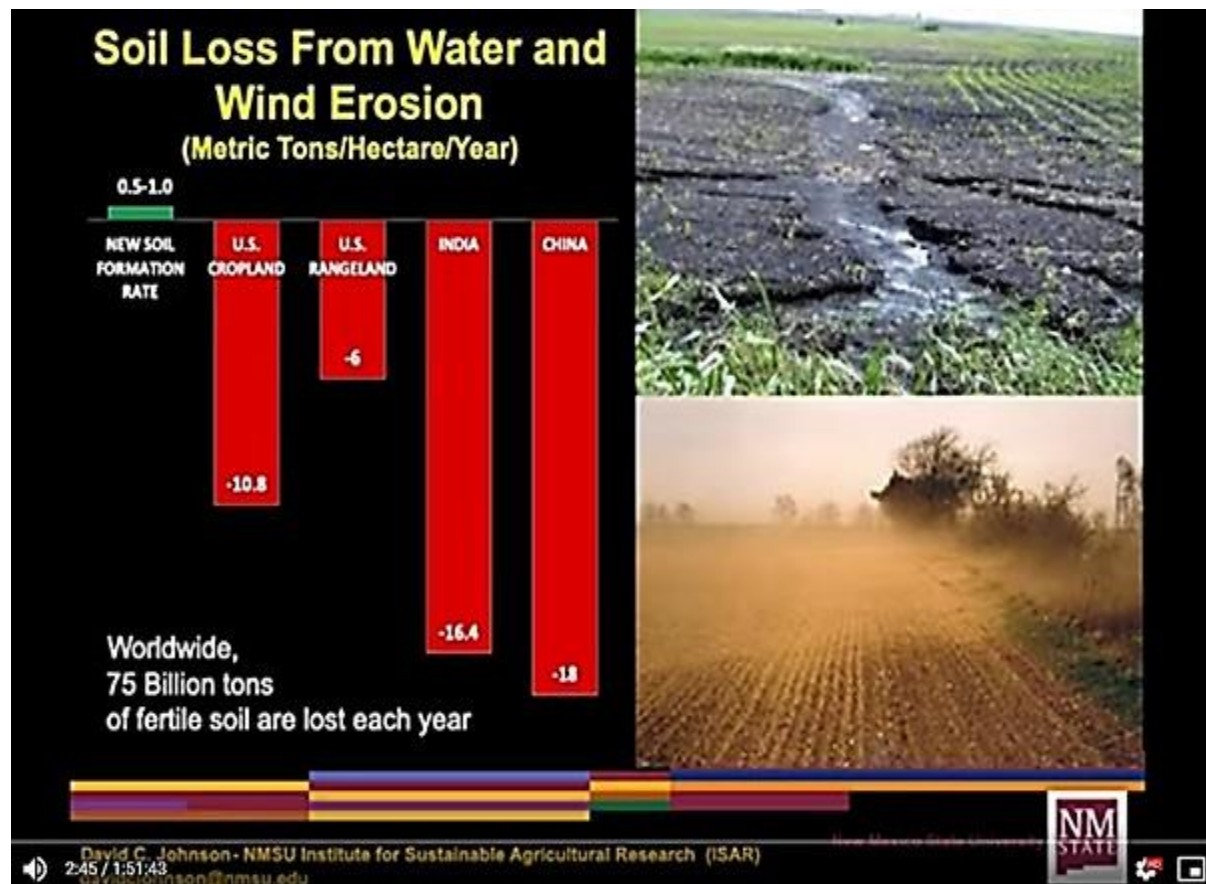


Fig. 110 Soil erosion continues as evidence by the slide from the UTube lecture titled ‘Dr David and Hui Chun Su Composting’ with very many thanks to the authors. (Johnson & Su, 2019)

Broader farming-related damage includes run-off due to heavy grazing or cultivation of unsuitable slopped land, combined with other factors such as larger, more open fields and more intensive agriculture. The need to build carbon and return organic material to the land to enhance water retention, integrate trees and hedges, and mitigate erosion becomes increasingly pressing.

43.1 DEGRADED AGRICULTURAL SOILS

Compared to the quality of unfarmed soils, the current baseline ‘health’ of soils is low. Dr Christine Jones, PhD, Founder of ‘Amazing Carbon’, succinctly and powerfully sets out the impact of soil degradation, including soil carbon loss, on her website. In a paper titled, ‘*Light Farming: Restoring carbon, organic nitrogen and biodiversity to agricultural soils*’ Jones notes, “Over the last 150 years, many of the world’s prime agricultural soils have lost between 30% and 75% of their carbon, adding billions of tonnes of CO₂ to the atmosphere. Losses of soil carbon significantly reduce the productive potential of the land and the profitability of farming.” (Jones, 2018a)

Furthermore, vast areas of land globally are severely degraded, resulting in the significant loss of agricultural land. "Inventories of soil productive capacity indicate human-induced soil degradation on nearly 40% of the world's arable land; this warns us of the ecological collapse of the world's productive soils" (Haiba, 2016) (Authors' underline) **"Soil degradation has intensified in recent decades, with around 30% of the world's cropland abandoned in the last 40 years due to soil decline. With the global population predicted to peak close to 10 billion by 2050, the need for soil restoration has never been more pressing."** (Jones, 2018a) (Authors' bold)

The Food and Agriculture Organisation of the UN report titled 'Nitrogen Inputs to agricultural soils from livestock manure' (FAO, 2018-a) observes, **"degraded soils are often located in areas where people are afflicted by poverty and malnutrition. Restoring and maintaining soil health will, hence, play an important role to help meet the food demands of growing populations in areas of the world where it is most needed."** (FAO, 2018-a) **"Considering that around 33 percent of the world's soil and 40 percent of the soils in Africa are already degraded, a special focus on the restoration of degraded soils and maintenance of soil health is required (FAO, 2011a)."** (FAO, 2018-a) (Author's emphasis)

A BBC story on degraded soils reported, *"The chair of IPBES, Prof Sir Bob Watson, told BBC News that around 3.2 billion people worldwide are suffering from degraded soils. "That's almost half of the world population," he said. "There's no question we are degrading soils all over the world. "We are losing from the soil the organic carbon and this undermines agricultural productivity and contributes to climate change. We absolutely have to restore the degraded soil we've got."* (Harrabin, 2019)

The BBC report continues, *"Prof Jane Rickson from Cranfield University, UK, added: "The thin layer of soil covering the Earth's surface represents the difference between survival and extinction for most terrestrial life". "Only 3% of the planet's surface is suitable for arable production and 75 billion tonnes of fertile soil is lost to land degradation every year"* (Harrabin, 2019).

At least the UN appears to be listening. *"With our current trends in production, urbanisation, and environmental degradation, we are losing and wasting too much land. We are losing our connection with the earth. We are losing far too quickly the water, soil, and biodiversity that support all life. At a time when every asset and every option to deliver benefits to people and the planet should be being harnessed, the availability of good quality land is declining. As the American author Mark Twain jokingly said, 'Buy land, they're not making it anymore'. He was absolutely correct. As an engine of economic growth and a source of livelihood for billions worldwide, we need to step back and transform the way we use and manage the land"* ('Global Land Outlook, First Edition', UN Convention to Combat Desertification, 2017).

Healthy soils are central to the well-being and health of populations. Marginal agricultural lands in low rainfall, low-income countries are particularly at risk. The destruction of forests and scrub, degradation of soils, and the use of bare ground NPK-based farming will lead to changes in hydrology and atmospheric conditions, reducing rainfall and exacerbating the impact of climate change on the entire region, including adjacent forests, adding to our critical environmental climate change-related issues.

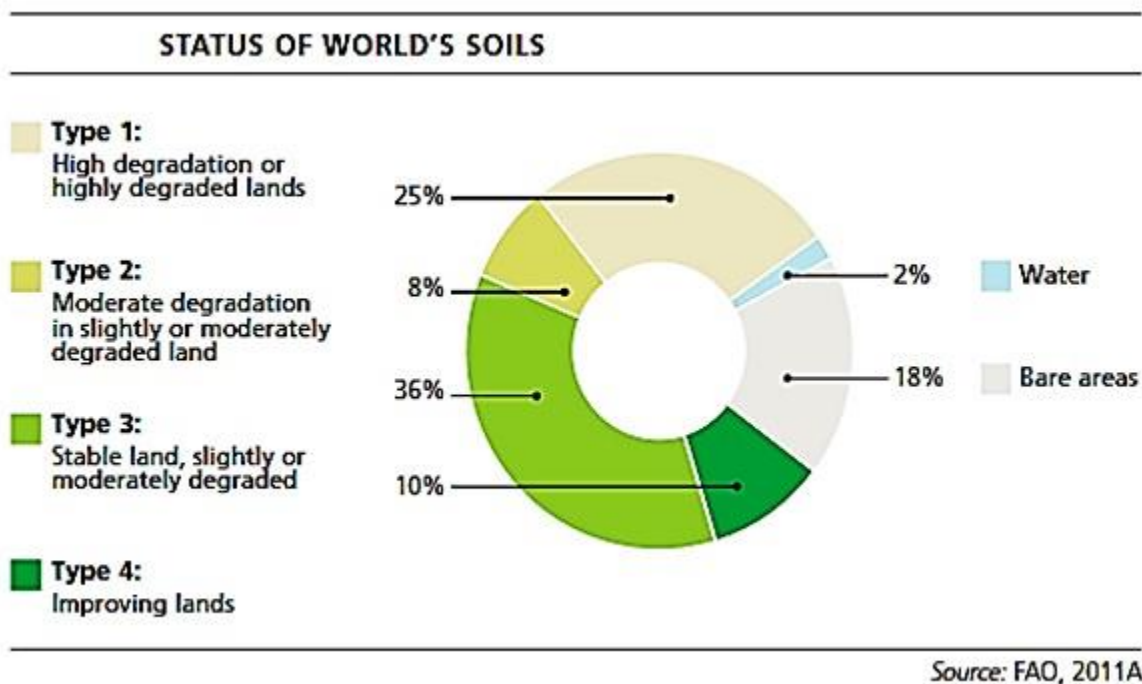


Fig. 111 Status of the world's soils from The Food and Agriculture Organization of the United Nations report, 2018, '*Nitrogen Inputs to agricultural soils from livestock manure*' with very many thanks to the authors. (FAO, 2018-a)

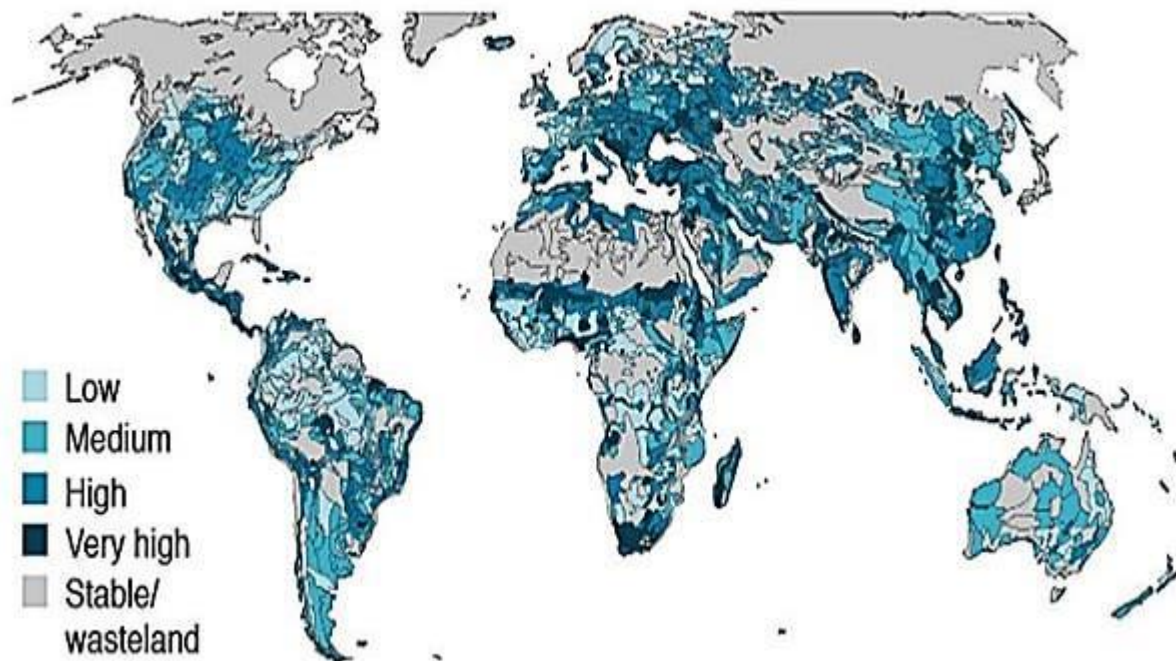
Southern Madagascar, the Sahel, and the Cerrado in Brazil arguably provide examples of the slow, long-term degradation of land and hydrology caused by bare-ground, monocrop, NPK farming.

In selective areas, India and China, in particular, have demonstrated that these trends can be reversed with simple changes in land management to optimise water capture and retention, as seen on the Loess Plateau. Regenerative agricultural practices can further enhance land recovery.

John A Menge, emeritus professor of plant pathology at the University of California, observes: *"Huge amounts of marginal agricultural land exist in Africa and South America and the proper use of this land may well decide the future of some countries. Increased use of agricultural land will provide for a greater economic base, larger agricultural productivity, and a better way of life for large populations in underdeveloped countries. Educating agriculturists to the importance of mycorrhizal fungi may allow developing countries to avoid the excessive use of energy, fumigants, and fertilisers associated with intensive agriculture"* (Menge, 1985).

There are numerous examples where severely degraded land has been restored to fertility and its hydrology improved using simple technologies, including landscaping for enhanced water capture and/or regenerative agriculture. As a result, those affected can earn a living by producing and selling nutritious food.

Areas worst affected by soil erosion



Source: ISRIC/GLASOD project



Fig. 113 From the BBC report 'Climate change being fuelled by soil damage, with many thanks to the Author and BBC – report' (Harrabin, 2019)



Fig. 112 "Dust storm approaching Stratford, Texas, April 18, 1935 (NOAA, George E. Marsh Album" with very many thanks to Dirt by D Montgomery, the author and USDA. (Montgomery, 2007)

Humans have a long history of degrading fertile agricultural land. This occurs at its worst in semi-arid regions subject to uncontrolled grazing, but is equally applicable if less visible in more northern agrarian nations.

Soil degradation remains a persistent issue globally, including in economically prosperous regions. An EU Commission report titled *'Life on Earth depends on healthy soils'* reports:

- *"There are 2.8 million potentially contaminated sites posing major health risks,*
- *Between 65-75% of agricultural soils with high nutrient levels at risk of eutrophication and potentially affecting biodiversity,*
- *Cropland soils losing Carbon at a rate of 0.5% per year while 50% of peatlands are drained and losing Carbon, both processes negatively contributing to the climate crisis*
- *24% of land presenting unsustainable water erosion rates,*
- *25% of land is at high and very high desertification risk, in Southern, Central and Eastern Europe in 2017,*
- *The costs associated with soil degradation in the EU exceed 50 billion Euros per year,*
- *Climate change is further exacerbating the pressure on soils and accelerate soil degradation"* (EIP-AGRI, 2022).

43.2 LAND DEGRADATION IN ADVANCED ECONOMIC COUNTRIES

Erosion is not limited to emerging economies. For example, in the UK, the BBC has reported 'Fen blow', a name given to wind erosion of soils in the English fenlands (often reclaimed marshes, so recognised historically as quality soils). A local person commented, *"You could barely see anything, and it really was like driving through Marmite"* (*'Fen Blow phenomenon: High winds and loose soil halt traffic—BBC News,' 2013*).



Fig. 114a. *"Fen Blow phenomenon: High winds and loose soil halt traffic - BBC News," 2013, With many thanks to the BBC. ('Fen Blow phenomenon: High winds and loose soil halt traffic - BBC News,' 2013)*

Governments, including those in Europe (Commission proposes a strategy to protect Europe's soils. 2006) and more widely global organisations, such as the United Nations, recognise the grave dangers of land degradation, loss of organic matter, the consequent loss and degradation of productive agricultural land, including due to wind and water-based erosion. (Harrabin, R. 2019) The EU document *'Down to Earth: Soil degradation and sustainable development in Europe, A challenge for the 21st century.'* (European Environment Agency, 2013), states;

"In many parts of the world, as well as in Europe, we are now testing the limits of the resilience and multi-functional capacities of soil. Globally, nearly 2 billion hectares of land are affected by human-induced degradation of soils (UN, 2000). The food needs of increasing populations is leading to even greater intensification of agriculture, stretching thereby the capacity of soils to release and absorb nutrients and chemicals." (European Environment Agency, 2013)



Fig. 115b. Soil erosion in a wheat field near Pullman USA with thanks to Wikipedia and the author Jack Dykinga. (Wikipedia, 2019b)

"Each year an additional 20 million hectares of agricultural land become too degraded for crop production, or are lost to urban sprawl. Soils are being degraded physically and chemically due to erosion, exhaustion (nutrient depletion) and pollution. Soil's diverse living organisms are being reduced, and consequently the cleaning and filtering capacities of soils in many localities are being damaged beyond repair. At the same time, abuse of soil organic

"Down to earth, down to basics" – solving soil problems will help solve other problems at the European and global levels. At the European level protecting soil will help to preserve Europe's resources, its identity and its ability to cope with change. At the global level, combating soil

degradation will help offset greenhouse gas emissions, will provide a better environment, will guarantee more food to an increasing population and will contribute to the economic progress of future generations.” (European Environment Agency, 2013)

The 2018 UN document titled *‘Summary for policymakers of the thematic assessment report on land degradation and restoration’* (IPBES, 2018) includes in bold the following comments:

-

- *“Combating land degradation and restoring degraded land is an urgent priority to protect the biodiversity and ecosystem services vital to all life on Earth and to ensure human well-being”.*
- *“Currently, degradation of the Earth’s land surface through human activities is negatively impacting the well-being of at least 3.2 billion people, pushing the planet towards a sixth mass species extinction, and costing more than 10 per cent of the annual global gross product in loss of biodiversity and ecosystem services.”*
- *“Investing in avoiding land degradation and the restoration of degraded land makes sound economic sense; the benefits generally by far exceed the cost.”*
- *“Timely action to avoid, reduce and reverse land degradation can increase food and water security, can contribute substantially to the adaptation and mitigation of climate change and could contribute to the avoidance of conflict and migration.”* (IPBES, 2018)



Fig. 116. Lubbock, Texas, USA “Blowing dust across the South Plains Wednesday afternoon as seen from a plane flying overhead. Photo courtesy of Chris Manno”, with thanks to National Weather Service NOAA.

Further, whilst laudable, land use policy documents often do not significantly incorporate the 'taboo' subject, an 'elephant in the room', how to close the agriculture, soil health, livestock and human, urine and faeces circle.

We need a new regenerative vision for agriculture, which includes recognising the value of natural resources and issues of sewage resource recycling. *"The problem calls for new policies, including fair pricing, fiscal policies, and strategic planning concerning the use of land and natural resources."* - Domingo Jiménez Beltrán, Executive Director, European Environment Agency (European Environment Agency, 2013).

44 DIVERSITY AND COOPERATION ARE KEY

The vast diversity of life forms in the soil biome is crucial to regulating Earth's biosphere ecosystems. The mycorrhizal, bacterial, and soil biome families play various roles. They mine, transport, process, and supply essential nutrients, including minerals, nitrates, and plant 'medicines', to their symbiotic essential partners, plants, in exchange for photosynthetic plant carbon sugars supplied via root exudates.

Yes, land-based plants can flourish without soil, but only where the necessary minerals and other nutrients, usually provided by soil mycorrhizal systems, are delivered directly by human-provided systems to their roots at saturation levels, in readily available soluble liquid form, as in hydroponics, and where the plants are protected from pests by humans. In other circumstances, to be healthy and flourish, plants need the assistance of mycorrhizal systems.

Soil biomes are immensely complex interactive systems. Not only are mycorrhizal systems diverse, but they are also, overall, cooperative and interconnected, yet competitive. The phrase '*world-wood web*' has been coined to try to create an understandable image of how extensive and interconnected mycorrhizal systems are. The plant 'nodes,' the root systems of trees and plants, and the mycorrhizal fungal and bacterial systems, which themselves are both nodes and form the cabling system, are responsive and interacting living elements of a vastly complex communication web, a nutrient and water creation and transport system, a symbiotic survival support network, with a species competitive twist.

Particular species have evolved their preferred bacterial and mycorrhizal systems and vice versa. Plants also interact with and exchange information and nutrients via the soil biome network. Thus, plant diversity and health are also reciprocally linked to mycorrhizal diversity and health through the exchange of nutrients, information, interlinked soil carbon sequestration potential, the common need to form healthy, profuse mycorrhizal systems, and nitrogen fixation.

Plant species diversity increases soil biome bacterial nitrogen production. Dr Christine Jones outlines in the video lecture '*Soil carbon: from microbes to mitigation*' (Jones, 2018c) and in '*Nitrogen: The Double-edged sword*,' (Jones, n.d.-b; Jones, 2018b) the multiyear long-running '*Jena experiment*', concluded and graphed, that the increase in soil-bacteria-produced nitrogen, was proportional to the number of cover crop species used.

germination, the internal and external seed biome interacts with the diversity of bacteria and fungi already present in soils and plant ecosystems to optimise root formation and nutrient exchange, including nitrates and phosphates.

Using bio-fertilisers, mature composts, and compost tea extracts, particularly in poor soil, assists plant germination, root formation, and provides the biological diversity and the resources a seed would expect to find in a mature, carbon-rich, diverse soil, assisting the development of plant/soil biome relationships necessary for optimal growth and health.

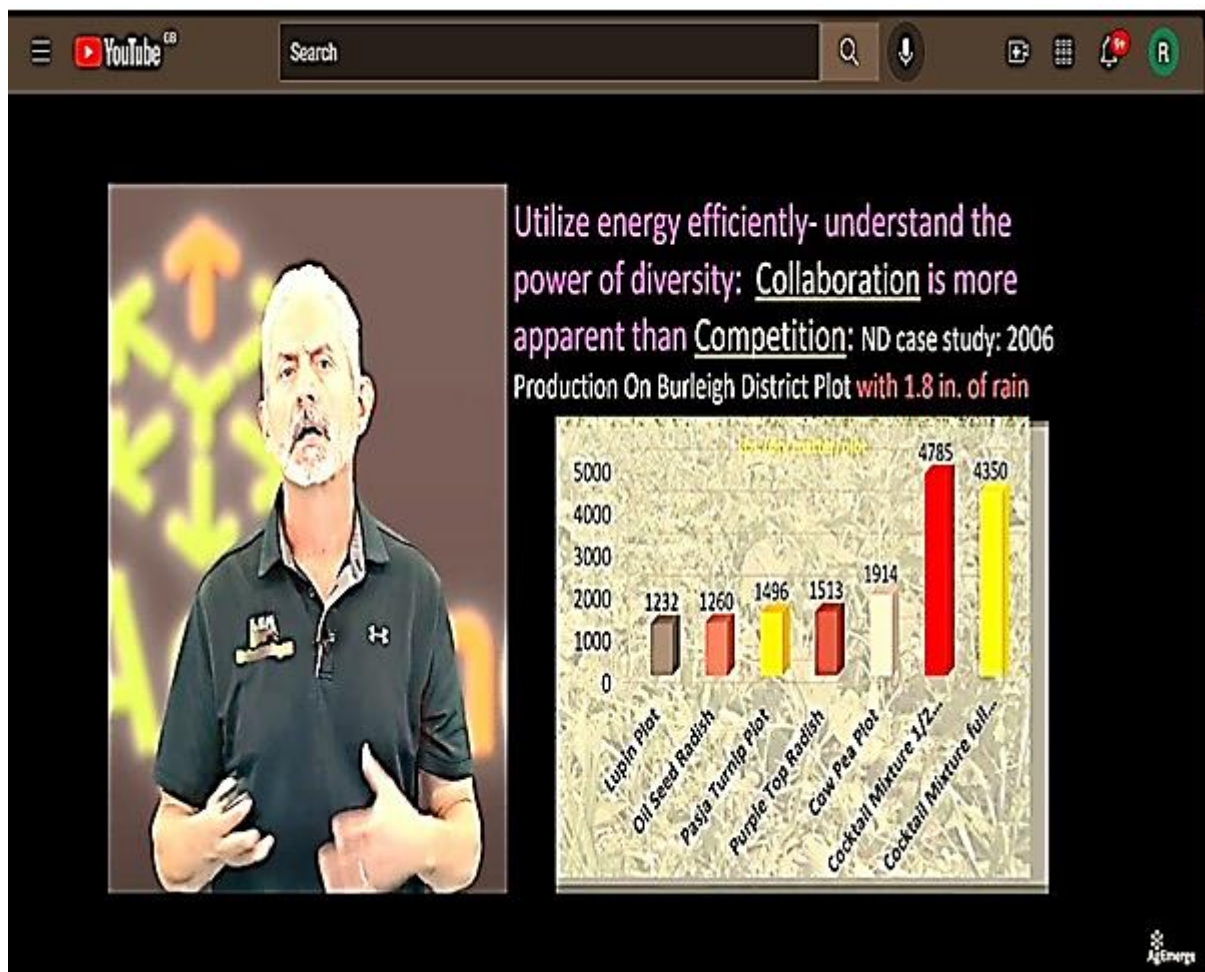


Fig. 118. Relative productivity with increasing species diversity. A slide from the UTube lecture '*Regenerative Agriculture Healing the World*' - By Ray Archuleta @ Carbon Summit, with very many thanks to the author. (Archuleta, 2021b)

Conversely, agrochemicals degrade ecological diversity. Ultimately, it is about keeping the world green, maximising the capacity of photosynthesis to help optimally and sustainably partition carbon between the Earth's crust, soil, atmosphere, ocean, and life forms, through diversity, and the competitive, evolved, highly complex and sophisticated, self-regulating Gaian systems.

Diverse soil microbiomes have evolved a complex subsoil web that has learned to interact with a vast diversity of plants in systems that work better together than apart. We ignore those evolutionary imperatives that regulate the planetary biome at our peril.

44.1 IMPORTANCE OF THE SOIL BIOME

The reasons for the importance of soil biome systems are simple and very obvious once grasped, but they are also crucial and fundamental. Like all living things, soil biome systems require an energy source to survive and thrive. They live in the dark, and even if they had access to light like humans, they cannot directly use sunlight to make molecular energy sources; thus, they are reliant on plants using sunlight energy to enzymatically transform carbon dioxide into biological energy substrates, sugars (carbohydrates) and fats (including the essential polyunsaturated omega 3 and 6 fatty acids linolenic and linoleic acid).

Whilst the primary currency of the bacterial, fungal / plant carbon-trade 'market' is in plant sugars, recent research points to an essential volume of trade in fatty acids. Indeed, fungi require lipids for their function but may have limited capacity to make all they need, which is suggestive that fungi are getting at least some of the lipids they need from plants or plant material (Wang, 2017). This concept is supported by the presence of significant amounts of essential fatty acids in soil fungi (Kühn, 2019).

Thus, sunlit plants supply plant sugars and essential fatty acids to the dark-dwelling denizens of the soil biomes in exchange for minerals mined from the soil, bacterial-produced nitrates, and other nutrients, including during dry spells, life-giving soil biome respiratory 'metabolic' water, which the mycorrhizal web transports to plant roots.

Thus, plants extract carbon dioxide from the atmosphere and turn it into organic carbon products, including plant sugars. Some are used to meet plants' structural and energy needs, and some are supplied to the soil biome. Plant sugars and degraded plant organic matter feed the soil biome, providing the material to build structural soil biomass, thus, over time, storing atmospheric carbon in the soil.

Aeons ago, photosynthesis of carbon dioxide 'on steroids' due to higher atmospheric carbon dioxide and greater land mass at the equator, so incident sunlight produced the coal and gas reserves we extract and use to build out and fuel our modern technological society, demonstrating the immense potential of the natural photosynthetic systems.

Bacteria, fungi, and various soil life forms have developed immensely sophisticated interlinked systems over millions of years to optimise their chances of survival, including reciprocally maximising the health and presence of photosynthetic plants that provide them with food.

The soil biome has systems to both make metabolic water and optimise water capture use and storage to ensure, as best they can, their food providers, plants, can keep growing at times of water shortage, thus continuously year-round, so far as possible, providing the plant sugars the soil biome needs, even in seasons of low rain.

It is a case of systemic optimisation of the chances of mutual survival by pragmatic cooperation based on mutually beneficial exchange of goods and services. In turn, humans and higher life forms depend on plants for sunlight-derived carbon-based energy, lipids, amino acids, carbohydrates, and wider nutrients for their existence.

Crucially, the bacteria in the soil biome also make nitrates, which cannot be made by plants but are essential to their growth. As well as mining and transport, mycorrhizal biome systems have even developed mechanisms, including epigenetic manipulation, to adapt the physiological responses of their plant partners, as well as supplying plants with ‘medicines’ and biologic chemicals to optimise plant health and survival, and to optimise mutual capacity thus to survive in times of limited water supply, and broader environmental stress. (Surprisingly, soil microbial systems supplied the basis of many of our antibiotics.)

More simply, these soil biomes, phosphate miners, nitrate factories, and self-extending, organised nutrient transport systems, capable of bi-directional communication and supply regulation, could be characterised as guardian angels to plants, providing them with the nutrients and medicines they need to survive and thrive. In return, these micro-organisms are paid handsomely by growing and photosynthesising plants, which supply carbon sugars, fats and other molecules to feed the subterranean biome population, keeping it bustling and diverse.

By understanding the crucial importance of soil biome activity to environmental function and health, we can pick our way back through the turmoil caused by our technological hubris-based belief that we can destructively dominate nature. We can rediscover the juncture at which we wandered off the well-worn, deep-set obligatory path to sustainability by reappreciating the evolutionary need to work with, not against, nature.¹

44.2 ‘GREETN’ IS GOOD – BARE SOIL WASTES SUNLIGHT AND CAN NOT CAPTURE CARBON

Green is good and not incompatible with ‘greed’. Initial indications suggest regenerative farming outcomes can be both more profitable and ecologically beneficial than 20th-century FATBAS bare-land farming. In the words of Christine Jones – “*Green is good - and yearlong green is even better*”.

Regenerative agriculture, by keeping land green as much as possible, thus optimising photosynthesis, helps maintain and heal rather than degrade Earth’s planetary ecosystems. The planet’s carbon regulatory systems, including soil moisture, atmospheric carbon dioxide-oxygen balances, temperature, and weather, function within the relatively stable parameters that permit life as we know it. As discussed, but worthy of restatement, when land is green, plants use sunlight energy for photosynthesis; energy is absorbed; carbon is sequestered; evapotranspired water vapour cools, and metabolic life-supporting water is produced.

In contrast, bare soil is ‘bad’. By transforming natural, year-round functioning ecosystems into vast agricultural lands, farmed using bare-soil fertiliser paradigms, we render huge soil areas bare for much of the year. As discussed, sunlight energy falling on bare ground heats soil

¹ A few species have alternative strategies to obtain mineral nutrients, including formation of specialist rooting systems, parasitism, and carnivory. Some including brassicas only form mycorrhizal associations when multiple species are present (Mkhathini, 2012).

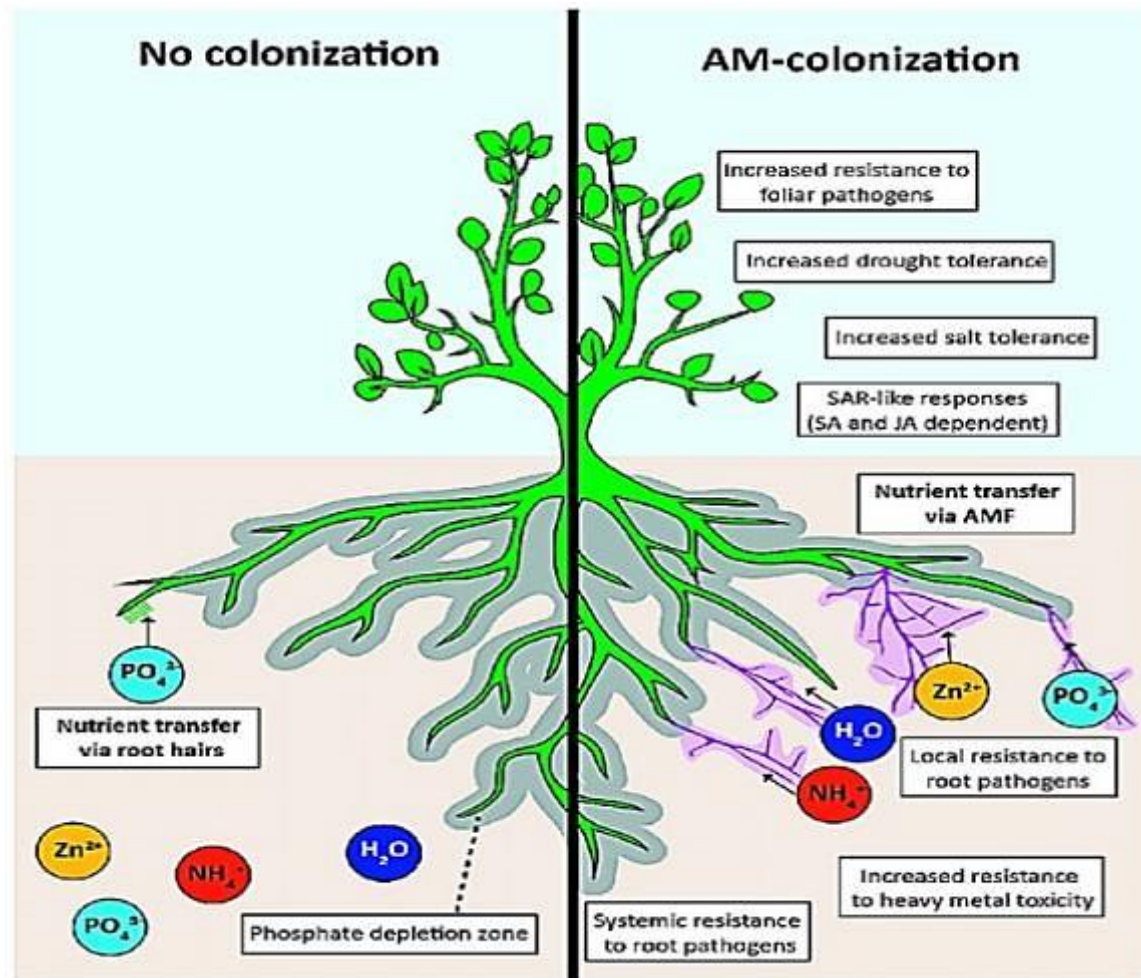


Fig. 119. The review observes, “The fungal mycelium colonizes roots of many plants even if they belong to different species, resulting into a common mycorrhizal network (CMN). This CMN is considered as a primary component of the terrestrial ecosystem with its significant effects on different plant communities, particularly on invasive plants (Pringle et al., 2009) and the fungal-mediated transport of phosphorus (P) and nitrogen (N) to plants (Smith and Read, 2008). Moreover, communal nutrients also relocate from fungi to the plant, along with other related effects, which is probably why AMF improve plant tolerance to biotic and abiotic factors. (Begum et al., 2019)

minerals, including silicates. The heat is retained and transferred by conduction, convection and infrared emission, to the atmosphere in contact with the land, causing regional heating and drying, and heats the ‘cloud-sphere’. Soils are desiccated, eroded, and desertified. The loss of plant evapotranspiration causes global drying. Heating of soils and the loss of latent heat cooling by water vapour contribute to atmospheric high-pressure events, including heat domes, which, as discussed, increase the risk of extreme climate events, such as fires and flooding.

44.3 ROLE OF SOIL FUNGI

The often-underrated importance of mycorrhizal fungal systems in alleviating plant stress (Diagne, 2020), including their role in promoting healthy, productive plant growth, is more technically outlined below by drawing on the publications of experts in the field.

Given the difficulty in effectively paraphrasing dense, technically knowledgeable, well-crafted material, and given the information value of it, a longer quote is included from the publication '*Role of Arbuscular Mycorrhizal Fungi (AMF) in Plant Growth Regulation: Implications in Abiotic Stress Tolerance*'. Readers are invited to read the publication, and particular thanks is extended to its author for it.

The review observes, "*The fungal mycelium colonizes roots of many plants even if they belong to different species, resulting into a common mycorrhizal network (CMN). This CMN is considered as a primary component of the terrestrial ecosystem with its significant effects on different plant communities, particularly on invasive plants (Pringle et al., 2009) and the fungal-mediated transport of phosphorus (P) and nitrogen (N) to plants (Smith and Read, 2008). Moreover, communal nutrients also relocate from fungi to the plant, along with other related effects, which is probably why AMF improve plant tolerance to biotic and abiotic factors.* (Begum et al., 2019)

They have the ability to improve characteristics of soil and consequently encourage plant development in normal as well as in stressful circumstances. AMF colonization improves tolerance of plants to stressful cues by bringing about several changes in their morpho-physiological traits. AMF are considered as natural growth regulators of a majority of terrestrial flora. AMF are used as bio-inoculants, and researchers encourage their use as prominent bio-fertilizers in sustainable crop productivity. Furthermore, AMF-inoculated soil forms more constant masses and significantly higher extra-radical hyphal mycelium than do the non-AMF-treated soils." (Begum, 2019)

The review, '*Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance*', further observes, "*Abiotic stresses hamper plant growth and productivity. Climate change and agricultural malpractices like excessive use of fertilizers and pesticides have aggravated the effects of abiotic stresses on crop productivity and degraded the ecosystem. There is an urgent need for environment-friendly management techniques such as the use of arbuscular mycorrhizal fungi (AMF) for enhancing crop productivity. AMF are commonly known as bio-fertilizers.* (Begum, 2019)

Moreover, it is widely believed that the inoculation of AMF provides tolerance to host plants against various stressful situations like heat, salinity, drought, metals, and extreme temperatures. AMF may both assist host plants in the up-regulation of tolerance mechanisms and prevent the down-regulation of key metabolic pathways. AMF, being natural root symbionts, provide essential plant inorganic nutrients to host plants, thereby improving growth and yield under unstressed and stressed regimes. The role of AMF as a bio-fertilizer can potentially strengthen plants' adaptability to changing environment. Thus, further research focusing on the AMF-mediated promotion of crop quality and productivity is needed. The present review provides a comprehensive up-to-date knowledge on AMF and their influence on host plants at various growth stages, their advantages and applications, and

consequently the importance of the relationships of different plant nutrients with AMF.” (Begum, 2019)

Ultimately, mycorrhizal interactions played a crucial role in the evolution of plants. “The mycorrhizal symbiosis is arguably the most important symbiosis on earth. Fossil records indicate that arbuscular mycorrhizal interactions [those that penetrate root cells] evolved 400 to 450 million years ago and that they played a critical role in the colonisation of land by plants. Approximately 80 per cent of all known land plant species form mycorrhizal interactions with ubiquitous soil fungi” (‘The Role of the Mycorrhizal Symbiosis in Nutrient Uptake of Plants and the Regulatory Mechanisms Underlying These Transport Processes’, Bucking, , 2012).

“The diagram demonstrates the mutualistic relationship between plants and their mycorrhiza, which is a fungus that helps plants take in key nutrients. The left side of this diagram shows the plant pathway of this relationship, where the host plant transfers between 4% to 20% of its photosynthetically fixed carbon, which is labelled “G” in this image because it represents glucose, to the mycorrhiza. On the right side of this diagram, the arbuscular mycorrhiza pathway, which branches off from the plant root, which is the brown cylinder-like figure in the image, provides the plant with nutrients, including, most importantly, phosphate and nitrate” (Wikipedia 2023a)

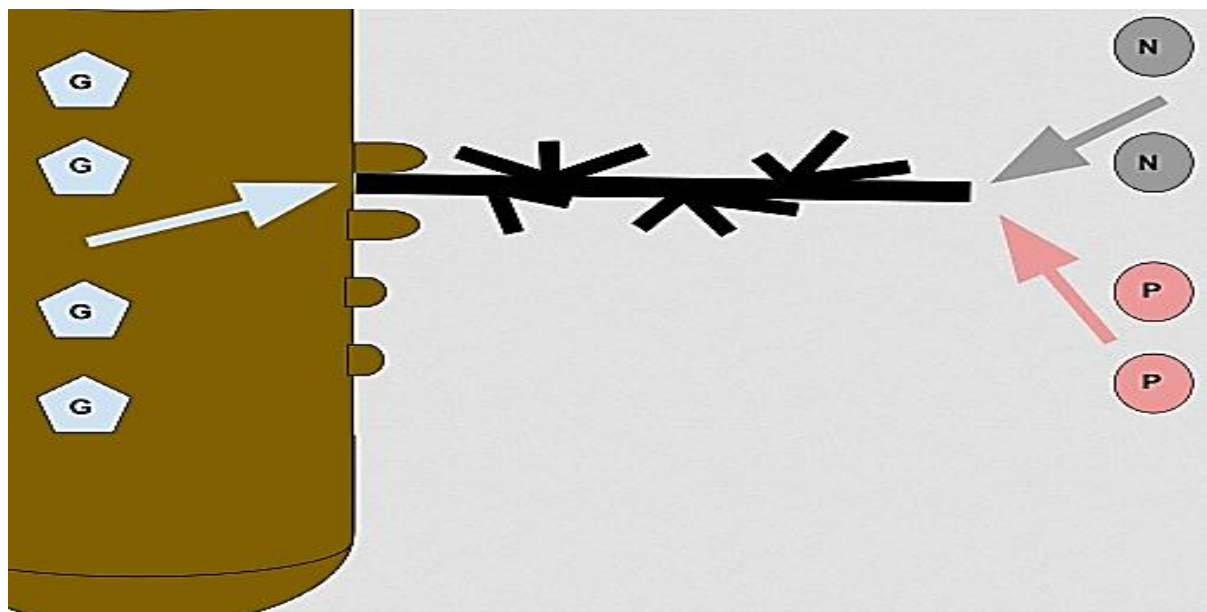


Fig. 120. “Mutualistic Relationship Between Plants and Mycorrhiza.svg” With many thanks to Wikimedia and author Ussyrne18. (Wikipedia 2023a)

Plant roots are relatively inefficient at abstracting minerals, trace elements and other things from soils. In contrast, mycorrhizal systems are efficient at abstracting minerals (Menge, 1985) by dissolution with organic acids and have access to both much more expansive soil volumes – (they can stretch for miles in forests) and interstitial spaces inaccessible to root hairs, so overall are vastly more capable of mineral abstraction than plant roots.

There is also constant bacterial exchange between plant tissues and the soil biome. Bacteria can modify epigenetic responses, including in plants, in response to drought. Bacterial and fungal spores, present on and within the seed, prepare it for the expected growing conditions and help provide the necessary biology for germination. The use of biocides inhibits the function of these essential evolutionary survival pathways.

45 FATBAS – FERTILISERS AGROCHEMICALS – FALLING PROFITS

As discussed above the profits of FATBAS farmers are falling. Some of the reasons are discussed below.

45.1 WASTAGE OF PHOSPHATE IN ORGANIC MATTER

Because we have lost sight of the value of carbon and wider minerals in soils and failed to focus on the negative impact of NPK and excess agrochemicals on soils, we no longer appreciate the need to return concentrated organic matter, including human and animal faeces, to the land. We have not adequately appreciated the negative environmental consequences of fertiliser and pollutant release on rivers and oceans, including damage through eutrophication.

Yes, as discussed in Volume 1, the return of human and industrial feed animal faeces and urine to the land is fraught with problems. The mixing of human urine and faeces with the broader waste stream; the high level of usage of pharmaceuticals and antibiotics in both animal and human urine and faeces; mineral imbalances in animal faeces, including heavy metals from feed additives and manured pastures (Menzi, 1985), and concentration of wider pollutants including agrochemicals generally, PFAS and microplastics makes safe recycling of human and animal waste extremely challenging. However, as discussed in volume one, there are opportunities to improve with change and research.

Before the emergence of artificial fertilisers and agrochemicals, it was the experience of populations reliant on continuous use of limited agricultural land over thousands of years, such as in China and Japan, that they were obliged, as individuals, families, and populations, to return all organic matter appropriately composted, including; faeces and urine, as well as canal mud; even their dead were buried in a family burial space next to their agricultural land; to the land; and to use nitrogen-fixing plants, as well as mixed species cropping, to ensure as far as feasible, productive land and healthy crops; thus adequate food, freedom from famine, and survival.

At that time, the Chinese were recycling all waste, including exporting human faeces from the cities, which was sufficiently valued to be paid for in gold. This was then composted for use on the land. Composting helps stabilise nitrogen and creates biology in the compost that assists seed germination, mycorrhizal sheath formation, and subsequent plant growth, soil health and microbial diversity.

In the previous century, prior to understanding the principles of regenerative agriculture, mono-cropping, ploughing, and bare land obliged the return of organic matter and biology in the form of compost to the land because it was essential to maintain the yields needed to feed families.

In the excitement of the emergence of the agricultural and agrochemical industries, historical wisdom from agricultural sages such as King, Howard, and Albrecht largely fell on stony ground. Little changed: over a hundred years later, the UN 2017 *'Global Land Outlook'* notes, *"Our inefficient food system is threatening human health and environmental sustainability: along with other degrading and polluting land uses focused on short-term returns, the current patterns of food production. . . largely fail to tackle these global challenges."* (GLOBAL LAND OUTLOOK First Edition, 2017).

45.2 PHOSPHATE FERTILISER FUTURE – A 'LIMITED' RESOURCE

Through regenerative agriculture, by optimising the soil biome, thus soil health and carbon content, we can maximise plants' capacity to access non-soluble soil phosphorus and hence minimise the demand for scarce rock phosphate, prolonging the availability of reserves should they be needed over the longer term.

In addition to the negative impact of the use of phosphate fertilisers on the soil biome, it is widely accepted that the current approach to phosphate provision is unsustainable. The comment piece *'How the great phosphorus shortage could leave us all hungry'* (Faradji, 2016) observes, *"These days, the cycle is broken. Each year 220m tonnes of phosphate rocks are mined, but only a negligible amount makes it back into the soil. Crops are transported to cities and the waste is not returned to the fields but to the sewage system, which mainly ends up in the sea. A cycle has become a linear process."* (Faradji, 2016) *"We could reinvent a modern phosphorus cycle simply by dramatically reducing our consumption. After all, less than a third of the phosphorus in fertilisers is actually taken up by plants; the rest accumulates in the soil or is washed away."* (Faradji, 2016) As ever, estimates vary.

Some phosphate from fertiliser accumulates in soil, but large amounts are washed into waterways and, ultimately, oceans, where it causes eutrophication and ecological imbalances, as evidenced by the massive amounts of Sargasso seaweeds washing up on Mexican beaches. *"Ordinary superphosphate is 80 per cent water-soluble and most of this can be washed deep into the soil or across it before annual plants have successfully established roots. Phosphorus is either dissolved and leached down into sandy soils or it runs across the surface when the soil profile fills up with water. On clay soils, the water flows across the surface to nearby drains and waterways with phosphorus dissolved or attached to clay particles"* ('Environmental impact of nitrogen and phosphorus fertilisers in high rainfall areas', n.d.). Much will end up in rivers, with a proportion reaching the oceans.

Interestingly, some of each soluble phosphate fertiliser application binds to soils and accumulates over time, a little more each year; thus, many soils now have high levels of stored non-soluble phosphates, solubilisable by mycorrhiza but not efficiently by plants. The Greenpeace review titled *'Phosphorus in agriculture Problems and solutions'* (Tirado, 2012) observes, *"Global studies of phosphorus imbalances found that phosphorus deficits covered 29% of the global cropland area and 71% had overall phosphorus surpluses. On average, developing countries had phosphorus deficits during the mid-20th century, but current phosphorus fertiliser use may be contributing to soil phosphorus accumulation in some rapidly developing areas, like China, together with relatively low phosphorus use efficiency. Even the*

notion of African soils being phosphorus depleted is contested by new analysis; there are vast areas where phosphorus excesses are more common although inefficiently used for food production.” (Tirado, 2012) Regenerative agriculture supports healthy mycorrhizal biomes that will extract and supply bound phosphates to plants in return for photosynthetic carbon sugars.

Importantly, and not to be forgotten, many of the world's farmers lack sufficient purchasing power to afford and utilise increasingly expensive phosphorus-based fertilisers; thus, it may no longer be economically feasible to continue growing crops, as seen in some areas of Estonia. The problem will be more acute in countries with less developed economies. Those excluded from fertiliser use due to non-affordability urgently need educational resources and de-risking to help them make the transition to regenerative agriculture, enabling them to maximise access to non-plant-available phosphates.

Fertiliser costs are likely to rise with increasing demand, ultimately due to limited supply, including geopolitical uncertainties in energy markets, with costs being magnified by rising fossil fuel prices. Further, using fossil fuels to produce artificial fertilisers is not sustainable.

Regenerative farming practices, combined with the return of locally appropriately sourced and collected faeces and urine, for example using vacuum WCs, used for biogas production then hyperthermophilically composted to be sufficiently free of pollutants, to the land, would provide a solution that was more economically affordable, and looking to the very long term environmentally sustainable, to maintain soil nutrients, including phosphate, nitrates, and organic carbon matter content. The difficulties and issues, including human concerns about the idea, current status, new technologies, and how the recycling of animal and human waste might be improved, are discussed in Volume 1.

Some soils will be unusually low or high in a specific mineral, which natural processes, including erosion, wind, grazing and dung distribution, will, over time, to some extent, even out.

This book is not against, indeed promotes the selective application of minerals where soils are genuinely deficient, but not the blanket use of phosphate fertiliser, particularly so where total soil phosphates accessible to mycorrhiza are sufficient for plant growth, provided regenerative agricultural systems are used.

It is unclear to what extent, if at all, current regenerative yields depend on many years' worth of bound phosphate from artificial fertilisers stored in soils accessible to mycorrhiza. Only time will tell, but it makes sense not to waste scarce phosphate resources

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45.3 NITROGEN

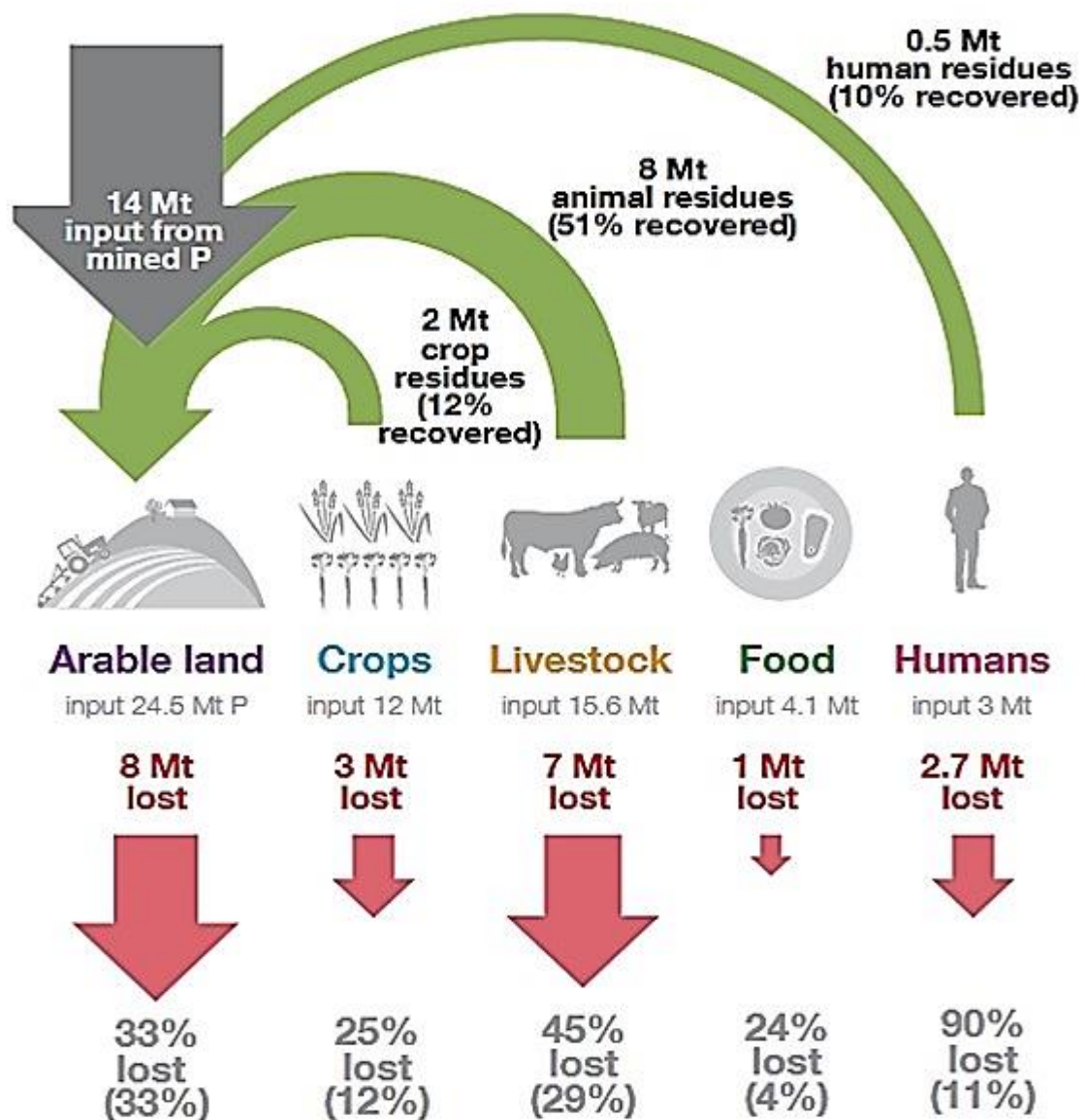


Fig. 121. "Simplified cycle of phosphorus in agriculture based on data from Cordell et al, 2009, and Cordell et al, 2011. Red arrows represent losses into water systems ultimately, and green arrows represent current recoveries into arable land from the different subsystems. The percentages under the red arrows represent the percentage losses from each subsystem and shown in brackets are the percentage losses relative to the total input into agriculture land. For example, the livestock system loses about 45 per cent of the phosphorus entering the livestock system itself, and this represents about a 29 per cent loss of the phosphorus entering the agriculture system overall. (We have excluded the flow up to the input into farm system, but for example, losses in phosphorus mining and processing can also be significant)" with very many thanks to the authors. (Tirado & Allsopp, 2012).

Nitrogen, a gaseous element essential to life, is present in large quantities in the atmosphere above every hectare of land. Nitrogen, “is a component of protein and DNA and as such, is essential to all living things. Prior to the Industrial Revolution, around 97 per cent of the nitrogen supporting life on Earth was fixed biologically.”

Plants and animals cannot access nitrogen directly from the air; it is made available in other forms by bacterial splitting and converting nitrogen gas into plant-accessible forms in low-oxygen pockets, including in nodule enclosures generally close to plant roots. This process is discussed in greater detail in Volume 1 on sewage. Over aeons, nature has produced verdant landscapes without the need for artificial nitrogen made by humans, utilising these symbiotic associations and processes.

1	Frankia sp. Ccl3	F/S
2	Frankia sp. EAN1pec	F
3	Frankia sp. EUN1f	F
4	Frankia sp. Eul1c	F
5	Frankia symbiont of Datisca glomerata	F
6	Sanguibacter keddicii	
7	Cyanothece sp. CCY0110	F
8	Nodularia spumigena	F
9	Bacillus megaterium	F
10	Caulobacter vibrioides	F
11	Mesorhizobium loti	S
12	Rhizobium etli	S
13	Rhizobium leguminosarum	S
14	Rhodopseudomonas palustris	S
15	Sinorhizobium meliloti	S
16	Xanthobacter autotrophicus	S
17	Azospirillum sp. B510	S
18	Azoarcus sp. BH72	
19	Pantoea sp. At-9b	
20	Azotobacter vinelandii	F
21	Stenotrophomonas sp. SKA14	

Free Living and Symbiotic N Fixing Microbes

41:31 / 1:51:43 Institute for Sustainable Agricultural Research (ISAR) New Mexico State University
 davidjohnson@nmsu.edu

Fig. 122 ‘Free Living and Symbiotic N Fixing Microbes’ from the YouTube lecture ‘Dr David and Hui Chun Su Composting’, with many thanks to the authors. (Johnson & Su, 2019)

Nitrogen-fixing bacteria, as do mycorrhiza, need plant sugars for energy. Bacteria, in return, supply nitrogen in plant-available form. Bacteria and mycorrhiza also use nitrogen for their own growth, some of which become immobilised and remain stored in soils in less soluble forms (Sadej, 2008).

Compost and organic matter, including soil life, contain phosphates and nitrates. They act as a reservoir that will be released over time. For example, for composts, “Rough estimates are that only 10 to 30 per cent of the nitrogen in these organic compounds will become available

in one growing season. Some of the remaining nitrogen will become available in subsequent years and at much slower rates than in the first year” ('Compost Use and Soil Fertility', n.d.)

In contrast, as discussed, applying soluble nitrogen in NPK fertiliser swamps plant roots with immediately accessible nitrogen, which, whilst encouraging photosynthetic growth, reduces the supply of carbon sugars and fats to the soil mycorrhizal biome. Indeed, as discussed, spraying a potted plant with foliar nitrogen resulted in a measurable, comparable loss in photosynthetic production of plant root exudates within only 30 minutes (Jones, (n.d.-c @6.5.18').

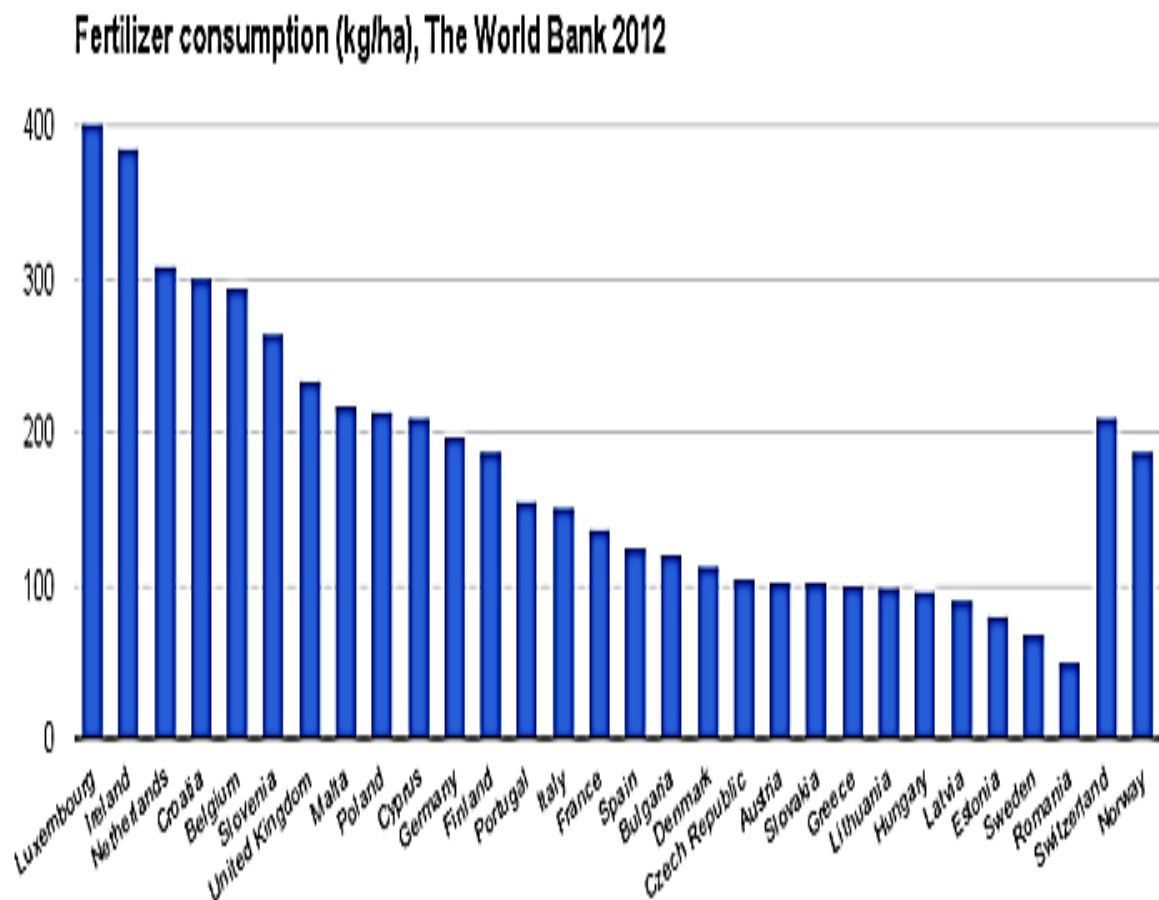


Fig. 123 NPK is a market now worth upwards of \$100 billion [£710 million] a year (Jones, 2017).

Artificial nitrogen supply creates a 'double whammy' because it stimulates carbon metabolism by the microbiome, as discussed below, and reduces the supply of sugar carbon exudates to the microbiome. When supplies of plant exudates are reduced, to stay alive, bacteria, viruses, and fungi in the soil are forced to draw down stored soil carbon, including through cannibalism of the soil biome, accelerating soil degradation.



Fig. 124 Eutrophication of the Potomac River, US, with thanks to Alexandr Trubetskoy.

45.4 RUN-OFF AND EUTROPHICATION

When artificial fertiliser or sewage sludge, nitrogen- and phosphate-rich runoff, washes into river and marine environments, there are multiple adverse effects, including eutrophication (Bingham, 2016). Indeed, only between 10 and 40 per cent of the nitrogen applied to the earth is taken up by plants.

Dr Christine Jones in *'Farming Profitably Within Environmental Limits'* (Jones, 2017) observes, "Globally, over \$100 billion of inorganic nitrogen fertilisers are applied to crops and pastures every year. Between 10% and 40% of the applied N is taken up by plants. Much of the remaining 60% to 90% is returned to the atmosphere as ammonia or nitrous oxide - or leached to aquatic ecosystems as nitrate." (Jones, 2017)

The FAO powerfully makes the point that while "this has contributed to the steep increase in crop production. . . inefficient management practices have led to large nutrient losses to the environment, thereby raising concerns on the long-term sustainability of the global agriculture sector" (FAO, 2018-a).

Composts are less prone to leaching than sludges, which are less prone to leaching than mineral fertilisers (Corrêa, 2006; Sadej, 2009; Czyżyk, 2014). Indeed, contrary to much mainstream thinking, the low content of easily soluble nitrogen in compost is arguably an advantage, as it limits the potential for runoff and helps keep plant carbon exudate flowing from roots into the soil.



Fig. 125 'Run-off of soil and fertiliser during a rainstorm, with thanks to Lynn Betts, Natural Resources Conservation Service, US Department of Agriculture.

Regenerative agriculture addresses many of these issues, as adequate yields of healthy crops can be achieved without the use of artificial fertilisers. Sludge is also not used in regenerative agriculture. Compost is used, but it does not leach significant nitrogen.

45.5 BLUE BABY SYNDROME

An arguably more significant but rarely discussed concern is that excess nitrites in drinking water can cause blue baby syndrome (a condition characterised by a lack of haemoglobin in the blood of young children) and may be a factor in the risk of stunting. Many people worldwide do not have access to centralised treated water systems. Further processes for removing nitrates are very costly, and this is particularly true for less well-off economies.

“Globally, an additional kilogramme of fertiliser per hectare increases yields by 4-5 per cent. However, the subsequent fertiliser run-off and release of nitrates into the water poses a risk large enough to increase childhood stunting by 11-19 per cent and decrease later-life earnings by 1-2 per cent” (Damania, 2019).

Thought-provokingly, it is posited, *“A conservative interpretation of this finding suggests that the vast subsidies accruing to fertilisers likely generate damage to human health that is as great as, or even greater than, the benefits that they bring to agriculture” (ibid).*

45.6 AGROCHEMICALS



With thanks to Adobe Stock ©

The review *‘Advances in agrochemical remediation using nanoparticles’*, (Sebastian, 2020) observes, *“Agrochemical pollution is a serious threat to environmental safety. Exposure to agrochemicals had deleterious health effects such as nervous system damage and cancer. Biological magnification of persistent agrochemicals also occurred.”* Sophisticated remediation options are being researched; however, avoiding unnecessary use in the first place should be the preferred option. Unlike organic farmers, regenerative farmers pragmatically do not rule out minimal use of agrochemicals, when necessary, but generally find that they rarely need to use them.

45.7 HERBICIDES AND BIOCIDES

Biocides, including fungicides, will reduce soil biome activity, including of microbes and fungi (Abd-Alla, 2000; Schreiner, 1997), which is counterproductive in terms of securing productive plants, given that the microbiome has an interest in maintaining plant health, for their own survival; and as well as supplying minerals, and nitrates, ‘to order’; and selectively deliver products that help plant immune function; and assist drought tolerance.

Improving soil microbiomes is a more effective and sustainable long-term strategy to counter plant diseases than relying on agrochemicals. Consistent with this, historically, Howard and King noted that plant disease fell with good land management, including composting. Through composting and appropriate management, Howard successfully reduced a range of diseases in various commercially grown crops, including tobacco, sugar, cotton, coffee and potatoes. (Howard, Sir Albert, 1945) bbbbbb

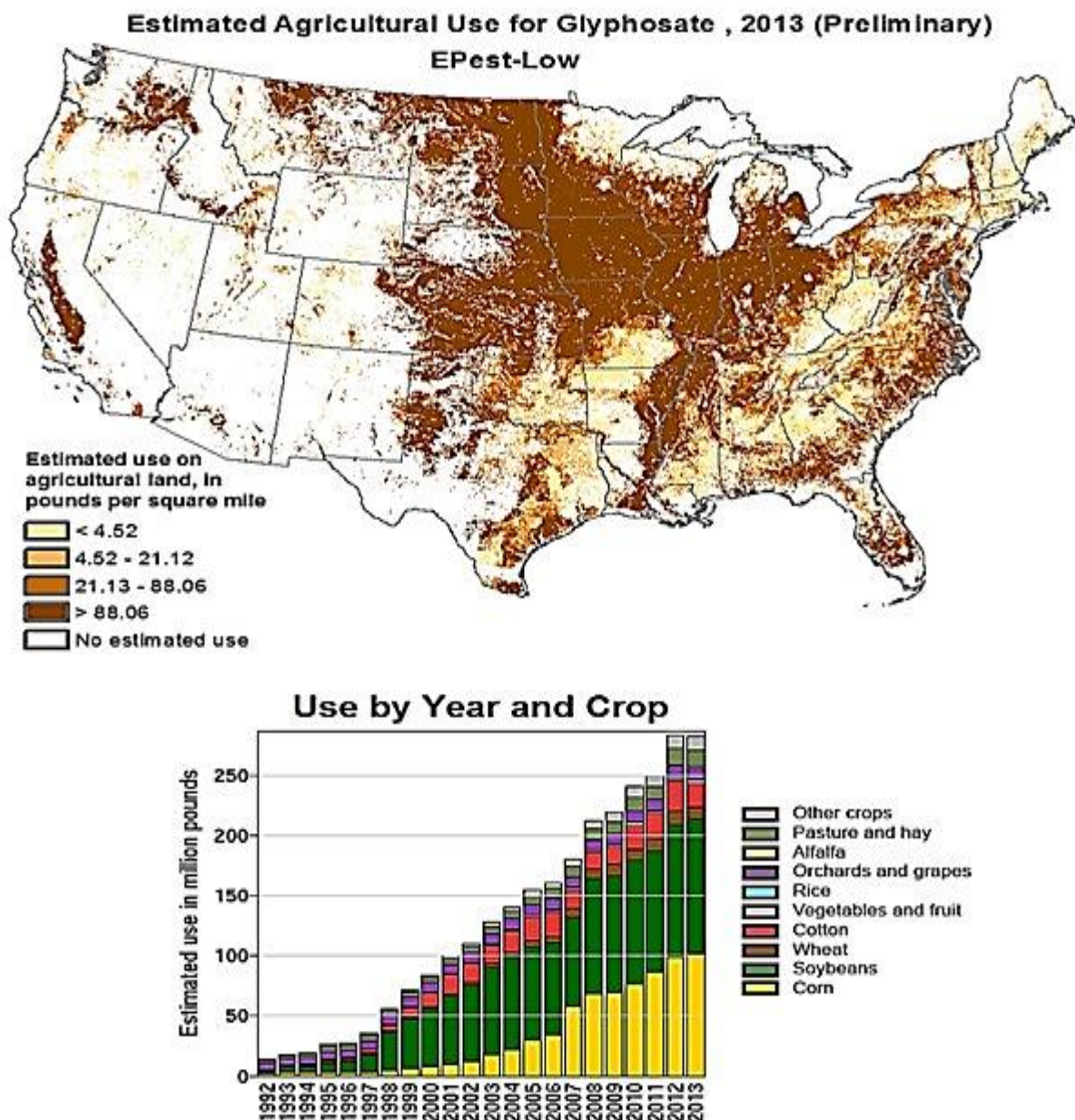


Fig. 126 '2013 Glyphosate Use Map', with many thanks to the USGS Pesticide National Synthesis Project

Similarly, King (King, 1911), an experienced and respected agronomist, observed few occurrences of common plant diseases in China during the 1900s. Modern regenerative farmers also report that in some cases, relatively quickly; in others, after several years, plant health improves, pests and predators reach a natural balance, and they find they rarely, if at

all, have to use agrochemicals, yet achieve better quality crops and acceptable equivalent yields with greater net profitability.

Initially marketed as Roundup by Monsanto, Glyphosate is the most used agricultural herbicide. *“Since the late 1970s, the volume applied has increased approximately 100-fold. Further increases are likely due to more and higher rates of application in response to the widespread emergence of glyphosate-resistant weeds”* (Myers, 2016). Despite many US lawsuits claiming it has carcinogenic properties, it continues to be used in huge quantities, even as part of some low-till regimes. In 2020, Bayer, which now owns Monsanto, agreed to a \$10 billion settlement. It may have a valuable place for limited usage, but certainly not as a central agricultural pillar.

Of relevance here and concern, glyphosate may also damage microorganisms in the soil. *‘Glyphosate reduced the mycorrhizal colonization and growth of both target and non-target grasses’* (Helander, 2018). A separate study noted attrition of microbial populations when subject to multiple applications of glyphosate. *“Our findings strengthen the notion that this agronomical practice has an unavoidable imprint on non-target microorganisms that are relevant components of the plant-soil feedbacks and that may be instrumental for ecosystem restoration”* (Lorch, 2021).

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Some regenerative farmers use herbicides to kill cover crops, allowing for the timely planting of cash crops. However, alternative techniques are being developed to minimise their usage. It is hoped that alternatives will prove more cost-effective and productive, allowing herbicide usage to diminish over time.

45.8 FATBAS PROFITS FALLING

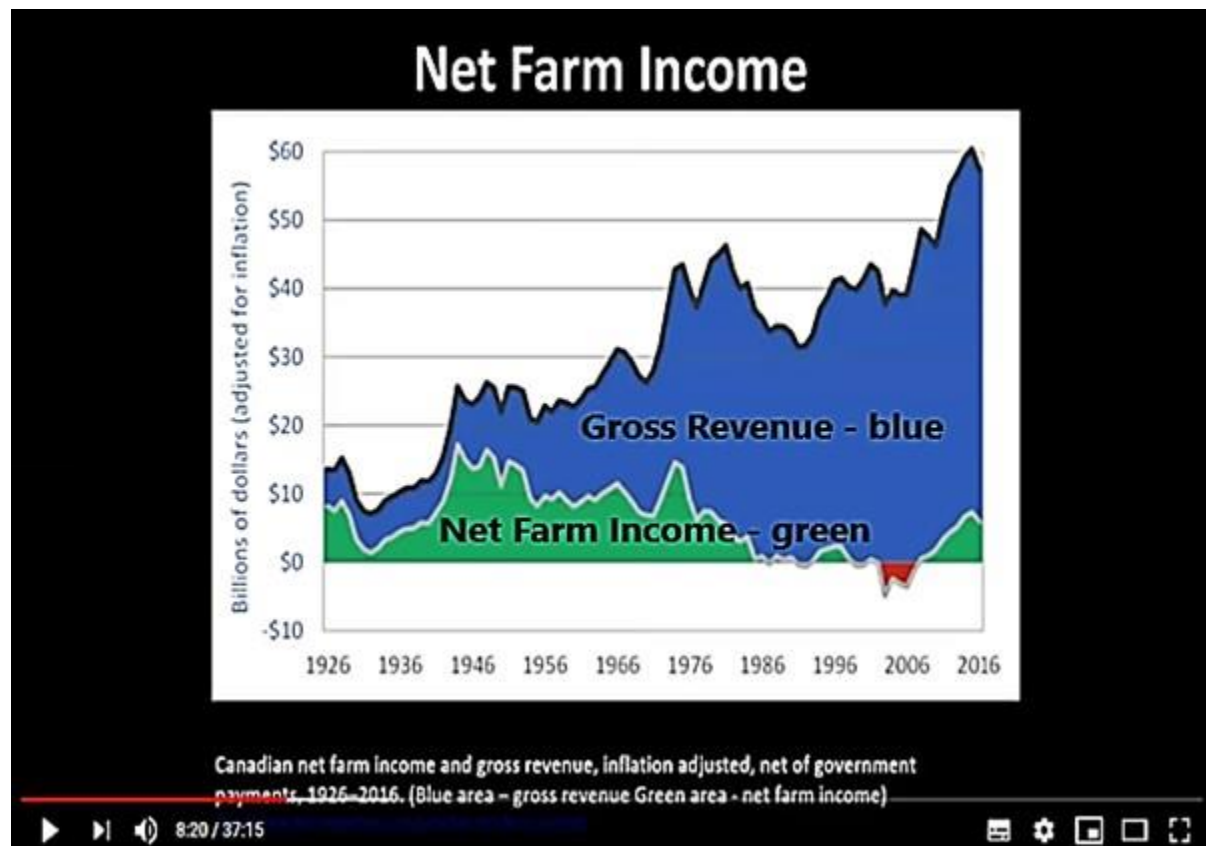


Fig. 127. Annotated slide from lecture by Dr Christine Jones – ‘Building New Topsoil Through The Liquid Carbon Pathway’ (@7.20) Conservation Tillage and Technology Conference 2019 with many thanks to the author. (Jones, n.d.-a)

The graph above shows that, in Canada, farm turnover has quadrupled in real terms from around \$15 billion in 1926 to nearly \$60 billion in 2016. However, net profits remain below \$10 billion, and the trend has been downward over the past 40 years.

46 FATBAS WIDER POLLUTANTS

46.1 HEAVY METALS FROM FERTILISERS AND FEEDS

Once again, practical experience and research suggest that regenerative agriculture, which allows for the production of equivalent yields and more profitable farming, can be achieved without using phosphate-based fertilisers. Cattle raised using regenerative principles are reported not to need mineral supplementation yet remain healthy and calve annually, saving farmers veterinary and supplement costs. Crops grown using regenerative principles have higher nutrient densities.

Substantial lowering of the use of phosphate-based fertilisers will have a host of further benefits, such as reducing the application of heavy metals to soils, including radionuclides,

and via animal diminished need for mineral supplements. This, in turn, will also improve livestock and human health.

Some people, pets, and livestock may need supplementation of specific, regionally scarce nutrients such as iodine. In the interest of optimising crop nutrient values, the soil testing and mineral soil supplement industry is expected to grow over time, enabling more precise assessment and meeting specific needs.

The content and range of heavy metals in fertilisers varies significantly and variously contributes to their long-term build-up in soils; *“Analysis of fertilizers commercially marketed in India, Italy, Australia, New Zealand, England and USA indicated that all phosphatic fertilizers contained significant and varying amounts of heavy metals” “Several studies have shown that these heavy metals in phosphatic fertilizers can subsequently accumulate in soil and become readily available to plants”* (Chibueze, 2012).

“Expressed in mg/kg PR (Phosphate rock), the ranges and median values were: Cd (5–47), Co (6–104), Cu (5–41), Cr (18–331), Li (2–9), Mn (11–6553), Ni (1–61), Pb (7–43), Rb (3–18), and Zn (54–576). The corresponding values of the nontrace metals expressed in g/kg were: Al (1.7–20.0), Ba (0–4.4), Ca (211–330), Fe (1.4–45.7), K (0.3–10.9), Mg (0.6–16.9), Na (1.0–22.8), and Sr (0.3–6.7). At the detection limit of 5 ng/mL, no cesium (Cs) was found in the PR analyzed.” (Kpombrekou, 1994) They will then be taken up by animals fed on such pastures and via feedstocks grown on such soils.

Cadmium is particularly toxic, negatively impacting most organs, and is a possible carcinogen. Mineral fertiliser can be a significant source of toxic cadmium. Levels vary significantly between phosphate sources. Cadmium uptake and behaviour in the soil, as well as accumulation by crops, are complex. *“Fertilization can increase the risk of Cd movement into the food chain through direct addition to the soil from some phosphate (P) fertilizers and indirectly from fertilizer-induced changes in Cd bioavailability. Because of the potential risk to human health, several countries have implemented regulations limiting the amount of Cd that can be present in P fertilizers”* (Roberts, 1994; Roberts, 2014).

Interestingly, a paper titled *‘Environmental impact of recycling nutrients in human excreta to agriculture compared with enhanced wastewater treatment’* observed, *“KEMI, the Swedish Chemical Agency, recommends a limit of 12 mg cadmium per kg phosphorus added to soil to keep safe levels (KEMI, 2008), but analyses of chemical fertilisers sold in Europe show median concentrations of 87 mg per kg phosphorus (2008).”* (Spångberg, 2014)

Fertilisers are also used to directly supplement feedstocks because they contain a range of minerals. Whilst they contain required essential minerals, they can also, as discussed, contain toxic metals such as cadmium. A significant proportion of metals in feed and supplements end up in livestock urine and faeces, which are spread on soils, further increasing soil heavy metals. Minerals in sewage and manure sludge will be taken up and concentrated by crops, fed to livestock, etc., creating the risk of a negative cycle of increasing excesses or imbalances of toxic, ‘heavy’ metals in the agricultural land food cycle.

Purification of the rock phosphate-derived mineral supplement is possible. However, the market demands cheap food, and the need for farmers to be profitable mitigates against this, as farmers are economically unable to cover the additional cost of feed supplement purification. Consequently, unpurified mineral livestock feed additives contribute to other sources of heavy metal soil pollution to the long-term detriment of soil, livestock, and human health.

As discussed, some heavy metals, such as copper and zinc, are essential to plant, livestock and human metabolism in appropriate quantities but are toxic in excess. In contrast, others, such as cadmium and lead, are toxic even at low concentrations. This is a complex topic, but reducing the addition of toxic heavy metals to soils and the wider food chain can only be beneficial.

46.2 SEWAGE SLUDGE AND SLURRY -

Sewage sludge is used as a soil conditioner in many countries, although some have banned its use for agriculture, instead incinerating it. Disposing of sewage sludge from current sewage systems is problematic for several reasons. The topic and potential alternatives are discussed in Volume 1. Given the current usage of sewage sludge, which generally contains a wide range of pollutants, including but not limited to antibiotics, on agricultural land, some of the issues are outlined below.

46.3 ANTIBIOTICS, PHARMACEUTICALS AND WIDER POLLUTANTS IN SEWAGE SLUDGE AND SLURRY

Thought-provokingly, many of our antibiotics were derived from molecules produced by soil-related bacteria. We have minimal knowledge on the implications for the soil biome of applications of sludge containing antibiotics, antibiotic-resistant bacteria, and mobile genetic elements. The paper ‘*Antibiotic resistance in grass and soil*’ observes, “*The use of manure in agriculture is a traditional and widespread practice and is essential for returning nutrients to the soil; however, the impact of continuous manure application on the environmental microbiome and resistome is unknown. The use of antibiotics in animal husbandry in therapeutic and sub-therapeutic doses creates a selective pressure for ARGs (antibiotic-resistant genes) in the gut microbiome of the animal, which is then excreted in the faeces. Therefore, the application of manure to agricultural land is a potential route for the transmission of antibiotic-resistant bacteria from livestock to crops, animals and humans. It is of vital importance to understand the mechanisms behind ARG enrichment and its maintenance both on the plant and within the soil microbiome to mitigate the spread of this resistance to animals and humans*” (Tyrrell, 2019)

The review, ‘*Antibiotics in the Soil Environment—Degradation and Their Impact on Microbial Activity and Diversity*’ observes, “*Antibiotics affect soil micro-organisms by changing their enzyme activity and ability to metabolise different carbon sources as well as by altering the overall microbial biomass and the relative abundance of different groups (i.e., Gram-negative bacteria, Gram-positive bacteria, and fungi) in microbial communities.*” (Cycoń, 2019), which, given the crucial role of the soil biome in natural environmental cycles, is not unimportant.

The paper, *'Native soil microorganisms hinder the soil enrichment with antibiotic resistance genes'* noted, whilst there was partial recovery with manure amendments, that *"There has been an increasing concern about the accumulation of ARGs in soils as they may be exchanged between soil bacteria and human pathogens. ARG are hence nowadays recognized as an emerging environmental pollutant. However, the factors contributing to the ARG dissemination and persistence in soil are not well understood yet."* (Pérez-Valera , 2019)

Effects may be persistent. The paper *'Enrichment of antibiotic resistance genes in soil receiving composts derived from swine manure, yard wastes, or food wastes, and evidence for multiyear persistence of swine Clostridium spp.'* observes *"The impact of amendment with swine manure compost (SMC), yard waste compost (YWC), or food waste compost (FWC) on the abundance of antibiotic resistance genes in soil was evaluated. Following a commercial-scale application of the composts in a field experiment, soils were sampled periodically for a decade, and archived air-dried. Soil DNA was extracted and gene targets quantified by qPCR. Compared with untreated control soil, all 3 amendment types increased the abundance of gene targets for up to 4 years post application." "Clostridia were significantly more abundant in the SMC-amended soil throughout the decade following application"* (Scott, 2018) (Authors underline).

Another paper reported elevated levels of swine Clostridium spp in the soil even a decade after receiving animal slurry (Scott, 2018). To reiterate, around 100,000 tonnes of antibiotics are used annually, and approximately 70 percent are used to treat livestock (Geetha, 2012; Gelband, 2015). A significant part of them – between 70 and 90 per cent – remain unmetabolised as they pass into the environment via rivers, oceans, and farmland. What damage they do is unknown, and research in this field is still in its infancy. The presence of antimicrobial resistance (AMR) in the broader environment is a growing and arguably underappreciated problem, including in Africa. (Tadesse, 2017),

Experts warn of possible dire consequences for the food chain where resistant bacteria multiply on agricultural land. *"The impact of continuous manure application on the environmental microbiome and resistome is unknown. The use of antibiotics in animal husbandry in therapeutic and sub-therapeutic doses creates a selective pressure for ARGs (antibiotic-resistant genes) in the gut microbiome of the animal, which is then excreted in the faeces. Therefore, the application of manure to agricultural land is a potential route for the transmission of antibiotic-resistant bacteria from livestock to crops, animals and humans. It is of vital importance to understand the mechanisms behind ARG enrichment and its maintenance both on the plant and within the soil microbiome to mitigate the spread of this resistance to animals and humans"* (Tyrrell, 2019).

In summary there is *"increasing concern about the accumulation of ARGs in soils as they may be exchanged between soil bacteria and human pathogens. ARG are hence nowadays recognised as an emerging environmental pollutant"* (Pérez-Valera, 2019).

Sewage water, sludge, and livestock slurry are applied to farmland. The issues of sewage sludge and slurry pollution are considered more deeply in Volume 1 on sewage. Current sewage and farm waste treatment methods do not remove most contaminants. In addition to pharmaceuticals, including antibiotics, sewage sludge contains an extensive range of

pollutants, including personal care products, endocrine disruptors, forever chemicals, industrial products, tyre particles, fabric microplastics from washing machines, heavy metals, bromide products, fire retardants etc. Many of these pollutants are taken up by plants and subsequently enter the food chain to varying degrees, discussed in more detail in volume 1.

At what point will mycorrhizal biomes become so deadened by the weight of contaminants, bare soils, lack of retained water, that toxicity and or degradation set in, and at what point do those effects damage soil systems to the point they can no longer, at least for a time, sufficiently accrete carbon, thus regulate the carbon partition cycle between earth's crust, atmosphere, ocean, soil and living things? That is a difficult question to answer, but it is certain that areas of degraded soil globally have been rising.

As far as sewage goes, it makes sense to collect and separate urine and faeces at source, using vacuum WC technology, and research and optimise the most practical and applicable technologies we have, including hyperthermophilic anaerobic digestion followed by hyperthermophilic composting, to as far as possible remediate these products and related genetic material, rather than putting treated, partially treated or untreated human and livestock faeces and urine from traditional sewage works, with the pharmaceuticals and antibiotics and extensive array of wider pollutants they contain into the environment. Alternative options for sewage treatment are discussed in greater detail in volume 1.

46.4 WIDER POLLUTANTS PAHs, PCBs. DIOXINS FROM SEWAGE SLUDGE AND WASTE WATER

This Volume considers a limited portion of the directly introduced pollutants, including pharmaceuticals, especially antibiotics, heavy metals, agrochemicals, and personal care products in sewage sludge.

As discussed in Volume 1 on sewage, the broader basket of pollutants includes a very extensive range of products from a variety of sources, domestic products, micro and nano-plastics from washing machines, industrial pollution, PCBs, PAHs, and dioxins, traffic, including tyre wear; atmospheric pollution from power plants and incinerators; motor traffic emissions; runoff sources, including roads, paved areas, rooves; and introduced substances such as herbicides, products discarded in drains, and car cleaning products.

Some chemicals accumulate in the semi-solid sewage sludge component due to their chemical characteristics, including structural charges; others accumulate in the liquid wastewater component. Both are applied to agricultural land, sludge as a fertiliser and conditioner, and sewage water for irrigation.

Sewage water is sometimes pragmatically applied to land where too high in pollutants to introduce directly into sensitive aquatic zones, yet is deemed safe for land application, in the hope the land will provide some remediation capacity, but at the cost of adding to soil pollution, with the risk and observed reality that pollutants, even if a very low levels, end up in food and feedstock.

Dioxins stand out because a significant portion of dioxins in sewage sludge likely originated in greywater, particularly washing machine water. *“Dioxins speciation in household wastewater and laundry wastewater is similar to those in the sediments of UWW (Urban Waste Water) collecting systems and sewage sludge. A mass balance indicates that 2-7 times more dioxins in sewage sludge originates from households than from urban runoff. Washing machine effluent is a major source of dioxins in household wastewater.”* (Thornton, 2001)

Other products in washing machine water may include *“pentachlorophenol-treated cotton from overseas, chloranil-based dyes in the fabric, fabric bleaching, soil and human skin.”* (*“Dioxins in San Francisco Bay | Region 9: Water | US EPA,”* n.d.) The difficulties in local treatment add to arguments for removing, so far as feasible, such products from washing machine formulations and new clothes. Treatment options are generally technical (Maier, 2016) and arguably not practical for most domestic applications.

As discussed in Volume 1, washing machines are also a significant source of microplastics (Lamichhane, 2018), which end up in sewage sludge and sewage water, thus soils, crops, livestock, rivers, oceans, marine creatures, and food generally. Legally enforced mandatory disposable filters on washing machines would help alleviate this problem.

Many of these wider pollutants are largely optional additives to the sewage waste stream. As discussed in Volume 1, collecting urine and faeces at the source using vacuum WC technologies would alleviate the addition of externally added pollutants by mixing urine and faeces with other water streams, including runoff. Removing contaminants from household products would also help alleviate pollution at the source.

46.5 GREYWATER IRRIGATION – PLANT POLLUTANT UPTAKE AND TOXICITY



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The reuse of grey water, household water excluding the WC component, is an emerging research area. Grey water contains a complex mix of pollutants, but it is much easier to remediate before it is mixed with urine and faeces.

As discussed, plants can, and do, uptake and concentrate pollutants; uptake will differ between toxicants as influenced by conditions, soils, and plant types. Many of those plants will be part of the human and livestock food chain, also incidentally, but not unimportantly, impacting wild species such as birds that feed on crops and crop residues.

Plant and thus food chain pollution effects may be more toxic where untreated water is used for crop irrigation, as happens in emerging economies, and more research is required. As always, results vary, and human nature is such that where commercial interests are involved, we are often reluctant to face, assess and take action on pertinent issues objectively.

46.6 WASTEWATER USAGE FOR AGRICULTURAL IRRIGATION

As previously noted, demand for water for agricultural use has led to the emptying of ancient aquifers. Countries have also turned to reusing treated wastewater from sewage plants not only for irrigation, but also to bolster drinking water supplies. The presence of pharmaceuticals in ground and drinking water from various sources is a ubiquitous global issue, albeit differing by extent. (Chander 2016)

“The application of municipal and industrial wastewater and related effluents to land dates back 400 years and now is a common practice in many parts of the world,” according to Wuana & Okieimen (2011). “Worldwide, it is estimated that 20 million hectares of arable land are irrigated with wastewater. In several Asian and African cities, studies suggest that agriculture based on wastewater irrigation accounts for 50 percent of the vegetable supply to urban areas” (ibid).

However, both these pathways carry the risk of exposing humans to toxins. Where treated wastewater is injected into aquifers, the pollutants are diluted but often persist. Irrigation potentially passes on contaminants to plants, which then can enter the food chain either directly through cereals, fruit, and vegetables for human consumption, or via livestock feed. If not addressed, pollution of irrigation water will inevitably create a feed-forward cycle of ever-increasing pollution. *“Although the metal concentrations in wastewater effluents are usually relatively low, long-term irrigation of land with such can eventually result in heavy metal accumulation in the soil” (Wuana, 2011).*

The problems are getting worse over time, as there has been an explosion in personal care and pharmaceuticals, including antibiotics, which, as discussed, is a particular issue due to the growth of antibiotic-resistant bacteria. We are also seeing emerging recognition of the potential impact of other pollutants, including the forever chemicals such as PFAS. There are many more contaminants of concern with observed negative health consequences that are on researchers' radar but not known to the broader public.

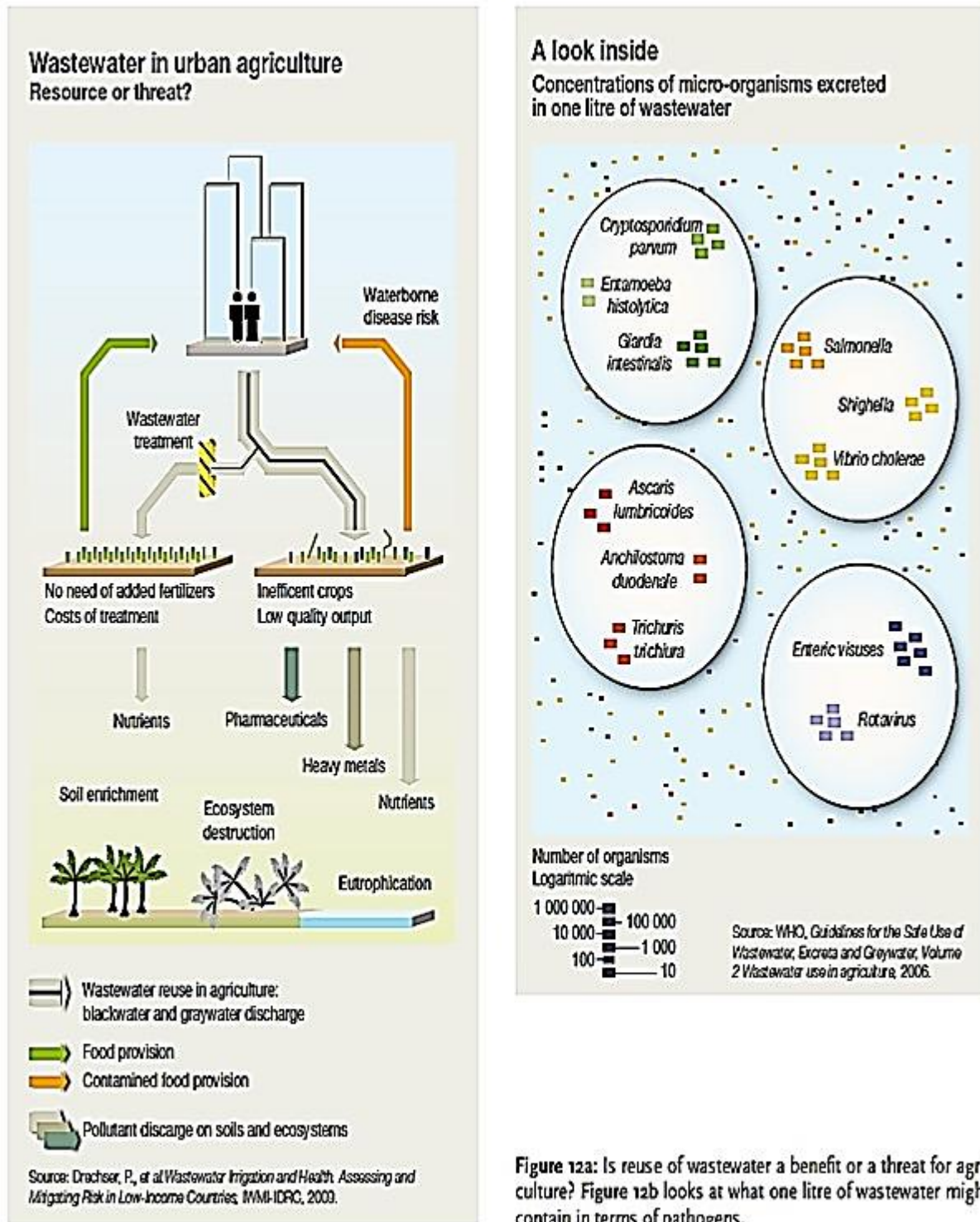


Fig. 128. With many thanks to the authors of 'Sick Water?' (Corcoran et al, 2010).

Regulations vary between countries and regional authorities. However, modern increases in pharmacological products and antibiotic-resistant bacteria in wastewater make decisions around its use for irrigation difficult. High-end treatment, such as reverse osmosis, is expensive and only economically affordable for treating water for human use in economically better-off countries. It is too expensive and technology-intensive for most countries to use

reverse osmosis to treat water for agricultural use. However, some better-off countries, such as in the Middle East, do so. Reverse osmosis is a very effective technology, but the pollutants removed have to be disposed of and are, of necessity, discharged into oceans or ground drains: out of sight, out of mind, but they have not magically vanished.

In the modern agriculture and food marketing model, which values price over nutritive value, farmers need to maintain what are often family businesses, their sole source of income, in very tight competitive markets with little profit margin cushion. Many farmers are thus obliged to do what they must, albeit pragmatically, knowing that their actions may have longer-term negative consequences. The alternative is often financial failure.



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For example, in the US, *“irrigating crops with reclaimed wastewater has been generally well accepted, both in the semi-arid western states and in Florida. The suitability of water for reuse is influenced by the chemical composition of the source water, mineral pick-up due to water use, and the extent of wastewater treatment”* (‘Use of Reclaimed Water and Sludge in Food Crop Production’, 1996; Brodin, National Research Council, 2018).

It is often believed that treated water is fit for irrigation due to “*advances in wastewater treatment technology*” (ibid). However, many contaminants, including pharmaceuticals, remain in secondary and tertiary treated sewage-derived water because most sewage treatment plants cannot remove them.

Toxicity risks in the West in relation to greywater irrigation are believed to be low due to lower water pollutant levels. A Californian study concluded, “*In summary, although previous studies under laboratory or greenhouse conditions showed that plants could substantially accumulate various kinds of PPCPs (pharmaceutical and personal care products) from nutrient solutions or soils, results from this study suggested that the accumulation of 19 frequently occurring PPCPs in 8 common vegetables irrigated with tertiary treated wastewater was limited under field conditions, and that human exposure to PPCPs through daily consumption of these PPCP-contaminated vegetables was likely to be small.*” (Wu, 2014) (Authors’ underline)

Indeed and ironically, there is an implicit recognition that water used for irrigation may not even meet standards for re-introduction into river systems, “*beneficial reuse can be more economical and/or technically feasible than employing the advanced wastewater treatment needed to meet the requirements for surface water disposal*” (ibid).

As an example, reclaimed wastewater from Bakersfield, California, is currently used to irrigate “*approximately 2,065 ha (5,100 acres) of corn, alfalfa, cotton, barley and sugar beets*”, a strategy involving “*more than 64,000 m³/day (16.9 million gal/day) of primary and secondary effluents from three treatment plants*” (ibid). “*To avoid wastewater discharge to sensitive receiving waters, the city of Tallahassee, Florida, has been using treated effluent for agricultural irrigation on city-owned farmland since 1966. About 68,000 m³/day (18 million gal/day) of secondary effluent are pumped approximately 13.7 km (8.5 miles) and irrigate about 700 ha (1,729 acres)*” (ibid). This is in the USA, the wealthiest country in the world.

Large-scale direct reuse of treated wastewater by reinjection into the water system occurs in many parts of the world, such as Mexico, where the proportion is as high as 28 per cent (*Guidelines on Sanitation and Health. Licence: CC BY-NC-SA 3.0 IGO.*, More widely, “*2.4 billion people live without access to improved sanitation facilities, and nearly 700 million people do not receive their drinking-water from improved water sources.*” (“UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) Archives | UN-Water,” n.d.). In some countries, greater water scarcity and economic realities require sewage water re-use, no matter the treatment level. Volume one on sewage, and volume three on water, consider agriculture and wider water pollution and supply, and its potential health consequences in greater detail.

Hopefully, it will soon be better understood that regenerative agriculture principles offer a more water-efficient, environmentally sustainable, and profitable alternative. Monocrop, bare-ground, NPK-based agriculture has arguably increased the requirement for agrochemicals to maintain yields, and it is acknowledged that the world needs to be fed. However, by rebalancing pests and predators, regenerative practices have achieved reasonable yields comparable to existing regional averages or better with minimal agrochemical input.

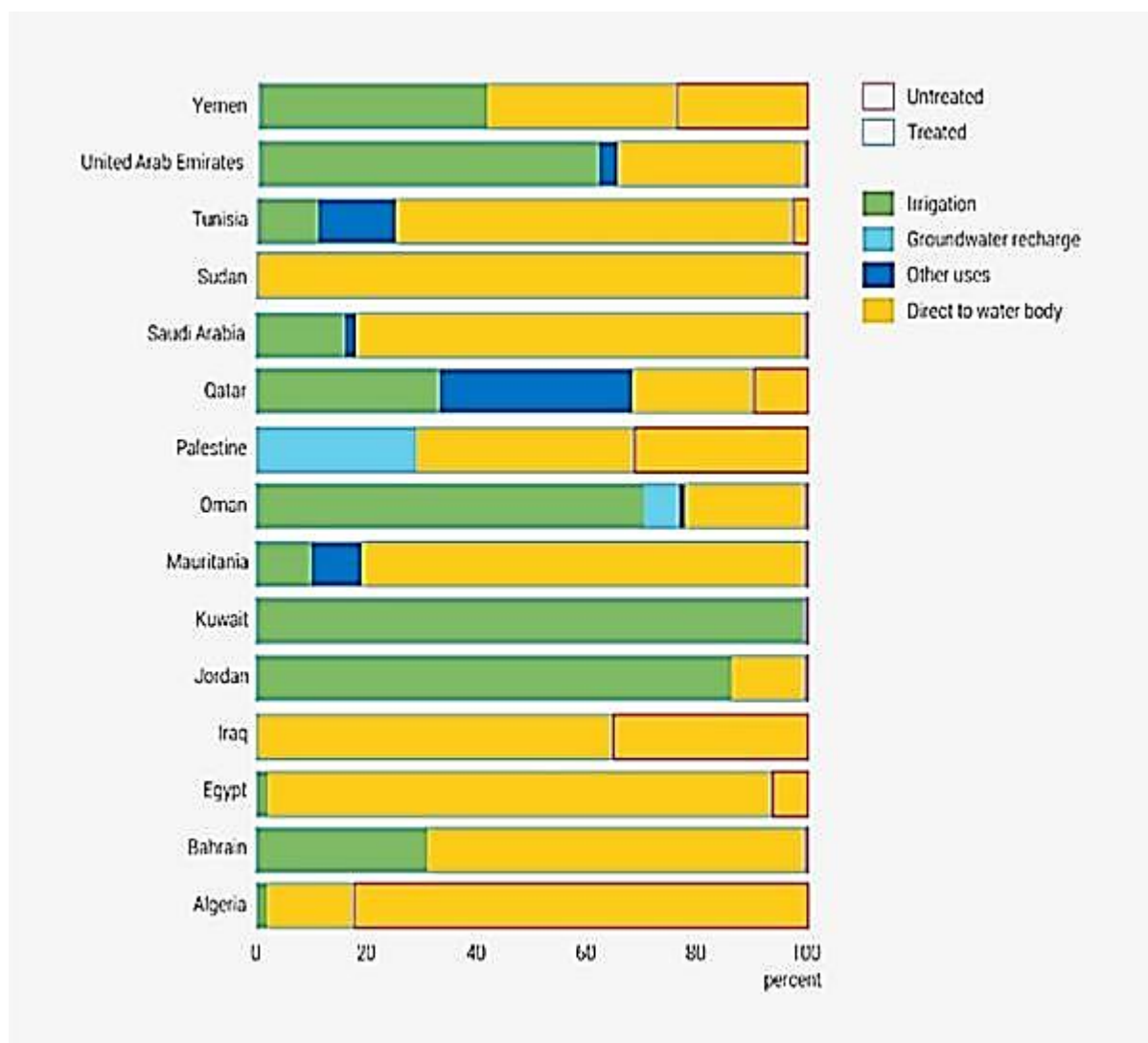


Fig. 129 Water reuse data illustrating the high reuse of untreated water, including by re-inclusion in the wider water body, with many thanks to the authors - Arab Countries Water Utilities Association (ACWUA), 2016 and Progress on Safe Treatment and Use of Wastewater (*Guidelines on Sanitation and Health*. Licence: CC BY-NC-SA 3.0 IGO., 2018)

46.7 INCINERATION

Incineration, be that of waste, sewage sludge, or crop stubble contaminated with agrochemicals, poses its own problems, like every solution. For example, the incineration process may release some airborne toxins. Even emissions from controlled plants give rise to issues because gas scrubbing is, at best, an imperfect art. Some of the toxins produced will inevitably be deposited on farmland. *"Sewage sludge incinerators potentially emit significant quantities of pollutants. The major pollutants emitted are: (1) particulate matter, (2) metals, (3) carbon monoxide (CO), (4) nitrogen oxides (NOx), (5) sulfur dioxide (SO2), and (6) unburned hydrocarbons. Partial combustion of sludge can result in emissions of intermediate products of incomplete combustion (PIC), including toxic organic compounds. Uncontrolled particulate emission rates vary widely depending on the type of incinerator, the volatiles and moisture*

content of the sludge, and the operating practices employed." ("Sewage Sludge Incineration", n.d.) Metals potentially present in emissions include Cadmium (Cd), Arsenic (As), and Mercury (Hg) ("Sewage Sludge Incineration", n.d.); similarly, elemental radioactive isotopes, e.g., iodine, might also be present, with long term adverse health implications.



With thanks to Adobe Stock ©

As discussed elsewhere, due to the potential of pharmaceutical and wider contaminants in sewage sludge, incineration is often a preferred sludge disposal route in some, but not all, European countries.

Incineration and disposal of the ash, albeit imperfect and in some cases potentially posing emission issues, does remediate organic contaminants but precludes the return of carbon, minerals, and other nutrients in compost to the land, but may allow recovery of some phosphate: *"inorganic fertiliser (e.g., mono-ammonium phosphate fertiliser, MAP) can be*

produced from metal-contaminated sewage sludge ash in a process whereby the metals are removed" (Kirchmann, 2017).

Some studies have associated living near incineration plants with potential health and developmental issues. The risk will depend on the quality of the gas 'scrubbing' technology, the operation parameters applied, the incinerated materials, and other factors.

46.8 BROMIDE

Bromide is a halogen and can thus impact health, particularly where iodine intake is insufficient, including through impaired thyroid function. Bromide may be released in industrial-related water discharges, including from discharges relating to flue gas scrubbing (Good, 2019), during energy production, including in coal plants and other sources. *"Anthropogenic sources of bromide include discharges from fossil fuel extraction activities, including oil and gas development and coal mining, coal-fired power generation, and flame-retardant textile production facilities, as well as other industrial sources. Discharges from these sources are associated with elevated bromide concentrations in rivers"* (Good & VanBriesen, 2019). This can create issues where industrial discharge is upstream of drinking water abstraction.

Plants will also take up bromide. Thus, ensuring livestock and humans have adequate access to iodine is essential. Inhibition of rain by heat domes prevents the transport of organic iodine compounds produced by ocean evaporation, the primary inland circulatory mechanism for

iodine, which is highly soluble and washes out quickly. High bromide will exacerbate a lack of iodine, which is important, given that many worldwide have insufficient iodine levels. Even in Western countries, insufficient iodine is a significant issue. For example, 70% of women in the Avon study UK were found to be iodine insufficient. Iodine is essential to health at all life stages, including, and of fundamental importance, to early brain development in utero, being essential to optimal neuronal migration from about week 7.

47 FOOD AND HEALTH – NUTRIENT DENSITY

As discussed, food too is a central concern . . . our food . . . needed to make and support healthy, intelligent, empathetic humans from conception onwards. (*“Poor Diet During Pregnancy May Have Long Term Impact On Child’s Health”*, n.d.) The ultimate aim of curating healthy, productive soils, is to provide us with the grains, fruit, vegetables and meat, we eat to, grow, develop optimal brains, function to the best of our genetic potential, optimise health, dream and prosper.

After all, humans are ultimately defined by the capacity of their brains for creative and abstract thought, empathy, higher human function, including musicality and appreciation of beauty, cooperation, complex thought capacity, and intelligence. These capacities, combined with relative longevity, thus the capacity to gain, curate, and pass on knowledge, are central to human well-being and survival as an ‘advanced’ species.

Far from being controversial, it is undoubtedly the commonest of sense that we need to be the best, most intelligent, empathetic, emotionally balanced species we can be if we are to survive in a resource-pressured, conflicted world subject to environmental degradation.

The issue of human health in relation to diet, degraded food, and pollution will be examined in greater detail in another book. However, throughout this review, we should not lose sight of the fact that as well as being key to climate, the end goal of farming regeneratively is surely to ensure optimal human nutrition, thus neurodevelopment, maximum cerebral function, and ultimately to allow us as a species to optimise the expression of our ‘humanity’.

47.1 MINERALS IN CROPS, SOILS AND UNDERLYING ROCK STRATA

‘Modern’ farming relies on artificial fertilisers and agrochemicals, thus inhibiting soil biome health. This, in turn, reduces crop nutritional quality, including crop mineral protein and wider nutrient content. (Ray, 2015) The problem is exacerbated because food production techniques, in the quest for increased profits, often pay insufficient attention to nutrient density.

For example, hydroponic growers often use a limited range of minerals in their plant-growing mediums. Plants grown in glasshouses are not exposed to or have limited exposure to UVB, which reduces their antioxidant content. Many food processing techniques to increase shelf life lead to significant damage to nutrients. The cumulative consequence is that humans, including importantly pregnant mothers, and infants are increasingly at risk of nutritional insufficiencies (*‘Food processing and nutrition - Better Health Channel’*, n.d.; Morrison & Regnault, 2016).

Crop breeding is another issue. Crops are generally bred for particular commercially attractive growing properties or disease resistance, but without any regard to the impact of selection for desired characteristics on nutrient content; indeed, it may be in some cases that the reason that the breeding of plants for specific traits imparts resistance, is because it has lower levels of particular nutrients essential to those pests, fungi or bacteria being selected against – we do not know - but in contrast, we do know the nutrient content of crops is falling for a variety of reasons.

Genetic modification of crops for non-nutritional characteristics is also generally done without regard for the implications on nutrient uptake and, thus, nutritional value and density. Interestingly, limited research suggests some older traditional varieties have higher nutrient density. The nutrient density of crops needs a greater research focus.

Microbiome biology will mine, extract, and transport bound and soluble minerals, and provide them in a form assimilable by plants. In so far as that mineral-containing plant material is exported to cities, not returned to the soil, or available from deeper layers, over very long-term time frames, minerals in soils must become depleted, and the system must progressively become less capable of supplying plants with the minerals they need, so subsequent harvests will become incrementally less nutritious. However, this will take a very long time, likely millennia, for most minerals, and it presumes they are not adequately replaced by rock strata below, volcanic and other dust, and by ruminants redistributing minerals in their urine and faeces.

Thus, in the immediate term, acknowledging the geology of soils and underlying geology, varies, soils may be richer or poorer in particular nutrients, there will be no general shortage of minerals, accessible to mycorrhizal systems, in immediately accessible soil media, and underlying rock strata that will be degraded over time. Some soils may need supplementation of individual minerals, and others may contain excessive amounts making resultant vegetation toxic to livestock, but that will only be clear once regenerative agriculture has determined what the soil biome (as against NPK farming) is unable to both supply and preferentially selects for.

47.2 FATBAS - REDUCTION IN FOOD MINERAL CONTENT

We have to better appreciate that *'The very things that speed growth — selective breeding and synthetic fertilizers — decrease produce's ability to synthesize nutrients or absorb them from the soil.'* (Burns, 2010) Crops grown under such conditions have been assayed and shown to contain fewer nutrients, including minerals and proteins.

At the same time, because of fertiliser usage, crop nutrient densities per unit weight have, it appears, fallen. Further, even when yield is lost with regenerative agriculture, an increase in nutritional density means any yield advantages of FATBAS, when present, are less clear-cut than they may first appear (Long, 2009).

Nutrients are best provided from the soil to plants by mycorrhiza and bacteria. Regenerative crops have higher nutrient density. Fertilisers contain a more limited range of nutrients than

soils. Plants supplied with NPK fertiliser have reduced access to the broader range of minerals in soils. NPK-based crops tend to have lower and skewed mineral content. They also may have higher nitrate content, which in grasses can be an issue for cattle health.

For example, raspberries fertilised with additional phosphates had higher phosphate content, but lower mineral content and greater dry matter; *“20% higher concentration of P than unfertilized plants (dry weight basis). However, the concentrations of all eight other measured minerals declined, usually by 20% to 55%. Fertilization produced large increases in plant dry matter, 37% at 22 ppm and 119% at 44 ppm”* (Davis, 2009).

More generally, observational data suggests that nutrient content in FATBAS crops, per unit weight, appears to be falling, which chimes with anecdotal reports from animal feedstuff purveyors, who, unlike human food purveyors, monitor key nutrient parameters in animal feed. Conversely, several reports suggest regenerative agriculture crops generally have higher nutrient values than FATBAS crops.

Consistent with reduced minerals in crops, magnesium levels have also fallen, *‘Magnesium deficiency in plants: An urgent problem’* (Guo, 2016), observed, *“Mg contents in historical cereal seeds have markedly declined over time, and two thirds of people surveyed in developed countries received less than their minimum daily Mg requirement”*. The paper further observes, *“Mg content in seeds declined markedly after 1968 in parallel to the Green Revolution and the history of heavy chemical fertilization in agriculture. Consequently, most people absorb lower Mg from cereals than the estimated indexes”*.

In humans, *“It is estimated that one-third of the world population is at risk for zinc deficiency; it is the fifth most important risk factor for disease in developing countries. Worldwide, an estimated 800,000 people die every year from zinc deficiency, which is comparable to the total mortality from malaria.”* However, we pay more attention to malaria, which is considerably more challenging to resolve (Udo de Haes, 2012).

The thought-provoking report by McCance and Widdowson (Thomas, 2003) on falls in food nutrient values between 1940 and 2002 indicates the actual scale of mineral loss from food due to a combination of the implementation of FATBAS and a lack of focus on crop nutrient values during crop breeding for particular characteristics.

The McCance and Widdowson data aligns with the expected general effects of NPK-driven agriculture and is thus profoundly concerning. The results are also consistent with several other studies. Further rises in nutrient densities of similar order are seen in crops with moves from FATBAS to regenerative agricultural principles, as discussed in more detail below.

Some people question the McCance and Widdowson data reproduced in the slide below. Many potential variables exist, including the origin of the foods selected for the assay, but the direction and general message of the data regarding nutrient depletion are logically sound and in agreement with other such data.

Thus, excessive use of commercial fertilizers replenishes the soil’s *‘foundational nutrients’*; nitrogen, phosphorus and potassium (NPK) (*“Fertilizer 101: The Big 3 - Nitrogen, Phosphorus*

and Potassium,” 2014); but due to a diminished mycorrhiza, depletes plant health pest resistance and nutrient and antioxidant density.

Things are as ever complex, but given observed soil degradation on farms using significant amounts of agro-fertilisers and chemicals, recorded falls in soil carbon, thus the reduction in energy and structural substrate support for soil biome life, which trade minerals and other nutrients for plant sugars, it would be logical, as indeed suggested by limited available data, that crop nutritional values have fallen (Esther, 2011).

Breaking or downregulating the symbiotic relationship between plants and the microbiome impedes plant access to a broader basket of minerals and support mechanisms, including genetic transcription-related plant adaptation prompted by the denizens of the soil biome, to promote their own well-being, by minimising the impact of adverse events and conditions, including drought, on their plant symbionts.

Additionally, research has demonstrated that the surface application of NPK promotes shallow root formation. A lack of root depth reduces direct root access to nutrients and water, making plants more susceptible to drought, less capable of directly accessing minerals and soil biome support services, and less able to supply sugar exudates to the soil biome. Logically, these deficient crops will be less nutrient-dense and more susceptible to pests and diseases.

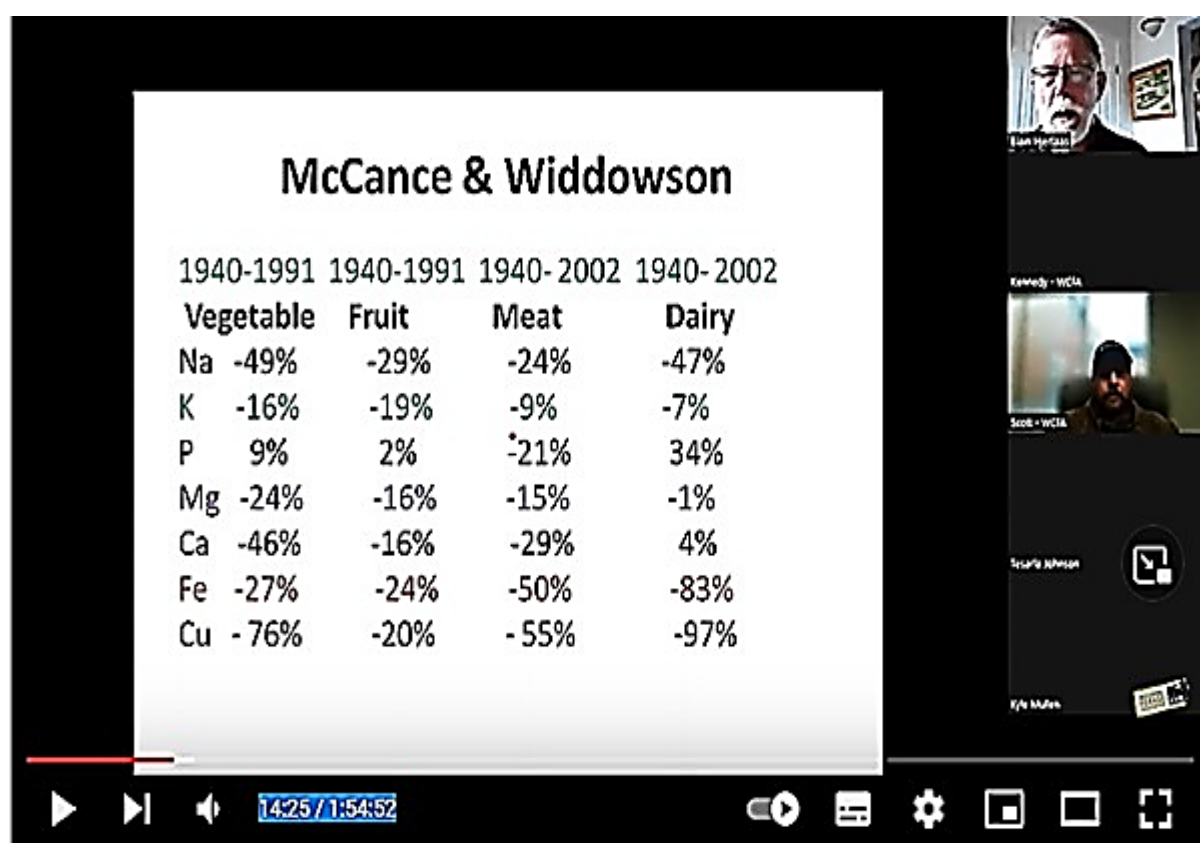


Fig. 130. A slide reporting McCance and Widdowson data (Thomas, 2003) from the UTube lecture Adaptive Grazing Webinar: by Blain Hjertaas with many thanks to the authors. (Hjertaas, 2022)

Ultimately, it is in the interests of mycorrhizal and bacterial soil systems to supply their plant symbionts, which photosynthesise and supply the carbon sugar/fats food sources needed by the soil biome, thus keeping plants healthy and free of pests, and even for specific species of mycorrhizae and bacteria to preferentially help particular plant varieties, where that specifically benefits them, and vice versa.

The review '*Nutrient Exchange and Regulation in Arbuscular Mycorrhizal Symbiosis*' (Wang, 2017) provides very useful background. Much remains to be researched, but it is clear that a better understanding of the very complex, nuanced, multifaceted symbiotic relationship between plants and mycorrhizal systems is crucial to efficient, sustainable farming, and nutrient-dense crops, including feedstock production.

Yes, the issue of nutrient density of crops is complex, an OECD document cited in Marles (Marles, 2017) observes that *"the average mineral content of a given wheat grain varies significantly from one part of the world to another. This appears to be a function of a number of factors, including the wheat variety, the growing and soil conditions, and fertilizer application. The mineral composition of wheat has more to do with environmental conditions, rather than varietal characteristics"* ("Consensus Document on Compositional Considerations for New Varieties of Bread Wheat (*Triticum aestivum*): Key Food and Feed Nutrients, Anti-nutrients and Toxicants," 2003).

In '*Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999*,' Davis also observed significant mineral variation in similar crops (Davis, 2004). Consistent with such variation, farming using low-till, high-variety cover crops, with no bare ground, no artificial inputs, or biological fertilisers has been shown to enhance plants' nutrient and phytochemical content and reduce the soil burden.

A 2022 study titled '*Soil health and nutrient density: Preliminary comparison of regenerative and conventional farming*', where ten successful regenerative farmers grew 1 acre (0.4 hectares) each of peas, sorghum, corn, or soybeans and results compared to the same crops produced on a neighbouring conventional farm, concluded:

- *Food grown on the regenerative farms contained, on average, more magnesium calcium, potassium and zinc; more vitamins (including B1, B12, C, E and K), and more phytochemicals", "higher levels of omega-3 fats and a more health-beneficial ratio of omega-6 to omega-3 fats than meat from local supermarkets".*
- *"Most notably, soil health appears to influence phytochemical levels in crops," the authors write, "indicating that regenerative farming systems can enhance dietary levels of compounds known to reduce risk of various chronic diseases."*
- *The regenerative farms also had overall healthier soil with more carbon content.* (Montgomery, 2022)

Return of organic matter to the soil in high biology compost and or seed treatment, combined with low till; high variety high cover crop use; using no artificial fertiliser, and minimal agrochemicals; results in; rising carbon levels in soil, greater microbial diversity, elimination of need for NPK fertilisers, minimal agrochemical requirements, as well as potentially better

yields; higher plant mineral and protein content, and health, as well as lower costs, and greater profits. Greater plant nutrient content, in turn, feeds through into healthier humans and livestock.

Consistent with this, several regenerative farmers have reported higher crop densities. The Haggerty's regenerative farm, which comprises many thousands of hectares in low-rain, sandy Western Australian soils, using regenerative principles, without fertilisers, and minimal use of agrochemicals, achieves greater mineral and protein crop content than their neighbours. They discovered their crops were more nutrient-dense because grain wagons filled to the grain line, when stopped for a police check, were found to be overweight. To work out why, they had their grain assayed. The results showed that their wheat had higher mineral and protein content, which allowed them to achieve premium prices for their grain. In addition, they sequester carbon in soil, improve hydrology, and farm more profitably.

47.3 LACKING NUTRIENTS – PASTURE COWS AND DAIRY

To produce milk, cows need plant-derived minerals and polyunsaturated lipids. Dr Christine Jones observes that fertiliser use on pastures of dairy farms promotes the production of more green material, but the fertilised grass is less nutrient-dense. Indeed, NPK fertilised grass is taller and more verdant, yet more likely to have lower nutrient value. Despite increased pasture growth, milk production from cattle eating lush nitrogen-fertilized pastures remains relatively stable, yet tellingly, it is lower in protein and likely other nutrients, including minerals. In contrast, cattle grazed on alpine pastures, and their milk products tend to have better nutrient and fat profiles, and flavour.

For example, in one experiment, *“cows consuming herbage cut from spring pastures which had received higher rates of N fertiliser, ate less dry matter, produced milk with a lower protein content and had a lower milk protein yield”* (Mackle, Parr & Bryant, 1996).

Other research makes related observations. *“It is suggested that superimposing high rates of nitrogen fertiliser on to existing dairying systems will not significantly improve animal performance and may have a negative effect on clover content and pasture quality”* (Harris, 1994). High nitrogen application can also negatively affect cattle health.

A five-year study using 250 or 750 kg of N per hectare also saw no milk yield difference (Coombe, 1980) but did increase nitrogen content; some suggest high nitrogen can impair cattle health. In contrast, as observed earlier, soil carbon-centric multispecies cover crop farming with rotational half-height grazing has improved milk yields, cattle health, and land-carrying capacity.

47.4 SOIL DESTRUCTION = NEEDLESS DEPRIVATION AND POVERTY

We are utterly reliant on our soils for food. More broadly, soils and the green and varied life they support are a key part of the biosphere that enables and regulates life on Earth. Land degradation, the inevitable consequence of the destruction of soil biology, erosion of geology, and damage to hydrology, is an age-old human-induced phenomenon that results in food

shortages, conflict, and, ultimately, the breakdown of civilisations. The difference is that we now have no excuses, as we understand the causes of soil degradation.

In 1939, Lowdermilk, in his book 'Conquest of the Land Through Seven Thousand Years' powerfully conveyed his concerns about soil degradation: *"If the soil is destroyed, then our liberty of choice and action are gone, condemning this and future generations to needless privations and dangers. So big is this job of saving our good lands from further damage and of reclaiming to some useful purpose vast areas of seriously damaged and ruined lands, that full cooperation of the individual interest of farmers with technical leadership and assistance of the Government is not only desirable, but necessary, if we are to succeed"* (Lowdermilk, 1939).

Almost 80 years later, we understand soil biology much better and must, at last, recognise that it is not only desirable but imperative that we act on Lowdermilk's enjoiner to look after our soils, as they not only feed us but help regulate our atmosphere and thus our climate. We must adopt regenerative, soil-health-focused agricultural practices to preserve the health and quality of our agricultural soils for future generations if our species is to '*live long and prosper*'. Sadly, broader society still does not understand this reality.

Regenerative agriculture should also include closing the nutrient cycle. Recycling through composting, human and livestock waste, organic matter, other nutrients and minerals, including nitrates and phosphates, was for centuries a central and integral part of maintaining productive use of land. Today, millions of tons of waste containing nutrients and minerals, including phosphate-rich material, are sent to landfills, incinerated, or disposed of in water courses, causing environmental damage to rivers and oceans because we have, as yet, not worked out in our 'modern' world, how best to collect and remediate human and livestock, faeces and urine, (and broader organic waste), and return it to the land; or adequately taken on board the need to look after our soils: yet we can send probes and telescopes deep into space and to other planets.

We have paid insufficient attention to many modern examples of farmers successfully and profitably using regenerative agricultural techniques. We ignore historical examples of sustainable agriculture, in particular, the ability of the Chinese, with continuous use of the same land over thousands of years, to feed up to 5 people an acre, without artificials, simply through the return of all organic matter to the soil, good practice including the planting of mixed species, and general soil maintenance and management – with current knowledge we could do even better.

We have also failed to take on board, sufficiently support and further research emerging evidence of the climate benefits of carbon-soil-centric regenerative-agriculture-based farms. Regenerative farms, using multispecies cover crops, half-height-grazing, and low till technology, with no input of artificial fertilisers, are achieving near equivalent or better cash crop yields of higher nutrient quality, with lower costs, so greater profits than FATBAS farmers. At the same time, regenerative agriculture is reducing pollution, increasing diversity, improving hydrology, and helping sequester carbon, thus, respecting the sophisticated regulatory mechanisms of the planetary Gaian biosphere that nourishes us, helping ensure future human planetary habitability.

47.5 NPK: YIELDS AND NUTRIENT DENSITY

Agriculture's industrialisation has helped massively reduce labour requirements and improved technology, knowledge, and plant breeds. Yields per acre for many crops have significantly increased over the last century due to greater planting density, better breeds, particularly for wheat and corn, and the availability of fertilisers to compensate for the diminution of soil biome activity and organic matter content.

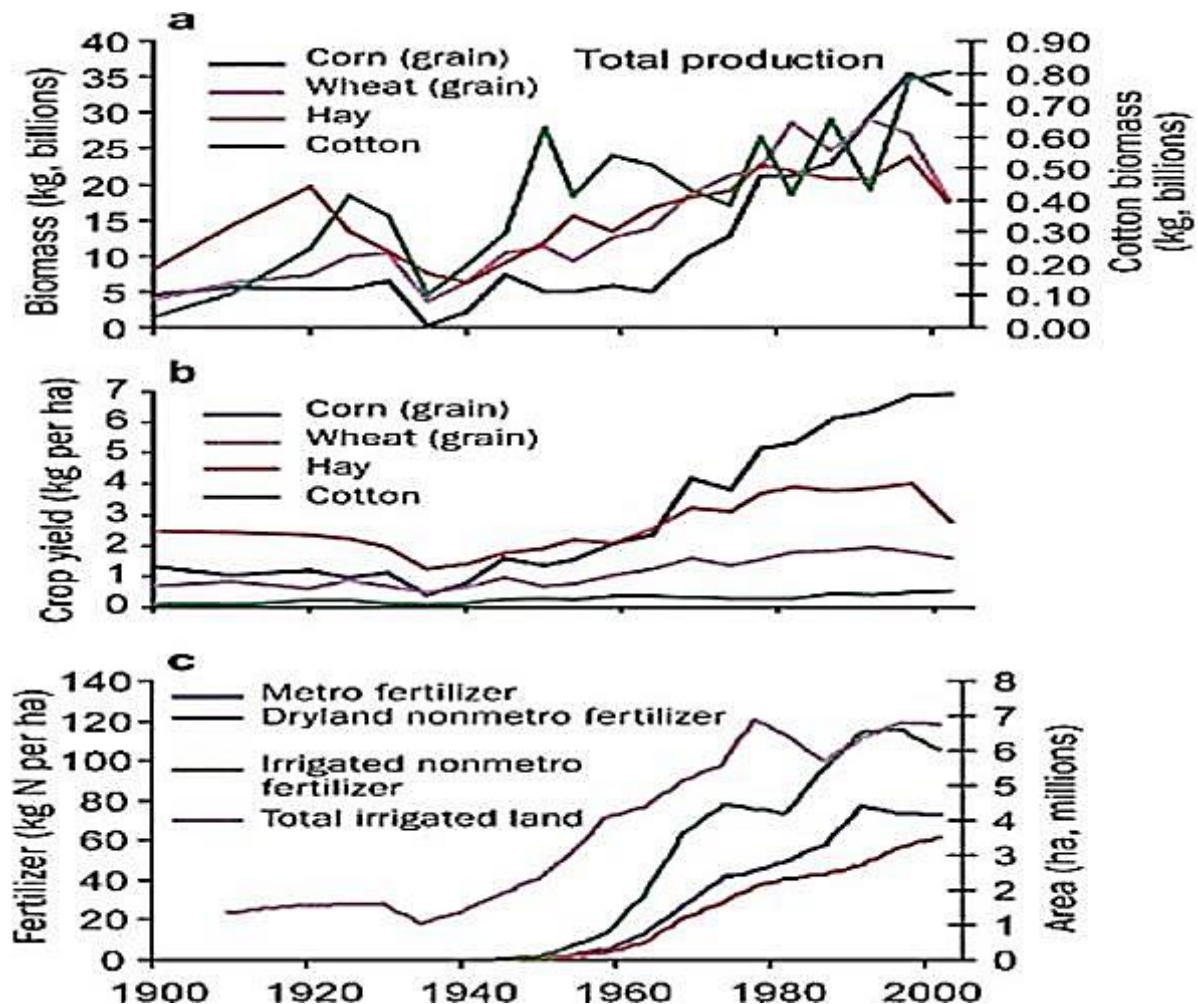


Fig. 131. From the paper 'Long-term Trends in Population, Farm Income, and Crop Production in the Great Plains', with many thanks to the authors: "Total Great Plains plant production for corn, wheat, hay and cotton, and (b) average Great Plains crop yields for the same crops. (c) Total area of Great Plains irrigated nonmetro land and average nitrogen inputs from fertiliser for metro, dryland nonmetro, and irrigated nonmetro land. Total production and yields have risen steadily since the 1930s, with the greatest increases in corn and hay, the crops that benefit most from irrigation. Cotton production and yields have grown the least. The bottom panel shows the growth of inputs: the rise of fertiliser application from very low levels to more than 100 kilograms per hectare for corn in 1992, and the large increases in irrigated land that took place from 1950 to 1974. Source: Gutmann (2005a)" (Parton, 2007).

Corn is very demanding of nitrogen, and artificial fertiliser has clearly helped yields. Corn yields per hectare roughly trebled over the same period. However, it is suggested that wheat, hay, and cotton returns have not increased hugely.

However, returns are plateauing, and soil health and hydrology are degrading badly. Maintaining crop yields is becoming increasingly complex, demanding, and costly, including in fertiliser, agrochemicals, and irrigation water. Further, FATBAS is proving to be unsustainable because of the damage it does to soils.

Indeed, regenerative farmers report matching average modern fertiliser-based yields while improving rather than degrading soils and increasing water sequestration. Consistent with this, initial yields were surprisingly high when, with diverse soil biomes rich in soil carbon, the American Great Plains were first ploughed. On the Great Plains, synthetic fertiliser soared between its arrival on a large scale in the late 1950s and the early 2000s.

Many soils already contain significant stores of the less soluble, bound forms of minerals, including phosphates, due to years of fertiliser application. For plants to gain access to these, it makes more sense to encourage mycorrhiza with compost biology rather than add more of the same.

48 MINERAL AVAILABILITY - MADE BY SUPER-NOVA NOT CROP ROTATION

Whilst multispecies cover-crop farming increases plant health and nutrient density by improving mycorrhizal activity, thus giving plants better access to soil minerals, etc., mycorrhiza are ultimately incapable of creating the rock particles and dust that make up the geological component of soil.

Table 3. Based on table 4 from *'Scarcity of micronutrients in soil, feed, food, and mineral reserves Urgency and policy options'*. Platform Agriculture, Innovation & Society with many thanks to the authors. (Udo de Haes *et al.*, 2012)

Table 4 Average levels of micronutrient elements in the Earth's crust, ranked according to level (Source: Rudnick and Gao 2003). ppm = parts per million.

Nutrient	ppm	Nutrient	ppm
Silicon	311,000	Chlorine	370
Iron	39,200	Chrome	92
Calcium	25,600	Zinc	67
Sodium	24,300	Nickel	47
Potassium	23,200	Copper	28
Magnesium	15,000	Cobalt	17
Aluminium	8,150	Boron	17
Manganese	775	Iodine	1.4
Phosphorus	655	Molybdenum	1.1
Sulphur	621	Selenium	0.09

Mineral elements form in supernovas, and minerals become part of the surface mantle when planets are created. Rock degradation by glaciers, general weathering, biological action, and volcanic activity accumulates rock dust and particles over time, forming the geological element of soils.

The rock-based mineral geological portion of soils is significant. Thus, mineral exhaustion will take a long time. However, the table above shows that critical nutritional elements, such as zinc, molybdenum, and, more so, selenium, are relatively limited in the earth's crust and, thus, soils. As discussed, some minerals, such as selenium and zinc, can be even lower in particular geological areas because the underlying rock contains limited amounts.

Minerals are essential to enzyme function, and enzyme function is central to all life forms. Thus, minerals are much more important than most realise to plants and soil life forms. For example, molybdenum is essential for nitrogen fixation by legumes (Udo de Haes, 2012).

The quantity of minerals stored in soils should be sufficient to supply agriculture for many generations. Dust, including volcanoes, erosion, and the breakdown of deeper rock strata by plants and weather, replaces them to some extent.

Deep-rooting cover crops, including grasses, some with roots that can extend 5 metres, with the assistance of mycorrhiza, can mine minerals from lower levels in soils and transport them to the surface for recycling in upper soil layers, but as the available minerals, and particularly trace minerals, are extracted, ultimately there will be mineral diminution even in deeper stored minerals in soils – but for some minerals, this may take hundreds if not thousands of years. However, as mentioned above, natural mechanisms will to varying extents, replace and recycle minerals.

48.1 CROP ROTATION DOES NOT CREATE MINERALS IN SOILS BUT IMPROVES SOIL BIOME FUNCTION

Albrecht, a noted American agronomist and author of perspicacity and vision, conducted fascinating research on crop rotation and mineral availability in soils. Albrecht grew plants from soil from all over the USA in tea chest containers. He demonstrated crop rotation, often suggested as a way of improving the mineral content of soils, instead accelerated the extraction by plants of minerals from the soil. Albrecht observed that crop rotation improved the health of the soil biome and its interaction with plants, thus enhancing the efficiency of plants in extracting minerals from the soil biome. Crop rotation did not miraculously de novo create minerals in the soil. As mentioned above, the creation of minerals is a galactic process.

Diversity improves plants' capacity to abstract minerals but cannot impact the soil's actual mineral content. However, in non-containerised soils, mineral availability and, thus, fertility may improve as minerals are mined and moved up by deep-rooting plants from deeper fragmented rock and subsoil layers.

However, crop rotation has other benefits. For example, it may help control diseases caused by phytopathogenic bacteria in cereal crops by rotating with crops that do not act as a host to the pathogen (Butsenko, 2021). However, as above, it does not ‘make’ minerals. Growing crops and exporting the seed and other organic matter in those plants also exports minerals, including to feed humans in densely populated conurbations. Under the current paradigm, those minerals end up in urine and faeces in a highly polluted sewage stream, precluding their safe return to soils, as discussed in Volume 1 on sewage.

48.2 NUTRIENTS ARE EXISTENTIAL TO PLANTS

Nutrient deficiencies, including minerals, can have severe consequences for the growth of plants. Plants require nitrates and phosphates as well as a range of minerals including “calcium (Ca), magnesium (Mg), and sulfur (S), as well as micronutrients including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), and molybdenum (Mo).” (Nguyen, 2024) and likely others for healthy growth.

For millions of years, plants have efficiently met these needs in natural ecosystems with the assistance of the soil biome, creating vast forests and savannahs that supported a huge number and diversity of wildlife without human intervention or the use of fertilisers.

Generations of farmers, for example, in China, have learnt that assisting natural processes with biological and natural mineral amendments helps secure the crops that feed them. History also teaches us that poor land management destroys ecosystems. Using concentrated soluble phosphates and nitrates was a misstep because it disturbed natural processes and symbioses essential to plant and soil health.

48.3 IODINE A SPECIAL CASE?

Iodine is highly soluble, washed out by rain, and can sublime; thus, it is not often found in quantity in porous substrates. Iodine is continuously recycled through the ocean emission of organic molecules of marine origin, with attached iodine, into the atmosphere, which is then transported inland in the rain. The marine migration of aquatic species, such as salmon and eels, inland via rivers transports iodine to the interior of land masses, from where it is distributed widely inland through several mechanisms. Plants and the soil biome will take up iodine, and over time, release it into water flows that return it to oceans. FATBAS speeds that process, resulting in lower iodine levels in the food chain.

Mountainous areas with limited amounts of ocean-derived rainfall tend to have low iodine in soils. As discussed, heat domes, by inhibiting the inland circulation of marine-derived rain, will have the secondary effect of reducing iodine in soils available to crops and, through grass, to herbivores. As discussed in the first volume on sewage and the third Volume on water, iodine is crucial to health, female reproduction, and brain development and function.

Whilst there is minimal research into the effect of iodine on crops, there are indications that it can positively impact yield and plant health if appropriately used. As discussed elsewhere, including in ‘*Seaweed in Agriculture and Horticulture*’ (Stephenson & Booth, 1968), reports suggest the use of seaweed-based foliar sprays and the residual salts from the production of

sea salt, which, if not dried will contain some iodine, may have very favourable effects on crop, crop pests such as spider mites, disease including blight, frost resistance, shelf-life, broader health, and yield.

Importantly, iodine deficiency and insufficiency are issues of significance in many countries, including the UK, where studies suggest that up to 70% of females are insufficient in iodine. Exposure to bromide additives in foods and indirectly through food additives and uptake from fumigated foods, plants, and treated furniture can exacerbate iodine insufficiency. This familial biological halide competitor may displace iodine in cells, with serious adverse health consequences.

Indeed, adequate iodine is essential to development in utero, including brain development. Iodine and omega-3 DHA are crucial to optimal neuronal migration, which starts early in development, possibly as early as week 7. At the extremes, severe iodine deficiency causes cretinism, which is seen in significant numbers in some parts of the world. Thus, low-level fortification of crops, including wheat (Cakmak, 2017) and other crops, as discussed more widely in *'Use of Iodine to Biofortify and Promote Growth and Stress Tolerance in Crops'* (Medrano-Macias, 2016) through use of sea-weed extract or sea salt residue foliar sprays, may have significant national health benefits helping prevent iodine insufficiency.

Importantly, Cakmak notes that foliar sprays at the appropriate time in the growth cycle, but not direct fertiliser application, increased the iodine content of seed. *"In contrast to the soil applications, foliar spray of KI and KIO₃ at increasing rates during heading and early milk stages did enhance grain iodine concentrations up to 5- to 10-fold without affecting grain yield."* (Cakmak, 2017)

Hence, the application of marine-based foliar sprays to crops, though improved mineral content, including iodine, would contribute to broader mineral intake and, thus, public health. Marine-based, mineral-rich, iodine-containing sprays derived from sea salt production residue would also likely improve plant yields, health, disease resistance, and shelf life, as reported in *'Seaweed in Agriculture and Horticulture'* (Stephenson & Booth, 1968). More research is required into the broader introduction and optimisation of a new and additional approach to helping optimise plant health and growth support, using foliar sprays containing iodine and marine derived minerals.

48.4 FATBAS - ULTIMATELY UNSUSTAINABLE

FATBAS is a causative in many of the elements of land-related climate change events as outlined above, which is in part due to the addiction to NPK, creating a downward spiral of human, agricultural and biological ecological poverty, because *"The application of high rates of inorganic N inhibits the microbial communities formed by associative diazotrophs and mycorrhizal fungi that are able to fix and transport atmospheric N for free."* (Jones, 2017) and drives down soil carbon and associated soil water retention leading to reduced evapotranspiration related cooling, global drying, and through bare soils global land-atmospheric heating.

Further the wasteful use of mined phosphate, a precious long-term resource, is unsustainable. *“Approximately 20 million tonnes of phosphorus are mined each year for fertilisers; almost half returns to the ocean – eight times the natural input”* (Corcoran, 2010).

“The other – often overlooked – factor is that a reliance on monoculture crops and low diversity pastures simplifies the soil microbiome. Lack of functional diversity produces a raft of negative consequences including an open invitation to pests and diseases, ultimately leading to increased use of fungicides and pesticides. Inevitably, loss of soil function results in more chemicals being applied, more damage to the wider environment and less profit for farmers” (ibid).



Fig. 132. Phosphate mine near Flaming Gorge, Utah, US, 2008 with thanks to Jason Parker-Burlingham.

49 SOIL LIFE - MYCORRHIZA, BACTERIA ET AL. FACILITATE PLANT GROWTH

As discussed more widely previously, a healthy, diverse, plant carbon sugar exudate-supported soil biome is essential to healthy, productive plant growth. Mycorrhizal biome soil systems provide a wide range of services, including mineral abstraction, phosphate provision, ‘medical’ services, binding of toxic metals, detoxification of biological molecules, desalination of soils, metabolic water provision, and improved water penetration and retention, as reflected in the slide below.

Further, everything is recycled, including essential soluble nutrients in dead bacteria, soil life, and their slime urine and faeces. These will be available for transport to plant roots, providing extra nutrients and reinforcing the importance of the microbiome functioning as an integrated ecosystem. *“Soil microbial composition is mainly related to plant diversity”* (Dwivedi, 2013).

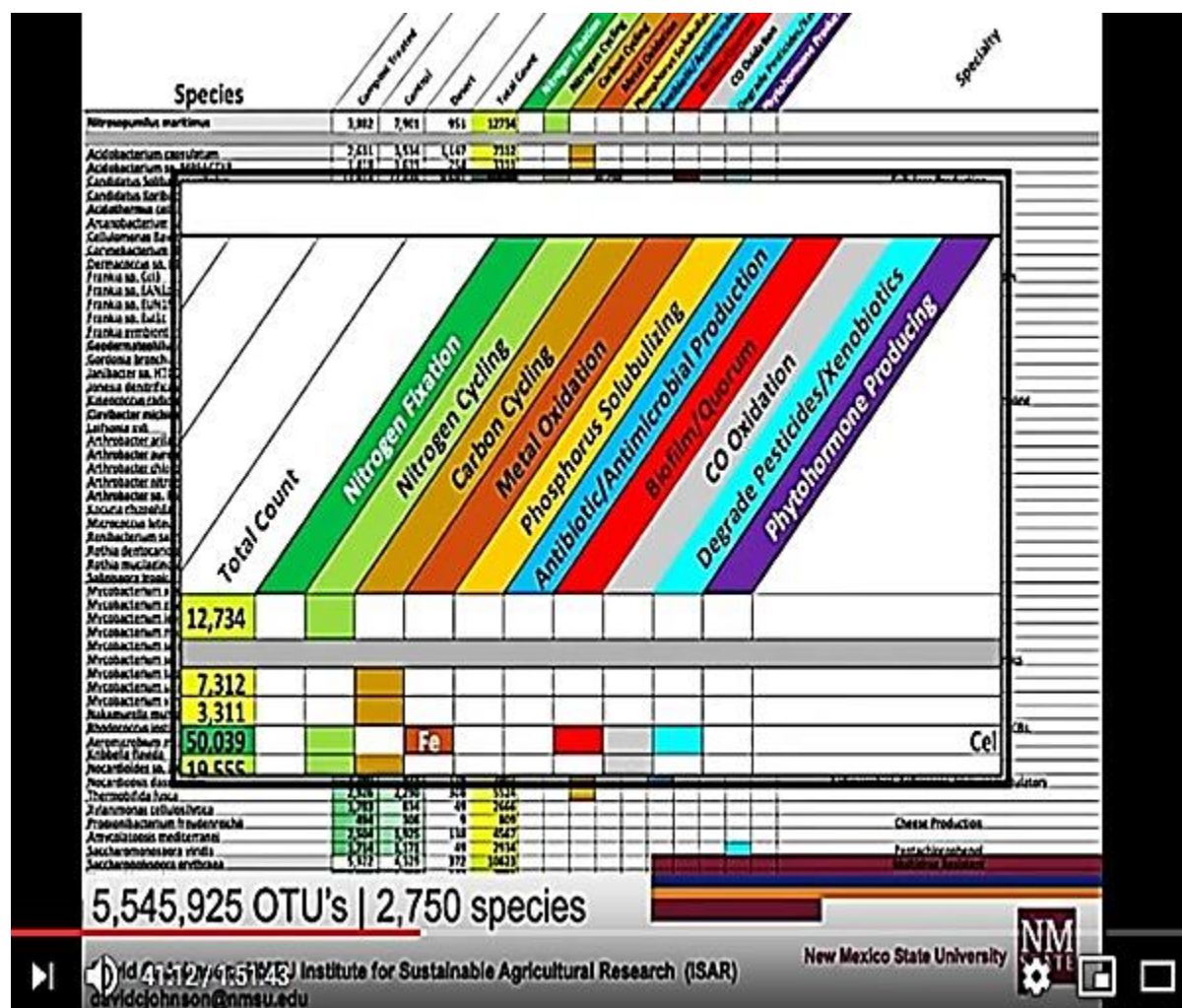


Fig. 133. Mycorrhizal systems have several functions and particular microbes will have their own specialities; from the YouTube lecture ‘Dr David and Hui Chun Su Composting’, with very many thanks to the authors. (Johnson & Su, 2019)

Mycorrhizae can dramatically improve plant growth; “For example, inoculation of fumigated sand or soil with VA mycorrhizal fungi will increase the growth of citrus by as much as 1600 percent; grapes by 4,900 percent, soybeans by 122 percent, pine by 323 percent, and peaches by 80 percent. Growth responses due to VA mycorrhizal fungi have been observed in cotton), tomatoes, corn, wheat, clover, barley, potatoes, ornamental plants, and in many other crops (Menge, 1985).

The mycorrhizal biome assists plants by mining, transporting, and supplying minerals and wider nutrients; “mycorrhizal fungi may increase the effective absorbing surface of a host root by as much as 10 times. Nutrient ions such as phosphorus, zinc, and copper do not diffuse readily through soil. Because of this poor diffusion, roots deplete these immobile soil nutrients from a zone immediately surrounding the root. Mycorrhizal hyphae extend into the soil past

the zone of nutrient depletion and can increase the effectiveness of absorption of immobile elements by as much as 60 times” . . . “Others have calculated that approximately 50cm of mycorrhizal hyphae per cm root is necessary to account for the uptake of phosphorus by mycorrhizal plants. . . Experimental observations indicate that plant roots can have more than 80 cm of mycorrhizal hyphae” (Menge, 1985)

Specific microbes have an affinity for particular metals, explaining why a more complex biome may promote better plant growth through more efficient selective nutrient acquisition.

Further, mycorrhiza and bacteria work in symbiosis to provide plants with nutrients. “VA (Vesicular-Arbuscular Mycorrhizae) mycorrhizal fungi stimulate plant absorption of phosphorus, zinc, calcium, copper, iron, magnesium, and manganese. Increased uptake of phosphorus is perhaps the most important benefit provided by mycorrhizal fungi” (Menge, 1985). Much is still to be learnt.

Metal Oxidation out of Soil Parent Material (Elemental Nutrient Acquisition)		
1	Candidatus Solibacter usitatus	Fe
2	Geodermatophilus obscurus	Mn
3	Arthrobacter nitroguajacolicus	Cr
4	Streptomyces albus	
5	Anoxybacillus flavithermus	
6	Bacillus sp. SG-1	Mn
7	Bacillus subtilis	Bo
8	Lysinibacillus fusiformis	Bo
9	Paenibacillus sp. Y412MC10	
10	Magnetospirillum magneticum	Fe
11	Cupriavidus metallidurans	Au
12	Albidiferax ferrireducens	Mn
13	Anaeromyxobacter sp. Fw109-5	
14	Pseudomonas fluorescens	Fe

Fig. 134. Microbial ‘Metal Oxidation and out of Soil Parent Material’ from the UTube lecture titled ‘Dr David and Hui Chun Su Composting’, with very many thanks to the authors. (Johnson & Su, 2019)

49.1 SOIL BIOME NITROGEN UPTAKE - CARBON LIMITING FACTOR

The importance of soil carbon, as the limiting factor in soluble nitrogen uptake, is helpfully discussed in the review, ‘Organic nitrogen storage in mineral soil: Implications for policy and management’ (Bingham & Cotrufo, 2016) repeated due to its importance, which observes,

“As we discuss below, the first step in the retention of added N is microbial processing driven by C availability, a driver of kinetic saturation. As the authors note, evidence for capacity saturation on the other hand is weak in most undisturbed temperate ecosystems. Many ecosystems with a variety of vegetation and soils have demonstrated an ability to retain most additional N, with exceptions being areas having obviously low capacity levels such as thin alpine soils.” (Bingham & Cotrufo, 2016) (Authors underline)

“The capacity of a soil to process N is increasingly being recognized as the bottleneck that leads to N saturation; this kinetic saturation appears to be driven by an imbalance of N inputs over C inputs, but factors that influence long-term N storage may play a role as well” (Bingham & Cotrufo, 2016)

In the review ‘Organic nitrogen storage in mineral soil: Implications for policy and management’ it was noted, *“Because N immobilization is now recognized to be driven by ecosystem properties such as edaphic qualities and microbial activity rather than the chemical characteristics of N compounds, more precise and targeted critical loads for N saturation can be developed.”* (Bingham & Cotrufo, 2016).

The paper further notes that consistent with this, *“forest soils with greater C content (such as old growth forests) rapidly integrate greater amounts of N into long-term storage than forest soils with lower C contents.”* (Bingham & Cotrufo, 2016)

While much research remains to be done, carbon in soils plays a number of central roles, including nitrogen fixation and availability, storage, and metabolism. Thus, a return to more ‘soil carbon centric’ farming that seeks to optimise the photosynthetic capacity of the land would be economically and environmentally beneficial, including by sequestering nitrogen and preventing run-off and nitrification of water sources.

49.2 pH

Soil pH is a significant factor in mineral uptake. The review, ‘Land contamination by metals: Global scope and magnitude of problem’, observes *“Among the various factors affecting transfer of metal pollutants to plants, pH-conditions in many instances are most important. Generally, the lowering of pH by one unit will increase metal solubility by factor 10.”* (Wolf, van den Brink & Colon, 2012) (Authors’ underline)

Clearly, pH impacts essential mineral uptake in plants, with a broader range of downstream impacts. *“At pH 7 the limit of 1mg Zn/L in soil equilibrium solution (which already may lead to slight depressions in yield for cabbage) would be attained at approximately 1200 mg Zn/kg in soil. However, at pH 6, maximum permissible Zn-concentrations in solution would be reached with 100 mg Zn/kg soil, at pH 5 it would be reached even at 40 mg/kg. It seems that under the latter conditions, pH 5, adverse effects can be found even in unpolluted soils.”* (Wolf, van den Brink & Colon, 2012)

More widely, for the above reasons, a combination of low pH and high levels of heavy metals could be a matter of particular concern in some areas. Consistent with this, research suggests raising pH, thus acidity, including with lime, reduces mineral uptake. *“Liming treatments*

resulted in trend of heavy metals availability decrement in all soils, but intensity of decrement differed considering initial soil acidity and initial heavy metals availability.” (Karalić, 2013)

Plants and mycorrhiza can alter pH locally to assist mineral abstraction, so things are complex, but developing healthy soils with an environmentally optimal pH would be desirable. Healthy plants alter soil Ph to optimise their growth prospects; they can “*increase or decrease rhizospheric pH up to 2–3 pH units, mainly by absorption or release of protons*” [pH impacts mineral availability], while “*plants can also modulate the symbiosis, by stimulating fungal metabolic activity and hyphal branching among other effects*” (Campos, 2018). Consistent with this, regenerative farmers report higher pH without adding lime.

49.3 DUNG BEETLES AND OTHER FREE TINY WORKERS

Dung beetles come in a vast variety of species, about 10,000, and perform critical roles in incorporating faeces into soils. A cow produces around 12 tons of dung a year; a herd of a hundred cows produces 1200 tons yearly. Thus, dung beetles perform invaluable free ‘services’, replacing costly heavy plant operations by moving, mixing and spreading this manure fertiliser into soils, with the additional benefits of causing no compaction and being ‘green’, with no time or financial costs. As invertebrates, they are killed by deworming chemicals. Thus, chemical deworming of cattle negatively impacts the regeneration of degraded ranges.

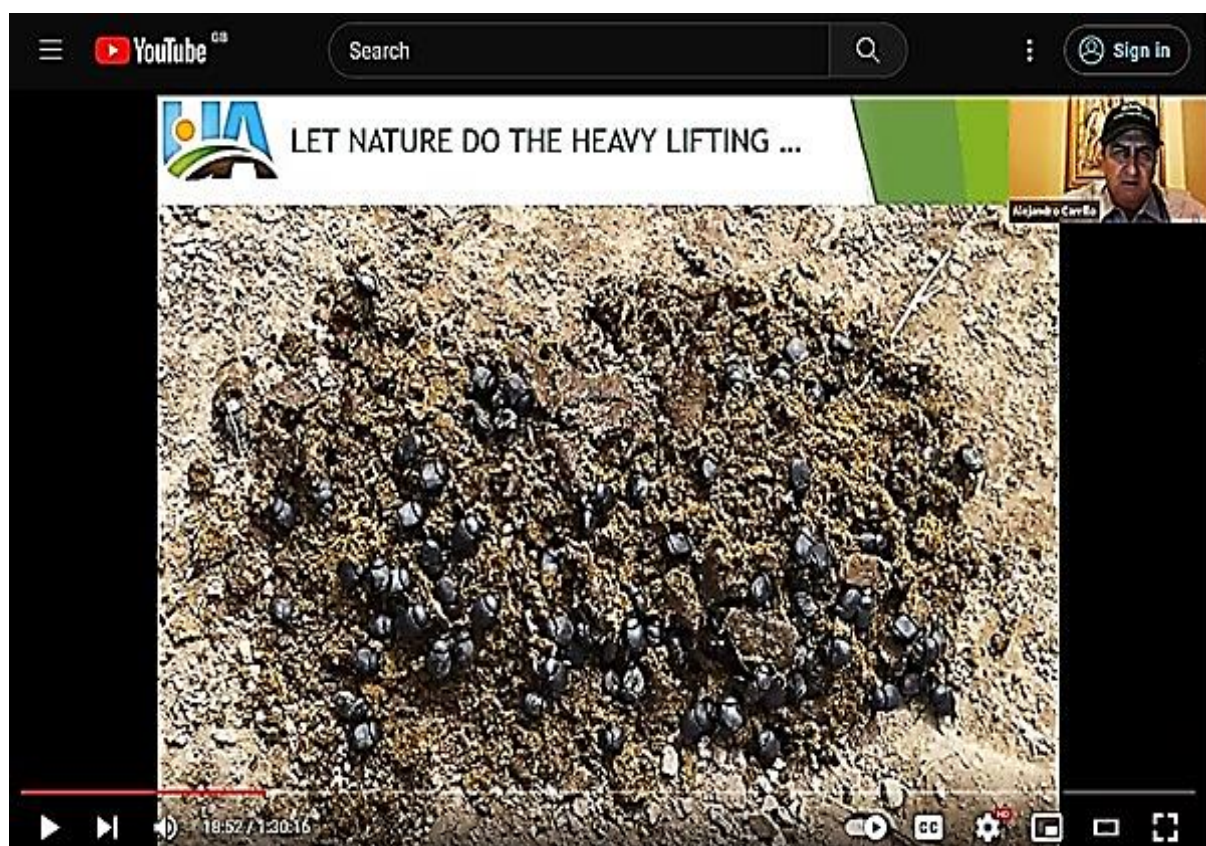


Fig. 135. Las Damas Ranch Mexico, slide from UTube video ‘*Building Resiliency: Ranch Resiliency with Alejandro Carrillo 10-28-21*’ showing dung beetles at work (Carrillo, 2021).

Farmers using regenerative practices see low worm infestations in cattle, which they believe is due to the constant moving of cattle and time gaps before re-grazing, reducing the opportunities for cattle to ingest parasitic eggs. Parasitic eggs from the cattle are a food source for birds and insects, making them pasture cleaners. This again emphasises the need for diversity and how complex interlinking natural symbioses must be understood better.

The soil biome contains a host of tiny creatures, from bacteria and fungi upwards, that help maintain soil carbon, diversity, support for plant symbionts, and prey-predator balance. As discussed, intensive agricultural practices and agrochemicals will kill or at least inhibit the soil biome and surface life.

Like dung beetles, worms also move vast amounts of soil. Healthy soil potentially contains millions of earthworms per acre, which rotate 20 to 40 tons of soil per year, simultaneously creating extensive networks of aeration and rainwater tunnels. Earthworm gut bacteria add to the soil's fungal and bacterial diversity, including nitrogen fixers, an additive nitrogen source to soils. Their mucal coatings are an excellent source of plant nutrients. They chelate minerals, making them more bioavailable and provide many other services (*Earthworms A Gardener's Best Friend*, n.d.).



Fig. 136. UTube video slide 'AgEmerge Breakout Session with Keith Berns' 2020 with very many thanks to the author and Ag Solutions Network. (Berns, 2020)

As already stressed, soil life provides a massive array of free eco-services. It is the entirety of the ecosystem that optimises soil health and plant growth. Nature has taken billions of years to evolve these sophisticated interlinked self-regulating systems, which delicately balance between being competitive and symbiotically assistive. That is what it takes to allow and maintain a diverse evolutionary ecosystem that optimises complexity and supports a stable system within given parameters. A drive to greater complexity is an essential, built-in evolutionary parameter.

49.4 INSECTS – PREY-PREDATOR BALANCE

Numerous farmers using regenerative principles report that they rarely or never have to resort to agrochemicals because pest issues that cause crop damage of economic significance are rare. A combination of healthier, more robust plants and natural predation seems to keep such issues within acceptable limits, and on a cost-benefit analysis basis, it is a better option than agrochemical deployment. Increased species diversity and the reappearance of butterflies and birds in healthy, living, and vibrant landscapes also make farmers, families, and communities happy.

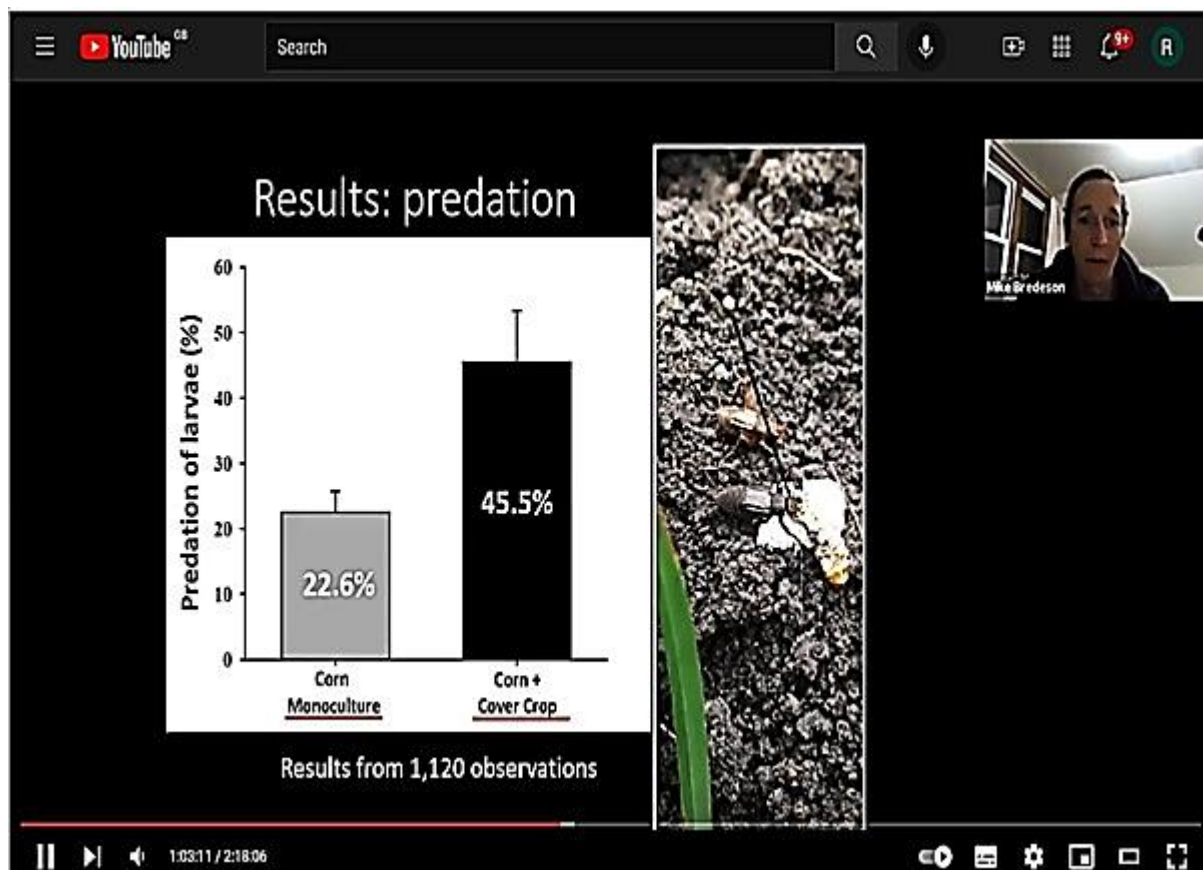


Fig. 137 *'Insects a little known force of nature shaping your farmland'* Mike Bredeson, PhD - regenerative agricultural practices including inter-row cropping increase predator number and balance with very many thanks to the author. (Bredeson, 2021)

50 PLANT DIVERSITY IS NOT OPTIONAL FOR CARBON SEQUESTRATION

Dr Christine Jones observes in *'Light Farming: Restoring carbon, organic nitrogen and biodiversity to agricultural soils'* that *"Diversity is not Dispensable"*. As discussed, plant diversity is necessary for a diverse, thriving soil microbiome. Further, different species have developed associations with their preferred bacterial and fungal species, creating wider interactive networks.

Research shows that the greater the variety of root exudate products, the greater the variety of organisms and the growth of the mycorrhizal and bacterial biome. *Plants live in association with diverse microorganisms, collectively called the microbiome. These microbes live either inside (endosphere) or outside (episphere) of plant tissues. Microbes play important roles in the ecology and physiology of plants.*" (Dastogeer, 2020)

For example, the paper *'Root exudate cocktails: the link between plant diversity and soil microorganisms?'* (Steinauer, 2016) helpfully observes, *"It has long been recognized that biodiversity is not only the result of ecosystem processes, but also an important driver of ecosystem functions itself. In aboveground–belowground interactions, plant diversity plays an essential role for ecosystem functioning. Alterations in plant diversity affect aboveground functions, such as plant productivity, and have an impact on belowground processes and soil biota"; "bacterial and fungal diversity increase with higher plant diversity"* The *"finding that soil microbial biomass increased successively from the control to the low-diversity and to the high-diversity exudate treatments emphasizes the pivotal role of root exudate diversity for total soil microbial biomass."*

"It is expected that the more diverse the plant community is, the more diverse the composition of root exudates, and consequently the higher soil microbial diversity will be. Thus, root exudates may represent the mechanistic link between the composition of the plant community and the composition and functioning of soil microbial communities" (Author's Underline).

Plant diversity is central to mycorrhizal diversity, health, and soil carbon sequestration potential. Dr Christine Jones explains in the video lectures *'Soil carbon: from microbes to mitigation'* (Jones, 2018c); *'Nitrogen: The Double-edged sword,'* (Jones, n.d.-b; Jones, 2018b); and in *"Farming Profitably Within Environmental Limits"* (Jones, 2017), concisely communicating the importance of multispecies cover crops for nitrogen production, biodiversity, environmental sustainability, and profitable farming in the terms:

"Comparisons of low-input high-diversity pastures with high-input low-diversity pastures indicate yields are either comparable - or higher - in low-input high-diversity systems. A German experiment in which fertiliser rates of 0, 100 and 200 kg N/ha/yr were applied to 78 experimental grassland communities of increasing plant species richness (1, 2, 4, 8 or 16 species; with 1 to 4 functional groups) showed higher diversity was a more important factor for pasture yield than nitrogen fertiliser." (Jones, 2017)

"Similarly, a UK study found that species rich-pastures averaged 43% higher herbage yield than species-poor pastures. Regression analysis showed that the variation in herbage yield

was related to differences in the number of non-leguminous herbs, suggesting the increased yield reflected the greater range of life forms present.” (Jones, 2017)

“In U.S. studies, Bruce Hungate and colleagues reported a strong link between plant diversity and carbon sequestration potential. The carbon storage capacity of native prairie with '11+' plant species was higher than the carbon storage capacity of CRP grasslands containing 5 or 6 species. The researchers suggested there would be economic, ecological and environmental advantages to increasing the number of species used in CRP plantings, despite the higher upfront costs.” (Jones, 2017)

“In summary, enhanced above - and below-ground diversity.”

- *creates a robust soil microbiome and supports common mycelial networks,*
- *increases soil carbon sequestration and carbon storage capacity,*
- *improves aggregate stability, soil structure and function,*
- *enhances the capacity of the soil to act as an effective biofilter,*
- *evens out feed availability throughout the year,*
- *maintains or improves herbage yield and milk production,*
- *reduces urinary N excretion by 20 to 50%,*
- *reduces reliance on N and P fertilisers, herbicides, insecticides and fungicides,*
- *optimises soil, plant, animal, and human health, water quality and farm profit.”*

(Jones, 2017)

50.1 DIVERSITY OF ROOT STRUCTURES - DEPTH AND CHARACTERISTICS

Different species of plants have different root structures that penetrate different depths, some reaching down many meters. A diverse variety of root types and structures, including soil depth penetration, optimises access to soil minerals and water and the potential for mycorrhizal interaction and nutrient exchange.

50.2 FUNGAL BACTERIAL SOIL RATIO IS IMPORTANT

Like plants, the soil biome needs nitrogen for structure and function. Carbon and nitrogen are both proportionally linked and key obligatory components of organic matter; thus, levels of carbon in unfertilised soils are linked through multiple mechanisms to levels of assimilable nitrogen derivatives available to the soil biome. Bacteria and fungi have differing carbon and nitrogen requirements.

Fungi require significant carbon for their structures. ‘SoilHealth’ observes, *“Fungi are generally much more efficient at assimilating and storing nutrients than bacteria. One reason for this higher carbon storage by fungi lies in the chemical composition of their cell walls. They are composed of polymers of chitin and melanin, making them very resistant to degradation. Bacterial membranes, in comparison, are phospholipids, which are energy-rich.”* Further,

“fungi need a greater amount of carbon to grow and reproduce and will therefore 'collect' the required amount of carbon available for this from the soil organic matter. Bacteria, however, have a lower C:N ratio (between 5:1 and 7:1) and a higher nitrogen requirement and take more nitrogen from the soil for their own requirements.” (‘SoilHealth’, n.d.) “The C, N, and P contents (percent of dry mass) of fungal biomass varied from 38 to 57%, 0.23 to 15%, and 0.040 to 5.5%, respectively.” (Zhang, 2017).

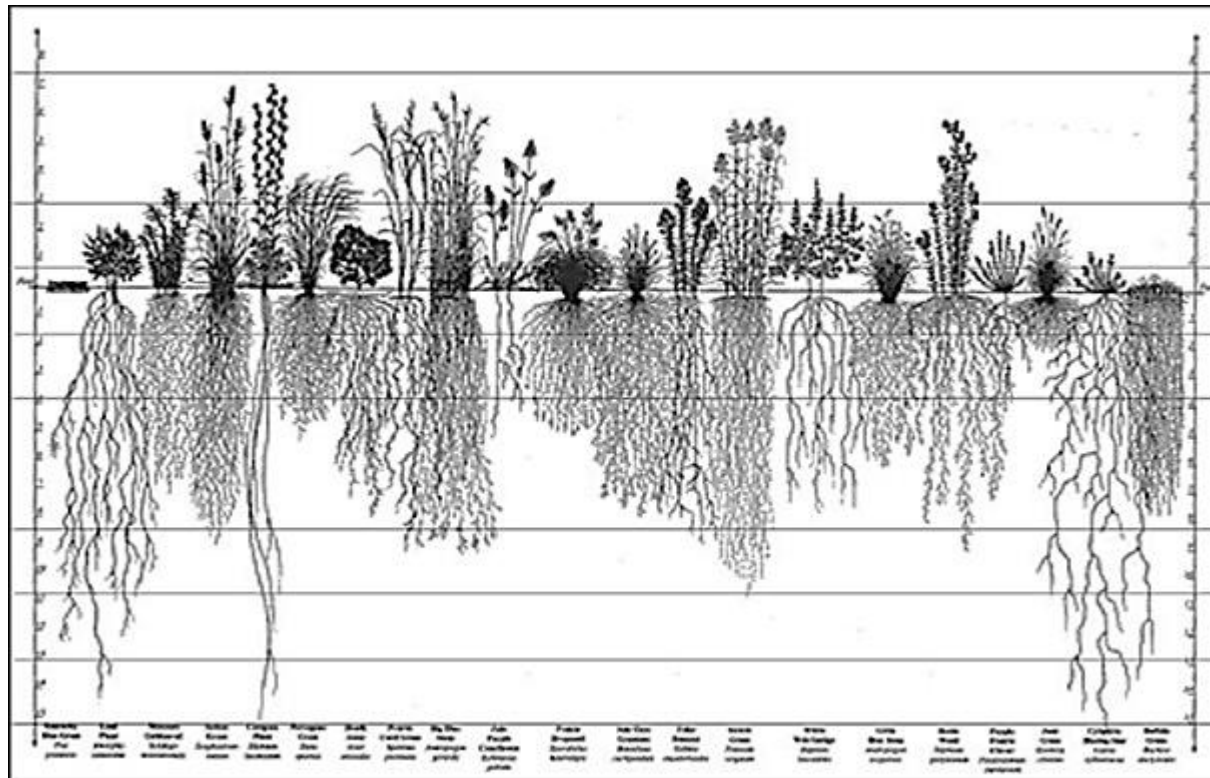


Fig 138 . *“The fundamental basis for encouraging use of native plant species for improved soil erosion control in streams and stormwater facilities lies in the fact that native plants have extensive root systems which improve the ability of the soil to infiltrate water and withstand wet or erosive conditions. Native plant species, like those listed in this Guide, often have greater biomass below the surface. Illustration provided by Heidi Natura of the Conservation Research Institute.”* With very many thanks to the author. (Natura, n.d.)

Thus, low soil carbon reduces fungal presence in soils, and higher soil carbon increases it. It would make evolutionary sense for the soil biome to sequester soluble nitrogen by organification, but this can only happen in quantity when sufficient carbon is available to create the required additional fungal structures (Farrell, 2014).

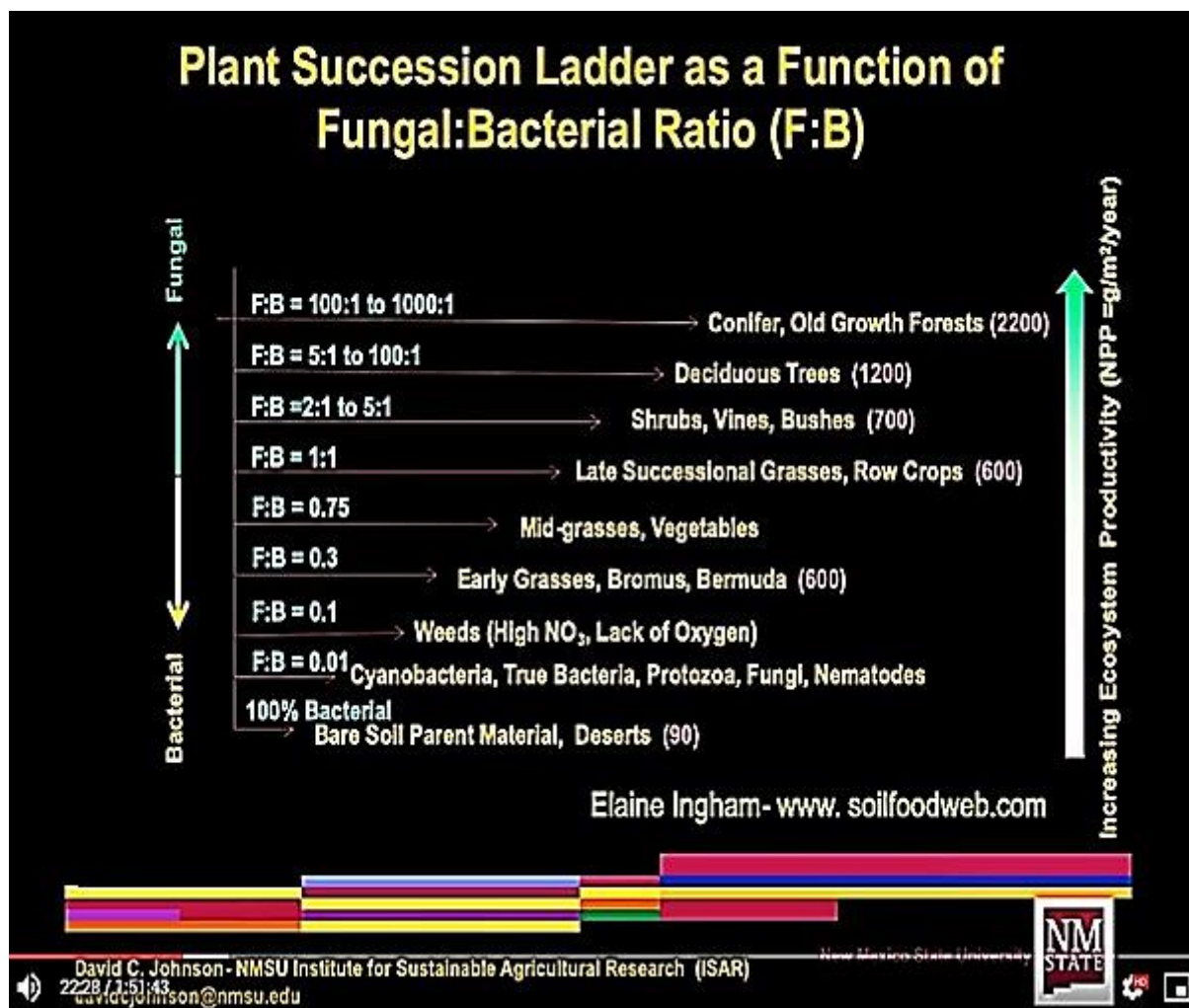


Figure 139 The balance of bacteria and fungi in soils changes with soil type and vegetation - from the YouTube lecture 'Dr David and Hui Chun Su Composting', Menoken Farm, with very many thanks to the authors. (Johnson & Su, 2019)

"The first step in the retention of added N is microbial processing driven by C availability" ('Organic nitrogen storage in mineral soil: Implications for policy and management', "The capacity of a soil to process N is increasingly being recognised as the bottleneck that leads to N saturation; this kinetic saturation appears to be driven by an imbalance of N inputs over C inputs, but factors that influence long-term N storage may play a role as well. Bingham & Cotrufo, 2016) [this author's bold and underlines]

As discussed above, in contrast, where soils are rich in carbon, they will sequester nitrogen, "forest soils with greater C content (such as old growth forests) rapidly integrate greater amounts of N into long-term storage than forest soils with lower C contents" (ibid).

Dr Johnson highlights the symbiotic change in the fungal and bacterial balance between various stages in soil evolution, from desert sand containing mainly bacteria to forest soils primarily containing fungi. The soil's microbiology will impact its ability to support life, from small desert succulents to trees in tropical forests. Further, the fungal bacterial ratios appear to change between differing locations.

Whilst more research is required, farmers can use regenerative agriculture strategies before the underlying science is fully understood because, on the ground, the evidence is that regenerative agricultural practices are effective, sustainable, economically profitable, better for the environment, and can produce near or equivalent yields of better nutritional value.

50.3 'MEDICINAL' SERVICES TO PLANTS

Collectively and individually, plants and mycorrhizal organisms have equal self-interest in maintaining each other's existence. Fungal and bacterial species can compete and be assistive or predatory, depending on which plant species' roots they prefer interacting with. They logically would seek to prevent their preferred plant symbiotes from being damaged by other competitive organisms - whether fungal, plant or insect - through the production and provision of protective organic compounds.

Menge observes: "*Ectomycorrhizal fungi* [types that remain living in the soil as opposed to endomycorrhizal types, which enter plant root cells] *have been reported to provide resistance to disease in many plants. Although mycorrhizae never confer complete immunity, they often appear to reduce the severity of disease or symptom expression*". *Resistance of ectomycorrhizae to disease may result from:*

- *mechanical protection by the mantle,*
- *better plant nutrition,*
- *production of antibiotics by the mycorrhizal fungus,*
- *competition for infection sites,*
- *formation of phytoalexins, and*
- *alteration of root exudates. (Menge, 1985),*

as well as producing antibiotics, phytoalexins, and antimicrobials, which accumulate at the site of an infection

Indeed, antibiotics used by humans originated in soil organisms, as noted in Dr Daniel Hillel's 2008 book, '*Soil in the Environment*'. He wrote: "*The term antibiotics was coined in the early 1940s by microbiologist Selman Waksman, who, together with his students at Rutgers University, extracted actinomycin and streptomycin from actinomycetes (diverse filamentous bacteria) found in the soil.*"

"The streptomycetes, belonging to the actinomycetes, account for well over two-thirds of these commercially and therapeutically significant antibiotics" (Hanekamp, 2010). Interestingly, *"Streptomycetes are members of the same taxonomic order as the causative agents of tuberculosis and leprosy (Mycobacterium tuberculosis and M. leprae)."* (Hanekamp, 2010). In addition to assisting humans, these products doubtless help maintain healthy, balanced soil and plant biomes.

Thus, streptomycetes—the building blocks of antibiotics—are naturally present in soils. This raises concerns about the possible impact of anthropogenic-resistant bacteria added to soils in sewage sludge and wastewater.

50.4 DETOXIFICATION OF POLLUTANTS AND HEAVY METAL SEQUESTRATION

The soil biome, as discussed, contains fungi and bacteria. Fungi have the potential for remediation of a wide range of organic and other pollutants. They can also selectively supply essential minerals required by plants and filter out toxic metals. As remarkable as this is, it would make sense, at an evolutionary level, for mycorrhizae to protect their plant hosts, including from toxic metals and pollution, given that plants and mycorrhizae in the natural world are almost utterly dependent on each other for survival.

We are putting large amounts of organic pollutants into soils via sewage sludge and wastewater application, airborne deposition of toxins, including from coal plants, incineration flue gases, stubble burn-off, and agrochemicals. Many toxins are long-lasting; *“The industrial use of PCBs was phased out in Europe during the 1980s-1990s, but 90 per cent of the contemporary emissions of PCBs are volatilised from soil”* (Thornton, 2001). However, more positively, remediation at varying levels does take place in soils. This is a vital service, given that otherwise, soils will be long-term repositories of organic pollutants, but we are at risk of damaging the soil biome with FATBAS and other contaminants such as antibiotic residues.

Mycorrhizal fungi and bacteria are key to these processes. *“Fungi possess the biochemical and ecological capacity to degrade environmental organic chemicals and to decrease the risk associated with metals, metalloids and radionuclides, either by chemical modification or by influencing chemical bioavailability”* (Harms, Schlosser & Wick, 2011).

An active, diverse, complex mycorrhizal biome, supported by diverse crops, will improve the retention of organic molecules and may improve remediation through greater biome diversity. The review *‘Untapped potential: exploiting fungi in bioremediation of hazardous chemicals’* notes, *“Fungi possess the biochemical and ecological capacity to degrade environmental organic chemicals and to decrease the risk associated with metals, metalloids and radionuclides, either by chemical modification or by influencing chemical bioavailability.”* (Harms, Schlosser & Wick, 2011)

More widely, *‘Diverse Metabolic Capacities of Fungi for Bioremediation’* (Deshmukh, Khardenavis & Purohit, 2016) notes that *“different fungal groups from a variety of habitats”* have roles *“in bioremediation of different toxic and recalcitrant compounds; persistent organic pollutants, textile dyes, effluents from textile, bleached kraft pulp, leather tanning industries, petroleum, polyaromatic hydrocarbons, pharmaceuticals and personal care products, and pesticides.”* (Deshmukh, Hardenavis & Purohit, 2016) *“Investigations into the microbial bioconversion of PAHs has shown that wood- and litter-decay fungi are efficient degraders of these organopollutants”* (Pozdnyakova, 2012).

Several factors influence the rate of breakdown, inactivation or removal of pollutants from soils and plant ecosystems, including bacterial and mycorrhizal interactions with pollutants, plant uptake, binding to organic or inorganic matter, thus solubility and mobility, removal by worms and other creatures, transport to deeper geological levels, and runoff (Magnér, 2016).

Soils rich in carbon, thus organic matter, will likely improve biological water contaminant remediation and filtration; *“Organic carbon also acts as a bio-membrane that filters pollutants and alleviates eutrophication in streams and coastal ecosystems”* (Hugar, Sorganvi

& Hiremath, 2012). A greater density and diversity of microorganisms will increase filtration and remediation.

Mycorrhizal species diversity, “*soil microbial composition, is mainly related to plant diversity*” (Dwivedi, 2013). Hence, the use of multispecies, with a mix of characteristics and types, low till, no fertiliser, no agrochemical, no bare ground farming, assisted by soil inoculants such as compost teas, will increase soil biome diversity, as well as the range of organisms in soils, which in turn have differing and expanded potential enzymatic capacities to metabolise organic molecules, including environmental pollutants.

51 ROTATIONAL GRAZING - BENEFIT OF LIVESTOCK TO FARMING

Rotational grazing of cattle and other livestock is used to maintain and help restore soil diversity and fertility and create economic value in areas otherwise unsuitable for arable farming, arguably outweighing any adverse potential effects on climate warming, including methane emissions. (Schwartz, 2013). In contrast, industrial feedlot farming poses several environmental issues outside this publication's scope (Thornton, 2001).

Those following regenerative livestock production find their livestock remains healthy with minimal intervention. Dung and urine from rotationally grazed livestock are naturally distributed in pasture and incorporated into soils, including by dung beetles, thus bypassing many of the issues above to the great benefit of the environment.

Like Turner, Howard was an advocate of mixed farming. “*A balance between livestock and crops is always maintained. Although crops are generally more important than animals in Eastern agriculture, we seldom or never find crops without animals. This is because oxen are required for cultivation and buffaloes for milk. (The buffalo is the milch cow of the Orient and is capable not only of useful labour in the cultivation of rice, but also of living and producing large quantities of rich milk on a diet on which the best dairy cows of Europe and America would starve. The acclimatisation of the Indian buffalo in the villages of the Tropics - Africa, Central America, the West Indies in particular - would do much to improve the fertility of the soil and the nutrition of the people.*” (Howard, 1943).

Modern regenerative farmers seem to agree that using livestock is not essential, but rotational grazing will speed up soil improvement, including the rate of carbon build-up. It has also significantly increased land livestock carrying capacity by multiples of two or more. Herbivores also allow the extraction of food and value from sloped and other land unsuitable for tillage.

Before human population expansion, vast numbers of methane-emitting ruminants used to roam savannahs, yet global warming was not an issue. Atmospheric methane increases are unquestionably a concern, but methane emission and consumption by soil bacteria is complex. We should be cautious about considering grass-grazed cattle as having the same climate effect as feed yard cattle. We need to better understand the biological interactions and complexities, and more so given appropriate cattle use, speeds soil carbon sequestration, thus atmospheric carbon dioxide capture. As mentioned above, ruminants, in sustainable numbers and regeneratively farmed, play important roles in maintaining ecosystems.

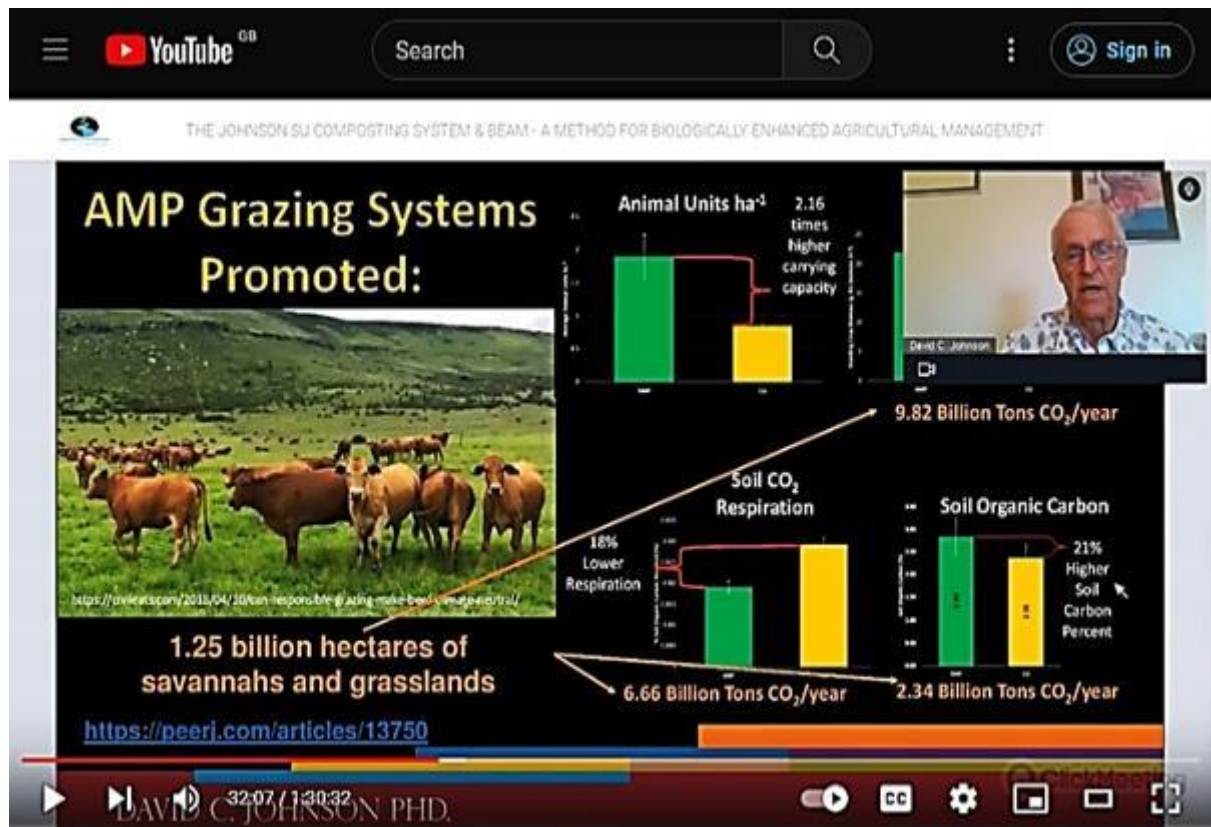


Fig. 140. Doubled carrying capacity, and soil carbon sequestration with Adaptive Multi-paddock Grazing 'AMP' aka 'rotational grazing'. Slide from the UTube lecture The Johnson Su Composting System & BEAM (Biologically Advanced Agricultural Management) with very many thanks to the authors. (Johnson & Su, 2022)

Grassland carbon sequestration could form part of a strategy to draw down atmospheric carbon dioxide. As discussed, successfully implementing a strategy to sequester a ton per hectare of global agricultural soils could buy time to develop sustainable energy sources.

51.1 GRAZING LEVELS AND PLANT ROOT MAINTENANCE

Livestock is often used as an integral part of soil-centric farming regimes. Cattle ingest fungi and bacteria, spread them in saliva, and return bacterially processed organic matter, bacteria and fungi to the earth, and their hooves distribute dung and urine while rooting out dead grasses and spreading seed.

Restricted high-density 'mob' grazing on an area to about 50 per cent of plant growth, s grazing fodder availability, maximising the overall production capacity of the land by preserving root mass, thus facilitating regrowth. Research suggests that by grazing not more than 50% in any one season, growth will be increased two to three times, compared to land that is grazed 70 percent. Clearly, the impact and capacity to re-graze or not in any given season will depend on the soil's health. However, in any circumstances, avoiding, the creation of bare ground, over grazing, and inadequate time for plant regeneration is essential.

“The relationship between leaf area removed and impact on roots was provided by FJ Crider, a researcher at the US Government’s Soil Conservation Service, as far back as 1955:

- *Up to 40 per cent leaf area removed = no effect on root growth*
- *50 per cent leaf area removed = 2-4 per cent root growth inhibition*
- *60 per cent leaf area removed = 50 per cent root growth inhibition*
- *70 per cent leaf area removed = 78 per cent root growth inhibition*
- *80 per cent leaf area removed = 100 per cent root growth inhibition*
- *90 per cent leaf area removed = 100 per cent root growth inhibition”*

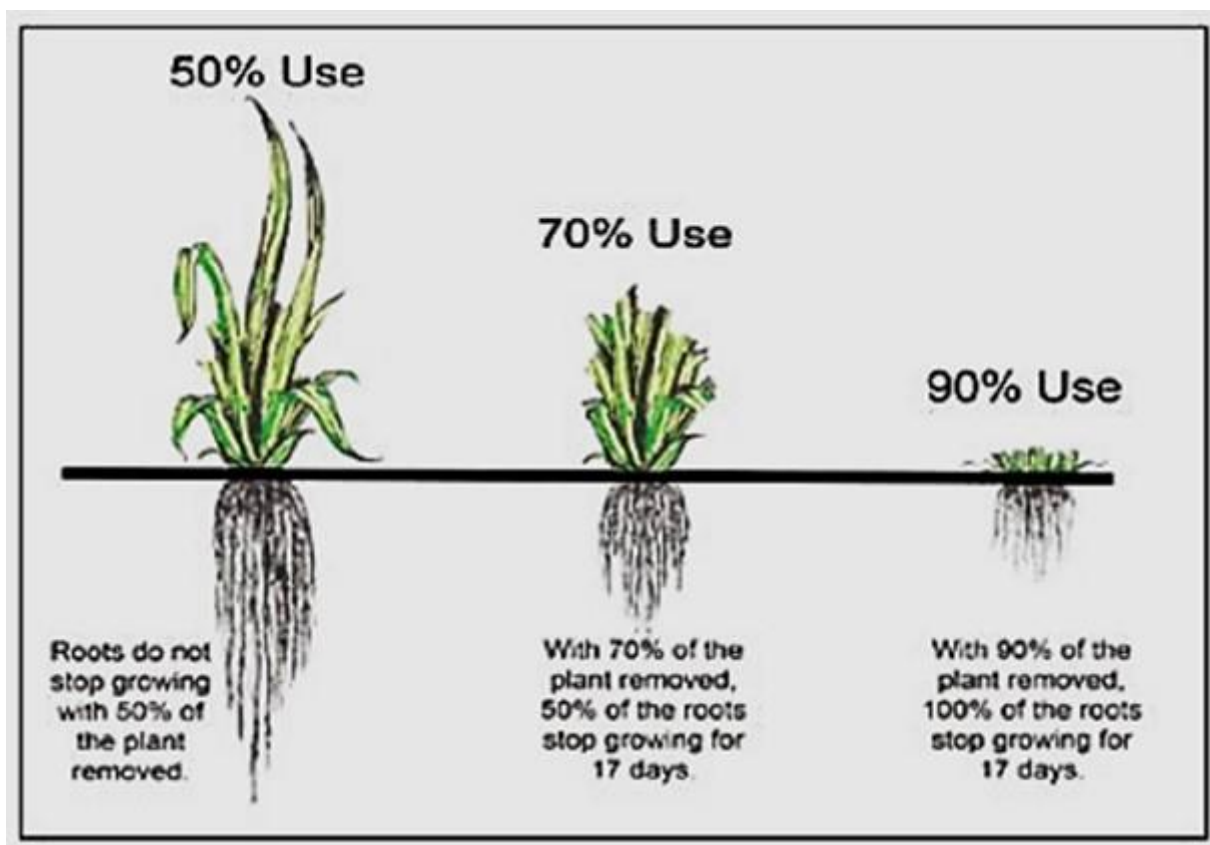


Fig. 141. Relative growth after different levels of grazing is illustrated ‘Great “Grass Farmers” Grow Roots’ (Voth, 2015).

Fostering root length and healthy, good-sized plants supports soil biome activity and diversity. As far as possible, year-round green plant material is needed for the maximal photosynthesis of carbon sugars, thus optimising their supply to the soil biome. The *in-situ* production and deposition of faeces and urine by grazing cattle will further increase organic matter, add biology to the soil, and promote reseeding and new growth.

51.2 APPROPRIATE MIMICKING LIVESTOCK MIGRATION STOPS DESERTIFICATION



Fig. 142. This park in the USA had not been grazed for over 70 years, making the point it is improper livestock usage, not livestock per se that contributes to desertification. Slide from 'How to green the world's deserts and reverse climate change' Allan Savory with very many thanks to the author and Ted Talks. (Savory, 2013)

It is posited by Allan Savory, author of several publications on planned holistic grazing and management, that in arid areas, impairment of reseeding by clumping of dead grass contributes to desertification. In a natural grassland system, Savoury suggests it is the grazing animals that remove annual dead grass clumps, spread seed, manure, and hoof till soils, replenishing bare ground; without them, there is no other natural mechanism to till, reseed, and fertilise. (Savory, 2013) Crucially, disturbance by grazing animals of dead grasses carpeting soils will promote clearance, reseeding, and regrowth that would not otherwise happen.

Before human intervention, all available grazing resources would have been utilised to a greater or lesser extent through the presence of a variety of wild indigenous species with a mix of feed methods and plant preferences, numbers multiplying, and species diversifying until they balanced available feedstock, according to species suitability to the conditions. Predators would have harassed large herds. Compact herds also defecate on their food source, obliging them to remain on the move, thus spreading seed, biology, nutrients including minerals, and manure.

There are a number of examples of controlled, non-destructive mob-grazed semi-desert areas of low rainfall, again becoming grass-covered, including in areas managed by Allan Savory in East Africa. Conversely, inappropriate over-continuous grazing will speed desertification.



Fig. 143. Planned grazing outcome in East Africa ‘*How to green the world's deserts and reverse climate change*’ A slide from a UTube talk by Abllan Savory with very many thanks to the author. (Savory, 2013)

Holistic Management International's website—catch-lined ‘*Healthy Land, Healthy Food, Healthy Lives*’—links to a valuable and extensive range of information on range-land management.

51.3 SPREADING SEED WITH CATTLE TO REGREEN DEGRADED RANGES

Moving cattle and other livestock regularly between pastures containing seeding species and adjacent areas with degraded soils and bare patches will assist the transfer of seeds, nutrients, and biology, thereby providing a mechanism to regenerate degraded lands. It is essential that once an area is reseeded by cattle movement, the seed is allowed to become established by moving the cattle onto new areas, and the area is not re-grazed for an appropriate time. Those implementing regenerative land management observe that, over time, native species, selected by evolutionary pressures over generations for their regional suitability, will return and again start to predominate.

51.4 LIVESTOCK DISTRIBUTE MINERALS

Crops will have different mineral compositions depending on the locations in which they were grown. Albrecht observed that migrating animals such as bison would not remain healthy if confined to one area due to the risk of nutrient imbalances. More of the nutrient value of feedstocks ends up in an animal’s manure than in the animal itself. “*Between 60 per cent and 95 per cent of the animal’s nutrient intake via feed is excreted via dung and urine containing undigested carbon and nutrients*” (Teenstra, 2014). Thus, migrant herbivores, and now cattle, move and circulate nutrients between locations, helping to even out immediate regional differences in soil mineral availability.

51.5 REDUCED VETERINARY COSTS

Turner, in the mid-1900s, in his book quoted above (Turner, 1951), about the benefits of farming using mixed cover crops and no artificial fertilisers, reported healthier livestock, including barren cattle becoming fertile, and as a result, *“an immense saving in the cost of manures (fertilisers) and veterinary and medicine bills.”*

A century later, New Zealand livestock farmers started to use multiple species for cattle grazing. *“They have found this greatly reduces need for; nitrogen and phosphorous fertilisers, insecticides, fungicides; displaces weeds, and has hugely reduced veterinary costs”*. They achieve better fertility and milk yields and reduce disease in their dairy herds, as did Turner and Howard. As discussed, Howard’s cattle remained foot and mouth symptom-free despite mixing with infected cattle for many years. In a lecture, Dr Jones quips farmers reportedly have even occasionally forgotten the vet’s number!

51.6 REDUCED NEED FOR AGROCHEMICALS

Farmers using regenerative agriculture, including Gabe Brown, the Haggertys, Dave Brandt, and Rick Clarke, report that they no longer or rarely need to use chemical pest or disease control. Plant health and disease resistance have improved, as has the variety of soil life, meaning that prey and predators are balanced, and single species are no longer capable of dominating. In contrast, monocropping and insecticides provide the perfect scenario for crop-specific pests to prosper.

52 AGRICULTURAL FACILITATORS

Several products and processes, including those outlined in the sections below, are, in principle, compatible with regenerative agriculture. They are not widely used, and some are limited by available resource levels, but they have all shown benefits to varying degrees and warrant further research.

52.1 MICROBIOME INOCULANTS

Howard showed that compost could improve the yields and health of many crops. Sir Albert Howard postulated that compost assisted mycorrhizal biome activity, facilitating plant growth—we now know he was right. A century or so later, wheat (Haggertys), cotton crops (below), and many others are producing higher yields following the application of compost extract, containing a rich microbiome of fungal spores and bacteria. Mark Tupman advises on priming seeds with inoculants (Tupman, 2022).

Dr Johnson’s Biologically Enhanced Agricultural Management (BEAM) system focuses on supporting soil organisms to increase productivity. He explains: *“The farming practices we’ve adopted over the past 150 years have been damaging to soil microbial communities. The first thing they really wiped out was the fungal community, which does both logistics and communication in the soil system. If you wanted to start a war, what would be the first two things you’d take out? Communication and logistics; it would be crippling, and that’s what we’ve done in agriculture. From there, the herbicides we’ve adopted are damaging to the structure of the bacterial community as well. We’ve hamstrung the soils we’re working on, to where they’re now living on life support.”*

When we bring the soil biological communities back, they have a phenomenal effect on productivity. Soil is a living organism, and you have to feed this organism. That means you have to have crops growing continually, either a commodity crop or a cover crop. Crops shuttle the energy from photosynthesis down to the soil system, as sugars, proteins and amino acids, which allow these organisms to survive” (Hayden, 2020).

Observations of the Farmers from Turkey:

- 85% less fertilizer used with no yield impact. Yields were better than cotton fields that received 100% fertilizer application = HUGE COST SAVINGS
- Yields were 4.2 metric tons cotton/ha (3,748 lb/acre)
- Crops did well despite government restricted irrigation and low rainfall (two irrigation events)
- No herbicides were used due to good weed suppression from the cover crop (100% displacement!)
- Observed biodiversity in their soil that they had not seen since their childhood!
- Have now taken this method to Romania for grain and oil seed crop production.

David Johnson

Image Courtesy of Spikas

THE JOHNSON SU COMPOSTING SYSTEM & BEAM - A METHOD FOR SUSTAINABLY ENHANCED AGRICULTURAL MANAGEMENT

Fig. 144. Improvements in cotton yields using BEAM (Biological Enhanced Agricultural Management), involving microbiome spore-rich compost extracts. Slides from the YouTube lecture, *The Johnson Su Composting System & BEAM (Biologically Advanced Agricultural Management)* with many thanks to the authors. (Johnson & Su, 2022)

The paper ‘Compost Addition Enhanced Hyphal Growth and Sporulation of Arbuscular Mycorrhizal (AM) Fungi without Affecting Their Community Composition’ found that “moderate (22.5 Mg/ha (1Mg. = 1 Mega-gram = 1Tonne) and high (45 Mg/ha) levels of compost addition significantly increased AM root colonisation and extraradical hyphal density compared with control.” “AM fungal spore density was significantly enhanced by all the compost rates compared with control... AM fungal growth was generally enhanced by organic fertilisation.” (Yang, 2018)

Simply adding microbes to depleted mycorrhizal biome soil can generate remarkable effects. *“Inoculation of fumigated sand or soil with VA mycorrhizal fungi will increase the growth of citrus by as much as 1,600 per cent; grapes by 4,900 per cent, soybeans by 122 per cent, pine by 323 per cent and peaches by 80 per cent. Growth responses due to VA mycorrhizal fungi have been observed in cotton, tomatoes, corn, wheat, clover, barley, potatoes, ornamental plants and in many other crops”* (Menge, 1985).

A study on pea growth, comparing mycorrhizal-inoculated specimens to a control sample under varying irrigation levels, found the former produced significantly bigger yields: 290.4 g/m² compared with 133.05 g/m². In addition, pea quality improved, and the crops became markedly more drought-resistant (Kristek, 2017).

Improvements in cotton crops, as evidenced by trials in the USA and Turkey using BEAM (Biological Enhanced Agricultural Management), involving microbiome spore-rich compost extracts as summarised in the slide above, are thought-provoking and commercially very interesting.

52.2 BACTERIAL FUNGAL AND FERMENTED FERTILISERS

Whilst the obvious starting point is the historically proven technique of using mature biologically diverse composts as an extract applied by injection, soak, drip and spray, or soil dressing (at risk of UV damage), considerable potential exists for the development of biological fertilisers, including improvements and derivatives of those developed from composts, and ferments.

The review *‘Harnessing Beneficial Microbes for Drought Tolerance: A Review of Ecological and Agricultural Innovations’* observes *“Beneficial microbes, often referred to as plant growth-promoting microorganisms (PGPMs), can enhance plant resilience to abiotic stresses such as drought by facilitating water uptake, modulating hormone levels, and improving soil structure. These microorganisms establish symbiotic relationships with plants, contributing to the host’s ability to adapt and thrive under adverse environmental conditions”* (Mikiciuk 2024).

Interestingly the study *‘Fermented potato fertilizer modulates soil nitrification by shifting the niche of functional microorganisms and increase yield in North China’* (Gong 2022) saw remarkable increases in yields concluding *“The results showed that applying fermented potato fertilizer could significantly increase crop yields by 165–399% compared to Control”*, which is attributed to altered soil biology, adding to evidence of the likely potential opportunities for biological fertilisers, a new emerging industry and market.

52.3 MICROMINERALS

The need for, and potential sources of, micronutrients, including microminerals and iodine and the consequent likely benefits of appropriate concentrations of foliar sprays based on the residue of sea salt production, rich in a wide range of marine-derived minerals, including phosphate, arguably is still not on the mainstream agenda. *“The issue of micronutrients has been given remarkably little attention in the research, agricultural policy and raw materials*

policies of the EU; this also applies to the private agendas of the private sector, particularly the farming sector and the feed and food industries. In all these frameworks, attention for this issue is urgently needed.” (Udo de Haes, 2012)

Minerals are difficult to extract, mix, and mine, expensive, and often rare. As discussed, rock phosphates contain a limited palette of minerals. They also contain sufficient amounts of heavy metals and radioactive nuclides to pollute soils. NPK fertilisers, as discussed, also block the supply of minerals to plants by the soil biome.

As mentioned above, there is little focus on microminerals and limited exploitable sources. Micromineral sources observed to increase yields and plant health include seaweed, sea salt residue, and rock dust, which are discussed in more detail below.

52.4 ROCK DUST

Rock dust has been successfully used as a soil conditioner and fertiliser since the late 1880s when flour mill owner Hensel noticed that applying grindstone residue to land improved crop yields and quality.

Hensel published *‘Stone Meal as a Fertilizer’* (Hensel, 1894) in the book *‘Bread From Stones’* (Hensel, 1894). As a result, he found himself in conflict with the chemical fertiliser industry (a nascent industry indeed existed then), vilified, his book removed from libraries, and his business destroyed. We are back to human nature, our inherent love of shiny new technologies, particularly ones that promise huge profits, and the denigration against the evidence of those who propose natural alternatives as viable options in part or whole.



With thanks to Adobe Stock

As noted earlier in the artificial fertilisers section, Hensel observed and warned that artificial fertilisers have adverse effects on plant growth. In contrast, he claimed that rock dust:

- (1) *"That Stone Meal creates healthier, tastier, more vitaminized and mineralized foods.*
- (2) *That Stone Meal creates immunity to insect infestation, worms, fungi and plant diseases of all kinds.*
- (3) *That Stone Meal improves the keeping and shipping quality of foods, so that they keep a long time, in contrast to the rapid deterioration of foods given abundant animal manure.*
- (4) *That Stone Meal helps plants to resist drought and frost, enabling them to survive when those fed on manure and chemicals perish.*
- (5) *That Stone Meal produces larger crops which are more profitable because the farmer is saved the expense of buying chemical fertilizers which are rapidly leached from the soil by rain-fall, whereas Stone Meal, being less soluble, is gradually released during the course of years and remain in the soil, being the most economical of fertilizers.*
- (6) *That foods raised with Stone Meal are better for human health and the prevention of disease than those grown with chemicals or animal manure.*
- (7) *That use of Stone Meal, in place of chemical or animal fertilizers, helps to end the spraying menace (by removing its cause) is proven by the fact that plants and trees grown with Stone Meal are immune to pests and so require no spraying."*

Evidence now points to his observations about the importance of minerals to plant health, nutrient density, and drought resistance being correct. Like Howard, his concerns about the adverse effects of artificial fertilisers on plant nutrient density and soil health were also well-founded.

Rock dust has made a limited comeback in the last few years, with numerous reports of beneficial effects on plant growth, health, and yields. Basalt, granite, and volcanic rock dusts are among the rock dusts used. Limestone is also used to regulate pH, but it will contain other soil nutrients. The review *'A Rock Dust Primer'* by Thomas Vanacore provides a helpful overview of the topic, including a sample mineral analysis abstracted below.

High-value basalt analysis from <i>'A Rock Dust Primer'</i> and with thanks to Thomas Vanacore		
46-51% Silicon dioxide	1-3% Phosphorus pentoxide	Toxic metals Arsenic <10 ppm Lead <5 ppm Thorium <3 ppm Uranium <.5 ppm
11-14% Aluminum oxide	8-1% Potassium oxide	
11-14% Iron oxide	15-50 ppm Nickel	
2% Manganese oxide	25-68 ppm Copper	
6-12% Calcium oxide	83-95 ppm Zinc	
3-4% Sodium oxide	20-320 ppm Boron	
3-6% Magnesium oxide	200-350 ppm Vanadium	
9-2% Titanium dioxide	45-275 ppm Chromium	
	5-2 ppm Molybdenum	

Several companies sell tested rock dust as a soil conditioner; anecdotal and market indications are that the product assists soil fertility, yields and health, but results are mixed. It is also being marketed as a mechanism to capture carbon (Buss, 2024), and significant

profits are being made by selling carbon credits. However, the topic is complex, and much remains unclear:

- Hensel, and others more recently, reported beneficial outcomes of rock dust on crop health, yields and nutrient density. For example, the study *'Potential of basalt dust to improve soil fertility and crop nutrition'* reported significant benefits using basalt *"basalt dust increased available phosphorus, potassium, calcium, and magnesium levels in the soil about twenty, ten, fifteen, and thirteen times higher than those without the basalt dust, respectively. Maize and bean plants grown in soils enriched with basalt dust showed macro and micronutrient accumulations, up to five times higher than plants without the use of basalt dust"* (Conceição, 2022).
- Conversely, a thesis study in Scotland titled *'The use of rockdust and composted materials as soil fertility amendments'* found no benefits from using a variety of rock dusts as an amendment compared to composted green waste, commenting *"no rockdust type increased plant growth beyond the yield in a greenwaste compost control"*, which is suggestive rock dust has limited usefulness in a soil with good biological diversity and adequate nutrients? (Campbell, 2009)
- Benefits may only be seen where there is no or limited NPK use and/or where the soil is low in a particular mineral in the rock dust.
- Dust size impacts soil residence time and soil biome/plant availability
- Minerals in rock dust are insoluble and require release by the action of the soil biome and or plant root acids
- Positive outcomes may be seen even on NPK-managed land if there is a significant deficit in a critical mineral
- More research is required into optimal usage to maximise yields and plant nutrient density
- It is unclear what circumstances will optimise carbon sequestration and how that splits between mineralisation of carbon and enhanced soil biome sequestration of carbon.
- Data on carbon sequestration amounts and time frames is limited, and outcomes are unclear.
- While potentially assisting mineral carbon dioxide sequestration into carbonates etc, given atomic ratios of mineral to other elements, availability in rock substrates, mechanisms for binding carbon dioxide including as carbonates, lack of evidence of formation of carbonates from minerals in fertilisers, competition for mineral cations by other soil substrate, organic pathways that utilise mineral cations; all of which is a mind numbingly complex cats-cradle of potential reactions to be debated by relevant experts in a host of specialisms, this author posits the likely primary mechanism of action of minerals increasing carbon sequestration in agricultural soils is by supporting soil biome organic carbon sequestration; consistent with this posit, a study *'The combination of crushed rock and organic matter enhances the capture of inorganic carbon in tropical soils'* concluded *"However, our results have shown that the magnitude of this capture is relatively small compared to other available strategies such as changes to soil management to increase organic matter in the soil, especially*

management associated with intense plant diversification in agricultural areas,” (Medeiros, 2024).

- There are considerable uncertainties regarding carbon capture rates, as discussed in the review *‘Are enhanced rock weathering rates overestimated? A few geochemical and mineralogical pitfalls’*.
- The complexities of and uncertainty as to mineral carbon capture rates do not detract from the observed capacity of rock dust used on some possibly mineral insufficient organic biology-rich soils to improve plant growth, nutrient density, soil health, and likely carbon content. Sea salt foliar spray may, through mineral provision to plants, achieve similar outcomes. More research is needed to tease out the nuances.
- Rock dust needs testing to ensure it does not contain excess heavy metals.

There is growing mainstream research into rock dust use in agriculture and for carbon capture, and more is needed. Whilst not all posits on the website of *‘Remineralise the Earth’* are agreed with by this author, it has a helpful section listing research on the topic (Remineralise the Earth, n.d).

However, and importantly, in assessing the capacity of rock dust as a significant global mechanism to capture carbon and improve agricultural crop quality and yields, the following need to be considered:

- 5 billion hectares are under human agricultural management.
- Mountains of suitable mineral-rich substrate to grind up are limited and finite.
- The product is heavy and voluminous.
- Transport is expensive and resource-intensive.
- Reapplication is required every few years.
- Some rocks are likely to contain high levels of undesirable minerals.

Rock dust is only expected to produce effective visible results in soils containing high levels of carbon and where other artificial, easily soluble fertilisers are not used, for the reasons discussed in other sections.

Overall, rock dust, when a waste product of the aggregate industry, has significant potential as an additive strategy for enhancing mineral availability; however, long-term usage of rock dust mined for the specific purpose of agriculture at a global scale is likely unsustainable. There are only a limited number of suitable mountains to grind up, and rock dust is bulky, heavy, and resource-costly to transport long distances.

As discussed above, sea salt residue would seem to be a better alternative to rock dust as a mineral fertiliser. It has a more consistent mineral profile, is more concentrated, bioavailable, and less bulky, making it easier to transport and apply. Its source, seawater, is constantly replenished with minerals by dissolved minerals from the land. Sea salt can be extracted with sunshine. Sea salt is a renewable green resource that is naturally replenished.

52.5 DOMESTIC AND OTHER ASH

In historical research, domestic ash, a mix of char and plant residue minerals, was shown, in some instances, to be more effective than manure and phosphate at promoting growth. Again, this powerfully makes the point that a range of minerals are required for plant, livestock, and human function and thus health.

For example, research on compost in the 1940s-50s, recorded in a book called '*Fertility From Town Wastes*' (Wylie, 1955), suggested that domestic ash collected with organic refuse for composting was an important component in optimising compost-dependent plant growth. They did some experimental work on the use of ash as an additive. Ash as a fertiliser in:

- Experiment 1 – Was more effective than manure on clover growth.
- Experiment 2 - Improved growth of grass, which made better livestock fodder.
- Experiment 3 - Restored grass growth where there was 'fog' and clover cover.
- Experiment 4 - Eliminated moss and restored clover not seen for ten years.
- Experiment 6 – When added to superphosphate, further improved growth.
- Experiment 7 – Produced better growth in clover.
- Experiment 8 – Produced better weather tolerance and harder crop stems.

However, modern domestic ash and house dust are likely more polluted than when they were successfully trialled in the 1930s. Ash from bio-power plants and other 'organic' fuel-using sources may, subject to pollutant content, present opportunities for inclusion in composts as an agent to prevent ammonia leeching, a source of minerals, a provider of char, and a compost improver.



With thanks to Adobe Stock

The role of ash in improving crop growth illustrates how subtle plants' mineral needs are, how little we understand about their metabolic pathways, and the importance of recycling mineral

nutrients to agricultural lands (Stephenson & Booth, 1968). Further, some caution regarding wood ash causing soil acidification is needed, but biologically active soils may be more resilient to this effect.

However, as set out in "*Recycling of ash—For the good of the environment?*" (Huotari, 2015), the use of ash must be carefully considered, particularly with respect to heavy metal contamination. For example, classes of ash such as fly ash (Mupambwa, 2015) and chicken manure ash pose particular potential risks. Nonetheless, careful consideration can maximise potential benefits when it is environmentally sustainable.

52.6 USE OF BIOCHAR, URINE EARTH CLAYS, ETC.

Biochar produced by various methods and from multiple substrates, including agricultural products (Jindo, 2014), is suggested to be a valuable soil additive, providing several services. The review '*Charcoal Volatile Matter Content Influences Plant Growth and Soil Nitrogen Transformations*' observes' "*charcoal additions can have a beneficial effect on highly weathered, infertile tropical soils by increasing the cation exchange capacity and plant nutrient supply, reducing soil acidity and Al toxicity, and improving fertilizer efficiency due to reduced nutrient leaching.*" (Deenik, 2010) While water retention was improved, the effect was not massive and needs to be compared with the impact of regenerative agriculture on water retention.

Biochar was used as a component in '*terra preta*' in the Amazon region, contributing to very fertile soils. Some of that carbon is still present 500-800 years later. Some suggest that high-carbon soils, including those in grasslands, have a significant 'biochar' pyrolysed carbon content. The stored carbon in both processes was derived from the combustion of carbon stored in forests or grass. Nonetheless, the possible capacity of biochar, some of which will end up being stored deep in soils, to sequester carbon into soils is intriguing.

Interestingly, the combination of biochar with cow urine in Nepal significantly increased yields. "*The urine-biochar treatment led to a pumpkin yield of 82.6 t·ha⁻¹, an increase of more than 300% compared with the treatment where only urine was applied, and an 85% increase compared with the biochar-only treatment. This study showed for the first time that a low-dosage root zone application of urine-enhanced biochar led to substantial yield increases in a fertile silt loam soil.*" (Schmidt, 2015; Schmidt, 2017).

On the negative side, grassland-type carbon, produced by the annual burn of 'crop stubble', contributes to as much as 50% of severe downstream urban air pollution, including smog. Where agrochemicals have been used, smoke will contain significant amounts of highly toxic residues *polychlorinated dibenzo-p-dioxins, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated dibenzofurans (PCDFs)* (Chaudhuri & Roy, 2017) as well as "*methane (CH₄), Carbon Monoxide (CO), Volatile organic compound (VOC) and carcinogenic polycyclic aromatic hydrocarbons.*" (INSIGHTSIAS, 2021) Soil heating consequent on crop burning, also reduces moisture and kills soil biome life in the upper soil layers. Combustible and air-transportable nutrients such as sulphur may also be lost.

A press article in India, where urban air pollution is a particular issue, reports in an article titled *'Stubble burning is back, smothering north India with concerns for the upcoming winter'* and notes *"Meanwhile in Delhi, in 2021, the 30-day average of its air quality index (AQI) in the stubble burning-affected month of November stood at 376 (very poor category) of which 11 days were such when AQI touched above 400 (severe category). The data of the System of Air Quality and Weather Forecasting and Research (SAFAR) also testified that the share of stubble burning in Delhi's toxic air varied between 25% and 48% during the peak season between November 4 and 13 last year."* (Gupta, 2022)

Further combustion at low temperatures may produce biochars that are not necessarily positive in promoting short-term crop enhancement. Some may have adverse effects on plant growth (lettuce) (Mikajlo, 2022), and Deenik observes, *"Plant growth response to charcoal-amended soils has been variable, with both negative and positive results reported in the scientific literature"* (Deenik, 2010). The interaction of biochar with phosphorus is complex and can be positive, but it is not always so (Glaser, 2015).

Where 'biochar' ash is an existing by-product of combustion under controlled conditions, for example, from the combustion of timber pellets in energy production plants, there may be significant net benefits to its utilisation as a soil additive, but careful assessment is required.

The review *'Characterization of Designer Biochar Produced at Different Temperatures and Their Effects on a Loamy Sand'* notes, *"Biochars produced from different feedstocks and under different pyrolysis conditions influenced soil physical and chemical properties in different ways; consequently, biochars may be designed to selectively improve soil chemical and physical properties by altering feedstocks and pyrolysis conditions."* (Novak, 2009)

In addition, by way of secondary uses, research suggests that additives, such as absorbent clays and related minerals, biochar, as well as plants including herbs, may have a role in shaping anaerobic digestion and composting outcomes including, nitrogen presence, remediation of organic toxicants, and removal of heavy metals.

The subject is more complex than it first appears. Different effects may be seen where NPK is and is not used. More research is required into using biochar by-products, such as from solid plant biofuel-derived ash, looking at the overall benefits and taking the whole production chain, downsides and benefits, including atmospheric pollution, into account.

52.7 VALUE OF URINE

Human and animal waste has significant resource value, and urine and faeces are, in a sense, free to small farmers. Even after composting, they would likely be considerably cheaper than artificial fertilisers, which are unaffordable for many in countries with developing economies. Yes, the issues of better systems of collection and remediation of biological and pharmaceutical contaminants need to be resolved.

A small study in Zimbabwe found that urine and humanure (faecal matter) on exhausted soils achieved more than twice the maize yields of fields with no treatment – 3,500 kg compared with 1,500 kg. Water requirements were also lower: 1,300 m³/ton versus 2,300 m³/ton. Also,

the yields delivered were greater than those from fields treated with artificial fertiliser. It concluded: *“The study showed that human urine is a good potential fertilizer instead of artificial fertilizers. The growth of cabbage and maize was equally good with urine-fertilized crops than artificially fertilized crops.”* *“Governments should revisit legislation and policies that concern human excreta management and disposal with a view of defining human excreta as a resource and not a waste”* (Hannila, 2008). However, the excreta used in this Zimbabwean study was unprocessed, giving rise to several environmental and health risk dilemmas.

A paper titled *‘Influence of Human Urine on Rice Grain Yield (Orzya sativa L.) and Selected Soil Properties in Abakaliki Southeastern Nigeria’* reported similar benefits from urine use, and observed *“An increase in the rate of urine application also resulted to an increase in rice grain yield and higher improvement in soil properties studied.”* (Njoku, 2017)

However, urine despite popular belief is not sterile and can contain a number of viruses and bacteria, as well as pharmaceuticals and other pollutants as discussed in much greater depth in volume 1 on sewage.

The development of simple collection-at-source-systems, hyperthermophilic anaerobic digestion for biogas, followed by hyperthermophilic composting technology, to as effectively as possible, remediate human and animal waste, needs to be developed as a matter of urgency, as discussed in Volumes One and Three.

Carbon in organic matter is a significant component of faeces. Carbon increases water retention, and compost provides biology to depleted soils. Thus, developing ways to close the circle with effective composting of human and animal waste within the context of regenerative agriculture will both help meet nutritional needs and mitigate climate change impacts, such as drought and famine.

52.8 SEAWEED

Seaweed provides a wide range of minerals, including microminerals and iodine. Historic commercial usage and related research suggest that seaweed, as a soil additive or foliar spray, improves plant health, keeping qualities, disease and pest resistance, growth, and livestock feed quality. However, self-evidently, supplies are limited, albeit expandable and renewable.

The book *‘Seaweed in Agriculture and Horticulture’* (Stephenson & Booth, 1968) is a trove of information on the subject. It sets out many observed benefits, including increased shelf life, resistance to pests, diseases, and frost, and better crop quality and yield. Seaweed extract may be a valuable addition to soluble compost extracts when used as organic fertiliser, seed treatments, drips, or sprays.

52.9 SEA SALT RESIDUE

As mentioned earlier, marine-extracted minerals, such as those found in the residue of sea salt production, ‘bitterns’, likely offer better prospects as a sustainable source of foliar mineral supplementation for global agriculture than many terrestrial options. Sea salt residue provides a full range of minerals, including micronutrients, some phosphate, and notably

iodine. Interestingly, the Haggerty's, I believe, use marine-based additives for their compost extract, which may well be of organic origin, but could very dilute sea salt residue as an additive replicate the beneficial effects?

Some use salt as part of an SRI protocol in a rice seed soak. Christine Jones and Mark Tupman (2022) suggest that mineral additives need careful use, as excess application at planting may inhibit plant growth. However, Tupman adds seaweed extract and mineral sources to his seed inoculant mix.

Stephenson and Booth, in "Seaweed in Agriculture and Horticulture" (Stephenson & Booth, 1968, p.107), reported a dramatic increase in the speed of emergence in seaweed extract-treated seed. Clearly, more research is needed.

Bitterns is the residue left over from an existing 'green' industry – i.e., sea salt production, sustainably powered by the sun's rays – so it is eminently renewable. As observed above, bitterns contain a full range of mineral elements, including phosphates (Atkins, 1926) and, where not wholly desiccated, will contain iodine. There is a virtually inexhaustible supply of seawater, which has its mineral content continuously replenished by rivers feeding into the oceans, a constant demand for the sodium chloride-rich edible salt element, and currently no shortage of incident sunshine to drive desiccation in dryer parts of the world.

Historically, sea salt residue has been successfully trialled by several low-key non-conventional farmers, who found it improved crop quality and yield. Interestingly, studies using solutions containing trace minerals such as nickel, vanadium, titanium, molybdenum and chromium hugely increased lettuce and asparagus growth.

Bitterns deployed in hydroponic systems boosted the antioxidant rating of green peppers. Sea salt residue is high in magnesium, often lacking in plants, but is *"required for chlorophyll formation and plays a key role in photosynthetic activity"* (Farhat, 2016). *"As magnesium is a nutrient with high mobility in plants, it is preferentially transported to source leaves to prevent severe declines in photosynthetic activity"* (ibid).

Several books have been written by early regeneratively inclined farmers on the subject of bitterns (Murray, 2003; Walters, 2005; Zeigler, 2014), but it has not been the subject of mainstream research and development, either as a foliar spray or additive to compost, soluble fertilisers.

Interestingly, users have not reported the use of bitterns causing soil salination thus far, and there does not appear to be a salinity problem following occasional inundation of agricultural land by seawater flood events; in fact, some suggest improved fertility. As discussed, healthy soil biome systems appear to counteract the effects of salination.

Sea salt production residue, bitterns, has not been the subject of mainstream agricultural research and development but arguably should be, as it offers considerable economic and environmental potential as a virtually inexhaustible, naturally replenished resource for the supply of trace and wider minerals, including iodine to plants/return of minerals to soils, and as a supplement to hydroponic solutions. It is an existing by-product of solar-driven sea salt

manufacture, and sea salt could be recovered from the discharges of desalination systems. Putting the desalination discharge to positive environmental use would also be of benefit by reducing damaging discharges into the ocean. Using the sea salt residue extract as an additive to compost solute fertilisers and as a mineral fertiliser in hydroponics systems might also be possible.

As mentioned above, soil salinity is not reported as a problem by those who use sea salt residue. The effects are generally positive, and several books have been written on sea salt residue use in agriculture (Murray, 2003; Walters, 2005; Zeigler, 2014). Clearly, more research is required, as this is an omission worth addressing and a potential industry waiting to happen.

53 CROP BURNING

On-the-spot incineration of stubble, stalks, grasses, and husks is commonplace worldwide and a significant source of pollution. Burning agricultural waste is another practice that not only adds to ecological problems but also wastes resources that could be part of the solution.

Using crop stubble for biochar also poses several environmental issues. These negatives and alternative use opportunity costs likely outweigh any possible benefits from adding stubble biochar as a soil amendment. Biochar is discussed in a later section.

Crop residue could be crimp-rolled to provide nutrients and soil cover, protect soils from erosion, and reduce transpiration and soil heating. In addition, residue provides food sources for surface soil bacteria and life in the soil biome, such as worms. Alternatively, crop residues could be added as a carbon source to compost ingredients, helping optimise carbon-nitrogen ratios and providing bulk to assist optimal aeration. It could be used as mob grazing fodder.

Full residue removal results instead in bare, unprotected soils, which speeds up evaporation, causes crusting, reduces rain penetration, and increases runoff, thus increasing the risk of erosion and downstream flooding. Burning also releases carbon as CO₂ and other pollutants, including dioxins, contributing to rising air pollution, airborne particulate matter, and atmospheric warming, thus the risk of global warming.

One study shockingly estimates that *“burning biomass, such as wood, leaves, trees and grasses – including agricultural waste – produces 40 per cent of carbon dioxide, 32 per cent of carbon monoxide, 20 per cent of particulate matter and 50 per cent of polycyclic aromatic hydrocarbons released into the environment around the globe”* ('Burning Agricultural Waste: A Source of Dioxins Factsheet', 2014).

The figures are significant and deeply thought-provoking, yet we focus almost exclusively on fossil fuel emissions when, in reality, all sources of pollutants and climate change accelerators, including atmospheric heating, need an effect-proportional focus. Burning off crop stubble produces significant heat, which must add to atmospheric warming. The carbon in crop waste is better used to protect soils; alternatively, a portion could have been used for biogas, and the balance returned to soils as compost, as discussed in Volume 1 on sewage.

The presence of herbicides exacerbates the pollution problem: *“Dioxin emissions increase by 150 times when biomass treated with 2,4-D (a herbicide) is burned”* (ibid). As well as being

released into the atmosphere, a proportion of these contaminants are retained and/or returned as dust settles or is deposited by rain as ash on the soil. Significant increases in soil dioxins are seen where crops such as corn stalks have been treated with pesticides.

The problems caused by crop burn-off are global; whilst commonplace in less developed countries, they also happen in rich countries. This Indian report provides a striking example of this global issue: *"The yearly practice of "stubble burning" in Northern India has far-reaching effects. Delhi, some 250 kilometers away, once again faces dangerous levels of smog as farmers burn off their fields to prepare for the next crop. It's a major cause of air pollution in the country."* ('India: Air pollution from annual 'stubble burning' 2021).

Crop burn-off has identified health risks. *"Pollutants emitted from agricultural burning, such as polycyclic aromatic hydrocarbons and very small particulates (PM 2.5), can cause cancer in humans as well as severe respiratory illnesses, coughing, phlegm and asthma. For example, during the season in which sugar cane is burned, an increase in asthma attacks has been observed in the population living near sugar cane fields in southern Louisiana in the United States. In fact, hospital admissions due to various respiratory problems increase by 50 per cent during this time of year. In Brazil, the world's largest sugar cane producer, elevated PM levels have also been observed, as well as an increase in respiratory problems, during the season when sugar cane is burned"* ('Burning Agricultural Waste: A Source of Dioxins Factsheet', 2014)



Fig. 145 Stubble burning in Essex, England, in 1986, with many thanks to John Roston.

In contrast, regenerative agriculture uses crop residue as a soil protectant and source of minerals and nitrates, directly or through composting and subsequent return to agricultural soils.

53.1 CROP RESIDUE BURNING CONTRIBUTES TO ICE LOSS

Sea ice loss contributes to climate change, part of a powerful feed-forward loop. The reflectivity of solar radiation by ice and snow is high; in contrast, the reflection of energy by water is low. It is an efficient absorber of solar energy (280-3,000nm), will transfer heat by conduction and convection and is an emitter of medium/long-infrared. As discussed, the incidence of solar energy on Earth is significant. It is reduced at the poles, but where it is significantly absorbed will contribute meaningfully to regional ground-level warming and atmospheric warming.

Water is also an excellent and voluminous long-term heat store with natural mixing mechanisms, which slows but increases the timescale of climate change. A summary of the Ice-albedo feedback mechanisms is helpfully set out on the Wikipedia page 'Ice-albedo feedback' (Wikipedia, Ice, 2025)

Consistent with this the review, *'Global warming due to loss of large ice masses and Arctic summer sea ice'* observes *"Most of this response (55%) is caused by albedo changes, but lapse rate together with water vapour (30%) and cloud feedbacks (15%) also contribute significantly."* (Wunderling, 2020)

As noted above microplastics are contributing directly and indirectly by acting as a host to bacteria to ice melt, *"We hypothesize that, due to their low density, microplastics in Arctic surface seawater will be readily incorporated in sea ice during initial sea ice growth, resulting in microplastic enrichment near the sea ice interface with the atmosphere. This enrichment could impact the absorption of incident solar radiation, with feedback on sea ice albedo and thus sea ice melt."* (Geilfus, 2019)

The review, *'Microbial colonization and degradation of marine microplastics in the plastisphere: A review'* observes *'Microplastics are colonized by bacteria, fungi, viruses, archaea, algae and protozoans, resulting in the biofilm referred to as the "plastisphere."* (Zhai, 2023). This effect would logically accelerate the colonisation of ice. Washing machines, and windblown microplastics from sewage products applied to soils, once dry, are significant sources of microplastics.

54 DESERT SOIL RECOVERY

Changing soil microbiology and carbon content through natural processes assisted by synergistic human intervention will improve the soil's ability to support differing plant types. Regenerative agriculture allows farmers to influence and build soils where the geological ground-up rock-dust substrate of very degraded soils is not eroded down to the bare rock; thus, they can bring desert soils back to life and recondition them by introducing the necessary fungal and bacterial biology.

A diverse, productive soil biome containing the necessary fungal and bacterial species suited to that environment and geology is essential to healthy plant growth, water retention and provision, and sustainable landscape development. The amount of carbon in and provided as plant sugar exudates to the soil and the mycorrhizal populations present will determine how that soil evolves and the capacity of plants to grow in it.

In real-world conditions (Fig. 23), Dr. Johnson has shown that these techniques can bring life back to desertified soils. Similarly, chicken manure compost is being used to successfully reclaim desert land in Saudi Arabia (Physorg, 2024).

By providing biologically rich compost, injecting extract, or coating the seed with extract from matured microbially diverse compost, which will contain bacteria and dormant fungal spores, it is possible to promote seedling, soil geology, interactions, and development of mycorrhizal biomes; thus, plant growth, root carbon exudate production capacity, and soil biome diversity and expansion. Given that desert-type soils are low in fungal biology, fungi in composts may be a key element in reclaiming deserts using these techniques.

Further, planting to provide diversity makes it possible to improve mycorrhizal biome development and function. Healthy, diverse mycorrhiza will result in better plant growth and a more effective symbiotic bidirectional nutrient supply. As discussed, adding artificial nitrogen and phosphates will inhibit these processes, as set out in the paper '*Synthetic nitrogen fertilizers deplete soil nitrogen: a global dilemma for sustainable cereal production*' (Mulvaney, 2009).

Conversely, laboratory work that relies on sterile soils as the basis for determining real-world farming solutions is puzzling, as sterile conditions do not remotely reflect real-world conditions and complexities. This research approach may be interesting, but Christine Jones points out that it has limited real-world relevance in a natural world dominated by plant-soil microbiome interactions.

54.1 DE-DESERTIFICATION - RESTORING FERTILITY

Simple techniques of land management for improved water retention, with regenerative techniques, are already being used to revive badly degraded bare land around the world. The power of nature, relevance, and potential to rapidly restore the land by restoring its biology, including biologically rich compost extracts, is evidenced by Dr Johnson's work on growing crops in light sandy desert soils. Different variants of techniques to restore soil biology have been used, including composts and compost tea extracts. Indeed, as knowledge increases over time, our capacity to restore soil biology will improve.

Vast swathes of China's Loess Plateau, which had become minimally productive, parched and severely eroded, have now been recovered with simple techniques, including the feeding of livestock in enclosures, earth dams, landscaping for water management, and terracing ('*Lessons of the Loess Plateau*', 2012). The use of regenerative agricultural principles would further improve this process. Farmlands have also been recovered in Australia, Ethiopia, India, Zimbabwe, Israel, Mexico, and China. John D Liu recorded the recovery of the Loess Plateau project. Land recovery projects in Mexico and Ethiopia are referenced as examples below.

Las Damas Ranch in Aldama County, Chihuahua, Mexico, provides a thought-provoking, well-documented case study into the capacity to regenerate degraded drying land. The neighbouring farms provide control and evidence of what has been achieved at Las Damas. A potted history is available online (Dean, n.d.). The ranch was purchased in 1985. The area had an average of 10 inches of rain annually, which has further reduced in recent years. In 2012,

the ranch started to make changes in how it operated. In 2018, it moved further towards optimal adaptive management principles involving regular moving of livestock and long rest periods between grazing. Consequent to the impact of these changes over time, they report tripled cattle carrying capacity and profitability (Dean, n.d.).



Fig. 146. The use of compost teas, as seed soaks, drips and foliar sprays, biologically rich mediums containing a wide range of bacteria, and fungal spores, particularly on degraded land, greatly improve seed germination, plant health and growth, and thus soil carbon sequestration rates. This is the second-year crop in a desert area in dry sandy soils, in soils pre-treated with BEAM compost. From the UTube video with very many thanks to the Authors. (Johnson & Su, 2022)

The changes at Las Damas are recorded in a number of YouTube videos illustrated below, such as '*Building Resiliency: Ranch Resiliency with Alejandro Carrillo 10-28-21*' Carrillo, A. (2021) discussed, charting their problems and progress over time using adaptive regenerative mob grazing grass management, longer rest periods, higher stocking levels, a variety of livestock, and optimal organisation of resources. Those who visit are very impressed by the positive changes over the years. The neighbouring properties, still using traditional management, bear witness to the extent of the improvement of the grazing quality, diversity and water resilience of the Las Damas Ranch. New lessons continued to be learnt, and the process is ongoing. Most remarkable of all, the ranch proprietors sense, based on their observations over the years, that then changes in vegetation cover and hydrology, logically through microclimatic moisture and airborne plant stoma-emitted bacteria, are slowly increasing cloud cover and possibly rainfall over Las Damas, which is feasible, and hopefully more than wishful thinking.

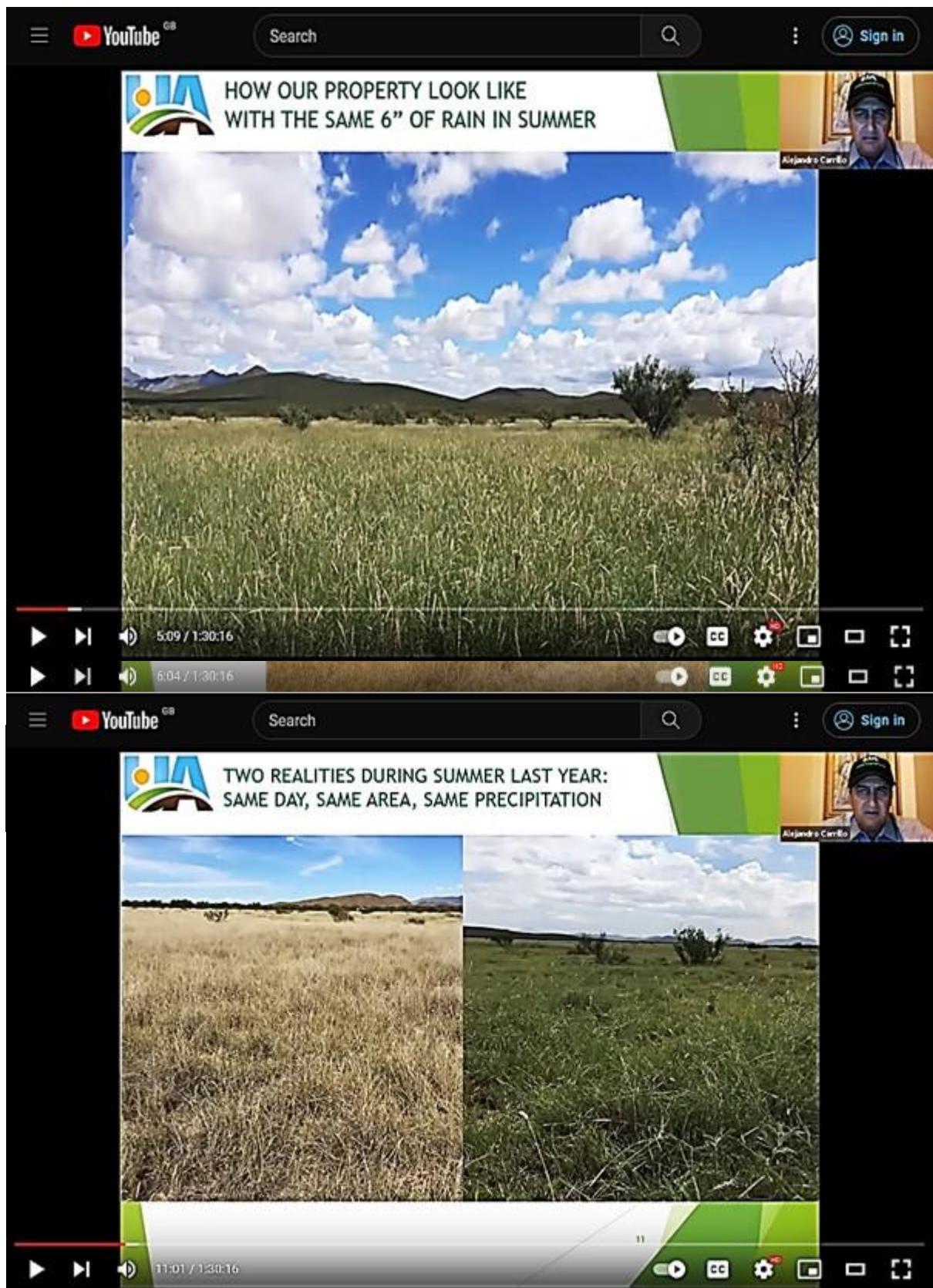


Figure 147 a and b. Las Dama Ranch Mexico, UTube video '*Building Resiliency: Ranch Resiliency with Alejandro Carrillo 10-28-21*' comparing regenerative outcomes with adjacent traditionally managed properties, many thanks to the authors (Carrillo, 2021).

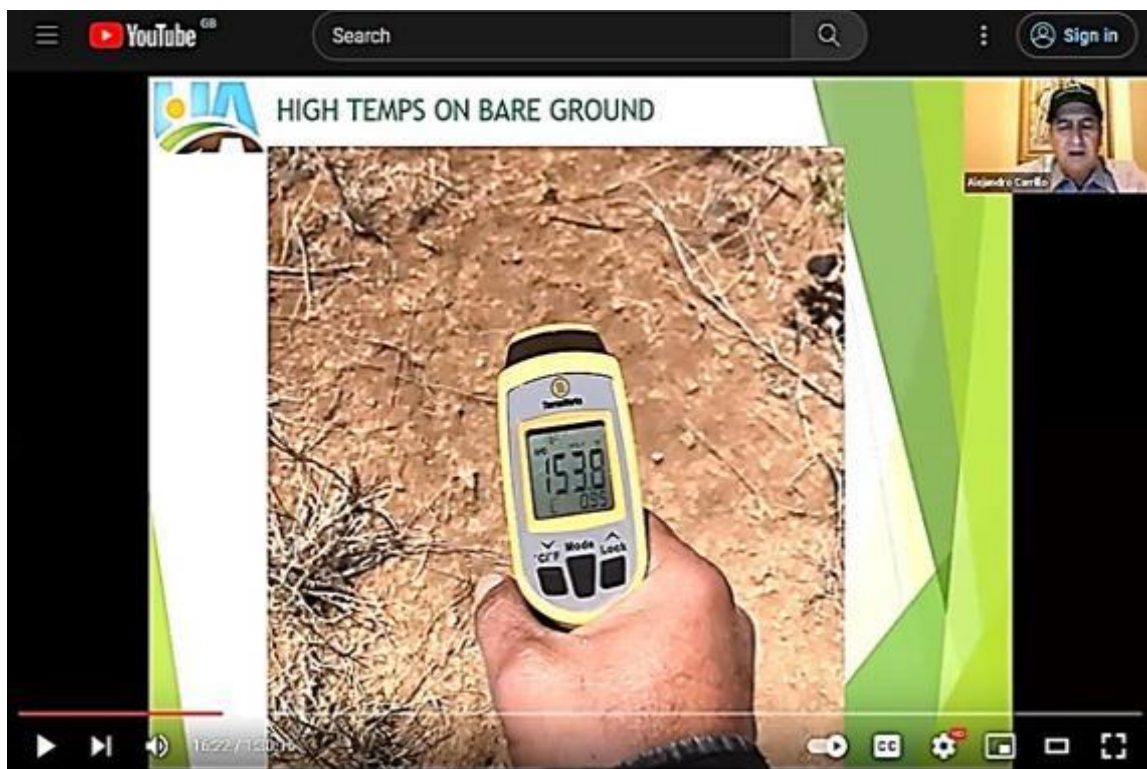


Figure 148 a and b Las Damas Ranch Mexico, two slides from the deeply thought provoking UTube video '*Building Resiliency: Ranch Resiliency with Alejandro Carrillo 10-28-21*', a photograph of rain, they observed they measured receiving slightly more than their neighbours, and a thought-provoking image of measured bare soil temperatures. With many thanks to the authors (Carrillo, 2021).

Similarly using basic regenerative principles, in Ethiopia, badly degraded lands, watersheds of the Nile, have been restored by again following simple, cheap natural available conservation strategies: basic earth dams retain water; restricting livestock grazing on steep upper slopes allows for regrowth of vegetation, and better water retention; terracing makes soils more stable; improving soil cover to protect soils, reducing soil temperatures and increasing plant transpiration, and providing land rights where they did not previously exist giving farmers a stake in making the earth sustainable.



Fig. 149. What had become a seasonal stream now again runs all year, and ground water levels have improved. 'Agroecology in Ethiopia: Converting Desert into Hyper-Productive Land Excerpts from Hope in a Changing Climate' with thanks to Food Abundance. ("Agroecology in Ethiopia: Converting Desert into Hyper-Productive Land," 2012)

Legesse Negash, emeritus professor of plant physiology at Addis Ababa University, observes in the YouTube video 'Regreening the desert':

"The most important issue for Africa - and I consider this Africa's 21-century burning issue - is restoration. No matter what else we do; we might be good at rocket science, nuclear science, but the environment, restoring this huge vast landscape, this degraded landscape, is critical for Africa, particularly for Ethiopia. Half of Ethiopia is mountain and this system is degraded. The degradation of this huge landscape is critical for not only Ethiopia, but also for the entire region, a catchment area for the Nile. Consider Egypt, look at Sudan, how can you support life in Egypt without restoring Ethiopia's mountains. So, this is regional, national and international." (Liu, 2012)



Figure 150 Legesse Negash, emeritus professor of plant physiology at Addis Ababa University *'Regreening the desert'*, with many thanks to the author. (Liu, 2012)

In the project in Ethiopia, it was reported and video recorded at the time that groundwater levels had risen and streams ran all year. Formerly, marginally productive areas with uncertain cropping supported families and brought life, hope, and the capacity to make sufficient income to educate and feed their children.

The inspirational videos telling the tale of these land reclamations are recommended viewing. *'Hope in a changing climate'* (Wollinger, 2010) and *'Agroecology in Ethiopia: Converting Desert into Hyper-Productive Land'* (2012) strongly make the key point: We need to appreciate the scale of the problem, the availability of potential solutions, and, crucially, implement those relatively simple and affordable recovery strategies, as they have done in the massive and successful Loess Plateau project in China.

Recovering and better utilising degraded lands - including major watersheds of economically significant rivers like the Nile – helps provide water and food and better prospects for military, political and economic stability to urban conurbations and rooted rural communities.

The vast improvements in the fertility and water status of the Loess Plateau and projects in Ethiopia show what cooperative human behaviour and simple common sense can achieve at minimal cost. Further, history teaches us that those who can feed and educate their families and feel hopeful about the future are less likely to resort to violence.



Fig. 151 a and b. Slides from the UTube video '*Regreening The Desert*' and '*Ecosystem restoration Ethiopia*' John D Liu documentaries - a generic thought-provoking satellite photo, and a photo of climate refugees, with many thanks to the author. (Liu, 2012)



Fig. 153 *'Regreening the desert'*, images of landscaping of the Loess Plateau after terracing, building of simple stone and earth dams, and removal of livestock, particularly goats from the erosion vulnerable upper slopes allowing natural vegetation and water retention to return. With many thanks to the author. (Liu, 2012)

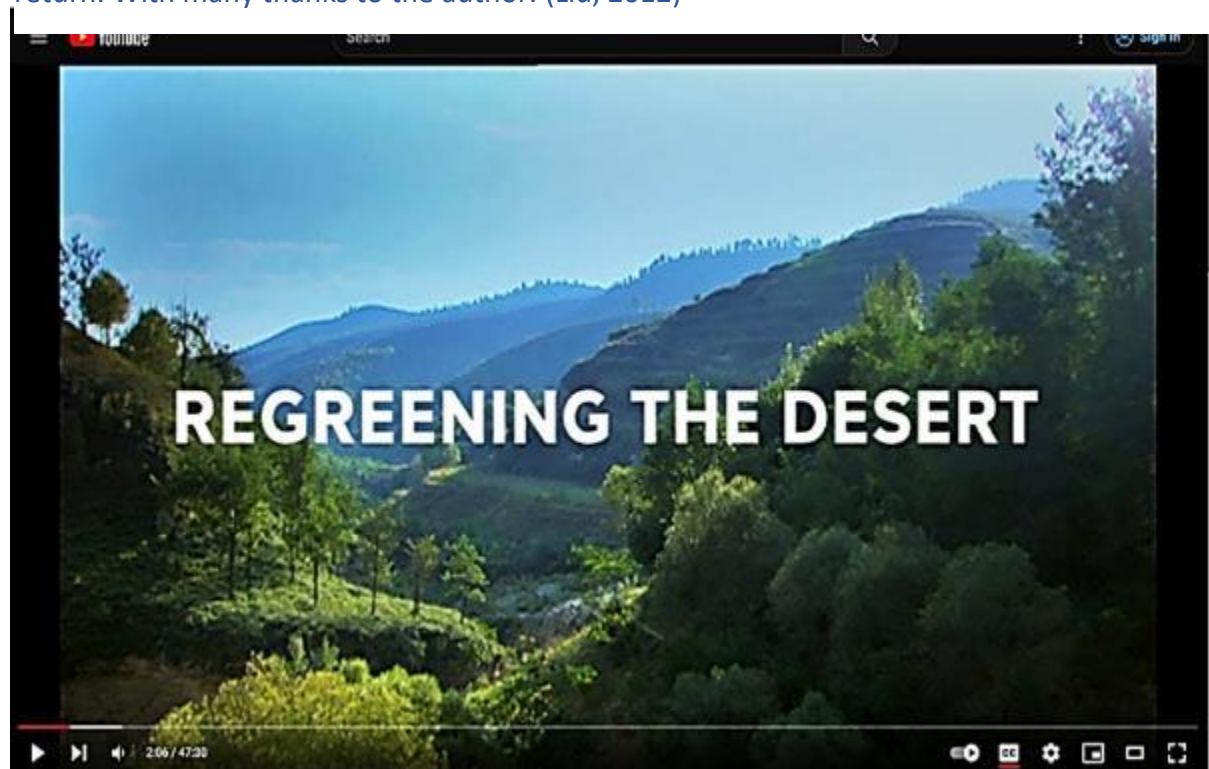


Figure 152 . *'Regreening the desert'*, images of landscaping of the Loess Plateau to recover farm land and prevent massive erosion of degraded soils, with many thanks to the author. (Liu, 2012).

Thus, landscaping to retain water, feeding livestock in enclosures, improving water retention in soils, improving the efficiency of water use by crops, and improving regional hydrology and weather through improved farming techniques are areas of research that should warrant massive effort and focus because they are cheap, apparently highly effective, available to all, and bring hope for a brighter future.

55 CLOSING THE SEWAGE CYCLE – FAECES URINE COMPOST

The modern issue of the unclosed cycle of soil, food, urine and faeces, and the use of partly processed or unprocessed sewage water and sewage sludge, disposed of primarily into rivers and onto land, remains to be resolved.

Sir Albert Howard, a leading light in the West on composting animal and human faeces and urine, clearly demonstrated the value of properly prepared biologically rich compost. His Indore composting techniques, improving yields and crop health, gained global traction before World War II. However, the emergence of artificial fertiliser in the 1950s diverted attention, albeit with misplaced confidence, and pushed aside the ‘old-fashioned’ use of composts.

As discussed in Volume 1, this will require human faeces and urine to be separated at source rather than ‘flushed and forgotten’ as part of a wastewater soup sent for treatment in a wastewater plant or dumped untreated into watercourses. Source-separated urine and faeces collected from vacuum WC systems could be anaerobically digested at the source, and the residue would need to be tankered or otherwise transported to specialist treatment centres.

The method most likely to best remediate the pharmaceuticals in faeces and urine and effectively deliver an end product safe enough to pragmatically apply to agricultural soils is hyperthermophilic anaerobic digestion followed by hyperthermophilic composting. This has the additional significant benefit of providing biogas for energy. Research is needed to improve such composting techniques further. The subject is discussed in more detail in Volume 1.

The benefits of quality compost include supplying carbon-rich microbial diversity and bound phosphates and nitrates to soils, fits neatly with regenerative agriculture, no-till, use of multi-variety crop cover, and intercropping.

In contrast to compost-supporting soil biology, “*Heavy digested slurry application decreased colonisation by internal hyphae* [endomycorrhizal fungi]” (Tobisa, 2017) has adverse effects similar to those seen with industrial fertiliser.

As discussed, sewage sludge applied to land contains a broad range of contaminants, which will, to varying extent, be taken up by plants (Kipper, 2010; Madikizela, 2018). The alternative is incineration or carbonisation. All sewage options pose their own issues, but the need to face the issue of sewage recycling is unavoidable, as it is very clear that the current disposal methods of faeces and urine are unsustainable. As discussed in volume one, there are a

number of options for better management of sewage, reduction in the pollutants it contains, and composting. Current practices are unsustainable, polluting and damaging human health.

56 FARMERS OF FORTY CENTURIES

Eminent US agronomist Dr. Franklin King has been referred to many times in this review. King was an experienced, respected soil and farming specialist. He was so inspired by what he saw and struck by its importance that he implores readers to heed the issues raised.

The final observations on agriculture written in the early 1900s, during his travels in East Asia, based on 40 centuries of Eastern farming, should be his, as they bear testament to the fact that the general principles of regenerative agriculture and their capacity to feed large populations are not new, revolutionary or unproven.

In the century since King wrote his book, we have taken a wrong turn, sometimes unknowingly using technologies that work against nature, sometimes unthinkingly seeking to dominate through destruction rather than optimising what nature has to offer by working cooperatively with it.

The King's Book records Chinese agricultural practices, representing the distillation of many centuries of observation, derived wisdom, and experience in the driven necessity of feeding large numbers of people on small acreages while keeping the same land in productive good health over many centuries.

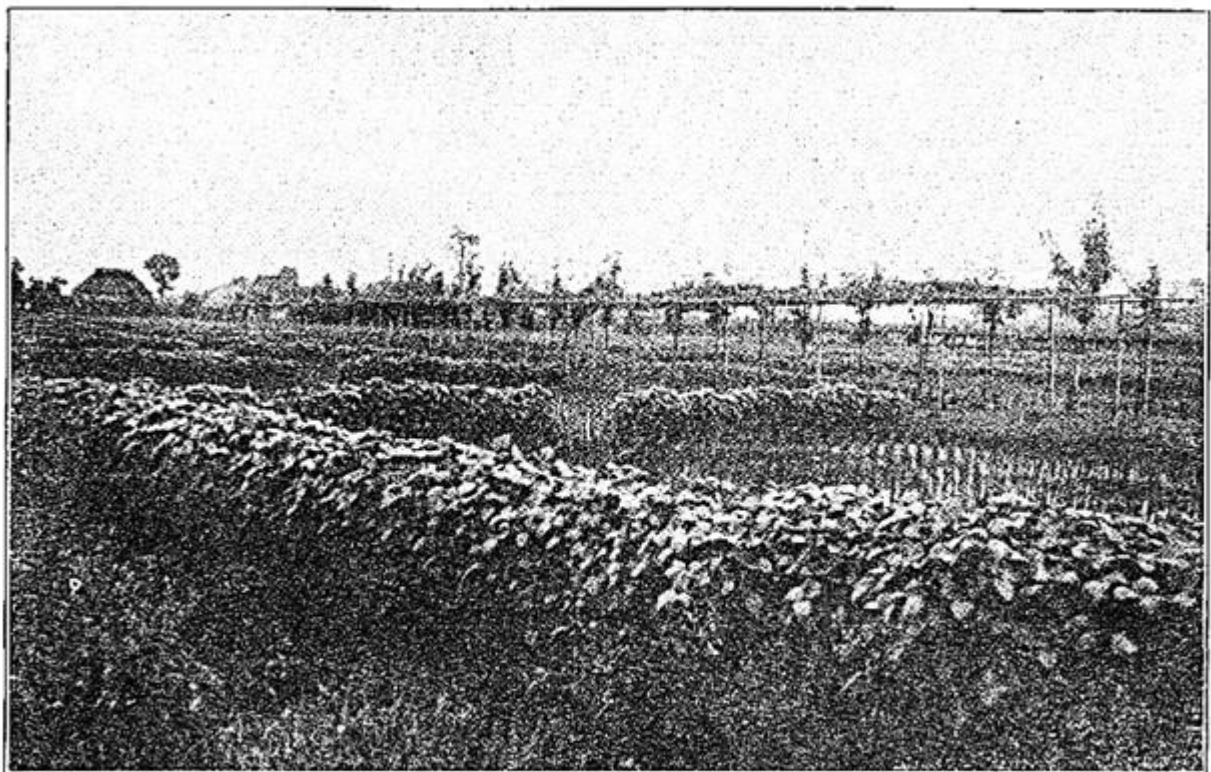


Fig. 154 Plate from 'Farmers of Forty Centuries'. Mixed farming maximising agricultural land capacity and creating diversity (King, 1911).

In *'Farmers of Forty Centuries – or Permanent Agriculture in China, Korea and Japan'* (1911), King is struck by the region's productivity, longevity and high standards of agricultural practices. He described practices, yields, disease resistance, soil maintenance and resultant crop quality. He notes the people were healthy and appeared emotionally balanced and contented. He states he very rarely witnessed arguments.

He repeatedly points out that nothing was wasted; everything organic, human and animal waste, and all organic matter, including indirectly their ancestors buried on their land, was composted and directly or indirectly returned to the land they farmed. He contrasted this constant recycling with the vast amounts of potential agricultural nutrients which are discarded and thus wasted in the West.

The Chinese and Japanese were obliged to be good farmers, to ensure the survival of them and their families. Dense populations and the limited availability of land suitable for optimal cultivation meant agricultural soils had to be tended with great care to maximise yields. Modern observational studies suggest such agricultural practices do indeed greatly improve drought resistance and general crop health.



Fig. —The young man is loading his boat with canal mud, using the long-handled clam-shell dredge which he can open and close at will.

Figure 155 Plate from *'Farmers of Forty Centuries'*. Canal mud was used as a soil improver (King, 1911).

In the late 1800s, China's most productive and populous areas provided food for several people per acre. For example, King notes in China's Shantung province, *"we talked with a farmer, having twelve in his family and who kept one donkey, one cow, both exclusively labouring animals, and two pigs on 2.5 acres of cultivated land"* (ibid).



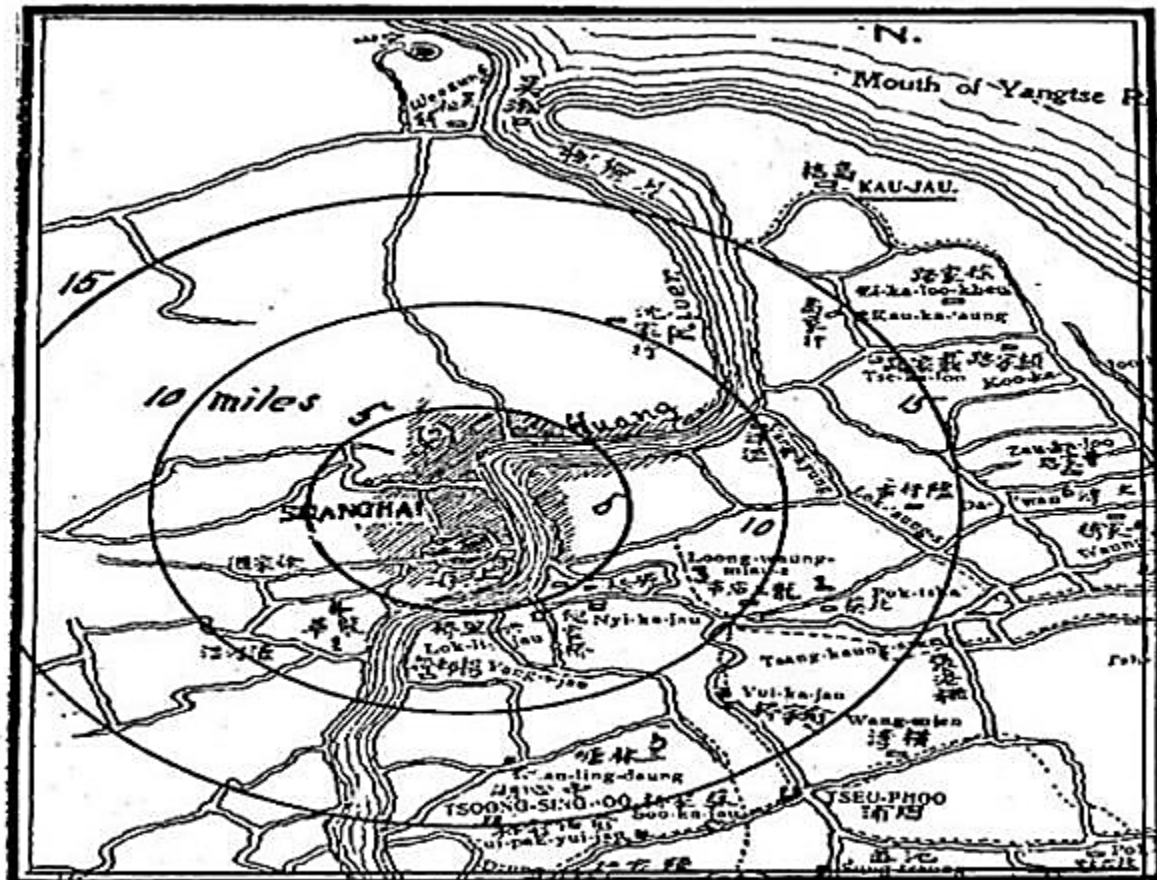
Fig. —Father and children returning from *genya* lands with herbage for use as green manure or for making compost. The daughter carries the tea kettle to supply their safe, sanitary drink.

Fig. 156. Plate from 'Farmers of Forty Centuries'. All available organic matter was returned to the land in one way or another, to improve soils and productivity (King, 1911).

Consequently, farming skills were finely honed and featured soil optimisation, intercropping with mixed species, use of nitrogen-fixing crops, and the return of all organic matter to the land, including human urine, faeces, and canal silt. Historically, ash was added too (Stephenson & Booth, 1968), as it contained residues of carbon and mineral nutrients, which can significantly improve plant growth. Organic material was often carefully and expertly composted.

Composting was highly organised and central to Chinese agriculture. *"Manure of all kinds, human and animal, is religiously saved and applied to the fields in a manner which secures an efficiency far above our own practices"* (ibid). Studies suggest that the use of human waste in the recent past was still valued in China. *"In China, [in 1995] about 30 per cent of urban human waste and 94 per cent of rural wastes are recycled"* (Childers, 2011), with the latter figure still as high as 84 per cent in 2007 (Liu, 2014). Illustrations from 'Farmers of Forty Centuries' show the lengths and effort farmers would go to create composts to improve their land and optimise its cropping potential. Note the kettle as a source of sanitised water.

By taking this approach to farming, the Chinese maintained the continuous productive use and fertility of large swathes of their agricultural soils for possibly in excess of 2,000 years.



—Map of country surrounding Shanghai, China, showing a few of the many canals on which the waste of the city is conveyed by boat to the farms.

Fig. 157. From *'Farmers of Forty Centuries'* (King), with many thanks to the author. (King, 1911)

Where less care of land was taken, such as on China's Loess Plateau, the land and its productive capacity degraded. As set out in Lowdermilk's book, the degradation of soil has been seen in a large number of civilisations globally.

In some ways, China is now Westernising, which brings its own issues. Hygiene concerns are driving the country to more centralised WC facilities and the implementation of a *'Toilet Revolution'* (Cheng et al., 2017). As a result, China will potentially face the same issues regarding sewage treatment and how to maintain soil fertility, as outlined in this review.

'The story of phosphorus: Global food security and food for thought' (Cordell, Drangert, & White, 2009) notes that Europe's recurring famines in the 17th and 18th centuries led to the need for better maintenance of soils. Strategies adopted included importing bones, using guano, and deploying night soil from urban environments. However, the use of composted night soil was abandoned with the advent of water-based Flush and Forget technology, which resulted in the disposal of piped sewage water into waterways and sludge onto agricultural land.

In his book, of Japan King noted: *“Dr Kawaguchi, of the National Department of Agriculture and Commerce, taking his data from their records, informed us that the human manure saved and applied to the fields of Japan in 1908 amounted to 23,850,295 tons, which is an average of 1.75 tons per acre of their 21,321 square miles of cultivated land in their four main islands” (King, 1911).* As previously noted, King observed in China that human faecal matter was paid for in gold and exported from cities for composting. Excrement from better-fed Europeans commanded a premium.

King also contrasted Western waste with Eastern obliged sustainability: *“The people of the United States and of Europe are pouring into the sea, lakes or rivers and into the underground waters from 5,794,300 to 12,000,000 pounds of nitrogen; 1,881,900 to 4,151,000 pounds of potassium, and 777,200 to 3,057,600 pounds of phosphorus per million of adult population annually.”*

King remarked acerbically: *“This waste we esteem one of the great achievements of our civilisation”* (ibid). Such profligacy with valuable nutrient resources persists to this day. Warming to his theme, he added: *“We are wont to think that we may instruct all the world in agriculture, because our agricultural wealth is great and our exports to less favoured peoples have been heavy; but this wealth is great because our soil is fertile and new, and in large acreage for every person. We have really only begun to farm well. The first condition of farming is to maintain fertility.”*

Only now is contemporary science catching up with what generations of Chinese hands-on farmers observed and which agricultural sages such as Hensel, Howard, and Albrecht screamed, unheard in publications of the day. They knew that soil maintenance - including using mixed species and returning to the earth the organic matter, biology, and wider nutrients in compost - is central to providing healthy crops and yields for generation after generation. They also observed that ‘artificial’ damaged soils and crops.

As discussed, Hensel, a miller and farmer, observed in the early 1900s that then artificial fertiliser was damaging soils and productivity. He was vilified for his thoughts by a nascent agrochemical industry. After a hundred years of much damage to our soils and climate, evidence from research and practical farm outcomes suggests his observations were soundly based.

Let us hope we may be witnessing the first green shoots of the emergence of agriculture that pays greater attention to maximising the photosynthetic capacity of the land to produce crops and sequester carbon, thus creating and maintaining soil fertility, as well as mitigating climate change, including planetary warming, droughts, and extreme weather events, and, if only through necessity, progress will be rapid.

For more extensive fine detail on regenerative agriculture, this review recommends video lectures – readily available online and many of them referenced here - by agronomists Dr Christine Jones, Dr David Johnson, and Dr Kristine Nicole, climate change specialist Dr Walter Jehne, and farmers Gabe Brown and Rick Clarke.

57 FARMING PROFITABLY

Dr Christine Jones explains in her video lecture, *'Building New Topsoil Through The Liquid Carbon Pathway'*, that bare soil fertiliser chemical-based farmers are spending more and making less.

Some suggest that farming profits and productivity in significant areas of the Great Plains in America would fail without artificial fertilisers due to low potassium and phosphorus. However, when first put to the plough, these soils were extremely fertile (Fixen, 2007), and it is likely that adequate minerals are still in non-soluble form.

Indeed, farmers moving to multispecies, cover crop, low till 'no' fertiliser application systems are seeing equivalent or better yields, healthier, higher quality, more nutrient dense premium price crops, reduced veterinary bills, and thus, increased profitability, as well as, improvement in; soil quality, carbon content, erosion management, biodiversity including of pollinators, greater water penetration, retention, drought resistance, plant water usage efficiency, and wellbeing.



Fig. 158 . Farmers making money in real life with Reg Gen Ag – practicalities – input reductions with 'regenerative' agriculture - 2021 AgEmerge Session with Rick Clarke (Clarke, 2021).

Rick Clarke has been using regenerative agriculture techniques for a number of years, and now farms with minimal or no fertiliser, agrochemicals, or herbicides, is organic-certified on much of his land, and achieves premiums for being organic and non-GMO. He is starting to

integrate livestock into his operations. On around 7000 acres, he saves over \$800,000 a year through reduced inputs. His family is now interested in continuing in the farming business.

Evidence is re-emerging, as initially reported by Howard, Albrecht, Turner and others, that the use of high variety mix cover crops, annuals, bi-annuals, and deep-rooted perennials; combined with low till farming; high biology compost or compost tea application; cycling cash crop and or livestock production; is resulting in cash crop; yields, nutrient density, and general quality; at least as good as or even above those of average conventional farms in the same geographic area, but with significantly reduced, or even no conventional fertiliser input and agrochemical input; so much lower input costs and thus greater overall profitability (*"Under Cover Farmers - Feature Length"*, 2012).



Fig. 159. A very large and productive potatoes plant! Image from 'Seaweed in Agriculture and Horticulture' by W A Stephenson with very many thanks to the author. (Stephenson & Booth, 1968).

This farmer chitted the seed potato on seaweed extract. He soaked the seed fortnightly in a 25% seaweed solution for two hours. He used bone meal, wood ash, straw, and compound fertiliser; cow, poultry, and pig manure; seaweed meal; and a foliar spray. In 1965, from 6 potato sets, he grew 563 lbs of potatoes. The image speaks for itself as to plants' growth

capacity and productivity, given adequate nutrients and appropriate productive soil conditions.

Clearly, there would be short-term costs in moving to more sustainable farming methods. However, early indications suggest that farming profits rise due to the considerable savings in agricultural product costs. Further, there are multiple critical environmental benefits, including a potentially positive rather than negative carbon footprint, sequestering rather than producing carbon dioxide, and water retention rather than drying.

Movement to multispecies cover crops, low till, and no fertiliser use, combined with, where practical, returning minerals and organic matter to soils in compost, clearly offers multiple economic and environmental benefits. Farmers also feel more positive because they are regenerating, rather than destroying, the biology and soil quality on their farms, which has the added benefit of encouraging younger generations to continue farming family homesteads.

Give plants the nutrients they need, and they will achieve remarkable growth, as evidenced by the SRI rice experience, successful regenerative farmers, and, at the extremes, those specialising in growing giant vegetables.

Yes, all the care that went into growing these exceptional potatoes would not have made them commercially viable. However, the potato plant's size and yield show that plants are very good at 'doing it for themselves' if we give them the nutrients and conditions needed for growth rather than polluting and poisoning their environment.

58 CONCLUSION

Through human intervention, agriculture now occupies a significant portion of the plant-productive, terrestrial land surface, climatically suitable for intensive sunlight-driven plant

Agricultural area over the long-term

Total areal land use for agriculture, measured as the combination of land for arable farming (cropland) and grazing in hectares.

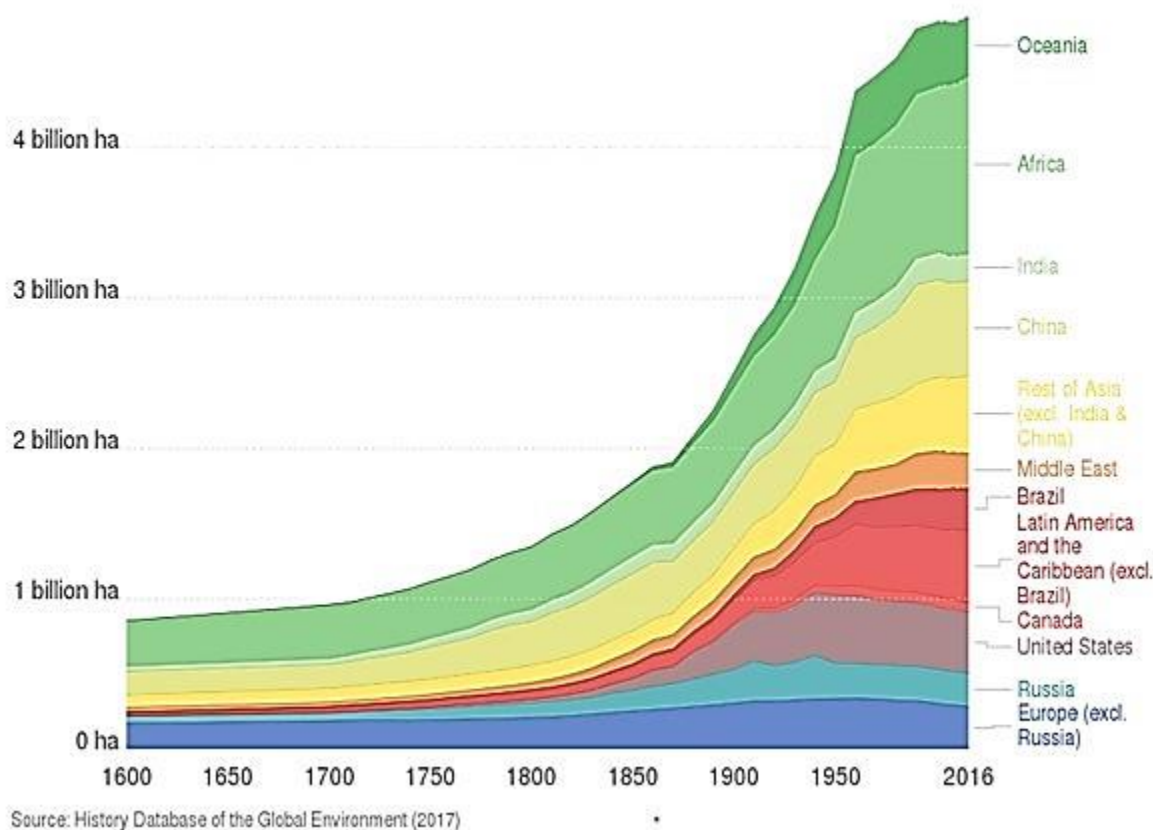


Figure 160 With thanks to Wikipedia and Our World in Data for the figure (Wikipedia, 2021)

growth. Humans have taken over the management of approximately 5 billion hectares of natural green productive ecosystems, a vast area of planetary significance, with capacity under human regulation to impact, even catastrophically destabilise, or alternatively to support, global environmental ecoservices and regulatory systems.

As discussed at the outset, the soil biome and their obligatory symbionts, plants, are crucial parts of the interlinked, interdependent and interactive global Gaian biosphere, climatic and broader life support, regulation systems that are crucial to maintaining a planetary ecosystem capable of supporting human and coexistent life.

Photosynthetic conversion of atmospheric and related oceanic carbon dioxide to organic carbon and sequestration in soils and ocean floors results in net oxygen production. Interdependent feedback systems, utilising sunlight energy for photosynthesis and evaporation, regulate the partition of carbon (an essential fundamental molecular building

block in cellular systems in lifeforms, including in soils); carbon dioxide (an atmospheric gas supplying carbon and oxygen); atmospheric oxygen levels (a reactant permitting energy intensive sophisticated life); ozone which protects our planetary surface from life killing UVC; levels of dissolved oxygen and carbon dioxide in oceans; and movement of water as respired moisture; between the earth's soils, atmosphere, oceans, and life forms; and by providing these life permissive services, also helps regulate the earth's climate within parameters that felicitously support extensive plant and soil ecosystems, and more sophisticated life, include humans.

This is a system that has evolved to be stable within a range of environmental and biological parameters and has been more or less so for very long time frames but will be subject to tipping points, causing the system to destabilise and reset, as has happened with multiple historical, significant, extinction events, as referenced earlier. New scenarios will emerge post extinction events, but if human behaviour leads to an Anthropocene extinction event, there is no guarantee that human civilisation, or the human species, will survive.

We understand that we are causing climate change through combustion of fossil fuels and broader system damage through pollution of various sorts. However, we do not, at a societal level, appreciate our choice to use the FATBAS bare ground, NPK, and agrochemical, based agriculture, which we have developed to grow our food, is a major modifiable factor in climate change, arguably at least as important, and as urgent, as the linked need for reduction of fossil fuel combustion.

Through our need to feed 'humanity', we turned vast areas of productive natural landscapes into agricultural food production resources. The desire for productivity and human love of new technologies that generate kudos, markets and profits, often without adequate reflection, led to the adoption of the FATBAS NPK bare ground agrochemical agricultural model, which initially showed great promise but, over time, led to the land degradation we now witness.

Through our current FATBAS agrochemical-dependent farming paradigms, we are unwittingly heavily degrading the soil biome and plant-dependant, free eco-service providing Gaian climate regulatory systems that we unconditionally rely on to keep our planetary climate within the stable bounds that allow humanity to continue to "live long and prosper".

Through the use of soluble nitrogen and phosphate-based fertilisers, combined with agrochemicals, exacerbated by pollutants, we have unknowingly intervened in these key ecosystem regulatory pathways, including the exchange by the soil biome of minerals and nitrates, for plant carbon sugar exudates, leading to massive soil carbon and related soil biome loss, with co-resultant; carbon dioxide emission, disturbance of hydrology thus weather systems, and related outcomes that contribute to droughts, floods and warming.

Destruction of the soil biome also leads to ecosystem imbalance, which leads to plant ill-health. We then seek to address the plant health issues, largely consequent on ecosystem imbalance, by the destruction of imbalance-related 'offending' biology through the application of often non-selective agrochemicals, which exacerbates and accelerates the

problems by further destroying soil biome life, thus magnifying existing ecoservice imbalances.

Apart from a few prescient historical sages, who went unheard, the wider agricultural community and the public were, and largely remain, unaware of the extent to which FATBAS agriculture negatively impacts the soil biome health and the Gaian; carbon, oxygen, carbon dioxide and water cycling regulatory systems, thus climate and broader life, including humans.

We have unknowingly performed an ecological system takeover, ousting natural systems, appointing ourselves de facto Gaian regulatory 'Controllers'. If we want both a long-term sustainable, supportive environment, and sustainable, productive, nutritious, profitable food chains, we need to fully understand and viscerally grasp that we are the new self-appointed Gaian planetary custodians, 'in loco "The Creator"' if you prefer. As self-appointed 'Controllers', 'CEOs' of our planetary ecosystems, we need to foster regeneration rather than degeneration: to nurture and sustain, to create, not kill, the soil biome soil and broader related ecosystems that enable our existence.

The one bright spot, is the realisation by the food industry that regenerative agriculture is a win-win-win: a win for them securing the sustainability of their food supply chains and improving their image, a win for their consumers and consumer aspirations, and a massive win for the environment. As listed earlier, many serious food players, global giants, are starting to invest seriously in regenerative agriculture and politely encouraging suppliers to provide them with regenerative agriculture crops. Recently, *"PepsiCo has unveiled plans to pump \$216 million into regenerative agriculture projects spanning 3 million acres of farmland in the US."* . . . *"We're putting our money where our mouth is"*. . . *"PepsiCo is focused on outcomes rather than being super-prescriptive about how farmers deploy regenerative ag tools."* *"measurable improvements in five areas: Carbon, soil health [soil organic matter, water-holding capacity, micro/macronutrients etc], biodiversity, watershed health [more efficient use of water and reducing pollution], and farmer livelihoods."* (Watson E, 2023) That is excellent news and hopefully indicative of future trends and broader corporate aspirations for a healthier world and society.

Similarly, it has very recently been announced that *"Irish Distillers and Heineken Ireland are coming together for a three-year collaboration that will support malting barley farmers in adopting regenerative agricultural practices on their farms."* (Ahern, 2023) These, and the other global giants listed earlier, have the balance sheet muscle, market reach and media budgets to 'body-swerve' a fertiliser and agrochemical industry that fails to refocus on bio-products, should the food industry see it is in their necessary interests to do so – and it appears they do.

So maybe there are green shoots of a brighter future emerging; nonetheless, more widely, our farming choices, as to whether we seek to regenerate or continue to kill our soil biomes, will likely determine whether or not we face inevitable ongoing and worsening, climate and related ocean events, climactic breakdowns, as foreshadowed by very recent media reports around the globe, very concerningly, of emerging patterns of increasingly regular 'climate events', fires, heatwaves, droughts, rain and storms, often reported as the worst in living

memory, including as most recently in Argentina. *“The South American nation Argentina which is known as the world's top exporter of processed soy and corn, has been bearing the brunt of a severe drought which is now considered as a key contributing factor behind the worsening economic crisis of the country.”* (*“In Pictures: Historic Drought Takes Toll On Argentina's Grain Harvest”* 2023)

We are now responsible for the environmental destiny of our only and environmentally fragile planetary home; *“there is no planet B”*. If we wish as a species “to be” rather than “not to be”, plan A should be the implementation of regenerative agricultural systems and land restoration, soil biome restitution, and consequential regreening of degraded land globally, and as a matter of urgency.

Ultimately, we logically risk triggering, likely Anthropocene reoccurrence, of historic ocean deoxygenation-based, hydrogen-sulphide-emission-related extinction events on this occasion due to eco-destabilisation by human FATBAS agricultural practices, together with the additive effects of our unsustainable massive fossil fuel combustion, wider environmental pollution, and consequent on less nutritious food and pollution, degrading human intellect, vision, insight, empathy, and capacity for Global cooperation.

END. Dated 01-06-2025.

59 BIBLIOGRAPHY

- Abbas N, Manzoor S, Saeed S, Husnain SM, Tariq M, Akhtar Z, Saira N, Yasmin G. Investigation of calcium silicate as a natural clay-based sunblock: Formulation and characterization. *Photodermatol Photoimmunol Photomed*. 2021 Jan;37(1):39-48. doi: 10.1111/phpp.12608. Epub 2020 Oct 3. PMID: 32969087.
<https://pubmed.ncbi.nlm.nih.gov/32969087/>
- Abd-Alla, M. H., Omar, S. A. & Karanxha, S. (2000). The impact of pesticides on arbuscular mycorrhizal and nitrogen-fixing symbioses in legumes. *Applied Soil Ecology*, 14(3), 191–200. [https://doi.org/10.1016/S0929-1393\(00\)00056-1](https://doi.org/10.1016/S0929-1393(00)00056-1)
- Abram, M. (2020). How to accurately measure the organic carbon content of soil. *Farmers Weekly*. Retrieved February 1, 2023, from <https://www.fwi.co.uk/arable/land-preparation/soils/how-to-accurately-measure-the-organic-carbon-content-of-soil>
- ADM (2024). 2024 Regenerative Agriculture Report
<https://www.adm.com/globalassets/sustainability/sustainability-reports/pdfs/adm-2024-regenerative-agriculture-report-1-compressed2.pdf>
- Agroecology in Ethiopia: Converting Desert into Hyper-Productive Land. (2012). *FoodAbundance*. Retrieved November 14, 2019, from <https://www.youtube.com/watch?v=mbEM6DCTK3Y>
- Ahern, D. (2023) Irish Distillers And Heineken Join Forces On Regenerative Agriculture Project For Malting Barley, Checkout. <https://www.checkout.ie/drinks/irish-distillers-and-heineken-join-forces-on-regenerative-agriculture-project-for-malting-barley-200582>
- Al-Bataina, B., Young, T. M. & Raneiri, E. (2016). Effects of compost age on the release of nutrients. *International Soil and Water Conservation Research*, 4(3), pp. 230-236.
<https://doi.org/10.1016/j.iswcr.2016.07.003>
- Albrecht papers. (n.d.). Retrieved October 29, 2019, from <https://soilandhealth.org/albrecht-page/>
- Albrecht, W. A. (1958). *Soil Fertility and Animal Health*. Fred Hahne Printing Company Webster City, Iowa.
- Allison, R. (2019). Three Canadian farmers reveal their secrets to soil health. *Farmers Weekly*. Retrieved February 1, 2023, from <https://www.fwi.co.uk/arable/land-preparation/soils/three-canadian-farmers-reveal-their-secrets-to-soil-health>
- Alter, R. E., Douglas, H. C., Winter, J. M., & Eltahir, E. A. B. (2018). Twentieth century regional climate change during the summer in the central United States attributed to agricultural intensification. *Geophysical Research Letters*, 45, 1586–1594.
<https://doi.org/10.1002/2017GL075604>
- ARTE. (2022). India: Sikkim - A Green New World. *ARTE.tv Documentary* Retrieved February 1, 2023, from https://www.youtube.com/watch?v=dBcmIXb_sPQ
- Arneth A, ... et al. (2018). IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems. <https://www.ipcc.ch/srccl/>
- Archuleta, R. (2012a). Soil health lessons in a minute: benefits of no-till farming NRCS Agronomist Ray Archuleta. *The USDANRCS*. Retrieved February 1, 2023, from https://www.youtube.com/watch?v=Rpl09XP_f-w

- Archuleta, R. (2012b). Soil health lessons in a minute: soil stability test' NRCS Agronomist Ray Archuleta. *The USDANRCS*. Retrieved February 1, 2023, from https://www.youtube.com/watch?v=9_ItEhCrLoQ
- Archuleta, R (2016). Annotated slide from UTube lecture 'No-till on the Plains'. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=rLHZNNdOpAc>
- Archuleta, R. (2021a). AgEmerge Breakout Session with Ray Archuleta. *Ag Solutions Network*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=odKOyQeQoLs>
- Archuleta, R. (2021b). Regenerative Agriculture, Healing The World - By Ray Archuleta @ Carbon Summit. *US Energy*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=QNW0ZN0XCpg>
- As CO₂ levels climb, millions are at risk of nutritional deficiencies. (2018). Retrieved October 25, 2019, from <https://phys.org/news/2018-08-co2-climb-millions-nutritional-deficiencies.html>
- Askew, K. (2021). Danone talks regenerative agriculture: Linking dairy and plant-based at a farm level can yield sustainability gains. *FoodNavigator.com*. Retrieved February 1, 2023, from <https://www.foodnavigator.com/Article/2021/08/24/Danone-talks-regenerative-agriculture-Linking-dairy-and-plant-based-at-a-farm-level-can-yield-sustainability-gains>
- Atakan, A., Özkaya, H. (2021) Arbuscular Mycorrhizal Fungi and Glomalin, 2371 Turkish Journal of Agriculture - Food Science and Technology, 9(12): 2371-2375, 2021 DOI: <https://doi.org/10.24925/turjaf.v9i12.2371-2375.4555>
- Aubert, P.-M., Schwoob, M.-H. & Poux, X. (2019). Agroecology and carbon neutrality in Europe by 2050: what are the issues? Findings from the TYFA modelling exercise. Retrieved November 1, 2019, from [https://www.iddri.org/sites/default/files/PDF/Publications/CatalogueIddri/D%C3%A9cryptage/201904-ST0219-TYFA GHG.pdf](https://www.iddri.org/sites/default/files/PDF/Publications/CatalogueIddri/D%C3%A9cryptage/201904-ST0219-TYFA%20GHG.pdf)
- Avasthe, R. K., Verma, S., Kumar, A. & Rahman, H. (2012). Performance of rice (*Oryza sativa*) varieties at different spacing under system of rice intensification (SRI) in mid hill acid soils of Sikkim Himalayas. *Indian Journal of Agronomy*, 57, 32-37.
- Barron-Gafford, G., Minor, R., Allen, N. *et al.* The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures. *Sci Rep* 6, 35070 (2016). <https://doi.org/10.1038/srep35070>
- Barros, N. (2021). Thermodynamics of Soil Microbial Metabolism: Applications and Functions. *Appl. Sci.* 2021, 11(11), 4962. <https://doi.org/10.3390/app11114962>
- Bashagaluke, J. B., Logah, V., Opoku, A., Sarkodie-Addo, J., & Quansah, C. (2018). Soil nutrient loss through erosion: Impact of different cropping systems and soil amendments in Ghana. *PLOS ONE*, 13(12), e0208250. <https://doi.org/10.1371/journal.pone.0208250>
- Baumhardt, R. L., Stewart, B. A. & Sainju, U. M. (2015). North American soil degradation: Processes, practices, and mitigating strategies. *Sustainability (Switzerland)*, 7(3), 2936-2960. <https://doi.org/10.3390/su7032936>
- Begum, N., Qin, C., Ahanger, M. A., Raza, S., Khan, M. I., Ashraf, M., Ahmed, N., & Zhang, L. (2019). Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance. *Frontiers in plant science*, 10, 1068. <https://doi.org/10.3389/fpls.2019.01068>

- Bergmann, M., Allen, S., Krumpen, T., Allen, D. (2023). High Levels of Microplastics in the Arctic Sea Ice Alga *Melosira arctica*, a Vector to Ice-Associated and Benthic Food Webs *Environmental Science & Technology* 2023 57 (17), 6799-6807 DOI: 10.1021/acs.est.2c08010 <https://pubs.acs.org/doi/10.1021/acs.est.2c08010>
- Berkley.edu (nd). Absorption / reflection of sunlight. <https://ugc.berkeley.edu/background-content/reflection-absorption-sunlight/>
- Berns, K. (2020). AgEmerge Breakout Session with Keith Berns; Carbonomics. *Ag Solutions Network*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=sFowLIYjRCI>
- Bezemer, M. (2019). Mixed farming increases rice yield, is resilient and sustainable. Retrieved February 1, 2023, from https://www.inktenaarde.nl/mixed_farming/
- Boston Consulting G, Carlsberg, One Planet Business for Biodiversity, (2025) Sowing Change, a report outlining six actionable recommendations to transform European agriculture and secure a more sustainable future. <https://www.carlsberggroup.com/newsroom/call-for-eu-action-on-regenerative-agriculture/>
- Brandt D. (2020). UTube Webinar '40 years of regenerative agriculture'. *Understanding Ag*. Retrieved February 1, 2023, <https://www.youtube.com/watch?v=wpF4b54l2T4>
- Brandt, L., King, J., Hobbie, S., Milchunas, D. G. & Sinsabaugh, R. L. (2010). The Role of Photodegradation in Surface Litter Decomposition Across a Grassland Ecosystem Precipitation Gradient. *Ecosystems*, 13, 765–781 (2010). <https://doi.org/10.1007/s10021-010-9353-2>
- Bredeson, M. (2021). A slide from the UTube lecture 'Insects a little known force of nature shaping your farmland'. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=ZWYiArIKoxc>
- Bingham, A. H. & Cotrufo, M. F. (2016). Organic nitrogen storage in mineral soil: Implications for policy and management. *Science of The Total Environment*, 551–552, 116-126. <https://doi.org/10.1016/j.scitotenv.2016.02.020>
- Bitterlich M, Sandmann M, Graefe J. Arbuscular Mycorrhiza Alleviates Restrictions to Substrate Water Flow and Delays Transpiration Limitation to Stronger Drought in Tomato. *Front Plant Sci*. 2018 Feb 16;9:154. doi: 10.3389/fpls.2018.00154. PMID: 29503655; PMCID: PMC5820414. <https://pubmed.ncbi.nlm.nih.gov/29503655/>
- Bottino, M.J., Nobre, P., Giarolla, E. *et al*. Amazon savannization and climate change are projected to increase dry season length and temperature extremes over Brazil. *Sci Rep* 14, 5131 (2024). <https://doi.org/10.1038/s41598-024-55176-5>
- Bousselhaj, K., Fars, S., Laghmari, A., Nejmeddine, A., Ouazzani, N., Ciavatta D A Bp, C., & Principale, Béni-Mellal, P. (2004). Nitrogen fertilizer value of sewage sludge co-composts. *Agronomie*, 24, 487–492. <https://doi.org/10.1051/agro:2004045>
- Britannica, (n.d.)mole <https://www.britannica.com/science/mole-chemistry>
- Brown, G. (2017a). Treating the Farm as an Ecosystem Part 3 with Gabe Brown. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=QwoGCDdCzeU>
- Brown, G. (2017b). Treating the Farm as an Ecosystem with Gabe Brown Part 1, The 5 Tenets of Soil Health. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=uUmlDqOD6-A>
- Brown, G. (2021) Gabe Brown discusses how Regenerative Agriculture is a solution to global challenges. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=TLwsn8snsMc>

- Brown, G. (2022). From Dirt to Soil: The Guys Get To Know Gabe Brown. Field Work. Retrieved February 1, 2023, from <https://www.fieldworktalk.org/episode/2022/05/18/from-dirt-to-soil-the-guys-get-to-know-gabe-brown>
- Brown, R. A. (2016a). Bioactive oxidised products of omega-6 and omega-3, excess oxidative stress, oxidised dietary intake and antioxidant nutrient deficiencies, in the context of a modern diet. In *Omega-3 Fatty Acids: Keys to Nutritional Health* (pp. 350–383). Springer International Publishing. https://doi.org/10.1007/978-3-319-40458-5_28
- Brown, R. A. (2016b). The crucial relevance of ala and la as primary peroxisomal beta-oxidation substrates, of oxidised la as the primary endogenous activator of PPAR gamma, and energy deficit as the primary activator of PPAR alpha. In *Omega-3 Fatty Acids: Keys to Nutritional Health* (pp. 451–463). Springer International Publishing. https://doi.org/10.1007/978-3-319-40458-5_32
- Brown, R. A. (2016c). The Linoleic-to-Linolenic Dietary Intake Ratio: The Fundamental Implications of Imbalance and Excess Looked at from Both a Functional and an Evolutionary Perspective: An Overview BT - *Omega-3 Fatty Acids: Keys to Nutritional Health*. In M. V Hegde, A. A. Zanwar, & S. P. Adekar (Eds.), *Omega-3 Fatty Acids* (pp. 321–348). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-40458-5_27
- Brown, R. A. (2016d). The roles of linoleic and alpha-linolenic acid, their oxylipins and the PPAR alpha-, delta and gamma-related peroxisomal pathways on obesity in the context of a “western” diet. In *Omega-3 Fatty Acids: Keys to Nutritional Health* (pp. 429–449). Springer International Publishing. https://doi.org/10.1007/978-3-319-40458-5_31
- Brown, R. A. (2021e). Oceanic oxygen 'gO2ing'; but where? Oxygen is not a ‘climate-insignificant atmospheric gas, of immense abundance’ - (total) 1,080,000GT. (est.). OB24D-0490 Conference: Ocean Science Meeting 2020 - AGU San DiegoAbstract ID: 645389, Conference: Ocean Science Meeting 2020 - AGU San DiegoAbstract ID: 645389
- Brown, R. A. (2022). Predestined? A Universal Evolutionary Origin of Life – UVC Protective Silicate ‘Shell-Cells’ - and a Zeolite-Exoskeleton-Proto-RNA, Selecting ‘Exactly’ 22 Amino Acids and Underlying the Codon System? (updated v.2). Retrieved February 1, 2023, from https://www.researchgate.net/publication/363539172_Predestined_A_Universal_Evolutionary_Origin_of_Life_-_UVC_Protective_Silicate_'Shell-Cells'_-_and_a_Zeolite-Exoskeleton-Proto-RNA_Selecting_'Exactly'_22_Amino_Acids_and_Underlying_the_Codon_System_upd
- Bryant L. (2015) NRDC Organic Matter Can Improve Your Soil's Water Holding Capacity <https://www.nrdc.org/bio/lara-bryant/organic-matter-can-improve-your-soils-water-holding-capacity>
- Buckeridge, K.M., Mason, K.E., Ostle, N. et al. (2022). Microbial necromass carbon and nitrogen persistence are decoupled in agricultural grassland soils. *Commun Earth Environ* 3, 114 (2022). <https://doi.org/10.1038/s43247-022-00439-0>
- Bucking, H., Liepold, E. & Ambilwade, P. (2012). The Role of the Mycorrhizal Symbiosis in Nutrient Uptake of Plants and the Regulatory Mechanisms Underlying These Transport Processes. In *Plant Science*. Dhal, N. K. and Sahu, S. C. (Eds). InTechOpen. <https://doi.org/10.5772/52570>

- Bugas, J., Conant, H., Hoo, S., Bellino, F., Unnikrishnan, S., Westerlund, M. (2023) Boston Consulting Group, 'Climate Change and Sustainability . . . Making Regenerative Agriculture Profitable for US Farmers'
<https://www.bcg.com/publications/2023/regenerative-agriculture-profitability-us-farmers>
- Burning Agricultural Waste: A Source of Dioxins Factsheet. (2014). Commission for Environmental Cooperation. Retrieved February 1, 2023, from <http://www.cec.org/files/documents/publications/11405-la-quema-de-residuos-agricolas-es-una-fuente-de-dioxinas-en.pdf>
- Burns, S. (2010). Nutritional value of fruits, veggies dwindling. NBC News. Retrieved February 1, 2023, from <https://www.nbcnews.com/health/health-news/nutritional-value-fruits-veggies-dwindling-flna1c9457205>
- Buss, W., Hasemer, H., Sokol, N.W. *et al.* Applying minerals to soil to draw down atmospheric carbon dioxide through synergistic organic and inorganic pathways. *Commun Earth Environ* 5, 602 (2024). <https://doi.org/10.1038/s43247-024-01771-3>
<https://www.nature.com/articles/s43247-024-01771-3#citeas>
- Butsenko, L., Pasichnyk, L., Kolomiiets, Y., Kalinichenko, A., Suszanowicz, D., Sporek, M. & Patyka, V. (2021). Characteristic of *Pseudomonas syringae* pv. *atrofaciens* Isolated from Weeds of Wheat Field. *Applied Sciences*. 11(1):286.
<https://doi.org/10.3390/app11010286>
- Butt E, Baker J, Bezerra F, von Randow C, Aguiar A, Spracklen D. (2023) Amazon deforestation causes strong regional warming. *Proc Natl Acad Sci U S A*. 2023 Nov 7;120(45):e2309123120. doi: 10.1073/pnas.2309123120.
<https://pubmed.ncbi.nlm.nih.gov/37903256/>
- Cabral, L., Soares, C. R. F. S., Giachini, A. J. & Siqueira, J. O. (2015). Arbuscular mycorrhizal fungi in phytoremediation of contaminated areas by trace elements: mechanisms and major benefits of their applications. *World Journal of Microbiology and Biotechnology*, 31, 1655-1664. <https://doi.org/10.1007/s11274-015-1918-y>
- Cakmak, I., Prom-u-thai, C., Guilherme, L.R.G., Rashid, A., Hora, K. H., Yazici, A., Savasli, E., Kalayci, M., Tutus, Y., Phuphong, P., Rizwan, M., Martins, F. A. D., Dinali, G. S. & Ozturk, L. (2017). Iodine biofortification of wheat, rice and maize through fertilizer strategy. *Plant and Soil*, 418, 319–335 (2017). <https://doi.org/10.1007/s11104-017-3295-9>
- Campbell, Nicola S. (2009) The use of rockdust and composted materials as soil fertility amendments. PhD thesis, University of Glasgow. <https://theses.gla.ac.uk/617/>
- Campos, P., Borie, F., Cornejo, P., López-Ráez, J. A., López-García, Á., & Seguel, A. (2018). Phosphorus Acquisition Efficiency Related to Root Traits: Is Mycorrhizal Symbiosis a Key Factor to Wheat and Barley Cropping? *Frontiers in Plant Science*, 9(752), 1-21.
<https://doi.org/10.3389/fpls.2018.00752>
- Cargill Regenconnect (2025) Cargill Surpasses 1 Million Enrolled Acres in Cargill RegenConnect®, Advancing Farmer Adoption of Regenerative Agriculture
<https://www.businesswire.com/news/home/20241112043432/en/Cargill-Surpasses-1-Million-Enrolled-Acres-in-Cargill-RegenConnect-Advancing-Farmer-Adoption-of-Regenerative-Agriculture>
- Carrillo, A. (2021). Building Resiliency: Ranching for resilience in the Chihuahuan Desert. *Understanding Ag*. Retrieved February 1, 2023, from https://www.youtube.com/watch?v=_mO1I5ys56E

- Carlsberg Group plans expanded regenerative barley usage across brands in the UK, Finland and France". (Carlsberg, 2023) <https://www.carlsberggroup.com/newsroom/carlsberg-group-plans-expanded-regenerative-barley-usage-across-brands-in-the-uk-finland-and-france/>
- Cercioglu, M., Udawatta, R., Anderson, S. (2025) Use of cover crops for sustainable management of soil condition and health: A review, *Soil Security*, Volume 18, 2025, 100177, ISSN 2667-0062, <https://doi.org/10.1016/j.soisec.2025.100177>.
<https://www.sciencedirect.com/science/article/pii/S2667006225000024>
- CGIAR, (2021). Low-emission technologies transform Vietnam's rice sector. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=AYRLODzZgFc>
- Chander, V., Sharma, B., Negi, V., Aswal, R. S., Singh, P., Singh, R. & Dobhal, R. (2016). Pharmaceutical Compounds in Drinking Water. *J Xenobiot.*, 6(1), 5774.
<https://doi.org/10.4081/xeno.2016.5774>
- Chaudhuri, S. & Roy M. (2017). Air pollution: Without alternatives, penalties against stubble burning will never work. O.P. Jindal Global University. Retrieved February 1, 2023, from <https://jgu.edu.in/blog/air-pollution-without-alternatives-penalties-against-stubble-burning-will-never-work/>
- Chen, T., Zhou, S., Liang, C., Hagan, D. F. T., Zeng, N., Wang, J., Shi, T., Chen, X., & Dolman, A. J. (2020). The Greening and Wetting of the Sahel Have Levelled off since about 1999 in Relation to SST. *Remote Sensing*, 12(17), 2723. <https://doi.org/10.3390/rs12172723>
<https://www.mdpi.com/2072-4292/12/17/2723>
- Cheval, S., Amihăsesei, V., Chitu, Z., Dumitrescu, A., Falcescu, V., et al. (2024) A systematic review of urban heat island and heat waves research (1991–2022), *Climate Risk Management*, Volume 44, 100603, ISSN 2212-0963,
<https://doi.org/10.1016/j.crm.2024.100603>.
<https://www.sciencedirect.com/science/article/pii/S2212096324000202>
- Chibueze, U. F., Akubugwo, E., Agbafor, K. N., Nnanna, L. A., Nwokocha, N. J. & Ekekwe, N. D. (2012). Appraisal of Heavy Metal Contents in Commercial Inorganic Fertilizers Blended and Marketed in Nigeria. *American Journal of Chemistry*, 2(4), 228-233.
<https://doi.org/10.5923/j.chemistry.20120204.07>
- Childers, D. L., Corman, J., Edwards, M. & Elser, J. J. (2011). Sustainability Challenges of Phosphorus and Food: Solutions from Closing the Human Phosphorus Cycle. *BioScience*, 61(2), 117–124. <https://doi.org/10.1525/bio.2011.61.2.6>
- Christensen, P. R., J. L. Bandfield, V. E. Hamilton, D. A. Howard, M. D. Lane, J. L. Piatek, S. W. Ruff, and W. L. Stefanov (2000), A thermal emission spectral library of rock-forming minerals, *J. Geophys. Res.*, 105(E4), 9735–9739, doi:[10.1029/1998JE000624](https://doi.org/10.1029/1998JE000624).
- Cierniewski, J.; Ceglarek, J. (2024) Annual Dynamics of Shortwave Radiation as Consequence of Smoothing Previously Plowed Bare Arable Land Surface in Europe. *Remote Sens.* 2024, 16, 2476. <https://doi.org/10.3390/rs16132476>
- Clarke, R. (2021). AgEmerge Breakout Session with Rick Clarke. *Ag Solutions Network*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=c9sm7l86hfA>
- Conceição, L. T., Silva, G. N., Silva Holsback, H. M., Oliveira, C. de F., Marcante, N. C., Martins, É. de S., Santos, F. L. de S., & Santos, E. F. (2022). Potential of basalt dust to improve soil fertility and crop nutrition. *Journal of Agriculture and Food Research*, 10, 100443. <https://doi.org/10.1016/j.jafr.2022.100443>
- Complex adaptive rice cultivation. (2014). *FSE Wageningen*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=gAe65rwU26s>

- Commission proposes strategy to protect Europe's soils. (2006). European Commission, IP/06/1241. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/IP_06_1241
- Compost Can Turn Agricultural Soils Into A Carbon Sink, Thus Protecting Against Climate Change. (2008). *ScienceDaily*. Retrieved October 29, 2019, from <https://www.sciencedaily.com/releases/2008/02/080225072624.htm>
- Compost Use and Soil Fertility. (n.d.). *Center for Agriculture, Food, and the Environment, University of Massachusetts Amherst*. Retrieved December 19, 2019, from <http://ag.umass.edu/vegetable/fact-sheets/compost-use-soil-fertility>
- Consensus Document on Compositional Considerations for New Varieties of Bread Wheat (*Triticum aestivum*): Key Food and Feed Nutrients, Anti-nutrients and Toxicants. (2003). *Organisation for Economic Co-operation and Development*. Retrieved November 1, 2019, from <http://www.oecd.org/env/ehs/biotrack/46815206.pdf>
- Coombe, N. B. & Hood, A. E. M. (1980). Fertilizer-nitrogen: Effects on dairy cow health and performance. *Fertilizer Research*, 1(3), 157–176. <https://doi.org/10.1007/BF01053129>
- Corcoran, E., Nellesmann, C., Baker, E., Bos, R., Osborn, D. & Savelli, H. (Eds). (2010). Sick Water? The central role of waste-water management in sustainable development. A Rapid Re-sponse Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal. <https://wedocs.unep.org/20.500.11822/9156>
- Cordell, D., Drangert, J. O. & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Change*, 19(2), 292–305. <https://doi.org/10.1016/j.gloenvcha.2008.10.009>
- Corrêa, R. S., White, R. E. & Weatherley, A. J. (2006). Effect of compost treatment of sewage sludge on nitrogen behavior in two soils. *Waste Manag.* 26(6), 614-619. <https://doi.org/10.1016/j.wasman.2005.09.008>
- Çuhac, C., Mäkiranta, A., Välisuo, P., Hiltunen, E. & Elmusrati, M. (2020). Temperature Measurements on a Solar and Low Enthalpy Geothermal Open-Air Asphalt Surface Platform in a Cold Climate Region. *Energies*, 13(4), 979. <https://doi.org/10.3390/en13040979>
- Cycoń, M., Mroziak, A. & Piotrowska-Seget, Z. (2019). Antibiotics in the soil environment—degradation and their impact on microbial activity and diversity. *Frontiers in Microbiology*, 10(338), 1-45. <https://doi.org/10.3389/fmicb.2019.00338>
- Czyżyk, F. & Rajmund, A. (2014). Influence of agricultural utilization of sludge and compost from rural wastewater treatment plant on nitrogen passes in light soil. *Polish Journal of Chemical Technology*, 16(1), 1–6. <https://doi.org/10.2478/pjct-2014-0001>
- Daniela, S., Francesco, S. & Elodie, V. (2022). The unseen effect of pesticides: The impact on phytobiota structure and functions. *Frontiers in Agronomy*, 4, 1-12. <https://doi.org/10.3389/fagro.2022.936032>
- Damania, R., Desbureaux, S., Rodella, A.-S., Russ, J. & Zaveri, E. (2019). *Quality Unknown. The Invisible Water Crisis*. Washington, DC: World Bank <https://www.worldbank.org/en/news/feature/2019/08/20/quality-unknown>
- Dartnell, L. (n.d.). Sparks of Life. Retrieved February 1, 2023, from http://lewisdartnell.com/sparks_page.htm
- Dastogeer, K. M. G., Tumpa, F. H., Sultana, A., Akter, M. A. & Chakraborty, A. (2020). *Current Plant Biology*, 23(100161), 1-9. <https://doi.org/10.1016/j.cpb.2020.100161>
- Davis, D. R. (2009). Declining Fruit and Vegetable Nutrient Composition: What Is the Evidence? *HortScience*, 44(1), 15-19. <https://doi.org/10.21273/HORTSCI.44.1.15>

- Davis, D. R., Epp, M. D. & Riordan, H. D. (2004). Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999. *Journal of the American College of Nutrition*, 23(6), 669–682. <https://doi.org/10.1080/07315724.2004.10719409>
- Davies, J. (2017). The business case for soil. *Nature*, 543, 309–311. <https://doi.org/10.1038/543309a>
- Dean, T. (n.d.). Las Damas Ranch, Aldama County, Chihuahua, Mexico, Las Damas Ranch Case Study. *UnderstandingAg*. Retrieved February 1, 2023, from https://understandingag.com/case_studies/las-damas-ranch-case-study/
- Deenik, J. L., McClellan, T., Uehara, G., Antal, M. J. & Campbell, S. (2010), Charcoal Volatile Matter Content Influences Plant Growth and Soil Nitrogen Transformations. *Soil Sci. Soc. Am. J.*, 74(4), 1259-1270. <https://doi.org/10.2136/sssaj2009.0115>
- Deshmukh, R., Khardenavis, A. A. & Purohit, H. J. (2016). Diverse Metabolic Capacities of Fungi for Bioremediation. *Indian Journal of Microbiology*, 56, 247-264. <https://doi.org/10.1007/s12088-016-0584-6>
- Diagne, N., Mariama Ngom, M., Djighaly, P., Fall, D., Hoher, V. & Svistoonoff, S. (2020). Roles of Arbuscular Mycorrhizal Fungi on Plant Growth and Performance: Importance in Biotic and Abiotic Stressed Regulation. *Diversity* 12(10), 370. <https://doi.org/10.3390/d12100370>
- Dioxins in San Francisco Bay | Region 9: Water | US EPA. (n.d.). Retrieved December 6, 2019, from <https://19january2017snapshot.epa.gov/www3/region9/water/dioxin/index.html>
- Doetterl, S., Berhe, A.A., Heckman, K. et al. A landscape-scale view of soil organic matter dynamics. *Nat Rev Earth Environ* 6, 67–81 (2025). <https://doi.org/10.1038/s43017-024-00621-2> https://www.fs.usda.gov/nrs/pubs/jrnl/2025/nrs_2025_doetterl_001.pdf
- Duke, P., Richaud, B. Arruda, R., Länger, J., K. Schuler, K., et al. 2023. Canada's marine carbon sink: an early career perspective on the state of research and existing knowledge gaps. *FACETS*. 8: 1-21. <https://doi.org/10.1139/facets-2022-0214> <https://www.facetsjournal.com/doi/10.1139/facets-2022-0214>
- Dwivedi, S., Sahrawat, K., Upadhyaya, H. & Ortiz, R. (2013). Food, Nutrition and Agrobiodiversity Under Global Climate Change. In *Advances in Agronomy*, Chapter 1. pp. 1–128. Academic Press Inc. <https://doi.org/10.1016/B978-0-12-407686-0.00001-4>
- Earthworms A Gardener's Best Friend. (n.d.). *Nature's Way Resources*. Retrieved February 1, 2023, from <https://www.natureswayresources.com/infosheets/earthworms.html>
- L'Ecuyer, T.S. (2017). Earth's Energy Balance. In *International Encyclopedia of Geography: People, the Earth, Environment and Technology* (eds D. Richardson, N. Castree, M.F. Goodchild, A. Kobayashi, W. Liu and R.A. Marston). <https://doi.org/10.1002/9781118786352.wbieg1132>
- Ehtasham, L., Sherani, S. H., Nawaz, F. (2024). Acceleration of the hydrological cycle and its impact on water availability over land: an adverse effect of climate change. *Meteorology Hydrology and Water Management*, 12(1), 1-21. <https://doi.org/10.26491/mhwm/188920>
- EIP-AGRI, (2022) Life on Earth depends on healthy soils. <https://ec.europa.eu/eip/agriculture/en/news/life-earth-depends-healthy-soils.html>
- Environmental impact of nitrogen and phosphorus fertilisers in high rainfall areas. (n.d.). *Agriculture and Food, Department of Primary Industries and Regional Development*. Retrieved December 17, 2019, from <https://www.agric.wa.gov.au/high-rainfall-pastures/environmental-impact-nitrogen-and-phosphorus-fertilisers-high-rainfall-areas>

- ENVIS, (2022a) ENVIS Hub: Sikkim. Status of Environment and Related Issues. Area, Production and Productivity of Maize in Sikkim. Retrieved February 1, 2023, from http://www.sikenvis.nic.in/Database/MaizeSikkim_4080.aspx
- ENVIS, (2022b) ENVIS Hub: Sikkim. Status of Environment and Related Issues. Area, Production and Productivity of Rice in Sikkim. Retrieved February 1, 2023, from http://www.sikenvis.nic.in/Database/RiceSikkim_4078.aspx
- EPA. (2021). *Reducing Urban Heat Islands: Compendium of Strategies*. U.S. Environmental Protection Agency. <https://www.epa.gov/heatislands/guide-reducing-heat-islands>
- Esther, G. & Newark, N. J. (2011). Dirt Poor: Have Fruits and Vegetables Become Less Nutritious? *Scientific American*. Retrieved November 1, 2019, from <https://www.scientificamerican.com/article/soil-depletion-and-nutrition-loss/>
- European Environment Agency. (2013). *Down to Earth: Soil degradation and sustainable development in Europe*. European Environment Agency, Bernan Associates distributor. Retrieved February 1, 2023, from <http://www.worldcat.org/title/down-to-earth-soil-degradation-and-sustainable-development-in-europe-a-challenge-for-the-21st-century/oclc/45959241>
- Falkenmark, M. (2013). Growing water scarcity in agriculture: future challenge to global water security. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 371(20120410). <https://doi.org/10.1098/rsta.2012.0410>
- FAO, IFAD, UNICEF, WFP and WHO. (2018). *The State of Food Security and Nutrition in the World 2018. Building climate resilience for food security and nutrition*. Rome, FAO. (2018). Retrieved February 1, 2023, from <http://www.fao.org/3/I9553EN/i9553en.pdf>
- FAO. (2024) The State of the Worlds Forests; Innovative approaches are bolstering the restoration of degraded lands and expanding agroforestry <https://openknowledge.fao.org/server/api/core/bitstreams/768ba59e-c692-47c3-9a13-3c3c10993396/content/src/html/restoration-degraded-lands-agroforestry.html#gsc.tab=0>
- FAO. (2011). *The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk*. Food and Agriculture Organization of the United Nations, Rome and Earth's'can, London. London: . Food and Agriculture Organization of the United Nations, Rome and Earth's'can. Retrieved from [fao.org/3/a-i1688e.pdf](http://www.fao.org/3/a-i1688e.pdf)
- FAO (2015). AQUASTAT - FAO's Global Information System on Water and Agriculture. Retrieved February 1, 2023, from <https://www.fao.org/aquastat/en/>
- FAO. (2018b) Global Soil Organic Carbon Map Technical report. Retrieved February 1, 2023, from <https://www.fao.org/3/I8891EN/i8891en.pdf>
- FAO, (2017). Soil Organic Carbon, the hidden potential. Retrieved February 1, 2023, from <https://www.fao.org/3/i6937e/i6937e.pdf>
- FAO. (2018a). Nitrogen inputs to agricultural soils from livestock manure. *New statistics*. Retrieved February 1, 2023, from <https://www.fao.org/documents/card/en/c/I8153EN>
- FAO. (2019a). FAOSTAT analytical brief 4, Drained organic soils - 1990–2019 -Global, regional and country trends. Retrieved February 1, 2023, from <https://www.fao.org/3/cb0489en/cb0489en.pdf>
- FAO. (2019b). FAOSTAT analytical brief 18, Emissions due to agriculture - Global, regional and country trends - 2000–2018. Retrieved February 1, 2023, from <https://www.fao.org/3/cb3808en/cb3808en.pdf>

- FAO. (2020a). STATE of KNOWLEDGE of SOIL BIODIVERSITY - Status, challenges and potentialities <https://www.fao.org/interactive/soil-biodiversity/en/>
<https://www.fao.org/global-soil-partnership/resources/publications/en/>
- FAO. (2021) Faostat Analytical Brief 16. Pesticides use Global, regional and country trends 1990–2018. Retrieved February 1, 2023, from <https://www.fao.org/documents/card/en/c/cb3411en/>
- FAO (2021a) The State Of The World's Land And Water Resources For Food And Agriculture Systems At Breaking Point
<https://openknowledge.fao.org/server/api/core/bitstreams/ecb51a59-ac4d-407a-80de-c7d6c3e15fcc/content>
- FAO. (2021) Land cover statistics Global, regional and country trends 2000–2019
<https://openknowledge.fao.org/server/api/core/bitstreams/9c99a5bc-a0f8-4c4a-a64d-1523c93afde1/content>
- FAO (2023) World Food and Agriculture – Statistical Yearbook 2023 | FAO | Food and Agriculture Organization of the United Nations. 2023. doi:10.4060/cc8166en. ISBN 978-92-5-138262-2. <https://openknowledge.fao.org/items/5c272dc7-e1b8-486a-b323-6babb174eee0>
- FAO (2024). World Food and Agriculture – Statistical Yearbook 2024. FAO. doi:10.4060/cd2971en. ISBN 978-92-5-139255-3.
<https://openknowledge.fao.org/items/43ef9f2c-a023-4130-81ce-dc5ac3f825ef>
- FAO China (2025) Increased impact of heat domes on 2021-like heat extremes in North America under global warming. Country briefs
<https://www.fao.org/gIEWS/countrybrief/country.jsp?code=CHN>
- FAO Soil Report. (n. d.) Recarbonization of Global Soils. Retrieved February 1, 2023, from <https://www.fao.org/3/ca6522en/CA6522EN.pdf>
- Faradji, C. & de Boer, M. (2016). How the great phosphorus shortage could leave us all hungry. Retrieved February 1, 2023, from <https://theconversation.com/how-the-great-phosphorus-shortage-could-leave-us-all-hungry-54432>
- Farhat, N., Elkhouni, A., Zorrig, W., Smaoui, A., Abdelly, C. & Rabhi, M. (2016). Effects of magnesium deficiency on photosynthesis and carbohydrate partitioning. *Acta Physiologiae Plantarum*. 38(145). <https://doi.org/10.1007/s11738-016-2165-z>
- Farming First. (2015) Olam Prize Shortlist: The Story Behind the Science of SRI-Rice. Retrieved February 1, 2023, from <https://farmingfirst.org/2015/03/olam-prize-shortlist-the-story-behind-the-science-of-sri-rice/>
- Farrell, M., Prendergast-Miller, M., Jones, D. L., Hill, P. W. & Condron, L. M. (2014). Soil microbial organic nitrogen uptake is regulated by carbon availability. *Soil Biology and Biochemistry*, 77, 261–267. <https://doi.org/10.1016/j.soilbio.2014.07.003>
- Faulkner E.H. (1945) Ploughman's Folly
https://journeytoforever.org/farm_library/ folly/ follyToC.html
- Fen Blow phenomenon: High winds and loose soil halt traffic. (2013). *BBC News*. Retrieved November 13, 2019, from <https://www.bbc.com/news/uk-england-22201168>
- Fertilizer 101: The Big 3 - Nitrogen, Phosphorus and Potassium. (2014). Retrieved November 1, 2014, from <https://www.tfi.org/the-feed/fertilizer-101-big-3-nitrogen-phosphorus-and-potassium>
- Fixen, Johnston, Mikkelsen, Murrell, Snyder & Stewart. (2007). The Fertility of North American Soils. (2007). *IPNI Canada*. Retrieved February 1, 2023, from <http://www.ipni.net/article/IPNI-3030>

- Follet, R. F., Paul, E. & Leavitt, S. W. (n.d.). Soil Carbon Sequestration and Age in the Historic Grasslands of the United States. Retrieved February 1, 2023, from <https://www.ltrr.arizona.edu/~sleavitt/GreatPlainsSoils.htm>
- Food processing and nutrition - Better Health Channel. (n.d.). Retrieved November 26, 2019, from <https://www.betterhealth.vic.gov.au/health/HealthyLiving/food-processing-and-nutrition>
- FuturePolicy.org. (n.d) Sikkim's State Policy on Organic Farming, India. <https://www.futurepolicy.org/healthy-ecosystems/sikkims-state-policy-on-organic-farming-and-sikkim-organic-mission-india/>
- Gadkari, P., McGuinness, L., Männistö, M., Kerkhof, L. & Häggblom, M. (2020). Arctic tundra soil bacterial communities active at subzero temperatures detected by stable isotope probing, *FEMS Microbiology Ecology*, 96(2). <https://academic.oup.com/femsec/article/96/2/fiz192/5645228>
- Le Gall, S., Bérard, A. Page, D., Lanoe, L., Bertin, N., Doussan, C. (2021). Increased exopolysaccharide production and microbial activity affect soil water retention and field performance of tomato under water deficit, *Rhizosphere*, Volume 19, 2021, !00408, ISSN 2452-2198, <https://doi.org/10.1016/j.rhisph.2021.100408>.
- García-García, A., Cuesta-Valero, F.J., Miralles, D.G. et al. Soil heat extremes can outpace air temperature extremes. *Nat. Clim. Chang.* (2023). <https://doi.org/10.1038/s41558-023-01812-3>
- Gates, D., Keegan, H., Schleter, J., Weidner, V. (1965) "Spectral Properties of Plants," *Appl. Opt.* 4, 11-20 https://opg.optica.org/directpdfaccess/770c017f-a25f-4767-a8be4a0a3b3f7383_13623/ao-4-1-11.pdf?da=1&id=13623&seq=0&mobile=no
- Gashaw, T., Bantider, A. & Silassie, H. (2014). Land Degradation in Ethiopia: Causes, Impacts and Rehabilitation Techniques. *Journal of Environment and Earth Science*, 4(9). <https://www.iiste.org/Journals/index.php/JEES/article/view/12963>
- Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, Tobias A, et al. (2015) Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *Lancet*. 2015 Jul 25;386(9991):369-75. doi: 10.1016/S0140-6736(14)62114-0. <https://pubmed.ncbi.nlm.nih.gov/26003380/>
- Gathorne-Hardy, A. (2013). A Life Cycle Assessment (LCA) of Greenhouse Gas Emissions from SRI and Flooded Rice Production in SE India, *Taiwan Water Conservancy Journal*, 61(4), pp. 111-125. <https://doi.org/10.35648/20.500.12413/11781/ii250>
- Gaylarde, C. C.; Baptista Neto, J. A.; da Fonseca, E. M. (2023). Microplastics in the cryosphere - a potential time bomb?. *Water Emerg. Contam. Nanoplastics* 2023, 2, 20. <http://dx.doi.org/10.20517/wecn.2023.27>
- Gebreselassie, S., Kirui, O. K. & Mirzabaev, A. (2015). Economics of land degradation and improvement in Ethiopia. In Nkonya, E., Mirzabaev, A., von Braun, J. (Eds). *Economics of Land Degradation and Improvement - A Global Assessment for Sustainable Development*. Economics of Land Degradation and Improvement in Ethiopia pp. 401–430). Springer, Cham. https://doi.org/10.1007/978-3-319-19168-3_14
- Geetha M. & Unnikrishnan, M. K. (2012). The Emerging Environmental Burden from Pharmaceuticals | *Economic and Political Weekly*. Retrieved October 22, 2019, from <https://www.epw.in/journal/2012/18/commentary/emerging-environmental-burden-pharmaceuticals.html>

- Geilfus, N., K.M. Munson, K., Sousa, J., Germanov, Y., Bhugaloo, S., Babb, D., Wang, F. (2019) Distribution and impacts of microplastic incorporation within sea ice, *Marine Pollution Bulletin*, Volume 145, 2019, Pages 463-473, ISSN 0025-326X, <https://doi.org/10.1016/j.marpolbul.2019.06.029>.
(<https://www.sciencedirect.com/science/article/pii/S0025326X19304758>)
- Gelband, H. & Laxminarayan, R. (2015). Tackling antimicrobial resistance at global and local scales. *Trends in Microbiology*, 23(9), 524-526.
<https://doi.org/10.1016/j.tim.2015.06.005>
- Ghimire, R., Bista, P. & Machado, S. (2019). Long-term Management Effects and Temperature Sensitivity of Soil Organic Carbon in Grassland and Agricultural Soils. *Sci Rep.*, 9, 12151. <https://doi.org/10.1038/s41598-019-48237-7>
- Glaser, B. & Lehr, V.-I. (2019). Biochar effects on phosphorus availability in agricultural soils: A meta-analysis. *Scientific Reports*, 9(1). <https://doi.org/10.1038/s41598-019-45693-z>
- Global Carbon Emissions. (n.d.). Retrieved November 1, 2019, from <https://www.co2.earth/global-co2-emissions>
- GLOBAL LAND OUTLOOK First Edition. (2017). *United Nations Convention to Combat Desertification*. Retrieved February 1, 2023, from https://knowledge.unccd.int/sites/default/files/2018-06/GLO_English_Full_Report_rev1.pdf
- Global Soil Organic Carbon Map, Version 1.0. (2017). Retrieved November 1, 2019, from <http://www.fao.org/3/a-i8195e.pdf>
- Gomes, L., Simões, S.J.C., Dalla Nora, E.L., de Sousa-Neto, E.R., Forti, M.C. & Ometto, J.P.H.B. (2019). Agricultural Expansion in the Brazilian Cerrado: Increased Soil and Nutrient Losses and Decreased Agricultural Productivity. *Land*, 8(1), 1-26.
<https://doi.org/10.3390/land8010012>
- Gong, L., Abbas, T., Wu, D. et al. Fermented potato fertilizer modulates soil nitrification by shifting the niche of functional microorganisms and increase yield in North China. *Plant Soil* 481, 111–126 (2022). <https://doi.org/10.1007/s11104-022-05622-y>
- Good, K. D. & VanBriesen, J. M. (2019). Coal-Fired Power Plant Wet Flue Gas Desulfurization Bromide Discharges to U.S. Watersheds and Their Contributions to Drinking Water Sources. *Environ. Sci. Technol.*, 53, 213–223
<https://pubs.acs.org/doi/10.1021/acs.est.8b03036>
- Graz University of Technology. (2023, January 25). Satellite data shows sustained severe drought in Europe. ScienceDaily. Retrieved February 17, 2023 from www.sciencedaily.com/releases/2023/01/230125104007.htm
- Gregory, P. (2017) 'Magic of Soil'. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=AWILIYSf5ts>
- Griggs Farms LLC (2021) How to Plant into Cover Crops.
<https://www.youtube.com/watch?v=ve5VJsNCSKo>
- Graham, E. A., Rundel, P. W., Kaiser, W., Lam, Y., Stealey, M., & Yuen, E. M. (2012). Fine-Scale Patterns of Soil and Plant Surface Temperatures in an Alpine Fellfield Habitat, White Mountains, California. *Arctic, Antarctic, and Alpine Research*, 44(3), 288–295.
<https://doi.org/10.1657/1938-4246-44.3.288>
<https://www.tandfonline.com/doi/full/10.1657/1938-4246-44.3.288#abstract>
- Guidelines on Sanitation and Health. Licence: CC BY-NC-SA 3.0 IGO. (2018). Geneva. Retrieved February 1, 2023, from <https://apps.who.int/iris/bitstream/handle/10665/274939/9789241514705-eng.pdf>

- Guinness World Records (2025) Highest wheat yield
<https://www.guinnessworldrecords.com/world-records/highest-wheat-yield>
- Guo, W., Nazim, H., Liang, Z. & Yang, D. (2016). Magnesium deficiency in plants: An urgent problem. *Crop Journal*, 4(2), 83-91. <https://doi.org/10.1016/j.cj.2015.11.003>
- Gupta, V. (2022) Stubble burning is back, smothering north India with concerns for the upcoming winter. Mongabay Series: Environment And Health. Retrieved February 1, 2023, from <https://india.mongabay.com/2022/10/stubble-burning-will-north-india-smother-again-before-winter/>
- Haas H. J., Evans C. E. & Miles E. F. (1957). Nitrogen and Carbon Changes in Great Plains Soils as Influenced by Cropping and Soil Treatments. *U.S. Department of Agriculture*. pp. 111. Retrieved February 1, 2023, from https://books.google.co.in/books?id=iLYXAAAAYAAJ&lr=&source=gbs_navlinks_s
- Haggerty, D. (2018). NutriSoil A New Agriculture, Di Haggerty Presentation. *NutriSoil Videos*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=m8fTJdSr61o>
- Haggerty, D. (2022). World breakthrough regenerative farming operations. *Smartsoil Media*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=bZi6a0HHauw>
- Haiba, E., Nei, L., Ivask, M., Peda, J., Järvis, J., Lillenberg, M., Kipper, K. & Herodes, K. (2016). Sewage sludge composting and fate of pharmaceutical residues-recent studies in Estonia. *Agronomy Research*, 14(5), 1583-1600.
https://www.academia.edu/64836709/Sewage_sludge_composting_and_fate_of_pharmaceutical_residues_recent_studies_in_Estonia
- Halmeck W. (n.d.) Quora - Plants absorb 83% of sunlight and 4% is used for photosynthesis. What happens to the remaining energy? <https://www.quora.com/Plants-absorb-83-of-sunlight-and-4-is-used-for-photosynthesis-What-happens-to-the-remaining-energy>
- Hanekamp, J. C. & Kwakman, J. H. J. M. (2010). Towards Intended Normal Use (Part I): A European Appraisal of the Chloramphenicol Case and some Thoughts on the Potential of Global Harmonization of Antibiotics Regulation. In *Ensuring Global Food Safety*, Ch 11, Academic Press, pp.193-208. <https://doi.org/10.1016/B978-0-12-374845-4.00011-4>
- Hannila, A. (2008). *Evaluation of Urine as Fertilizer for Maize And Cabbage Production in Kaloko Village, Zambia*. Thesis. Tamk University of Applied Sciences. Retrieved February 1, 2023, from http://www.huussi.net/wp-content/uploads/2013/06/Antti_Hannila_Final_thesis.pdf
- Hardy, J. (n. d.). Microbial Showers. The Rain Making Bacteria. Retrieved February 1, 2023, from <https://www.hardydiagnostics.com/wp-content/uploads/2016/05/Ice-Forming-Bacteria.pdf>
- Harms, H., Schlosser, D., & Wick, L. Y. (2011). Untapped potential: Exploiting fungi in bioremediation of hazardous chemicals. *Nature Reviews Microbiology*, 9, 177-192.
<https://doi.org/10.1038/nrmicro2519>
- Harrabin, R. (2019). Climate change being fuelled by soil damage - report - BBC News. Retrieved October 29, 2019, from <https://www.bbc.com/news/science-environment-48043134>
- Harris, S. L., Penno, J. W., & Bryant, A. M. (1994). Effects of high rates of nitrogen fertiliser on dairy pastures and production. *Proceedings of the New Zealand Grassland Association*, 56, 27–31. <https://doi.org/10.33584/jnzg.1994.56.2129>
- Hatziminaoglou, E. et al 2015 *ApJ* **803** 110 <https://iopscience.iop.org/article/10.1088/0004-637X/803/2/110>

- Hausfather, Z. (2018). Analysis: Fossil-fuel emissions in 2018 increasing at fastest rate for seven years. *Carbon Brief Clear on Climate*. Retrieved February 1, 2023, from <https://www.carbonbrief.org/analysis-fossil-fuel-emissions-in-2018-increasing-at-fastest-rate-for-seven-years>
- Hayden, J. (2020). Soil carbon sequestration is a natural consequence of doing things right. *Rodale University*. Retrieved February 1, 2023, from <https://rodaleinstitute.org/blog/soil-carbon-sequestration-is-a-natural-consequence-of-doing-things-right/#:~:text=Soil%20carbon%20sequestration%20is%20just,square%20meter%2C%20without%20any%20amendments>
- Heinberg, R. & Bomford, M. (2009). The Food and Farming Transition- Towards a Post Carbon Food System. *Post Carbon Institute*. <https://doi.org/10.13140/RG.2.1.4960.4725>
- Helander, M., Saloniemi, I., Omacini, M., Druille, M., Salminen, J. P. & Saikkonen, K. (2018). Glyphosate decreases mycorrhizal colonization and affects plant-soil feedback. *Sci Total Environ.*, 642, 285-291. <https://doi.org/10.1016/j.scitotenv.2018.05.377>
- Hejna M, Gottardo D, Baldi A, Dell'Orto V, Cheli F, Zaninelli M, Rossi L. (2018) Review: Nutritional ecology of heavy metals. *Animal*. 2018 Oct;12(10):2156-2170. doi: 10.1017/S175173111700355X. Epub 2018 Jan 8. PMID: 29306340.
- Hensel, J. (1894). *Bread From Stones - A New and Rational System of Land Fertilization and Physical Regeneration*. Tri-State Press, Long Creek, South Carolina.
- Hermann S. (2006) *Human-Environment Relationships in Drylands - with a Focus on the West African Sahel*, University of Arizona. <https://repository.arizona.edu/handle/10150/196053>
- Higher carbon dioxide levels increase plant growth, not nutritional value - Farm and Dairy. (2018). Retrieved February 1, 2023, from <https://www.farmanddairy.com/news/higher-carbon-dioxide-levels-increase-plant-growth-not-nutritional-value/502211.html>
- Hills, J., Jones, C. & Cutler, C. (2021). Amount of Organic Matter in Soil In *Building Soils for Better Crops- Ecological Management for Healthy Soils*; Chapter 3. 4th Ed, Magdoff, F. & Van, E. H. (Eds). SARE Outreach.
- Hillel, D. (2008). Soil Biodiversity. In *Soil in the Environment*, Elsevier, pp. 163–174. <https://doi.org/10.1016/B978-0-12-348536-6.50017-4>
- Hjertaas, B. (2022). Adaptive Grazing Webinar: Blain Hjertaas. *West-Central Forage*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=vn8KC3EdWUY>
- Ho, S. (2021). Nestlé Commits \$1.2B To Regenerative Agriculture, Says It's Ready To Pay Premiums For Raw Materials. *Green Queen*. Retrieved February 1, 2023, from <https://www.greenqueen.com.hk/nestle-regenerative-farming-funding/>
- Hoffmann, L., Eggers, S., Allhusen, E., Katlein, C., Peeken, I. (2020). Interactions between the ice algae *Fragillariopsis cylindrus* and microplastics in sea ice, *Environment International*, Volume 139, 2020, 105697, ISSN 0160-4120, <https://www.sciencedirect.com/science/article/pii/S0160412019339789>
- Honeycutt, W. (2021). Economics of Soil Health on 100 Farms. *Soil Health Institute*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=qaQCRPVj4EQ&list=PLdFVkeklZuqwrwgwDzTGIQSnTtCsOI8W3o&index=14>

- Höpfner, M., M. Milz, S. Buehler, J. Orphal, and G. Stiller (2012), The natural greenhouse effect of atmospheric oxygen (O₂) and nitrogen (N₂), *Geophys. Res. Lett.*, 39, L10706, doi:10.1029/2012GL051409.
<https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2012GL051409>
- Houghton, R. A., F. Hall, and S. J. Goetz (2009), Importance of biomass in the global carbon cycle, *J. Geophys. Res.*, 114, G00E03, doi:10.1029/2009JG000935
<https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2009JG000935>
- Howard, A. (1943). *An Agricultural Testament*. Oxford University Press, New York and London. Retrieved February 1, 2023, from
http://www.journeytoforever.org/farm_library/howardAT/ATtoc.html
- Howard, A. (Sir Albert) (1947). *The Soil and Health*. (see also The Soil and Health and Journey to Forever references) First Edition. The Devin-Adair Company.
http://journeytoforever.org/farm_library/howardSH/SHToc.html
- Howard, A. (Sir Albert)(1945) *Farming and Gardening for Health or Disease*
 Faber and Faber Limited 24 Russell Square London.
https://journeytoforever.org/farm_library/howardSH/SHToc.html
- Hugar, M., Sorganvi, V., & Hiremath, G. M. (2012). Effect of Organic Carbon on Soil Moisture. *Indian Journal Of Natural Sciences*, 3(15), 1191–1235. Retrieved from
<http://tnsroindia.org.in/JOURNAL/ISSUE%2015.pdf>
- Hughes, J. & Brown, G. (2021). Future Farming. *UK Department for Environment, Food and Rural Affairs*. Retrieved February 1, 2023, from
<https://defrafarming.blog.gov.uk/2021/05/11/in-conversation-with-a-soil-health-pioneer/>
- Hu H, Geng S, Zhu Y, He X, Pan X, Yang M. Seed-Borne Endophytes and Their Host Effects. *Microorganisms*. 2025; 13(4):842. <https://doi.org/10.3390/microorganisms13040842>
- Huotari, N., Tillman-Sutela, E., Moilanen, M. & Laiho, R. (2015). Recycling of ash – For the good of the environment? *Forest Ecology and Management*, 348, 226-240.
<https://doi.org/10.1016/j.foreco.2015.03.008>
- INSIGHTSIAS. (2021). Stubble Burning and its impact on health: GS Paper 3 Retrieved February 1, 2023, from <https://www.insightsonindia.com/2021/11/06/stubble-burning-and-its-impact-on-health/>
- Impey, L. (2019). Grower slashes inputs with soils focus and variety blends. *Farmers Weekly*. Retrieved February 1, 2023, from <https://www.fwi.co.uk/arable/land-preparation/soils/grower-slashes-inputs-with-soils-focus-and-variety-blends>
- In Pictures: Historic Drought Takes Toll On Argentina's Grain Harvest. (2023) “The South American nation Argentina which is known as the world's top exporter of processed soy and corn, has been bearing the brunt of a severe drought which is now considered as a key contributing factor behind the worsening economic crisis of the country.”
<https://www.outlookindia.com/international/in-pictures-historic-drought-takes-toll-on-argentina-s-grain-harvest-photos-271840?photo-1>
- India: Air pollution from annual 'stubble burning'. (2021). *DW, Made for minds*. Retrieved February 1, 2023, from <https://www.dw.com/en/india-air-pollution-from-annual-stubble-burning/av-59805601>

- IPBES. (2018). *Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Scholes, R., Montanarella, L., Brainich, A., Barger, N., Brink, B. T., Cantele, M., Erasmus, B., Gardner, T., Holland, T. G., Kohler, F., Kotiaho, J. S., Von Maltitz, G., Nangendo, G., Pandit, R., Parrotta, J., Prince, S., Sankaran, M. & Willemen, L. (Eds.). Bonn, Germany: IPBES secretariat.
https://www.ipbes.net/sites/default/files/spm_3bi_ldr_digital.pdf
- Jacott, C.N., Murray, J.D. & Ridout, C.J. (2017). Trade-Offs in Arbuscular Mycorrhizal Symbiosis: Disease Resistance, Growth Responses and Perspectives for Crop Breeding. *Agronomy*, 7(75). <https://doi.org/10.3390/agronomy7040075>
- Jacks, G. V. & Whyte, R. O. (1939). *The rape of the earth : a world survey of soil erosion*. London: Faber.
- Jakubus, M. (2016). Estimation of phosphorus bioavailability from composted organic wastes, *Chemical Speciation & Bioavailability*, 28:1-4, 189-198, DOI: 10.1080/09542299.2016.1227687
<https://www.tandfonline.com/doi/full/10.1080/09542299.2016.1227687>
- Jameson, P., Midtby, L., Walbom, L., Møller, S., Mikkelsen J. (2024) Boston Consulting Group, The Potential of Regenerative Agriculture in Denmark. <https://web-assets.bcg.com/916d/b62202e6442ba690c15414dcf409/bcg-the-potential-of-regenerative-agriculture-in-denmark-jan-2024-r.pdf>
- Jamei E, Chau HW, Seyedmahmoudian M, Mekhilef SS, Sami FA. Green roof and energy - role of climate and design elements in hot and temperate climates. *Heliyon*. 2023 May 4;9(5):e15917. doi: 10.1016/j.heliyon.2023.e15917.
<https://pubmed.ncbi.nlm.nih.gov/37215798/>
- Jehne, W. (n.d.). Regenerate Earth. Retrieved February 1, 2023, from <http://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf>
- Jehne, W. (2015). The Natural History of Water on Earth. Biodiversity for a Livable Climate. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=eiPDUDT9HjA>
- Jehne, W. (2017a). Regenerating the Soil Carbon Sponge. *Didi Pershouse*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=3nC6j80sLZo>
- Jehne, W. (2017b). Restoring Water Cycles to Naturally Cool Climates and Reverse Global Warming. *Didi Pershouse*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=K4ygsdHJjdl>
- Jeong, E., Abdellaoui, N., Lim, J.Y. et al. (2024). The presence of a significant endophytic fungus in mycobiome of rice seed compartments. *Sci Rep* 14, 23367
<https://doi.org/10.1038/s41598-024-73550-1>
- Jindo, K., Mizumoto, H., Sawada, Y., Sanchez-Monedero, M. A. & Sonoki, T. (2014). Physical and chemical characterization of biochars derived from different agricultural residues. *Biogeosciences*, 11, 6613–6621. <https://doi.org/10.5194/bg-11-6613-2014>
- Johnson, D. C. (2017). The BEAM approach. *Carbon Link*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=79qpP0m7SaY>
- Johnson, D. & Su, H. (2019). Dr David and Hui Chun Su Composting. *Menoken Farm*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=Nxkvz6liaMo>
- Johnson, D. & Su, H. (2022). The Johnson Su Composting System & BEAM (Biologically Advanced Agricultural Management). *Lower Blackwood LCDC*. Retrieved February 1, 2023, from https://www.youtube.com/watch?v=n_t7zOmmXN4

- Johnston-Monje D, Gutiérrez JP, Lopez-Lavalle (2021) LAB. Seed-Transmitted Bacteria and Fungi Dominate Juvenile Plant Microbiomes. *Front Microbiol.* 2021 Oct 22;12:737616. doi: 10.3389/fmicb.2021.737616. PMID: 34745040; PMCID: PMC8569520.
<https://pubmed.ncbi.nlm.nih.gov/34745040/>
- Jones, C. (n.d.-a). Building New Topsoil Through The Liquid Carbon Pathway For Long Term Productivity And Profit, 2019 Conservation Tillage and Technology Conference, March 5 - 6, 2019, Ada, OH, USA. Retrieved February 1, 2023, from
https://www.youtube.com/watch?v=C3_w_Gp1mLM
- Jones, C. (n.d.-b). Nitrogen: the double-edged sword. Retrieved February 1, 2023, from
[https://www.amazingcarbon.com/PDF/JONES%20%27Nitrogen%27%20\(21July14\).pdf](https://www.amazingcarbon.com/PDF/JONES%20%27Nitrogen%27%20(21July14).pdf)
- Jones, C. (n.d.-c). Summer 2018 Field Day. Retrieved November 1, 2019, from
<https://www.youtube.com/watch?v=LuM2tnX-KJI>
- Jones, C. (2011). Carbon that counts. New England and North West 'Landcare Adventure Retrieved November 1, 2019, from
<https://www.amazingcarbon.com/PDF/JONES%27CarbonThatCounts%27.pdf>
- Jones, C. (2017). Farming Profitably Within Environmental Limits. Retrieved February 1, 2023, from [http://amazingcarbon.com/JONES-FarmingProfitablyPUREADVANTAGE+REFS\(21Feb18\).pdf](http://amazingcarbon.com/JONES-FarmingProfitablyPUREADVANTAGE+REFS(21Feb18).pdf)
- Jones, C. (2018a). Light Farming: Restoring carbon, organic nitrogen and biodiversity to agricultural soils. Retrieved February 1, 2023, from www.amazingcarbon.com
- Jones, C. (2018b). Nitrogen: The double-edged sword. Bionutrient Food Association. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=rIXqmksTUQQ>
- Jones, C. (2018c). Soil Carbon: From microbes to mitigation. Bionutrient Food Association. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=2xZ7nfc7BQk>
- Jones, C. (2019a). No-till on the Plains 2019 Christine Jones Community Tipping Points. *No-till on the Plains*. Retrieved February 1, 2023, from
<https://www.youtube.com/watch?v=NqV1b4ps-sE>
- Jones, C. (2019b). Quorum Sensing In The Soil Microbiome. *Conservation Tillage and Technology Conference*. Retrieved February 1, 2023, from
https://www.youtube.com/watch?v=K8_i1EzR5U8
- Jones, C. (2021). 'Soil health and water security. *NM Healthy Soil Working Group*. Retrieved February 1, 2023, from
<https://www.youtube.com/watch?v=IP1juBfZS9E>
- Jones, C. (2022) Profit, Productivity, and NPK with Dr Christine Jones. *Lower Blackwood LCDC*. Retrieved February 1, 2023, from
<https://www.youtube.com/watch?v=EX6eoxxoWKI>
- Journey to Forever. The Soil and Health. (n.d.). Retrieved December 17, 2019, from
http://journeytoforever.org/farm_library.html#clifton
- Kakouridis A, Hagen JA, Kan MP, Mambelli S, Feldman LJ, Herman DJ, Weber PK, Pett-Ridge J, Firestone MK. Routes to roots: direct evidence of water transport by arbuscular mycorrhizal fungi to host plants. *New Phytol.* 2022 Oct;236(1):210-221. doi: 10.1111/nph.18281. Epub 2022 Jul 1. PMID: 35633108; PMCID: PMC9543596.
<https://pubmed.ncbi.nlm.nih.gov/35633108/>

- Kakouridis A, Yuan M, Nuccio EE, Hagen JA, Fossum CA, Moore ML, Estera-Molina KY, Nico PS, Weber PK, Pett-Ridge J, Firestone MK. Arbuscular mycorrhiza convey significant plant carbon to a diverse hyphosphere microbial food web and mineral-associated organic matter. *New Phytol.* 2024 May;242(4):1661-1675. doi: 10.1111/nph.19560. Epub 2024 Feb 15. PMID: 38358052.
- Karalić, K., Lončarić, Z., Popović, B., Zebec, V. & Kerovec, D. (2013). Liming effect on soil heavy metals availability. *Poljoprivreda*, 19(1), 59–64. Retrieved from <https://hrcak.srce.hr/file/153352>
- Kellogg announces regenerative ag program for Lower Mississippi Basin rice farmers. (2022). *Successful Farming*. Retrieved February 1, 2023, from <https://www.agriculture.com/crops/conservation/kellogg-announces-regenerative-ag-program-for-lower-mississippi-basin-rice>
- Khater, A. E. M. (2012). Uranium and trace elements in phosphate fertilizers-Saudi Arabia. *Health Physics*, 102(1), 63–70. <https://doi.org/10.1097/HP.0b013e3182289c17>
- Khater, A. E. M. & AL-Sewaidan, H. A. (2008). Radiation exposure due to agricultural uses of phosphate fertilizers. *Radiation Measurements*, 43(8), 1402–1407. <https://doi.org/10.1016/j.radmeas.2008.04.084>
- Khan, S. A., Mulvaney R. L. & Boast, C. W. (2007). The myth of nitrogen fertilization for soil carbon sequestration. *Journal of environmental quality*, 36(6), 1821-1832. <https://doi.org/10.2134/jeq2007.0099>
- Kim, T. (2018). Mitigation of Ecuadorian Earthquake Impact. *Open Journal of Earthquake Research*, 7, 195-219. doi: 10.4236/ojer.2018.73012
- King, F. H. (1911). *Farmers of 40 Centuries. Organic Farming in China, Korea, and Japan*. Jonathan Cape, London. Retrieved February 1, 2023, from http://journeytoforever.org/farm_library/King_Farmersof40Centuries.pdf
- Kipper, K., Herodes, K., Lillenberg, M., Nei, L., Haiba, E. & Litvin, S. V. (2010). Plant uptake of some pharmaceuticals commonly present in sewage sludge compost. In *ICBEE 2010 - 2010 2nd International Conference on Chemical, Biological and Environmental Engineering, Proceedings*, 261–264. <https://doi.org/10.1109/ICBEE.2010.5653590>
- Kirchmann, H., Börjesson, G., Kätterer, T. & Cohen, Y. (2017). From agricultural use of sewage sludge to nutrient extraction: A soil science outlook. *Ambio*, 46(2), 143–154. <https://doi.org/10.1007/s13280-016-0816-3>
- Klein, J. (2021a). Cargill aims to connect farmers to carbon offset buyers. *Green Biz*. Retrieved February 1, 2023, from <https://www.greenbiz.com/article/cargill-aims-connect-farmers-carbon-offset-buyers>
- Klein, J. (2021b). Walmart digs into regenerative agriculture. The giant global retailer has a long supply chain that it needs to decarbonize. *Green Biz*. Retrieved February 1, 2023, from <https://www.greenbiz.com/article/walmart-digs-regenerative-agriculture>
- Kluber, L. A., Carrino-Kyker, S. R., Coyle, K. P., DeForest, J. L., Hewins, C. R., Shaw, A. N., Smemo, K. A. & Burke, D. J. (2012). Mycorrhizal Response to Experimental pH and P Manipulation in Acidic Hardwood Forests. *PLoS ONE*, 7(11), e48946. <https://doi.org/10.1371/journal.pone.0048946>
- Koneswaran, G. & Nierenberg, D. (2008). Global farm animal production and Global warming: Impacting and mitigating Climate Change. *Environmental Health Perspectives*, 116(5), 578–582. <https://doi.org/10.1289/ehp.11034>

- Koumoundouros, T. (2023). Fluke Discovery of Ancient Farming Technique Could Stabilize Crop Yields. *Science Alert*. Retrieved February 1, 2023, from <https://www.sciencealert.com/fluke-discovery-of-ancient-farming-technique-could-stabilize-crop-yields>
- Kpombrekhou-A, K. & Tabatabai, M. A. (1994). Metal contents of phosphate rocks. *Communications in Soil Science and Plant Analysis*, 25(17–18), 2871–2882. <https://doi.org/10.1080/0010362940936923> 1
- Kristek, S., Kristek, A., Guberac, V., Stanisavljević, A. & Rašić, S. (2017). The Influence Of Mycorrhizae On Pea Yield And Quality In Drought Caused Stress Conditions. *Cereal Research Communications*, 35, 681–684. <https://doi.org/10.1556/CRC.35.2007.2.129>
- Kühn, J., Schweitzer, K., Ruess, L. (2019). Diversity and specificity of lipid patterns in basal soil food web resources. *PLoS One*. 14(8), e0221102. <https://doi.org/10.1371/journal.pone.0221102>
- Khumairoh, U. (2018) Mixed farming increases rice yield. Retrieved February 1, 2023, from <https://www.renature.co/articles/mixed-farming-increase-rice-yield/>
- Kurth, T., Subei, B., Plötner, P., Bünger, F., Havermeier, M., Krämer, S. (2023) Boston Consulting Group, The Case for Regenerative Agriculture in Germany— and Beyond <https://web-assets.bcg.com/20/43/809680664811998e155baeee1e30/the-case-for-regenerative-agriculture-mar2023.pdf>
- Lab analysis finds near-meat and meat not nutritionally equivalent: Neither is good or bad, they are just not the same, authors say. (2021). *ScienceDaily*. Retrieved January 5, 2023, from www.sciencedaily.com/releases/2021/07/210706153026.htm
- Lal P, Shekhar A, Gharun M, Das NN. (2023) Spatiotemporal evolution of global long-term patterns of soil moisture. *Sci Total Environ*. 2023 Apr 1;867:161470. doi: 10.1016/j.scitotenv.2023.161470. Epub 2023 Jan 10. PMID: 36634770. <https://pubmed.ncbi.nlm.nih.gov/36634770/>
- Lal (2024) Managing Soil Health for Carbon Sequestration and Water Conservation, Ohio State University https://csgmidwest.org/wp-content/uploads/2024/07/Sunday-Ag-Rural_Rattan-Lal2.pdf
- Lau WK, Kim KM. Robust Hadley Circulation changes and increasing global dryness due to CO2 warming from CMIP5 model projections. *Proc Natl Acad Sci U S A*. 2015 Mar 24;112(12):3630–5. doi: 10.1073/pnas.1418682112. <https://pubmed.ncbi.nlm.nih.gov/25713344/>
- Langemeier, M., & Zhou L. (2022) International Benchmarks for Wheat Production <https://ag.purdue.edu/commercialag/home/resource/2022/05/international-benchmarks-for-wheat-production-2/>
- Lamichhane, G. (2018). *Analysis of microfibers in waste water from washing machines*. Thesis, Metropolia University of Applied Sciences. Retrieved February 1, 2023, from https://www.theseus.fi/bitstream/handle/10024/141278/Lamichhane_Ganesh.pdf?sequence=1&isAllowed=y
- Lessons of the Loess Plateau. (2012). *EcoPointAsia TV*. Retrieved November 14, 2019, from <https://www.youtube.com/watch?v=8QUSIJ80n50>
- Li, H., Yu, C., Wang, F., Chang, S. J., Yao, J. & Blake, R. E. (2016). Probing the metabolic water contribution to intracellular water using oxygen isotope ratios of PO₄. *Proc Natl Acad Sci U S A*, 113(21), 5862–5867. <https://www.pnas.org/doi/10.1073/pnas.1521038113>

- Lindsey, R. (2024) Climate Change: Atmospheric Carbon Dioxide NOAA
<https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide>
- Liu, J. D. (2012). Regreening the Desert with John D. Liu. *Vpro documentary*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=IDgDWbQtIKI>
- Liu, J. D. (2013). Ecosystem restoration Ethiopia – John D. Liu. *Ecosystem Return Foundation*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=8f8Yqgj-TXg>
- Liu F., Peng H., Marshall J. E. A., Lomax, B. H., Bomfleur, B., Kent, M. S., Fraser, W. T. & Jardine, P. E. (2023). Dying in the Sun: Direct evidence for elevated UV-B radiation at the end-Permian mass extinction. *Sci Adv.*, 9(1), 1-11.
<https://doi.org/10.1126/sciadv.abo6102>
- Liu, Y., Huang, J.-K. & Zikhali, P. (2014). Use of Human Excreta as Manure in Rural China, *Journal of Integrative Agriculture*, 13(2), 434-442, [https://doi.org/10.1016/S2095-3119\(13\)60407-4](https://doi.org/10.1016/S2095-3119(13)60407-4)
- Liu, Y., Shi, G., Mao, L., Cheng, G., Jiang, S., Ma, X., An, L., Du, G., Johnson, N. C. & Feng, H. (2012). Direct and indirect influences of 8 yr of nitrogen and phosphorus fertilization on Glomeromycota in an alpine meadow ecosystem. *The New Phytologist*, 194(2), 523–535. <https://doi.org/10.1111/j.1469-8137.2012.04050.x>
- Long, C. (2009). Industrially Farmed Foods Have Lower Nutritional Content | MOTHER EARTH NEWS. Retrieved November 26, 2019, from <https://www.motherearthnews.com/nature-and-environment/nutritional-content-zmaz09jjzraw>
- Lorch, M., Agaras, B., García-Parisi, P., Druille, M., Omacini, M. & Valverde, C. (2021). Repeated annual application of glyphosate reduces the abundance and alters the community structure of soil culturable pseudomonads in a temperate grassland. *Agriculture, Ecosystems & Environment*, 319, <https://doi.org/10.1016/j.agee.2021.107503>
- Lowdermilk, W. C. (1939). Conquest of the Land Through Seven Thousand Years. Retrieved February 1, 2023, from http://journeytoforever.org/farm_library/Lowd/Lowd1.html
- Ma, Y., Woolf, D., Fan, M. et al. Global crop production increase by soil organic carbon. *Nat. Geosci.* 16, 1159–1165 (2023). <https://doi.org/10.1038/s41561-023-01302-3>
- MacArthur, E. (2022). How greenhouse gas emissions from rice can be minimised through regenerative production. *Ellen MacArthur Foundation*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=FuB9u1lOpS4>
- Mackle, T. R., Parr, C. R., & Bryant, A. M. (1996). Nitrogen fertiliser effects on milk yield and composition, pasture intake, nitrogen and energy partitioning, and rumen fermentation parameters of dairy cows in early lactation. *New Zealand Journal of Agricultural Research*, 39(3), 341–356.
<https://doi.org/10.1080/00288233.1996.9513194>
- Madikizela, L. M., Ncube, S. & Chimuka, L. (2018). Uptake of pharmaceuticals by plants grown under hydroponic conditions and natural occurring plant species: A review. *The Science of the Total Environment*, 636, 477–486.
<https://doi.org/10.1016/j.scitotenv.2018.04.297>
- Magnér, J., Rosenqvist, L., Rahmberg, M., Graae, L., Eliaeson, K., Örtlund, L., Fång, J. & Brorström-Lundén, E. (2016). *Fate of pharmaceutical residues - in sewage treatment and on farmland fertilized with sludge*. IVL Swedish Environmental Research Institute.

- Maier, D., Benisek, M., Blaha, L., Dondero, F., Giesy, J. P., Köhler, H. R., Richter, D., Scheurer, M. & Triebkorn, R. (2016). Reduction of dioxin-like toxicity in effluents by additional wastewater treatment and related effects in fish. *Ecotoxicology and Environmental Safety*, 132, 47–58. <https://doi.org/10.1016/j.ecoenv.2016.04.036>
- Majlesi, S., Juutilainen, J., Kasurinen, A., Mpamah, P., Trubnikova, T., Oinonen, M., Martikainen, P. & Biasi C. (2019). Uptake of Soil-Derived Carbon into Plants: Implications for Disposal of Nuclear Waste. *Environ Sci Technol.*, 53(8), 4198-4205. <https://doi.org/10.1021/acs.est.8b06089>
- Major Indian and Global Brands collaborate with Govt. of Madhya Pradesh (India), farmers, and civil society to promote regenerative agriculture and sustainable sourcing. (2020). *IDH*. Retrieved February 1, 2023, from <https://www.idhsustainabletrade.com/news/major-indian-and-global-brands-collaborate-with-govt-of-madhya-pradesh-india-farmers-and-civil-society-to-promote-regenerative-agriculture-and-sustainable-sourcing/>
- Mao W, Wu Y, Li Q, Xiang Y, Tang W, Hu H, Ji X, Li H. (2024) Seed endophytes and rhizosphere microbiome of *Imperata cylindrica*, a pioneer plant of abandoned mine lands. *Front Microbiol.* Jul 24;15:1415329. doi: 10.3389/fmicb.2024.1415329. PMID: 39113844; PMCID: PMC11303138.
- Manaye, A., Negash, M., & Alebachew, M. (2019). Effect of degraded land rehabilitation on carbon stocks and biodiversity in semi-arid region of Northern Ethiopia. *Forest Science and Technology*, 15(2), 70–79. <https://doi.org/10.1080/21580103.2019.1592787> <https://www.tandfonline.com/doi/full/10.1080/21580103.2019.1592787#abstract>
- Mannette, A. (2021). Kansas farmers get payments for improving ecology of soil. *The Hutchinson News*. Retrieved February 1, 2023, from <https://eu.hutchnews.com/story/news/2021/10/13/general-mills-kansas-environment-health-esmc-agriculture-program-pays-farmers/8442812002/>
- Maphosa, S., Steyn, M., Lebre, P., Gokul, J., Convey, P., et al. (2025) Rhizosphere bacterial communities of Namib Desert plant species: Evidence of specialised plant-microbe associations, *Microbiological Research*, Volume 293, 128076, ISSN 0944-5013, <https://doi.org/10.1016/j.micres.2025.128076>.
- Marles, R. J. (2017). Mineral nutrient composition of vegetables, fruits and grains: The context of reports of apparent historical declines. *Journal of Food Composition and Analysis*, 56, 93-103. <https://doi.org/10.1016/j.jfca.2016.11.012>
- Marquis, C. (2021). rePlant Fuels Food System’s Shift To Regenerative Agriculture With \$2 Billion For Farmers To Build Soil Health. *Forbes*. Retrieved February 1, 2023, from <https://www.forbes.com/sites/christophermarquis/2021/10/05/replant-fuels-food-systems-shift-to-regenerative-agriculture-with-2b-soil-fund-and-support-for-farmers/?sh=5097cd6d63a0>
- Mars Petcare (2025) Mars Petcare Thailand wins at FMCG Asia Awards 2024 for regenerative agriculture initiative <https://fmcg.asia/co-written-partner/event-news/mars-petcare-thailand-wins-fmcg-asia-awards-2024-regenerative-agriculture-initiative>
- Mattar, C., Santamaría-Artigas, A., Ponzoni, F., Pinto, C. T., Barrientos, C., & Hulley, G. (2018). Atacama Field Campaign: laboratory and in-situ measurements for remote sensing applications. *International Journal of Digital Earth*, 12(1), 43–61. <https://doi.org/10.1080/17538947.2018.1450901>

- Mathi, (2023) Small Farmers and Entrepreneurs Offer New Hope for Africa's Degraded Lands. World Resources Institute. <https://www.wri.org/insights/farmers-restore-africas-degraded-lands>
- Mayer, A., Hausfather, Z., Jones, A. D. & Silver, W. L. (2018). The potential of agricultural land management to contribute to lower global surface temperatures. *Science Advances*, 4(8). <https://doi.org/10.1126/sciadv.aag0932>
- Mbow, C., Brandt, M., Ouedraogo, I., De Leeuw, J., & Marshall, M. (2015). What Four Decades of Earth Observation Tell Us about Land Degradation in the Sahel? *Remote Sensing*, 7(4), 4048-4067. <https://doi.org/10.3390/rs70404048>
- McCain. (n. d.) McCain's Regenerative Agriculture Framework. Retrieved February 1, 2023, from <https://www.mccain.com/media/4036/mccain-foods-regenag-framework.pdf>
- McKeague, J., Cline, M. (1963), Silica in Soils Joint contribution as No. 71 of the Soil Research Institute, Canada Department of Agriculture, Ottawa, and as Agronomy paper No. 602, Cornell University, Ithaca, New York., Editor(s): A.G. Norman, *Advances in Agronomy*, Academic Press, Volume 15, Pages 339-396, ISSN 0065-2113, ISBN 9780120007158, [https://doi.org/10.1016/S0065-2113\(08\)60403-4](https://doi.org/10.1016/S0065-2113(08)60403-4).
- McKinsey and Company.(2023) The agricultural transition: Building a sustainable future. <https://www.mckinsey.com/industries/agriculture/our-insights/the-agricultural-transition-building-a-sustainable-future>
- McSweeney, R., Tandon, A. (2024) Mapped: How climate change affects extreme weather around the world <https://interactive.carbonbrief.org/attribution-studies/index.html>
- Medeiros, F., Theodoro, S., Carvalho, A., Oliveira, V., Oliveira, L., et al. (2025) The combination of crushed rock and organic matter enhances the capture of inorganic carbon in tropical soils, *Journal of South American Earth Sciences*, Volume 152, 2025, 105254, ISSN 0895-9811, <https://doi.org/10.1016/j.jsames.2024.105254>.
- Medrano-Macías, J., Leija-Martínez, P., González-Morales, S., Juárez-Maldonado, A. & Benavides-Mendoza, A. (2016). Use of Iodine to Biofortify and Promote Growth and Stress Tolerance in Crops. *Front. Plant Sci.*, 7(1146), 1-20. <https://doi.org/10.3389/fpls.2016.01146>
- Meisel (2022). Tackling Extreme Heat through Urban Forestry in Delhi; The case for a more thoughtful approach to the city's trees. <https://rmi.org/tackling-extreme-heat-through-urban-forestry-in-delhi/>
- Meister, W. (2021). Regenerative rice farming in Cambodia with no-till and cover crops Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=94B-mJqNQHY>
- Menge, J. A. (1985). *Mycorrhiza Agriculture Technologies*. In *Innovative Biological Technologies for Lesser Developed Countries*. Chapter X. Workshop Proceedings (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA13P-F-29, July 1985). <https://www.princeton.edu/~ota/disk2/1985/8512/851212.PDF>
- Menzi, H. & Kessler, J. (1998). Heavy metal content of manures in Switzerland. International Conference on Management Strategies for Organic Waste Use in Agriculture, Antony (France) FAO/CEMAGREF. <http://ramiran.uvlf.sk/doc98/FIN-ORAL/MENZI.pdf>
- Middle A (Various). Climate Phoenix. Associate Professor | School of Arts, Media and Engineering, Arizona State University. <https://scholar.google.de/citations?user=DS2xTKMAAAAJ&hl=de>

- Mikajlo, I., Pourrut, B., Louvel, B., Hynšt, J. & Záhora, J. (2022): Plant-soil nitrogen, carbon and phosphorus content after the addition of biochar, bacterial inoculums and nitrogen fertilizer. *Journal of Plant Nutrition*, 46(4), 541-551.
<https://doi.org/10.1080/01904167.2022.2043369>
- Mikiciuk, G., Miller, T., Kisiel, A., Cembrowska-Lech, D., Mikiciuk, M., Łobodzińska, A., & Bokszczanin, K. (2024). Harnessing Beneficial Microbes for Drought Tolerance: A Review of Ecological and Agricultural Innovations. *Agriculture*, 14(12), 2228.
<https://doi.org/10.3390/agriculture14122228>
- Millions in India may face nutritional deficiencies due to CO2 rise: Study - The Hindu BusinessLine. (2018). Retrieved October 25, 2019, from
<https://www.thehindubusinessline.com/economy/agri-business/millions-in-india-may-face-nutritional-deficiencies-due-to-co2-rise-study/article24804059.ece>
- Milman, O. (2015). Earth has lost a third of arable land in past 40 years, scientists say | Environment | The Guardian. Retrieved October 21, 2019, from
<https://www.theguardian.com/environment/2015/dec/02/arable-land-soil-food-security-shortage>
- Mir, Y.H., Shah, A.M., Shah, T.I., Bangroo, S.A., Jaufer, L., Kader, S., Mincato, R.L., Marković, R. (2023). Methodological challenges in estimating soil organic matter: A review. *Agriculture and Forestry*, 69 (4): 275-283. doi:10.17707/AgricultForest.69.4.19
<http://www.agricultforest.ac.me/data/20231215-19%20Mir%20et%20al..pdf>
- Mitter B, Pfaffenbichler N, Flavell R, Compant S, Antonielli L, Petric A, Berninger T. (2017) Naveed M, Sheibani-Tezerji R, von Maltzahn G, Sessitsch A. A New Approach to Modify Plant Microbiomes and Traits by Introducing Beneficial Bacteria at Flowering into Progeny Seeds. *Front Microbiol.* Jan 23;8:11. doi: 10.3389/fmicb.2017.00011. MID: 28167932; PMCID: PMC5253360.
- Mkhathini, K. M. (2012). Effects of cover crops-green manure on cabbage yield (*Brassica oleracea* var. *capitata* L.) cultivar conquistador. Retrieved February 1, 2023, from
<https://www.semanticscholar.org/paper/Effects-of-cover-crops-green-manure-on-cabbage-L.-Mkhathini/fe4cb988d07e6fb64f8e21d91a025df2e27a67d6>
- Mohanty, A., Islam, M., Kumar, G., Kumar, A. (2014). Enhancing Rice (*Oryza sativa*) Productivity through Demonstrations of SRI Method of Cultivation in Mid-Altitude Region of Indo-Himalayan Belt of Sikkim. *Indian Research Journal of Extension Education*, 14(3), 88-92.
https://scholar.google.co.in/citations?view_op=view_citation&hl=en&user=doKzROwAAAAJ&citation_for_view=doKzROwAAAAJ:qjMakFHDy7sC
- Monbiot G. (2025) What's in the millions of tonnes of sludge spread on to UK farmland? Toxic waste – and ministers don't care. *Guardian Newspaper*.
<https://www.theguardian.com/commentisfree/2025/mar/21/tonnes-sludge-uk-farmland-sewage-farms-toxins-food-system>
- Montgomery, D. R. (2007). *Dirt : the erosion of civilizations*. 1st Ed. University of California Press. pp. 295.
- Montgomery, D. R., Biklé, A., Archuleta, R., Brown, P. & Jordan, J. (2022). Soil health and nutrient density: Preliminary comparison of regenerative and conventional farming. *PeerJ*, 10, e12848. <https://doi.org/10.7717/peerj.12848>
- Morrison, J. L. & Regnault, T. R. H. (2016). Nutrition in pregnancy: Optimising maternal diet and fetal adaptations to altered nutrient supply. *Nutrients*, 8(6), 342.
<https://doi.org/10.3390/nu8060342>

- Mulvaney, R. L., Khan, S. A., & Ellsworth, T. R. (2009). Synthetic nitrogen fertilizers deplete soil nitrogen: a global dilemma for sustainable cereal production. *J Environ Qual.*, 38(6), 2295-314. <https://doi.org/10.2134/jeq2008.0527>
- Mupambwa, H. A., Dube, E. & Mnkeni, P. N.S. (2015). Fly ash composting to improve fertiliser value - A review. *South African Journal of Science*, 111(7-8), 1-6. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0038-23532015000400008
- Murray, M. (2003). *Sea Energy Agriculture*. Acres USA. pp. 109
- Myers, J.P., Antoniou, M.N., Blumberg, B., Carroll, L., Colborn, T., Everett, L. G., Hansen, M., Landrigan, P. J., Lanphear, B. P., Mesnage, R., Vandenberg, L. N., Vom Saal, F. S., Welshons, W. V. & Benbrook, C. M. (2016). Concerns over use of glyphosate-based herbicides and risks associated with exposures: a consensus statement. *Environ Health*, 15(19), 1-13. <https://doi.org/10.1186/s12940-016-0117-0>
- NASA (2024) Land Surface Temperature & Vegetation, Earth Observatory, https://earthobservatory.nasa.gov/global-maps/MOD_LSTD_M/MOD_NDVI_M
- NASA (n.d) Climate science Investigations (CSI) NASA <https://www.ces.fau.edu/nasa/>
- NASA Facts (n.d.) National Aeronautics and Space Administration. The Balance of Power in the Earth-Sun System https://www.nasa.gov/wp-content/uploads/2015/03/135642main_balance_trifold21.pdf?emrc=5b9a71
- NASA poster (n.d.) Energer budget Diagram Poster https://web.archive.org/web/20140421050855/http://science-edu.larc.nasa.gov/energy_budget/
- National Parks Board (2017) A Handbook On Developing Sustainable Highrise Gardens Bringing Greenery Skywards. <https://www.nparks.gov.sg/-/media/srg/files/nparks-skyrise-greenery-handbook.pdf>
- Natura, H. (n.d.). Root systems of Praire Plants. Retrieved February 1, 2023, from https://www.oakgov.com/water/resources/education/Documents/EnvEducation/native_plant_root_system_schematic.pdf
- Nelson, T. (2011) Cold Facts on Global Warming. <https://www.randombio.com/co2.html>
- Nelson, E.B. (2018). The seed microbiome: Origins, interactions, and impacts. *Plant Soil* 422, 7–34 <https://doi.org/10.1007/s11104-017-3289-7>
- Nichols, K. (2019). No-till on the Plains. Retrieved November 1, 2019, from <https://www.youtube.com/watch?v=fbSiRHksTmc>
- Njoku, C., Agwu, J. O., Uguru, B. N. & Mbah, C. N. (2017). Influence of Human Urine on Rice Grain Yield (*Orzya sativa* L.) and Selected Soil Properties in Abakaliki Southeastern Nigeria. *International Journal of Environment, Agriculture and Biotechnology*, 2(2), 844–849. <https://doi.org/10.22161/ijeab/2.2.36>
- NOAA, (2016) Carbon Dioxide observations from 2005 to 2014 showing the seasonal variations and the difference between northern and southern hemispheres, National Oceanic & Atmospheric Administration, Earth System Research Laboratory, Global Monitoring Division, Photo Gallery <http://www.esrl.noaa.gov/gmd/ccgg/gallery/figures/index.html>
- Noggle, S. (2019). Paulding County Cover Crop Research Results. *Conservation Tillage and Tedchnology Conference*. Retrieved November 14, 2019, from <https://www.youtube.com/watch?v=aFN76jYE36g>

- Novak, J. M., Lima, I., Xing, B., Gaskin, J. W., Steiner, C., Das, K. C., Ahmedna, M., Rehrah, D., Watts, D. W., Busscher, W. J. & Schomberg, H. (2009). Characterization of Designer Biochar Produced at Different Temperatures and Their Effects on a Loamy Sand. *Annals of Environmental Science*, 3. Retrieved February 1, 2023, from <https://openjournals.neu.edu/aes/journal/article/view/v3art5>
- Nguyen, K., Nguyen, H Phuoc, N., Nguyen, K (2024). A comprehensive review of rock dust for soil remineralization in sustainable agriculture and preliminary assessment of nutrient values in micronized porous basalt rock from Nghe-An province, Vietnam", Vietnam J. Sci. Technol., vol. 61, no. 4, Jul. 2024. https://www.researchgate.net/publication/384018415_A_comprehensive_review_of_rock_dust_for_soil_remineralization_in_sustainable_agriculture_and_preliminary_assessment_of_nutrient_values_in_micronized_porous_basalt_rock_from_Nghe_An_province_Viet_Nam
- Nugent, A., DeCou, D., Russell, S., Karamperidou, C. Press Books (n.d.) Atmospheric Processes and Phenomena. <https://pressbooks-dev.oer.hawaii.edu/atmo/front-matter/preface/>
- Ogden, L. E. (2014). Life in the Clouds. *BioScience*. 64(10), 861–867. <https://doi.org/10.1093/biosci/biu144>
- Ontl, T. A. & Schulte, L. A. (2012). Soil Carbon Storage. *Nature Education Knowledge*, 3(10). Retrieved February 1, 2023, from <https://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/>
- Onwuka, B. & Mang, B. (2018). Effects of soil temperature on some soil properties and plant growth. *Adv Plants Agric Res*. 8(1), 34-37. <https://doi.org/10.15406/apar.2018.08.00288>
- Paredes, C., Bernal, M. P., Cegarra, J., Roig, A. & Navarro, A. F. (1996). Nitrogen tranformation during the composting of different organic wastes. In *Progress in Nitrogen Cycling Studies*, Springer Netherlands, pp.121–125. https://doi.org/10.1007/978-94-011-5450-5_19
- Parton, W. J., Gutmann, M. P. & Ojima, D. (2007). Long-term Trends in Population, Farm Income, and Crop Production in the Great Plains. *BioScience*, 57(9), 737–747. <https://doi.org/10.1641/b570906>
- Paul, A., Dziallas, C., Zwirnmann, E., Gjessing, E. T. & Grossart, H-P. (2012). UV irradiation of natural organic matter (NOM): impact on organic carbon and bacteria. *Aquat Sci.*, 74, 443–454. <https://doi.org/10.1007/s00027-011-0239-y>
- Paungfoo-Lonhienne, C., Lonhienne, T., Rentsch, D., Robinson, N., Christie, M., Webb, R. I., Gamage, H. K., Carroll, B. J., Schenk, P. M. & Schmidt, S. (2008). Plants can use protein as a nitrogen source without assistance from other organisms. *Proc Natl Acad Sci U S A*, 105(11), 4524-4529. doi: <https://doi.org/10.1073/pnas.0712078105>
- Pausata, F., Gaetani, M., Messori, G., Berg, A., Maia de Souza, D., Sage, R., Peter B. deMenocal, P. (2020). The Greening of the Sahara: Past Changes and Future Implications, *One Earth*, Volume 2, Issue 3, 2020, Pages 235-250, ISSN 2590-3322, <https://doi.org/10.1016/j.oneear.2020.03.002>.
- Pearson, J. N. & Jakobsen, I. (1993), The relative contribution of hyphae and roots to phosphorus uptake by arbuscular mycorrhizal plants, measured by dual labelling with 32P and 33P. *New Phytologist*, 124(3): 489-494. <https://doi.org/10.1111/j.1469-8137.1993.tb03840.x>

- Pérez-Valera, E., Kyselková, M., Ahmed, E., Sladeczek, F. X. J., Goberna, M. & Elhottová, D. (2019). Native soil microorganisms hinder the soil enrichment with antibiotic resistance genes following manure applications. *Sci Rep.*, 9(1), 1-10.
<https://doi.org/10.1038/s41598-019-42734-5>
- Petty, G. W., & Tran, H. K. (2023). Seventy-year trends in ship-reported oceanic precipitation frequency. *Geophysical Research Letters*, 50, e2023GL104270.
<https://doi.org/10.1029/2023GL104270>
- PennState College, (n.d) The PennState College of Earth and Mineral Sciences. "Greenhouse Effect," and Global Warming https://www.e-education.psu.edu/meteo3/l2_p7.html
- Philpott, T. (2010). New research: synthetic nitrogen destroys soil carbon, undermines soil health'. *Grist*. Retrieved February 1, 2023, from <https://grist.org/article/2010-02-23-new-research-synthetic-nitrogen-destroys-soil-carbon-undermines/>
- Plant Health Cure, (2019). The long term effect of chemical fertilizers on soil health. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=YMW2uLumAQw>
- Poinar K. (2012). The Carbon Cycle in the Mantle Implications for timescales, geochemistry, and mantle convection PCC 588 Project.
<https://ubwp.buffalo.edu/glaciermodelinglab/wp-content/uploads/sites/104/2019/11/CCinMantle.pdf>
- Poor Diet During Pregnancy May Have Long Term Impact On Child's Health, Study Suggests. (n.d.). *ScienceDaily*. Retrieved November 26, 2019, from <https://www.sciencedaily.com/releases/2008/06/080630200951.htm>
- Poux, X. & Aubert, P.-M. (2018). An agroecological Europe in 2050: multifunctional agriculture for healthy eating. Findings from the Ten Years For Agroecology (TYFA) modelling exercise. Retrieved November 1, 2019, from <https://www.soilassociation.org/media/18074/iddri-study-tyfa.pdf>
- Pozdnyakova, N. N. (2012). Involvement of the Ligninolytic System of White-Rot and Litter-Decomposing Fungi in the Degradation of Polycyclic Aromatic Hydrocarbons. *Biotechnology Research International*, 2012, 1–20.
<https://doi.org/10.1155/2012/243217>
- Error! Hyperlink reference not valid.** Potato News Today. (2022). McCain enters the Metaverse: Introducing 'Regen Fries', new partnerships to educate consumers on regenerative farming. <https://www.potatonewstoday.com/2022/10/30/mccain-enters-the-metaverse-introducing-regen-fries-new-partnerships-to-educate-consumers-on-regenerative-farming/>
- Pringle, A., Bever, J. D., Gardes, M., Parrent, J. L., Rillig, M. C., Klironomos, J. N. (2009). Mycorrhizal symbioses and plant invasions. *Ann. Rev. Ecol. Evol. Syst.*, 40, 699–715. doi: 10.1146/annurev.ecolsys.39.110707.173454
- Procurement Resource (2023) Leading wheat production regions.
<https://www.procurementresource.com/blog/wheat-producing-regions-in-the-usa>
- Ray, C. C. (2015). A Decline in the Nutritional Value of Crops. Retrieved November 1, 2019, from <https://www.nytimes.com/2015/09/15/science/a-decline-in-the-nutritional-value-of-crops.html>
- Reints, R. (2018). Rising Levels of Carbon Dioxide Can Lead to Nutritional Deficiencies in Hundreds of Millions, Study Says | Fortune. Retrieved October 25, 2019, from <https://fortune.com/2018/08/27/study-carbon-dioxide-nutritional-deficiency/>

- Reicosky. (2014) 'Tillage and Carbon Management: Nutrient Re-Cycling Synergies' AGVISE seminars, Jan 7-9, 2014. Retrieved February 1, 2023, from <https://www.gwct.org.uk/media/841527/Reicosky-Tillage-and-carbon-management.pdf>
- Remineralise the Earth, (n.d.) Publications <https://www.remineralize.org/publications/>
- Rijkers, R., Dekker, M., Aerts, R. and Weedon, J. T. (2022). Maximum summer temperatures predict the temperature adaptation of Arctic soil bacterial communities. *Biogeosciences Discuss. [preprint]*, <https://doi.org/10.5194/bg-2022-184>
- Robbins (2022) Global 'Stilling': Is Climate Change Slowing Down the Wind? Yale Environment 360 Published at the Yale School of the Environment <https://e360.yale.edu/features/global-stilling-is-climate-change-slowing-the-worlds-wind>
- Roberts, A. H. C., Longhurst, R. D. & Brown, M. W. (1994). Cadmium status of soils, plants, and grazing animals in New Zealand. *New Zealand Journal of Agricultural Research*, 37(1), 119–129. <https://doi.org/10.1080/00288233.1994.9513048>
- Roberts, T. L. (2014). Cadmium and phosphorous fertilizers: The issues and the science. *Procedia Engineering*, 83, 52–59. <https://doi.org/10.1016/j.proeng.2014.09.012>
- Robinson A. (2021). The Regenerative Ag Debate for Growing Potatoes, is it Possible? *SpudSmart*. Retrieved February 1, 2023, from <https://spudsmart.com/the-regenerative-ag-debate-for-growing-potatoes-is-it-possible/>
- Rockström J, Lannerstad M, Falkenmark M. (2007) Assessing the water challenge of a new green revolution in developing countries. *Proc Natl Acad Sci U S A*. 2007 Apr 10;104(15):6253-60. doi: 10.1073/pnas.0605739104. Epub 2007 Apr 2. PMID: 17404216; PMCID: PMC1851042.
- Rouhollahi, R., Whaley, D., Byrne, J., Boland, J. (2022) Potential residential tree arrangement to optimise dwelling energy efficiency, *Energy and Buildings*, Volume 261, 111962, ISSN 0378-7788, <https://doi.org/10.1016/j.enbuild.2022.111962>.
- Sadej, W. & Przekwas, K. (2008). Fluctuations of nitrogen levels in soil profile under conditions of a long-term fertilization experiment. *Plant Soil Environ.*, 54(5), 197–203. <https://www.agriculturejournals.cz/pdfs/pse/2008/05/03.pdf>
- Sadej, Wiera, Bowszys, T. & Namiotko, A. (2009). Leaching of nitrogen forms from soil fertilized with sewage sludge. *Ecological Chemistry and Engineering A*, 16(8), 1001–1008. <file:///C:/Users/Admin/Downloads/Sadej.pdf>
- Sahoo, S., Gilleaudeau, G. (2023) *et al.* Basin-scale reconstruction of euxinia and Late Devonian mass extinctions. *Nature*. <https://doi.org/10.1038/s41586-023-05716-2> <https://www.sciencedaily.com/releases/2023/03/230308112104.htm>
- Sanad, M. N. M. E. AL-Huqail, A. A., Ibrahim, M. M. & Hauvermalee, A. L. (2020). Prediction of the crosstalk regulation model between the abscisic acid (ABA) signaling and peroxisome abundance during drought stress in wheat (*Triticum aestivum* L.). *Current plant biology*, 24(100176). <https://doi.org/10.1016/j.cpb.2020.100176>
- Savory, A. (2013) 'How to green the world's deserts and reverse climate change' Ted Talk. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=vpTHi7O66pl>
- Sherwood, S. C., W. Ingram, Y. Tsushima, M. Satoh, M. Roberts, P. L. Vidale, and P. A. O'Gorman (2010), Relative humidity changes in a warmer climate, *J. Geophys. Res.*, 115, D09104, doi:10.1029/2009JD012585. <https://agupubs.onlinelibrary.wiley.com/action/showCitFormats?doi=10.1029%2F2009JD012585>

- Schmidt, H.-P., Pandit, B. H., Cornelissen, G. & Kammann, C. I. (2017). Biochar-Based Fertilization with Liquid Nutrient Enrichment: 21 Field Trials Covering 13 Crop Species in Nepal. *Land Degradation & Development*, <https://doi.org/10.1002/ldr.2761>
- Schmidt, H., Pandit, B., Martinsen, V., Cornelissen, G., Conte, P. & Kammann, C. (2015). Fourfold Increase in Pumpkin Yield in Response to Low-Dosage Root Zone Application of Urine-Enhanced Biochar to a Fertile Tropical Soil. *Agriculture*, 5(3), 723–741. <https://doi.org/10.3390/agriculture5030723>
- Schreiner, R. P. & Bethlenfalvay, G. J. (1997). Mycorrhizae, biocides, and biocontrol 3. Effects of three different fungicides on developmental stages of three AM fungi. *Biology and Fertility of Soils*, 24(1), 18–26. <https://doi.org/10.1007/BF01420215>
- Schwartz, J. D. (2013). *Cows save the planet and other improbable ways of restoring soil to heal the earth*. Chelsea Green Pub. Retrieved February 1, 2023, from <https://www.chelseagreen.com/product/cows-save-the-planet/>
- Scientific Research Documenting and Explaining SRI. (n.d.). Retrieved February 1, 2023, from http://sri.ciifad.cornell.edu/conferences/IRC2014/booth/SRI_published_research_handout_2014.pdf
- Scott, A., Tien, Y.-C., Drury, C. F., Reynolds, W. D. & Topp, E. (2018). Enrichment of antibiotic resistance genes in soil receiving composts derived from swine manure, yard wastes, or food wastes, and evidence for multiyear persistence of swine *Clostridium spp.* *Canadian Journal of Microbiology*, 64(3), 201–208. <https://doi.org/10.1139/cjm-2017-0642>
- Schostag, M., Stibal, M., Jacobsen, C. S., Bælum, J., Taş, N., Elberling, B., Jansson, J. K., Semenchuk, P. & Priemé, A. (2015). Distinct summer and winter bacterial communities in the active layer of Svalbard permafrost revealed by DNA- and RNA-based analyses. *Front Microbiol.*, 6, 1-13. <https://doi.org/10.3389/fmicb.2015.00399>
- Schlesinger, W., & Jasechko, S. (2014) Transpiration in the global water cycle, *Agricultural and Forest Meteorology*, Volumes 189–190, Pages 115-117, ISSN 0168-1923, <https://doi.org/10.1016/j.agrformet.2014.01.011>.
- Schmidt-Rohr K. Oxygen Is the High-Energy Molecule Powering Complex Multicellular Life: Fundamental Corrections to Traditional Bioenergetics. *ACS Omega*. 2020 Jan 28;5(5):2221-2233. doi: 10.1021/acsomega.9b03352. PMID: 32064383; PMCID: PMC7016920. <https://pubs.acs.org/doi/10.1021/acsomega.9b03352#>
- Sebastian, A., Nangia, A. & Prasad, M. (2020). Advances in agrochemical remediation using nanoparticles. In book: *Agrochemicals Detection, Treatment and Remediation*, Chapter 18, pp. 465-485. <https://doi.org/10.1016/B978-0-08-103017-2.00018-0>
- Selibas, D. (2022). This type of agriculture is boosting yields, whilst also restoring nature in Mexico. Retrieved February 1, 2023, from <https://www.weforum.org/agenda/2022/08/regenerative-agriculture-in-mexico-boosts-yields-while-restoring-nature/>
- SEVIR (2024) Championing Sustainable Agriculture in Niger <https://reliefweb.int/report/niger/championing-sustainable-agriculture-niger>
- Sewage Sludge Incineration. (n.d.). Retrieved February 1, 2023, from https://gaftp.epa.gov/ap42/ch02/s02/final/c02s02_jan1995.pdf
- Sharon, O., Sun, X., Ezrati, S., Kagan-Trushina, N., Sharon A. (2023). Transmission Mode and Assembly of Seed Fungal Endophyte Communities in Wheat and Wheat Wild Relatives. *Phytobiomes Journal* 7:1, 113-124 <https://apsjournals.apsnet.org/doi/10.1094/PBIOMES-11-22-0084-R>

- Sher, A., Li, H., ullah, A. et al. Importance of regenerative agriculture: climate, soil health, biodiversity and its socioecological impact. *Discov Sustain* 5, 462 (2024). <https://doi.org/10.1007/s43621-024-00662-z>
- Sikkim. (n. d.). Cereals. *Government of Sikkim, Horticultural Department*. Retrieved February 1, 2023, from <https://sikkim.gov.in/departments/horticulture-cash-crop-department/cereals>
- Sikkim. (2004). State Policy on Organic Farming. Government of Sikkim. Retrieved February 1, 2023, from <http://scstsenvis.nic.in/WriteReadData/links/Sikkim%20Organic%20Policy%202015-401740061.pdf>
- Sikkim. (2010). Sikkim Organic Mission. Policy Vision and Mission. Retrieved February 1, 2023, from http://ofai.s3.amazonaws.com/Sikkim_Policy%20vision%20n%20mission.pdf
- Sunil, S., Bhagwat, G., Gnana, S., Vincent, T., Palanisami, T. (2024) Microplastics and climate change: the global impacts of a tiny driver, *Science of The Total Environment*, Volume 946, 2024, 174160, ISSN 0048-9697, <https://doi.org/10.1016/j.scitotenv.2024.174160>
- Smallwood, M. (n.d.). *Regenerative Organic Agriculture and Climate Change A Down-to-Earth Solution to Global Warming*. Rodale Institute. Retrieved February 1, 2023, from <https://rodaleinstitute.org/wp-content/uploads/rodale-white-paper.pdf>
- Smith, D. L. & Johnson, L. C. (2003). Expansion of *Juniperus virginiana* L. in the Great Plains: Changes in soil organic carbon dynamics, *Global Biogeochem. Cycles*, 17, 1062. <https://doi.org/10.1029/2002GB001990>
- Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U, Towprayoon, S., Wattenbach, M. & Smith, J. (2008). Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363, 789–813. <https://doi.org/10.1098/rstb.2007.2184>
- Soil Health Institute. (2021) Economics of Soil Health Systems, A Comprehensive Evaluation Across Nine States. https://soilhealthinstitute.org/app/uploads/2022/01/100-Farm-Fact-Sheet_9-23-2021.pdf
- SoilHealth. (n.d.). Fungi vs. bacteria. Retrieved February 1, 2023, from <http://www.soilhealth.com/soil-health/organisms/fungi-bact/>
- Solomon, S., Qin, D., Manning, M., Marquis, M., Averyt, K., Tignor, M. M. B., Miller, H. L.-R. & Chen, Z. (2007). Climate change 2007: The physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 996. Retrieved February 1, 2023, from https://www.ipcc.ch/site/assets/uploads/2018/05/ar4_wg1_full_report-1.pdf
- Southey, F. (2021). Sustainability at the source: How Unilever is addressing deforestation, living wages, and regenerative agriculture. *FoodNavigator.com*. Retrieved February 1, 2023, from <https://www.foodnavigator.com/Article/2021/09/30/Sustainability-at-the-source-How-Unilever-is-addressing-deforestation-living-wages-and-regenerative-agriculture>
- Spångberg, J., Tidåker, P. & Jönsson, H. (2014). Environmental impact of recycling nutrients in human excreta to agriculture compared with enhanced wastewater treatment. *Sci Total Environ.*, 493, 209-19. <https://doi.org/10.1016/j.scitotenv.2014.05.123>

- Spera, S. A., Galford, G. L., Coe, M. T., Macedo, M. N., Mustard, J. F. (2016). Land-use change affects water recycling in Brazil's last agricultural frontier. *Glob Chang Biol.*, 22(10), 3405-3413. <https://doi.org/10.1111/gcb.13298>
- SRI International Network and Resources Center. (n.d.). Retrieved February 1, 2023, from <http://sri.ciifad.cornell.edu/videos/index.html>
- SRI Introduction: The spread of SRI in East Africa. (2012). *FloodedCellar*. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=J3N4qrhADQo>
- Steinauer, K., Chatzinotas, A. & Eisenhauer, N. (2016). Root exudate cocktails: the link between plant diversity and soil microorganisms? *Ecology and Evolution*, 6(20), 7387–7396. <https://doi.org/10.1002/ece3.2454>
- Stephenson, W. A., & Booth, E. (1968). *Seaweed in Agriculture and Horticulture: W. A. Stephenson, Ernest Booth: Amazon.com: Books* (1st Editio). London: Faber and Faber, pp. 231. Retrieved February 1, 2023,
- Strauss, T. (2023) What is regenerative agriculture and how can it help us get to net zero food systems? 3 industry leaders explain. *RacetoZero*. Retrieved February 1, 2023, from <https://climatechampions.unfccc.int/what-is-regenerative-agriculture-and-how-can-it-help-us-get-to-net-zero-food-systems-3-industry-leaders-explain/>
- Sockdale, O., Pradeep, P., Brennan, T., Chen, R. (2024) Revitalizing fields and balance sheets through regenerative farming. McKinsey and Company, <https://www.mckinsey.com/industries/agriculture/our-insights/revitalizing-fields-and-balance-sheets-through-regenerative-farming>
- Strutt & Parker. (2021). Regenerative Agriculture. A guide to the main principles and key considerations for farming businesses exploring regenerative agriculture methods. BNP Paribas Group. Retrieved February 1, 2023, from <https://rural.struttandparker.com/wp-content/uploads/2021/06/Regenerative-Agriculture.pdf>
- Syers, J. K., Johnston, A. E. & Curtin, D. (2008). Efficiency of soil and fertilizer phosphorus use Reconciling changing concepts of soil phosphorus behaviour with agronomic information. Retrieved February 1, 2023, from <https://www.fao.org/3/a1595e/a1595e02> and pdf <https://agris.fao.org/agris-search/search.do?recordID=XF2009437445>
- Syngnetia (2025 May) Syngenta and PepsiCo reward farmers for regenerative farming practices. <https://www.businesswire.com/news/home/20250320349801/en/Syngenta-and-PepsiCo-reward-farmers-for-regenerative-farming-practices>
- Syngnetia (2025 January a). A steward of the soil - How regenerative agriculture approaches are reviving the land. Syngenta News Service. <https://www.syngenta.com/agriculture/sustainable-agriculture/soil-health/a-steward-of-the-soil>
- Syngnetia (2025 Jan b.) Hel-ping plants to help themselves - Nurturing nature with biostimulants, biomarkers and AI. Syngenta News Service <https://www.syngenta.com/agriculture/agricultural-technology/biostimulants-helping-plants-to-help-themselves>
- Syngnetia (2024 Dec.) Transforming corn's impact Improving efficiency and profitability for both growers and livestock producers. Syngenta News Service <https://www.syngenta.com/agriculture/sustainable-agriculture/transforming-corns-impact>

- Tadesse, B. T., Ashley, E. A., Ongarello, S., Havumaki, J., Wijegoonewardena, M., González, I. J., & Dittrich, S. (2017). Antimicrobial resistance in Africa: A systematic review. *BMC Infectious Diseases*, 17(616), 1-17. <https://doi.org/10.1186/s12879-017-2713-1>
- Teenstra, E., Vellinga, T., Aektasaeng, N., Amatayakul, W., Ndambi, A., Pelster, D., Germer, L., Jenet, A., Opio, C. & Andeweg, K. (2014). *Global Assessment of Manure Management Policies and Practices*. Wageningen University and Research. Retrieved February 1, 2023, from https://www.wur.nl/upload_mm/a/2/f/8a7d1a1e-2535-432b-bab5-fd10ff49a2b1_Global-Assessment-Manure-Management.pdf
- Tessema, B. G., Daniel, H., Adimassu, Z. & Wilson, B. (2021). Soil Carbon Storage Potential of Tropical Grasses: A Review. In *Botany - Recent Advances and Applications*, Ghimire, B. K. (Ed.). IntechOpen. <https://doi.org/10.5772/intechopen.97835>
- The international "4 per 1000" Initiative. Soils for Food Security and Climate.(n.d.). Retrieved November 1, 2019, from <https://www.4p1000.org/#title348>
- Theoi Greek Mythology, (nd.) (Retrieved 11th Feb. 2023) <https://www.theoi.com/Protogenos/Gaia.html>
- The Soil and Health. (n.d.). Journey to Forever, Online Library. Retrieved February 1, 2023, from http://journeytoforever.org/farm_library.html
- Thomas, D.(2003). A study on the mineral depletion of the foods available to us as a nation over the period 1940 to 1991. *Nutr Health*, 17(2), 85–115. <https://doi.org/10.1177/026010600301700201>
- Thomas, R. et al (2017) Scaling Up Sustainable Land Management And Restoration Of Degraded Land (With Disclaimer) Affiliation: Global Land Outlook, UNCCD https://www.researchgate.net/publication/319751085_SCALING_UP_SUSTAINABLE_LAND_MANAGEMENT_AND_RESTORATION_OF_DEGRADED_LAND_DISCLAIMER/references#fullTextFileContent
- Thornton, I., Butler, D., Docx, P., Hession, M., Makropoulos, C., McMullen, M., Nieuwenhuijsen, M., Pitman, A., Rautiu, R., Sawyer, R., Smith, S., White, D., Wilderer, P., Paris, S., Marani, D., Braguglia, C. & Palerm, J. (2001). Pollutants in urban waste water and sewage sludge. Luxembourg. Retrieved February 1, 2023, from https://ec.europa.eu/environment/archives/waste/sludge/pdf/sludge_pollutants_xsum.pdf
- Tirado, R. & Allsopp, M. (2012). 'Phosphorus in agriculture, Problems and Solutions' Campaigning for sustainable agriculture, greenpeace.org. Retrieved February 1, 2023, from <https://www.greenpeace.to/greenpeace/wp-content/uploads/2012/06/tirado-and-allsopp-2012-phosphorus-in-agriculture-technical-report-02-2012.pdf>
- Toop, G. (2022). The state that proved it's possible to go 100% organic. Retrieved February 1, 2023, from <https://www.greenpeace.org/aotearoa/story/the-state-that-proved-its-possible-to-go-100-organic/>
- Tobisa, M., Uchida, Y., Iwasa, S., Tsukiyama, T., Asano, Y., Kirimura, M. & Sugimoto, Y. (2017). Effect of digested slurry on the dry matter production and arbuscular mycorrhizal colonization of two genotypes of Zoysia grass. *Journal of Agricultural Science*, 155(10), 1565–1576. <https://doi.org/10.1017/S0021859617000703torrellia>
- Torrella, K. (2022) Sri Lanka's organic farming disaster, explained,.Vox. Retrieved February 1, 2023, from <https://www.vox.com/future-perfect/2022/7/15/23218969/sri-lanka-organic-fertilizer-pesticide-agriculture-farming>

- Trémolet, M., Fleckenstein, M., Da Silva, A., Villela, F. (2021) UNDP. Transforming food systems – from the ground up. UNDP. Retrieved February 1, 2023, from <https://www.undp.org/blog/transforming-food-systems-ground>
- Treseder, K. K. (2004). A meta-analysis of mycorrhizal responses to nitrogen, phosphorus, and atmospheric CO₂ in field studies. *New Phytologist*, 164(2), 347–355. <https://doi.org/10.1111/j.1469-8137.2004.01159.x>
- Tupman, M. (2022) Priming Your Seeds for Success. Lower Blackwood LCDC. Retrieved February 1, 2023, from <https://www.youtube.com/watch?v=k1Hy5gllrvM>
- Turner, N. (1951). *Fertility Farming*. London: Faber and Faber Limited. http://journeytoforever.org/farm_library/turner/turnerToC.html
- Tyrrell, C., Burgess, C. M., Brennan, F. P. & Walsh, F. (2019). Antibiotic resistance in grass and soil. *Biochemical Society Transactions*, 47(1), 477–486. <https://doi.org/10.1042/BST20180552>
- Udo de Haes, H., Voortman, R., Bastein, T., Bussink D., Rougoor, C. & van der Weijden, W. J. (2012). Scarcity of micronutrients in soil, feed, food, and mineral reserves Urgency and policy options. *Platform Agriculture, Innovation & Society*. Retrieved February 1, 2023, from https://www.iatp.org/sites/default/files/scarcity_of_micronutrients.pdf
- UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) Archives | UN-Water. (n.d.). Retrieved December 23, 2019, from https://www.unwater.org/publication_categories/glaas/
- UN (n.d.) Three-quarters of Earth's land became permanently drier in last three decades: UN <https://www.unccd.int/ru/node/27457>
- UNCDD (2025) Three billion people globally impacted by land degradation <https://news.un.org/en/story/2024/12/1157651#:~:text=Globally%20up%20to%2040%20per,climate%2C%20biodiversity%20and%20people%27s%20livelihoods.>
- Under Cover Farmers - Feature Length. (2012). USDA NRCS East National Technology Support Center. Retrieved December 19, 2019, from <https://www.youtube.com/watch?v=nWXCLVCJWU>
- United States. Congress. (1985), Innovative Biological Technologies for Lesser Developed Countries: Workshop Proceedings, Office of Technology Assessment, Congress of the U.S., Office of Technology Assessment, Original from the University of California <https://ota.fas.org/reports/8512.pdf>
- University of Illinois at Urbana-Champaign. (2007). "Nitrogen Fertilizers Deplete Soil Organic Carbon." *ScienceDaily*. Retrieved February 1, 2023, from www.sciencedaily.com/releases/2007/10/071029172809.htm
- Upoff, N., Anas, I., Rupela, O. P., Thakur, A. K. & Thiagarajan, T. M. (2009). Learning about positive plant-microbial interactions from the System of Rice Intensification (SRI). *Aspects of Applied Biology*, 98, 29-54. Retrieved February 1, 2023, from https://repository.ipb.ac.id/bitstream/handle/123456789/63583/ART2009_IAC.pdf?sequence=1&isAllowed=y
- URA (2024) A Green & Liveable City Singapore Urban Design Guidebook A Green & Liveable City. <https://www.ura.gov.sg/-/media/Corporate/Resources/Publications/Books/UD-Guidebook-2- Green and Liveable City 2024.pdf>
- Urbansky, E. T., Brown, S. K., Magnuson, M. L. & Kelty, C. A. (2001). Perchlorate levels in samples of sodium nitrate fertilizer derived from Chilean caliche. *Environmental Pollution*, 112(3), 299–302. [https://doi.org/10.1016/s0269-7491\(00\)00132-9](https://doi.org/10.1016/s0269-7491(00)00132-9)

- U'Ren, J.M. and Zimmerman, N.B. (2021). Oaks provide new perspective on seed microbiome assembly. *New Phytol*, 230: 1293-1295.
<https://doi.org/10.1111/nph.17305>
- USDA Magdof (2021) Importance of regenerative agriculture: climate, soil health, biodiversity and its socioecological impact, 4th edn. Sustainable Agriculture Research & Education, 2021. | Series: Handbook series ; bk. 10 <https://www.sare.org/wp-content/uploads/Building-Soils-for-Better-Crops.pdf>
- Use of Reclaimed Water and Sludge in Food Crop Production. (1996). National Academies Press. <https://doi.org/10.17226/5175>
- Van Biezen, M. (2018) Astronomy - Ch. 9.1: Earth's Atmosphere (19 of 61) How H₂O Absorption Spectrum Compares to CO₂
<https://www.youtube.com/watch?v=XIBsjBvRTew>
- van Dijkhorst, H., Kuepper, B. & Piotrowski, P. M. (2018). Cerrado Deforestation Disrupts Water Systems and Poses Business Risks for Soy Producers. Chain Reaction Research. Retrieved February 1, 2023, from <https://chainreactionresearch.com/wp-content/uploads/2018/10/Cerrado-Deforestation-Disrupts-Water-Systems-and-Poses-Business-Risks-for-Soy-Producers-2.pdf>
- van Vliet, et Al. (2021). Metabolomics comparison of plant-based meat and grass-fed meat indicates large nutritional differences despite comparable Nutrition Facts panels. *Scientific Reports*; 11 (13828). <https://doi.org/10.1038/s41598-021-93100-3>
- Venditti, B., Parker, S. (2024) Visualizing Global Energy Production in 2023
<https://elements.visualcapitalist.com/visualizing-global-energy-production-in-2023/>
- Video: Seasonal changes in carbon dioxide. (2015). NASA. Retrieved Feb 1, 2023, https://climate.nasa.gov/climate_resources/152/video-seasonal-changes-in-carbon-dioxide/
- Voices from the field | Awash Basin, November 2018. REACH: Improving water security for the poor. (2018). voices from the field
https://www.youtube.com/watch?time_continue=93&v=A_w7odR1UAA
- Voth, K. (2015). Great “Grass Farmers” Grow Roots. *On Pasture*. Retrieved February 1, 2023, from <http://onpasture.com/2015/11/09/great-grass-farmers-grow-roots/>
- Walters, C. (2005). Fertility from the ocean deep. Nature’s perfect nutrient blend for the farm. *Acres U.S.A.* pp. 192.
- Wang, W., Shi, J., Xie, Q., Jiang, Y., Yu, N. & Wang, E. (2017) Nutrient Exchange and Regulation in Arbuscular Mycorrhizal Symbiosis. *Mol Plant*. 10(9), 1147-1158.
<https://doi.org/10.1016/j.molp.2017.07.012>
- Wagner, S. (2011). Biological Nitrogen Fixation. *Nature Education Knowledge*, 3(10), 15.
<https://www.nature.com/scitable/knowledge/library/biological-nitrogen-fixation-23570419/>
- War, A, Bashir I, Reshi Z, Kardol P, Rashid I. (2023). Insights into the seed microbiome and its ecological significance in plant life. *Microbiol Res.* Apr;269:127318. doi: 10.1016/j.micres.2023.127318. Epub 2023 Feb 2. PMID: 36753851.
<https://www.sciencedirect.com/science/article/pii/S0944501323000198>
- Watson, A. J., Lenton, T. M. & Mills, B. J. W. (2017). Ocean deoxygenation, the global phosphorus cycle and the possibility of human-caused large-scale ocean anoxia. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 375, 1-14. <https://doi.org/10.1098/rsta.2016.0318>

- Waston, E. (2023) "PepsiCo to pump \$216m into US regenerative ag: 'We're putting our money where our mouth is'" AFN News <https://agfundernews.com/pepsico-to-pump-216m-into-us-regenerative-ag-projects>
- WEF Thomson E. (2024). Cities are using nature to cut urban temperatures – by 2°C in one case. <https://www.weforum.org/stories/2024/01/nature-positive-cities-tackle-extreme-heat/>
- WEF (2024) How direct biomass estimation can improve forest carbon accounting <https://www.weforum.org/stories/2024/03/how-direct-biomass-estimation-can-benefit-forest-carbon-accounting/>
- Wei PS, Hsieh YC, Chiu HH, Yen DL, Lee C, Tsai YC, Ting TC. Absorption coefficient of carbon dioxide across atmospheric troposphere layer. *Heliyon*. 2018 Oct 6;4(10):e00785. doi: 10.1016/j.heliyon.2018.e00785. PMID: 30302408; PMCID: PMC6174548. <https://doi.org/10.1016/j.heliyon.2018.e00785>
- Wetzel, R. G. & Tuchman, N. C. (2005). Effects of atmospheric CO₂ enrichment and sunlight on degradation of plant particulate and dissolved organic matter and microbial utilization. *Archiv für Hydrobiologie*, 162(3), 287-308. <https://doi.org/10.1127/0003-9136/2005/0162-0287>
- Wellman, M., DiBartola, S., Kohn, C. (2006). - Applied Physiology of Body Fluids in dogs and Cats. In Fluid, Electrolyte, and Acid-Base Disorders in Small Animal Practice. DiBartola, S. P. (ed.), Chapter 1, Third Edition, W.B. Saunders, pp. 3-26. <https://veteriankey.com/applied-physiology-of-body-fluids-in-dogs-and-cats/>
- Weng, X., Sui, X., Liu, Y. Yang, L. & Zhang, R. (2022). Effect of nitrogen addition on the carbon metabolism of soil microorganisms in a *Calamagrostis angustifolia* wetland of the Sanjiang Plain, northeastern China. *Ann Microbiol*, 72(18). <https://doi.org/10.1186/s13213-022-01674-8>
- Weyant, C., Brandeau, M. L., Burke, M., Lobell, D. B., Bendavid, E. & Basu, S. (2018). Anticipated burden and mitigation of carbon-dioxide-induced nutritional deficiencies and related diseases: A simulation modeling study. *PLoS Medicine*, 15(7). <https://doi.org/10.1371/journal.pmed.1002586>
- What is Soil Carbon Sequestration? FAO soils portal. (n.d.). *Food and agricultural Organization of the United Nations*. Retrieved November 1, 2019, from <http://www.fao.org/soils-portal/soil-management/soil-carbon-sequestration/en/>
- WHO. (2016) Protecting Health from Climate Change. [https://www.who.int/docs/default-source/wpro---documents/hae---regional-forum-\(2016\)/climatechange-factsheet-rfhe.pdf?sfvrsn=75d570fd_2](https://www.who.int/docs/default-source/wpro---documents/hae---regional-forum-(2016)/climatechange-factsheet-rfhe.pdf?sfvrsn=75d570fd_2)
- Wikipedi. (2019a). Erosion. Retrieved November 13, 2019, from <https://en.wikipedia.org/wiki/Erosion>
- Wikipedia. (2019b). Land degradation. Retrieved February 1, 2023, from https://en.wikipedia.org/wiki/Land_degradation
- Wikipedia. (2019c). Magnesium in biology. Retrieved February 1, 2023, from https://en.wikipedia.org/wiki/Magnesium_in_biology
- Wikipedia. (2021) Agricultural land. Retrieved 21 december 2021. https://en.wikipedia.org/w/index.php?title=Agricultural_land&oldid=1061324216
- Wikipedia. (2022) The Great Stink. Retrieved February 1, 2023, from https://en.wikipedia.org/w/index.php?title=Great_Stink&oldid=1127722459
- Wikipedia. (2022a) Nitrogen Cycle Retrieved February 1, 2023, from https://en.wikipedia.org/w/index.php?title=Nitrogen_cycle&oldid=1129556751

- Wikipedia. (2022b) Solar Irradiance.
https://en.wikipedia.org/w/index.php?title=Solar_irradiance&oldid=1129249470
- Wikipedia. (2023a) Retrieved March 12th 2023. Mutualistic Relationship Between Plants and Mycorrhiza.svg https://commons.wikimedia.org/w/index.php?title=File:Mutualistic_Relationship_Between_Plants_and_Mycorrhiza.svg&oldid=643090326
- Wikipedia. (2024) Agriculture.
https://en.wikipedia.org/w/index.php?title=Agricultural_land&oldid=1262695281#cite_note-10
- Wikipedia. (2025) Ice–albedo feedback
https://en.wikipedia.org/w/index.php?title=Ice%E2%80%93albedo_feedback&oldid=1272898046
- Wolf, K., van den Brink, W. J. & Colon, F. J. (2012). Contaminated Soil '88: Second International TNO/BMFT Conference on Contaminated Soil, 11–15 April 1988, Hamburg, Federal Republic of Germany, Springer Science & Business Media, pp. 1009.
- Wollinger, A. (2010). Hope in a Changing Climate. Retrieved February 1, 2023, from https://www.youtube.com/watch?time_continue=1032&v=kK8z0qDtE2g
- World Meteorological Organisation, (2024) Record carbon emissions highlight urgency of Global Greenhouse Gas Watch <https://wmo.int/media/news/record-carbon-emissions-highlight-urgency-of-global-greenhouse-gas-watch>
- Wu, X., Conkle, J. L., Ernst, F. & Gan, J. (2014). Treated Wastewater Irrigation: Uptake of Pharmaceutical and Personal Care Products by Common Vegetables under Field Conditions. *Environ. Sci. Technol.*, 48(19), 11286–11293. https://docksci.com/treated-wastewater-irrigation-uptake-of-pharmaceutical-and-personal-care-product_5a92ec56d64ab2f82ae6f6bf.html
- Wuana, R. A., & Okieimen, F. E. (2011). Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks and Best Available Strategies for Remediation. *ISRN Ecology*, 2011, 1–20. <https://doi.org/10.5402/2011/402647>
- Wunderling, N., Willeit, M., Donges, J.F. *et al.* Global warming due to loss of large ice masses and Arctic summer sea ice. *Nat Commun* **11**, 5177 (2020).
<https://doi.org/10.1038/s41467-020-18934-3>
- Wylie, J. C. (1955). Fertility from Town Waste. Faber and Faber Ltd., London.
- Wysocański, W., Węgrzyn, E., Lembicz, M. *et al.* (2021). Fungal microbiota in seeds, seedlings and mature plants of raspberry (*Rubus ideaus* L.). *Eur J Plant Pathol* 161, 815–820 <https://doi.org/10.1007/s10658-021-02364-y>
- Xu, X., Li, T., Zhen, J., Chen, J., *et al* (2023) Characterization of Microplastics in Clouds over Eastern China, *Environmental Science & Technology Letters* 11(1)
 DOI:10.1021/acs.estlett.3c00729
<https://pubs.acs.org/doi/abs/10.1021/acs.estlett.3c00729>
- Yamamuro, S. *et al.* (2002). Uptake of carbon and nitrogen through roots of rice and corn plants, grown in soils treated with ¹³C and ¹⁵N dual-labeled cattle manure compost. *Soil Science and Plant Nutrition*, 48(6), pp. 787–795.
<https://doi.org/10.1080/00380768.2002.10408704>
- Yang, W., Gu, S., Xin, Y., Bello, A., Sun, W. & Xu, X. (2018). Compost addition enhanced hyphal growth and sporulation of arbuscular mycorrhizal fungi without affecting their community composition in the soil. *Frontiers in Microbiology*, 9, 1–13.

- Yuan, H., Zhang, Y., Huang, X. *et al.* (2024). Exploration of the Existence Forms and Patterns of Dissolved Oxygen Molecules in Water. *Nano-Micro Lett.* **16**, 208
<https://doi.org/10.1007/s40820-024-01427-z>
- Zare-Maivan, H., Khanpour-Ardestani, N. & Ghanati, F. (2017). Influence of mycorrhizal fungi on growth, chlorophyll content, and potassium and magnesium uptake in maize. *Journal of Plant Nutrition*, *40*(14), 2026–2032.
<https://doi.org/10.1080/01904167.2017.1346119>
- Zeigler, A. (2014). *Seawater concentrate for abundant agriculture*. Acres U.S.A. pp. 120.
- Zeng, Y., Jia, L., Menenti, M. *et al.* Changes in vegetation greenness related to climatic and non-climatic factors in the Sudano-Sahelian region. *Reg Environ Change* *23*, 92 (2023).
<https://doi.org/10.1007/s10113-023-02084-5>
- Zhai X, Zhang XH, Yu M. Microbial colonization and degradation of marine microplastics in the plastisphere: A review. *Front Microbiol.* 2023 Feb 17;14:1127308. doi: 10.3389/fmicb.2023.1127308. PMID: 36876073; PMCID: PMC9981674.
<https://pmc.ncbi.nlm.nih.gov/articles/PMC9981674/>
- Zhang, J. & Elser, J. (2017). Carbon:Nitrogen:Phosphorus Stoichiometry in Fungi: A Meta-Analysis. *Frontiers in microbiology*, *8*(1281), 1-9.
<https://www.sciencedirect.com/science/article/pii/S2351989423003426>
- Zhang S, Hu W, Zhang J, Yu G, Liu Y, Kong Z, Wu L. Long-term cultivation reduces soil carbon storage by altering microbial network complexity and metabolism activity in macroaggregates. *Sci Total Environ.* 2024 Jun 20;930:172788.
<https://www.sciencedirect.com/science/article/abs/pii/S0048969724029358>
- Zhang, X., Zhou, T., Zhang, W. *et al.* (2023) Increased impact of heat domes on 2021-like heat extremes in North America under global warming. *Nat Commun* *14*, 1690 (2023).
<https://doi.org/10.1038/s41467-023-37309-y>
- Zheng, Y., Li, F., Hao, L., Shedayi, A. A., Guo, L., Ma, C., Huang, B & Xu, M. (2018). The optimal CO₂ concentrations for the growth of three perennial grass species. *BMC Plant Biology*, *18*(1). <https://doi.org/10.1186/s12870-018-1243-3>
- Zhou, X., Hu, C., Wang, Z., Distribution of biomass and carbon content in estimation of carbon density for typical forests, *Global Ecology and Conservation*, Volume 48, 2023, e02707, ISSN 2351-9894, <https://doi.org/10.1016/j.gecco.2023.e02707>.
- Zhou, S., Williams, A. Berg, A., Cook, B., Zhang, Y., Hagemann, S., R. Lorenz, R., Seneviratne, S., Gentile, P. (2019) Land–atmosphere feedbacks exacerbate concurrent soil drought and atmospheric aridity, *Proc. Natl. Acad. Sci. U.S.A.* *116* (38) 18848-18853,
<https://doi.org/10.1073/pnas.1904955116>
- Zomer, R. J., Bossio, D. A., Sommer, R. & Verchot, L. V. (2017). Global Sequestration Potential of Increased Organic Carbon in Cropland Soils. *Scientific Reports*, *7*(15554).
<https://doi.org/10.1038/s41598-017-15794-8>

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Table 2. Annual incident solar energy (total incoming energy both before and after albedo reflection) converted to petawatt-hours per year (PWh/year) for direct comparison to human energy production. Calculations account for a spherical Earth and latitudinal variations in solar irradiance. The table highlights the colossal scale of solar energy relative to human activities, and the immense consequent importance of reducing surface heating and minimising incidence on bare and degraded soils, desert and urban with their related sensible heat atmospheric warming capacity, and conversely optimising the photosynthetic carbon capture and latent evapotranspiration cooling and related climate benefits of green growing material.48

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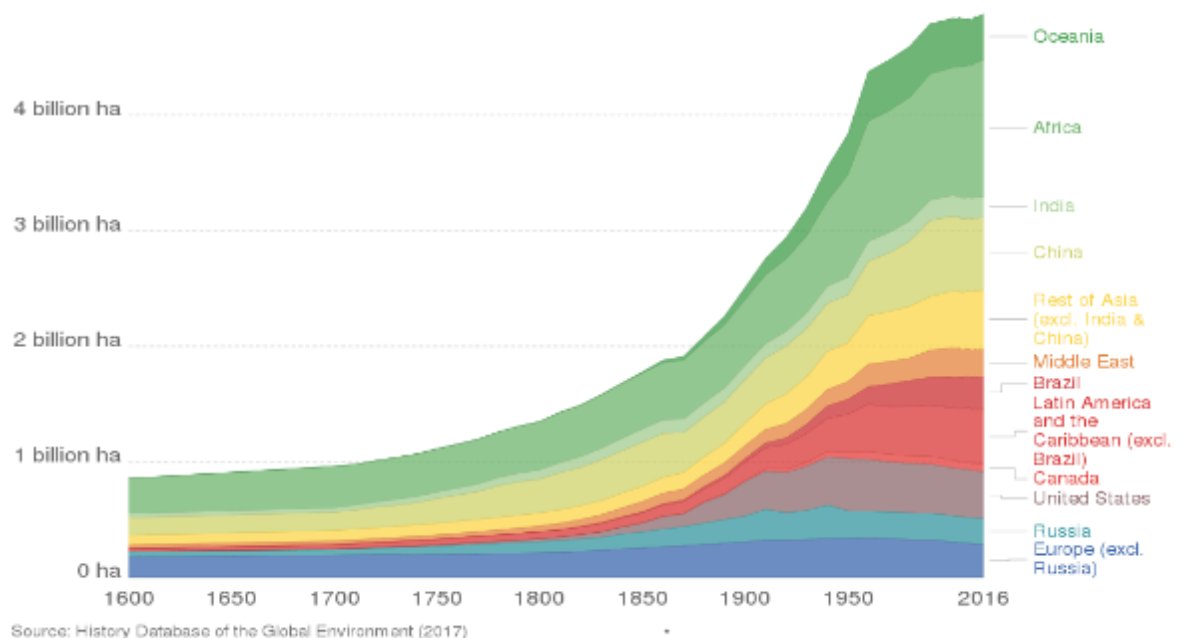
- **A point summary**

The way we farm strongly influences:

- **Carbon apportionment between earth's crust, atmosphere, ocean, soil, and life: –**
 - As discussed, plants supply photosynthetic energy carbon exudates, which in turn provide the dark soil biome with substrate for their structure and energy. Without sunshine, and photosynthetic land and marine life-forms, there would be no oxygen; no carbon sugar exudates; hence no soil biome, and without a soil biome to support plant growth, plant-based oxygen production, and regulate and buffer atmospheric and oceanic carbon dioxide levels, terrestrial life would be very limited.
- **Soil carbon is largely dependent on soil life**
 - Living things are made of carbon. Much of carbon in the soils is in living things and their detritus. Life in the soil biome is largely reliant on the provision of photosynthetic plant sugar exudates for energy.

Agricultural area over the long-term

Total areal land use for agriculture, measured as the combination of land for arable farming (cropland) and grazing in hectares.



- **Bare soil heating and global warming; -**
 - The re-radiated solar energy incident on billions of hectares of human created bare soils, is a very large number (be that permanent degraded bare or between-

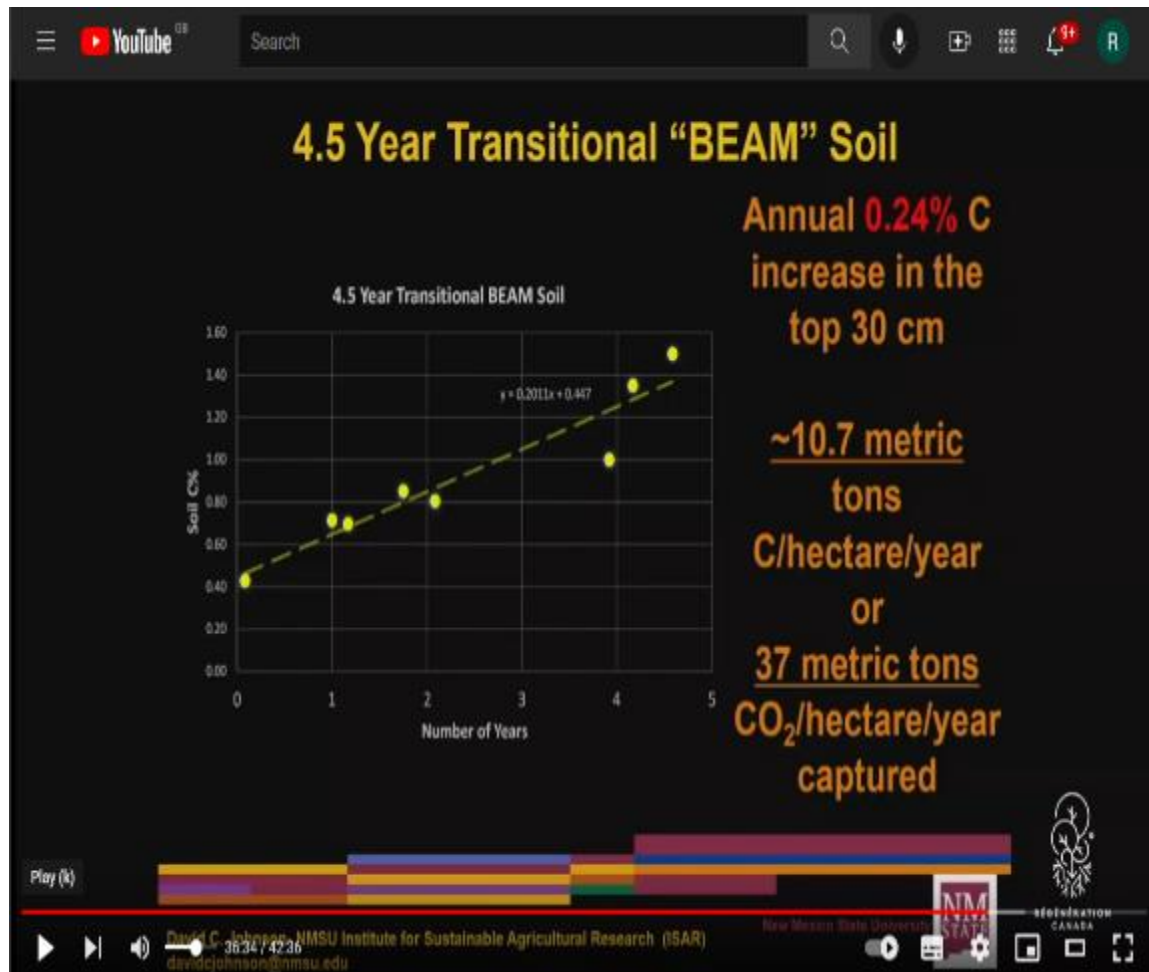
crops bare). That energy desiccates and crust soils, and kills soil biology. Soils reach temperatures sufficient to kill soil biome biology in the surface layers. Visible and ultraviolet sunlight heat energy is absorbed by terrestrial surfaces, re-radiated in the infra-red spectrum: that which is not reflected into space, has to go somewhere, namely the atmosphere, land surface, or oceans, thus contributing to planetary warming.

The total area of land area of earth under cultivation is more than 4 billion hectares, of which approximately 1.3 billion is arable, although figures vary. The incident sunlight at the equator is approximately 800watts per square meter. If one guessed that arable land is bare of a quarter of the year, and received sunlight for 5 hours a day, 1,300,000,000 hectares times 10,000 (m.sq. per hectare), times 90 days, times 400 watts (half best incidence rate) = 2,340,000 tera watts (a million million watts), which many times more than the global annual fossil fuel consumption of 120,000 TW <https://ourworldindata.org/fossil-fuels> Yes, very much 'back of an envelope' calculations, and a portion will be re-irradiated into space, but the figures illustrate bare land heating could significantly contribute to global warming.

Conversely that sunlight energy could be directed to plant growth, and the extraction of carbon, and oxygen, from carbon dioxide, helping cool the planet, and providing a whole range of other eco-services at the same time.

- **Soil carbon sequestration rates: -**

- A healthy soil biome provided with adequate carbon sugar exudate, will sequester some of it, reducing atmospheric carbon dioxide and increasing oxygen. As discussed earlier, if a ton per hectare of carbon was sequestered in all agricultural land, by using soil centric regenerative agriculture, that would total between 4 to 8 billion tons. Over a number of years figures of that order, could 'buy time' for development of low carbon, fission and fusion energy sources, carbon capture, synthetic and hydrogen fuels, and general moves to more sustainable living. Extraction of that energy and sequestration of it as carbon in soils will cool the planet, (the reverse of burying fossil fuels), as will many of the other ecoservices provided.
- Gabe Brown, the Haggertys, Dr Johnson, and others, suggest that more than a tonne a year of carbon per acre could be sequestered into soils using regenerative agricultural practices. There are no other available current or prospective options that show anywhere near this capacity to mitigate climate change; and it is proven free technology; thus, it would make a great deal of sense to trial their regenerative agriculture systems at a larger scale as a matter of urgency. Surely this should be given the same priority as human technology based chemical and mechanical carbon capture.



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From a UTube video lecture by Dr David Johnson, growing without fertiliser, using the 'The BEAM (Biologically Enhanced Agricultural Management') Approach' (Johnson, 2017)

- **Bare Soils**
 - Bare soils reemit UV and visible light as heat adding to global warming. Crusted bare soils reduce infiltration leading to damage to hydrological systems, run off, erosion, flooding, eutrophication; add to heat domes, reduce moisture circulation, encouraging drought, fires, and reduce rainfall.
- **Agrochemicals and tillage**
 - Destruction of soil life, thus soil carbon, is exacerbated by agrochemicals and tillage.
- **The productivity and health of plants: -**
 - To be healthy and productive, plants and their roots, require biome produced and transported: nitrates (biome bacteria manufactured), minerals including

phosphates, (biome mycorrhiza mined), and 'medicine' (biome made), which are provided by the soil biome to plants in exchange for photosynthetic carbon sugars.

- **Atmospheric oxygen levels: -**
 - Sequestering carbon into soils represents a reduction of carbon dioxide and gain of oxygen in the atmosphere.
- **Oceanic oxygen: –**
 - We need to consider oxygen as a climate gas, and be aware that increasing atmospheric carbon dioxide means a reduction in oxygen. There are huge amounts of oxygen in the atmosphere, a million gigatons, but much less in the oceans, about eight thousand gigatons, of which approximately half is in the upper ocean layers and the rest in deep ocean current. It is very possible we are losing oceanic oxygen much faster than we realise – we simply do not have the data to be sure. Oceanic oxygen and atmospheric oxygen are constantly exchanged across the ocean surface, in a balance determined by the laws of nature. Thus, each will try and maintain the system stable status quo: crucially replenishment from the oceans of what is a small relative usage of atmospheric oxygen due to combustion and respiration of soil carbon, say a 40GT annual loss, would represent a significant loss to the ocean upper layers, possibly half a percent or more – a worrying but rational scenario that requires further investigation.
- **Sunlight incident on living plants: -**
 - When sunlight energy is absorbed by living plants, rather than bare-ground, that energy, rather than being converted to heat, is; used to transmute carbon dioxide into organic molecules; evaporate water, and absorbed by antioxidants etc. Some of that energy is stored as organic carbon in soils, and used sustain and build life in the biome.
- **Water retention in soils is proportionate to soil carbon**
 - The capacity of soils to absorb, retain water. and indeed, also to respire metabolic water, is related to the level of organic carbon, thus soil biome life and related activity in the soil. Water in soils is present in the life that makes up soils. It is transported by living things, and in channels made by living things, 'life'. It is stored in pores and gels created by the life in soils. Also 'metabolic water' is made by living things.
- **Metabolic water: -**
 - When plants and the living denizens of the soil biome respire to make energy, they produce metabolic water, further assisting cooling capacity, and providing a useful cushion during dry spells. The quantity of life in soils in tons is massive. Thus, plants play a crucial role in helping maintain a cooler planet. On a small-scale, city parks illustrate the capacity of plants to cool, through the mechanisms described.
- **Local hydrology depends on soil carbon: -**
 - Water retained and released by soils creates local hydrology.
- **Local weather:**
 - Plant growth respiration and transpiration affect atmospheric moisture levels and bacterial seeding of clouds. Plants host and transpire large amounts of cloud seeding bacteria. Soil carbon and related water retention, as well as their

cooling effect, further affect local hydrology, including through facilitating inland movement of oceanic moisture systems, so again impact regional climate.

- **Sunlight incident on dead plants: -**
 - When sunlight is absorbed by dead plants, it is used to break down organic matter, which then provides bacteria with substrate, thus again is being used to maintain life processes rather than produce instant heat. Further dead plant material shades the soil, preventing temperature rise, and by retaining moisture, creating micro-climates, hence protecting the soil biome.
- **Drought resistance: -**
 - Retention and release of water in soils governs localised drought resistance, plant transpiration, so local atmospheric moisture, thus indirectly regional hydrology, and more widely weather both at a local and wider level.
- **Soil aeration: -**
 - Aeration of soils is dependent on plant roots, soil aggregates, and burrowing life forms in the biome
- **Greater rain permeability of soils – reduced flooding and risk management costs**
 - Farmers moving to regenerative practices are seeing rain permeability increasing from one inch to several inches an hour after a few years of regenerative agriculture, which will reduce: flooding thus, crop loss, water loss, erosion, downstream damage loss of life and cost, silting, eutrophication, and water wastage. Retention in rain in soils conversely improves local hydrology and climate.
- **Pollution and Eutrophication: –**
 - The use of artificial fertilisers, soluble phosphates and nitrates, as well as switching off the obligation of plants to supply carbon exudates to the soil biome, results in eutrophication of rivers and seas, damaged ecosystems including contributing to deoxygenation. Use of sewage sludge creates similar dysregulation issues, as well polluting land with heavy metals, unremediated pharmaceuticals, and personal care products. The use of agrochemicals kills soil biology, and adds to pollution of soil rivers and oceans.
- **Health of oceans: –**
 - The health of the oceans is damaged by eutrophication, excessive runoff from erosion, and declining oxygen.
- **Sustainability and Diversity of Species: –**
 - Moving to regenerative soil health multispecies centric farming leads to greater species diversity and sustainability.
- **Farming energy and artificial energy demanding resource requirements: –**
 - Regenerative agriculture reduces tillage, artificial fertiliser and agrochemical inputs, resulting in significant energy savings that reduces the global carbon dioxide burden.
- **Health of plants and livestock: -**
 - Plants and livestock produced using regenerative agricultural principles will be healthier. Healthier better nourished livestock needs less pharmaceuticals including antibiotics.
- **Human health, IQ, and behavioural traits: -**

- Ultimately humans are what they eat. Optimal human development in utero, early years, and throughout life, requires optimal nutrition. Optimal human neurological development and function, intelligence, empathy, abstract thought, and higher human function, is logically heavily dependent on nutrition, clean water and freedom from excessive pollution.
- **Farmers profits, health, satisfaction and sustainability:**
 - Regenerative agriculture is more profitable, better for farmers' health and well-being, and is more sustainable.

From an agricultural perspective, understanding the relevance and importance of the soil biome to plant and planetary health is the nub of it. Maintenance of soil quality obliges return of organic carbon to soil through a combination of:

- No bare soils.
- Maintain soil cover.
- Reduce tillage to zero where possible.
- Mixed cover crops that optimise each square metre of soil sunlight exposure, allowing plants to fix maximum carbon through photosynthesis, optimising soil carbon sequestration, metabolic water creation, water retention and beneficial microclimates,
- Where feasible mix agriculture with livestock half-height grazing to disturb dead grasses, provide manure, spread seed and biology, and help even-out mineral availability.
- No use of artificial soluble fertilisers, with possible rare exceptions.
- Sea salt residue rich in a wide range of minerals including iodine, has been successfully used as a mineral foliar spray, is a green fertiliser, endlessly renewable, and may have significant potential in improving; crop nutrient quality, shelf life, and wider health (more research required).
- Minimise use of agrochemicals – most regenerative agriculturalists find they are rarely necessary.
- Maximise soil biological diversity and immediate availability, including by using composts and compost teas with rich biology, as seed soaks, (Johnson, 2022 @22.00) plant foliar, and land treatments,
- Develop technologies to enable as far as possible, the safe return to the soil of all organic matter, including composted human and livestock faeces and urine, (likely through hyperthermophilic composting, of excreta separated at source, to minimise contaminants,) returning carbon, minerals and soil biology to the soil biome, thus closing the environmental and economic: grow; eat; excrete, fertilise, cycle.

The above principles underlie regenerative agriculture. Implementation of the above principles in whole or in part, are already resulting in better, cash crop yields, nutrient density, water retention, and soil carbon; as well as plant health and quality, livestock health, and profitability, compared to those of average conventional farms in comparable geographic areas – and all with saving in agricultural inputs and fuel, thus further increasing profitability.

Multiple productive civilisations have foundered as landscapes became barren. In the 21st century, we already recognise the destructive nature of slash-and-burn lifestyles on long-term land fertility, and we see the increasingly negative impacts of modern farming techniques built around bare land and artificial fertilisers.

Industrialisation of agriculture through mechanisation and automation is essential for affordable food production. High technology has the capacity to amaze and also transform life, but it cannot replace the ecoservices provided by the soil biome, which help maintain soil plant and planet health, as well as minimising; global warming, extreme weather events, and water shortages, at the same time providing the nutritious food needed to create and support large numbers of human beings with optimal intelligence and empathy.

Never before has there been such a premium on intelligence, empathy and abstract thought capacity, as the risks faced by *homo sapiens*, including competition for resources, are, magnified by the stresses of massive global populations, aspiring to ever more technological lifestyles.

Ironically, that same ingenuity, so often focused on siloed projects in pursuit of economic advantage - will be our demise if we continue to fail to take a long-term, joined-up, sustainable agronomist's approach to soil management, that respects nature's evolutionary Gaian climate regulatory systems.

If we are to avoid repeating the mistakes of history, we must take much better care of our soils and wider agricultural landscape. Put simply, loss of soil quality must eventually result in loss of capacity to feed humankind.

The lessons from history are clear; will we learn them?

- **Key factors**

- **No use of phosphates or nitrate fertilisers is key:** nitrogen and phosphates discourage plants from supplying carbon sugar exudate to mycorrhiza, and increases metabolism of mycorrhizal biomes, speeding soil carbon loss (The contention is supported by biological pathways, limited research and observational evidence – farmers fully adopting regenerative techniques are making more money, and often seeing equivalent or improved yields)
- **Minimise use of agrochemicals and biocides** - most regenerative farmers report finding they do not need agrochemicals for pest and disease control, due to better crop health, and higher number of natural predators. Biocides kill the biology of the soil biome which is counter productive
- **Minimise use of herbicides through alternate crop termination**, including where feasible 'destructive grazing', albeit some whilst transitioning do use herbicides, and particularly in higher latitudes, where cover crops preceding a cash crop, may not be sufficiently mature to effectively crimp roll. There are negative environmental and financial costs to using herbicides, and conversely a financial

premium for organic crops.

- **Avoid use of ivermectin or similar** as worming agents as their presence in livestock faeces kill soil insects including dung beetles; reports suggest cattle fed using half height mob-grazing with daily or more frequent moves to fresh pastures, are less susceptible to gut infestations, and farmers find they do not need to use deworming agents.
- **Diversity at every level is key** - multi species / multi-function including of root depth and type, intercropping / cover crops, (Jenna studies as explained by Christine Jones) and / or improved soil biology using compost, and extracts, **will sufficiently supplement nitrogen to remove need for artificial application**, even for nitrogen demanding crops such as corn, as well as improving soil etc.
- **No bare ground - keep land green and growing, or at least covered all year, to optimise photosynthetic capacity**, using: perennials (Ingham, Haggerty); multispecies (more than 6-8) cover crops (Jones, Brown) (cover crops may sequester carbon faster than perennials, but perennials are in ground longer) (or a mix thereof); optimising photosynthetic carbon dioxide conversion capacity / incident energy optimisation, maintaining soil biology; protecting soils from high temperatures, wind and water erosion; hugely improving rain permeability and retention; increasing metabolic water production, and controlling soil transpiration.
 - **Use minimum disturbance planting techniques**, including planting into living cover crops which are roller crimped some days after - no or minimal soil disturbance - horizontal slicing and turning of soils, kills biology, and inverts and severs water transport pathways.
 - **Coat seeds with compost extract inoculant, and or use soil inoculants and foliar spray, providing the seed, and you plant with immediate access to the biology necessary to form mycorrhizal fungal bacterial root sheath support systems – which in turn provide plants with accessible bacterial produced nitrogen, and microbiome mined minerals including phosphates.**
 - **Only graze to half height- 'mob grazing'** - more than 50% reduction of green matter may result in loss of root mass, as well as photosynthetic leaf area, which slows re-growth.
 - **Marine mineral sources** (also containing iodine) as foliar sprays or coating to seeds or tubers - e.g., seaweed and derivatives have been observed to be of benefit - it is believed the Haggerty compost extract seed treatment contains marine based products – logically, and based on limited observational evidence, the residue of sea salt production, low in sodium but high in magnesium with a wide range of micro-minerals, and if not desiccated - iodine, would make a useful foliar spray or additive to seed inoculants - a new potential industry? Seaweed based sprays were used with great success in the 1940s.
 - **Return to land appropriately composted aerobic organic matter where available.**
 - **Slurries and sludges should be NOT used** as rich in available phosphates and nitrates leading to run-off, and may contain a wide range of pollutants including heavy metals, microplastics, including pharmaceutical residues.
 - Anaerobic sludge may supply unhelpful soil biology – more research required
 - Care is needed in composting of agricultural and domestic waste as some biocides are persistent and may inhibit germination.

- **Optimise soil mycorrhizal biome quantity health and diversity.**
- **Farmers report whilst regenerative agriculture can be successfully implemented, is more profitable, sustainable and satisfying, it does require a flexible mind-set, an information support network, and more so as it is an emerging skill set, thus farmers should proceed with means appropriate caution.**

Regenerative agriculture often results in:

- equivalent or better yields,
- better crop nutrient, mineral and protein content,
- more nutritious feed stock,
- better prices for better nutrient quality crops,
- carbon sequestration,
- greater metabolic water production capacity so drought resistance,
- increased diversity of soil biology, and plant variety use, so wider biodiversity,
- better water percolation retention so drought resistance,
- changed improved local hydrology and microclimate,
- reduced flooding, thus downstream damage, as well as earlier post rain field access,
- reduced water run-off land erosion,
- reduced nitrification eutrophication of water ways and oceans,
- plant emission of bacteria that form nuclei for water drops, thus clouds and rain,
- reduced pollution by agrochemicals, and consequent negative impact on diversity,
- greatly reduced agrochemical input costs,
- better livestock health and reduced veterinary costs,
- greater profits for farmers,
- protected soil surfaces,
- reduction in soil 'albedo', thus diminished heat re-radiation / heat domes etc.,
- more stable soil temperatures,
- increased air moisture thus cooling,
- slower but sustained soil moisture respiration so reduced risk of fire in dry seasons,
- likely positive climate mitigation,
- regeneration of dry degraded landscapes,
- more interest in new generations taking on family farms,
- and generally greater sustainability.

Suggestion

- ❖ De-risk farmers to try techniques outlined in the links below -
- ❖ Measure - prior to; during; and post study -
- o Fertiliser and agrochemical use pre and post transition;
 - o Initial total soil mineral levels (soluble and bound), to ensure not insufficient in phosphates, selenium, sulphur, boron, iodine etc;
- o Initial soil carbon at various depths;
- o Water retention;
- o Historic and new yields and crop mineral and protein content;
- o Soil diversity - observation and photographic recording, though to full assays and DNA

profiling, depending on usage resources and purpose.

- ❖ For those using mixed farming also keep data on -
 - o cattle health and related costs;
 - o milk yields and composition;
 - o land carrying capacity;
 - o birth rates etc.

❖ Using the steps below economic conversion to regenerative agricultural principles may not take that long - some see benefit in a year, others suggest 2-3 years - but clearly times will vary. Practical application, observation and recording of outcomes, prior education, prudence, and working within means and capacity is prudent – not all transitioning to regenerative agriculture find an optimal road. Clearly soil will continue to improve over longer time frames.

If techniques make farmers and the food industry more appreciated by the public, with more stable sustainable profits, the science will follow. We must respect nature, optimising plant yields, nutrient value, and health, by working with nature, thus ensuring sustainability, because the agricultural food chain is now so large it forms part of the earth's carbon oxygen partition regulatory systems.

● General Background videos

A mixed basket of videos by experts giving both an overview, and some gritty reality, to try and underline regenerative agriculture is capable of feeding the world, improving; plant health, nutritional value and yield; as well as making money, and helping mend and sustain the planet, but there are potential pitfalls on the path to a more sustainable profitable future.

UNFAO Soil Organic Carbon - the treasure beneath our feet

<https://www.youtube.com/watch?v=Ymy0IO7nizw>

UNFAO Soils: Our ally against climate change

https://www.youtube.com/watch?v=8_69vy7ZBxE

UNFAO Soils: a hidden resource

<https://www.youtube.com/watch?v=YdBpLfhuZuk>

UNFAO Soil Organic Carbon – the treasure beneath our feet

<https://www.youtube.com/watch?v=Ymy0IO7nizw>

UNFAO Honduras Quesungual System

<https://www.youtube.com/watch?v=7kHEmcex3sA>

Plant Health Cure BV The long term effect of chemical fertilizers on soil health

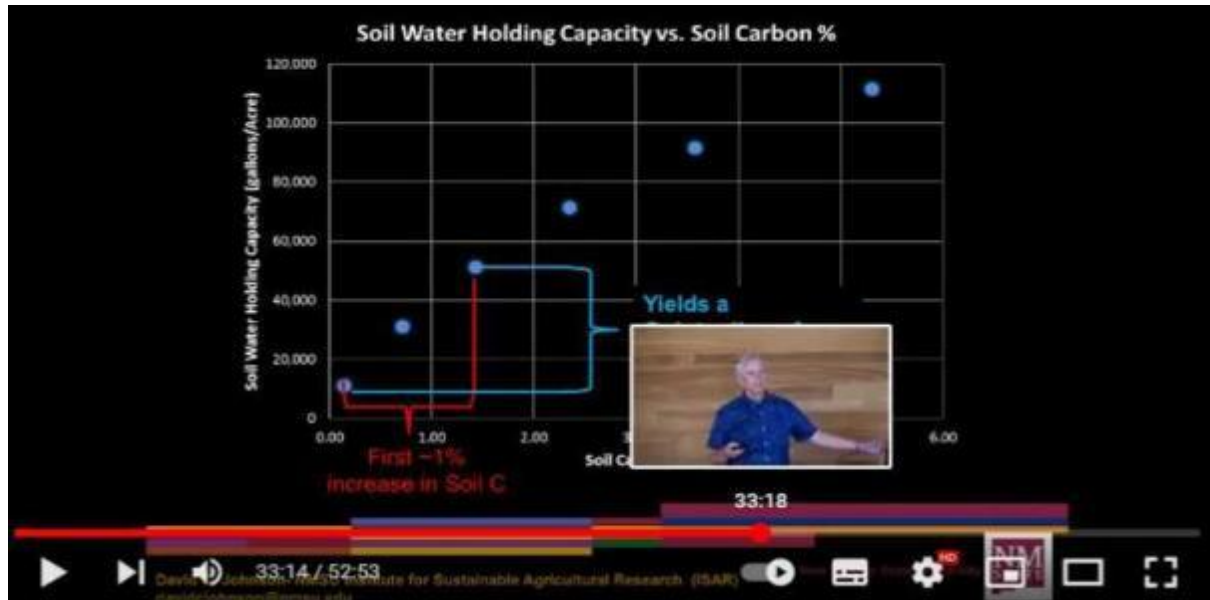
<https://www.youtube.com/watch?v=YMW2uLumAQw>

The Magic of Soil –

A helpful overview

<https://www.youtube.com/watch?v=AWILIYSf5ts>

Soil Carbon and water retention



Soil carbon and water retention capacity - SOLUTIONS BENEATH OUR FEET - David C Johnson's presentation part 1 <https://www.youtube.com/watch?v=XIB4QSEMzdg&t=1s> (see below)

Regenerative rice farming using cover crops, crimp rolling and low till planting – yields health and resilience increasing substantially, with improvements even in the first year

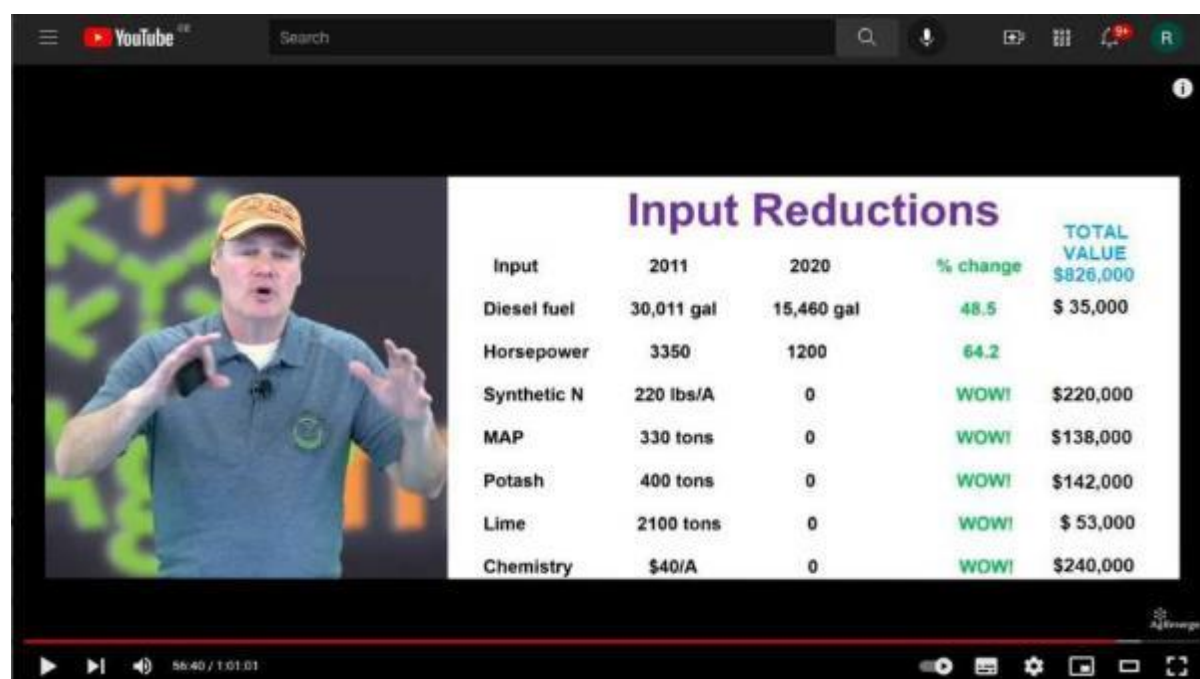
<https://www.youtube.com/watch?v=94B-mJqNQHY>



'Ecosystem restoration Ethiopia', John D Liu (2013), with many thanks to the author. A regeneration perspective - a succinct summation of the importance of natural biology in mitigating climate change - <https://www.youtube.com/watch?v=8f8Yqgj-TXg> - See further links below

The long-term effect of chemical fertilizers on soil health - Plant Health Cure BV
<https://www.youtube.com/watch?v=YMW2uLumAQw>

No-till on the Plains - Ray Archuleta
<https://www.youtube.com/watch?v=rLHZNNd0pAc>



Carbonomics - AgEmerge Breakout Session with Keith Berns - an allegory of soil carbon as an economy - concise and thought provoking <https://www.youtube.com/watch?v=sFowLIYjRCI>

Adaptive Grazing Webinar; West-Central Forage - Hjertaas, B.
<https://www.youtube.com/watch?v=vn8KC3EdWUY>

Farmers making money in real life with Reg Gen Ag - practicalities - 2021 AgEmerge Breakout Session with Rick Clarke (slides amalgamated to include financial values).
<https://www.youtube.com/watch?v=c9sm7I86hfA>

Regenerative Agriculture Healing the World - and ex NPK proponent who worked as USDA - impassioned - a wider overview - By Ray Archuleta @ Carbon Summit
<https://www.youtube.com/watch?v=QNW0ZN0XCpg>

Dr David Johnson - microbial scientist - excellent overview - a soil inoculation perspective
https://www.youtube.com/watch?v=aGjIt6e_ggQ

David Brandt, Dan DeSutter, David Kleinschmidt hosted by Gabe Brown - talk and Q and A Take it to the bank Increasing profitability in a corn soy rotation -useful practical background
<https://www.youtube.com/watch?v=loyvVaqoK0>

Gabe Brown - Senator Heinz Award - Working With Nature Regenerative Farming, Living Soil and the

Future of Our Food - "As the winner of the 2021 Heinz Award for the Environment, SHA and UA co-founder, Gabe Brown, has used the honor to introduce even more consumers and policy makers to the hope in healthy soil." <https://www.youtube.com/watch?v=XPfNWeM7W4>

Can Regenerative Agriculture Reverse Climate Change and Chronic Disease? Dr Mark Hyman talks to Dr A Williams

<https://www.youtube.com/watch?v=pEmnPmttoSo>

Natural sequence farming: How Peter Andrews rejuvenates drought-struck land | Australian Story - An inspiring example of land regeneration and improving hydrology

<https://www.youtube.com/watch?v=-4OBcRHX1Bc>

Economics of Soil Health on 100 Farms – Soil Health Institute – Funded by Cargill

<https://www.youtube.com/watch?v=qaQCRPVj4EQ&list=PLdFVkeklZuqwrwDzTGIQSnTtCsOI8W3>

Agriculture - Gabe Brown - No till on the plains - Iowa - Regenerative farmer with a focus on profitability

<https://www.youtube.com/watch?v=uUmlDq0D6-A>

Treating the Farm as an Ecosystem with Gabe Brown Part 1, The 5 Tenets of Soil Health

<https://www.youtube.com/watch?v=RARFGkX3HBI>

Treating the Farm as an Ecosystem Part 2 with Russell Hedrick

<https://www.youtube.com/watch?v=yAKRjgWsPXE>

Gabe Brown - Midwest Soil Health Summit 2021

Christine Jones - Australian agronomist

<https://www.youtube.com/watch?v=EX6eoxxoWKL>

Fireside Chat with Dr. Christine Jones and Ray Archuleta

<https://www.youtube.com/watch?v=EX6eoxxoWKL>

Profit, Productivity, and NPK with Dr Christine Jones

<https://www.youtube.com/watch?v=Xtd2vrXadJ4GB>

"Secrets of the Soil Sociobiome" - Dr. Christine Jones

<https://www.youtube.com/watch?v=dr0y EEKO9o>

Dr. Christine Jones - "The Nitrogen Solution"

<https://www.youtube.com/watch?v=ISjbVxTyF3w>

Dr Christine Jones - "The Phosphorus Paradox"

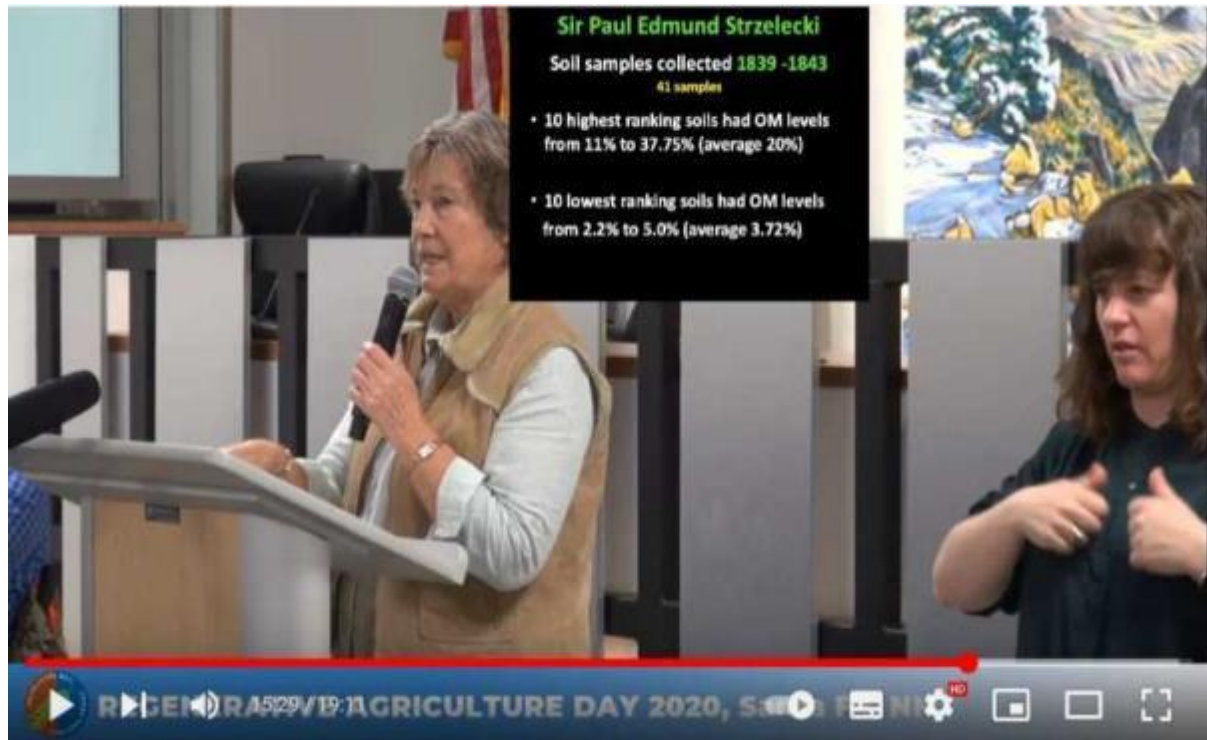
<https://www.youtube.com/watch?v=rIXqmksTUQQ>

Christine Jones -- Nitrogen: The double-edged sword

<https://www.youtube.com/watch?v=2xZ7nfC7BQk>

<https://www.youtube.com/watch?v=IP1juBfZS9E>

Dr. Christine Jones: Soil health and water security (DATA 1830 Australian Soils from Kew highest organic matter 11-37.5%!)



Christine Jones -- Soil Carbon: From microbes to mitigation

<https://www.youtube.com/watch?v=C3wGp1mLM>

Dr. Christine Jones - Building New Topsoil Through The Liquid Carbon Pathway

<https://www.youtube.com/watch?v=K8i1EzR5U8&t=247s>

Dr. Christine Jones - Quorum Sensing In The Soil Microbiome

<https://www.amazingcarbon.com/>

Christine Jones web site with multiple documents

Haggerty - wheat growers Australia

Di and Ian Haggerty of Prospect Pastoral farm approx. 30,000ha in the wheatbelt Western Australia, with about 11 inches of rain and sandy light soils, salt issues etc, using their own regenerative farming practices they call Natural Intelligence Farming. They reportedly achieve equivalent yields, better mineral and protein content, soil carbon sequestration, better drought resistance, and are recovering salinized land. A number of videos about them including:

<https://www.youtube.com/watch?v=GsfXC29w>

Dianne Haggerty & Stuart McAlpine - Leading innovators in the WA farming landscape

<https://www.youtube.com/watch?v=m8fTJdSr61o>



Haggerty treated seed at 36 hours compared to neighbours at 60 hours

Image below - *Mycorrhizal sheath on wheat seedlings*. Image from '*Quorum Sensing In The Soil Microbiome (Understanding The Role Of Soil Microbial Interactions For Soil Health)*' (Jones, 2019b), presented at the 2019 Conservation Tillage and Technology Conference, March 5 - 6, 2019, Ada, Ohio, US. With many thanks to the author.



<https://www.google.com/search?client=firefox-b-d&q=haggerty+wheat+australia>

Did you remember the roots?

- **Dr. Elaine Ingham - explaining soil biology in 'non-specialist friendly language**

How important are roots to plants?

Weeds — only 20% of the energy fixed into roots

Grasses 60% of their energy goes

Vegetables up to 75% into the roots

Proportion of exudate into roots - indication by species - Dr Elaine Ingham - From 'How to Build Great Soil Part 1' - for link see below videos by Dr Ingham below - different speakers present different perspectives - Dr Ingham includes information as to the roles of wider soil life over and above bacteria and fungi, and also focuses a lot on differences between aerobic and anaerobic soils, and the importance of soil biology - others focus more on cover crops and not leaving soil bare - combining different expert perspectives provides a more rounded understanding of the issues, to which can be added scientific papers and research.

<https://www.youtube.com/watch?v=ErMHR6Mc4Bk>

How to Build Great Soil - A Soil Science Masterclass with Dr. Elaine Ingham (Part 1 of 4) (Parts 2 and 3 are more specialist looking at bacteria etc and included below)

<https://www.youtube.com/watch?v=GTdTxX qKnk>

How to Build Great Soil - A Soil Science Masterclass with Dr. Elaine Ingham (Part 4 of 4) (including examples on yield improvements on real farms, and discussion of compost)

Introduction to Soil Microbes - Dr David Johnson

The BEAM Approach

<https://www.youtube.com/watch?v=79qpP0m7SaY&t=10s> Dr Johnson focuses on the importance of soil microbiology, and the role of carbon in water retention:

https://www.youtube.com/watch?v=34gvBb3gP0E&feature=emb_logo

- Soil loss rate degradation
- Evolution of soil biome - relevance to carbon capture
- Interconnection of biome
- Relevance of human biome
- Nutrient acquisition and pathogen protection
- Fungal bacterial balance

The microbes Role in Soil Carbon Sequestration (there are other videos in this series)

<https://www.youtube.com/watch?v=4 lqj4ME01s>

The 'BEAM' 'Biologically Enhanced Agricultural Management' approach - Dr David Johnson

<https://www.youtube.com/watch?v=79qpP0m7SaY>

- Seed coating with compost extract thus providing the seed with immediate access to a nascent fungal and bacterial biome that will assist efficiently formation of mycorrhizal sheaths, thus assisting nutrient provision including minerals and nitrates . . . 'BEAM' system plus permanent cover:
 - o Improving soil biology to increase production
 - o 10.7 to 19 metric tons per hectare per year increased soil carbon o 5 tons above and 5 tons below ground organic matter in one year. Up to 10 tons ha carbon in initial years

The Johnson-Su composting bioreactor

https://www.youtube.com/watch?v=n_t7zOmmXN4

The Johnson Su Composting System & BEAM (Biologically Advanced Agricultural Management) 2022

https://www.youtube.com/watch?v=Muw42tFC4Ss&feature=emb_logo

Qualities of composts - optimising spore production - low pollution and smell - aerobic - reduction in saline dairy manure content due to uptake by biome (would this desalination be applicable to soils) - bacteria in communities have a much wider range of functions - spraying of range land improvements including return of species not seen for a long time using slurry sprays - use as seed inoculant microbial spores + minerals - milk and molasses mix for seed - use of sea salt ? glyphosate 1/50 kill aspergillus 1/100 kills half - users many improvements crops water etc -

<https://www.youtube.com/watch?v=XIB4QSEMzdg&t=1s>

SOLUTIONS BENEATH OUR FEET - David C Johnson's presentation part 1

<https://www.youtube.com/watch?v=djcxGnqXGIY>

SOLUTIONS BENEATH OUR FEET - Panel Discussion part 2

Dr. David Johnson & Hui-Chun Su

<https://www.youtube.com/watch?v=7q5zv1ovfj0>

Managing Soils for Soil Carbon Sequestration: Dr David Johnson on Engineering Microbiology

<https://www.youtube.com/watch?v=18FVVYKU9gs>

- Compost system - low water usage
- Fungal bacterial ratio
- 70% energy returned to soil
- Carbon capture transitional pricing

How do farmers make it happen, and what are the risks?

<https://www.youtube.com/watch?v=S1dAIdmOdkg>

The Carbon Cycle - Related videos on practicalities and commercial aspects of carbon projects - second level viewing unless carbon credit systems are of particular interest -

https://www.youtube.com/watch?time_continue=13&v=MSm4ypBBlp0&feature=emb_logo

What is a soil carbon project worth?

Ag Solutions Network - Keith Berns

'Carbonomics' 2020 AgEmerge Breakout Session with Keith Berns

<https://www.youtube.com/watch?v=sFowLIYjRCI>

Rick Clarke - Farming 7000 acres with no artificial inputs and making money

2021 AgEmerge Breakout Session with Rick Clarke

<https://www.youtube.com/watch?v=c9sm7l86hfA>

Rick Clarke Part 1 Introduction To Farming Green With Diverse Covers

<https://www.youtube.com/watch?v=Kdog8woEyKg>

Rick Clarke Part 2 A Regenerative Organic Approach

<https://www.youtube.com/watch?v=8GwxevUEwTQ>

Rick Clarke Part 3 The Economics

<https://www.youtube.com/watch?v=8031RDYKpco>

The Roots of Your Profits - Dr Elaine Ingham, Soil Microbiologist, Founder of Soil Foodweb Inc

A powerful overview a slightly different perspective on the above interspersed with fascinating new insights and slide material

<https://www.youtube.com/watch?v=x2H60ritjag>

The Roots of Your Profits - Dr Elaine Ingham, Soil Microbiologist, Founder of Soil Foodweb Inc

<https://drive.google.com/fileZd/0B6tV3TorfmstbXlIUU5yMXB2MWM/view>

Life in the soil - presentation

<https://www.youtube.com/watch?v=xzthQyMaQaQ>

Building Soil Health for Healthy Plants by soil scientist Dr. Elaine Ingham

<https://www.youtube.com/watch?v=N 2i9AUGmmg>

How to Build Great Soil - A Soil Science Masterclass with Dr. Elaine Ingham (Part 2 of 4)

<https://www.youtube.com/watch?v=tXVL4zSXbM>

How to Build Great Soil - A Soil Science Masterclass with Dr. Elaine Ingham (Part 3 of 4)

http://ecologiesurleweb.free.fr/docs/Docs_agir/Lombricomposteur/Brew%20Manual%20compost%20tea.pdf

The Compost Tea Brewing Manual - Free PDF

An overview by a former Govt Advisor and farmer Ray Archuleta

<https://www.youtube.com/watch?v=Fwv-HJnGHMA>

PhD Presenting at Nobel Conference - Soil Scientist formerly worked for USDA

- **Rice farming**

Regenerative rice farming – Walt Meister - using cover crops, crimp rolling and low till planting – yields health and resilience increasing substantially, with improvements even in the first year – been seen and adopted by adjacent farmers – more profitable as well as easier

<https://www.youtube.com/watch?v=94B-mJqNQHY>

COMPLEX ADAPTIVE RICE CULTIVATION – <https://www.renature.co/articles/mixed-farming-increase-rice-yield/> using ducks chickens to clear weeds between rows of rice,, fish in irrigation water to provide nutrients, nitrogen fixers planter on banks between fields – better resilience and high yields using no artificial inputs

<https://www.youtube.com/watch?v=gAe65rwU26s>

Beyond the rice grain. How rice farmers are repositioning to sustainably grow rice. – East Africa - sustainable rice cultivation, inter/rotational cropping with leguminous species and management of crop waste streams in line with sustainable agriculture and reducing green house gas emissions from rice farming.

<https://www.youtube.com/watch?v=-Fh7rotYHwo>

SRI Introduction: The spread of SRI in East Africa

<https://www.youtube.com/watch?v=J3N4qrhADQo>

<https://farmingfirst.org/2015/03/olam-prize-shortlist-the-story-behind-the-science-of-sri-rice/>

Quadrupled yields with no artificial inputs – yields increased from 2 to 4-6 tonnes per hectare using local seed

SRI Training

SRI Training 1: Seed germination & nursery preparation

https://www.youtube.com/watch?v=v9sqOm_NtF0

SRI Training 2: Field preparation & transplanting

<https://www.youtube.com/watch?v=rjatdzbppZc>

SRI Training 3: Weeding & water management

<https://www.youtube.com/watch?v=xYzeZ7qiwLE>

SRI Training 4: A new stick gives you blisters

https://www.youtube.com/watch?v=6A4z2W_7peU



Two rice plants of same variety held by Cuban farmer Luis Romero. The plant on right was removed when 9 days old and transplanted into an SRI growing environment, with wide spacing, no continuous flooding of the field, and organic matter enrichment.

List of research papers from Cornell – SRI v Conventional rice production

http://sri.ciifad.cornell.edu/conferences/IRC2014/booth/SRI_published_research_handout_2014.pdf

Rodale Institute

<https://www.youtube.com/watch?v=HuRpEA1sFow>

Can Regenerative Agriculture Reverse Climate Change? | One Small Step

A simple video for the general public, providing evidence that regenerative agriculture can match NPK yields, encouraging people to buy regenerative certified products

Optimising natural nitrogen in soils

Interesting discussion on optimisation of nitrogen in soils using cover crops. There are a variety of views, and these offer further thought-provoking material

Go Deep, Go Early - Effective Cover Cropping for Nitrogen Capture

<https://www.youtube.com/watch?v=yCXoh7BqxNw>

GREAT soils short term green manure strategies for intensive growers

<https://www.youtube.com/watch?v=PZ6cGBQjF8c>

Q and Answer

Q&A with Understanding Ag Team 7-1-21

<https://www.youtube.com/watch?v=6Ubs9khA8hw>

- **Regen Ag and Climate - Walter Jehne - Healthy farm Australia**

A climate specialist - clear thinking - concise - interesting arguments - a very helpful overview (evolution and albedo is more complex than presented) - impact on hydrology on climate change - impact of soil carbon on 'climate change' avoidance of systemic aridification -

Water and weather

<https://www.youtube.com/watch?v=eiPDUDT9HjA>

"The Natural History of Water on Earth", 2015

<https://www.youtube.com/watch?v=K4ygdsHJjdl>

Regenerating the Soil Carbon Sponge

<https://www.youtube.com/watch?v=3nC6j80sLZo>

Walter Jehne: Regenerating the Soil Carbon Sponge

<https://www.youtube.com/watch?v=123y7jDdbfY>

"The Soil Carbon Sponge, Climate Solutions and Healthy Water Cycles". 2018

https://www.youtube.com/watch?time_continue=47&v=K4ygdsHJjdl&feature=emb_logo

Restoring Water Cycles to Naturally Cool Climates and Reverse Global Warming

Examples of recovery of degraded landscapes

Pastoralists - marginal land recovery - soil carbon sequestration and improved hydrology

<https://www.youtube.com/watch?v=vpTHi7O66pl>

How to green the world's deserts and reverse climate change = Allan Savory

<https://www.youtube.com/watch?v=WUMQVqtjUAQ>

Can sheep save the planet? Yes - says Allan Savory!

Ethiopia

<https://www.youtube.com/watch?v=mbEM6DCTK3Y&t=2s>

Agroecology in Ethiopia: Converting Desert into Hyper-Productive Land

China

<https://www.youtube.com/watch?v=3RqsUD6fyGk>

Two generations spent 55 years building world's largest man-made forest in Saihanba, N. China

<https://www.youtube.com/watch?v=8QUSIJ80n50>

Lessons of the Loess Plateau

<https://www.youtube.com/watch?v=wwDNemiLE9k>

Ecosystem Based Adaptation, - by, John D. Liu, FULL VIDEO, The Great Work Of Our Time

Australia

<https://www.youtube.com/watch?v=-4OBcRHX1Bc>

Natural sequence farming: How Peter Andrews rejuvenates drought-struck land | Australian Story

<https://www.youtube.com/watch?v=V6m-XIPnqxl>

Changing Paradigms | Regenerative Agriculture: a Solution to our Global Crisis? | Full Documentary

India

<https://www.youtube.com/watch?v=LOEWM6XzWGo>

NREGA-MP--Watershed Development

<https://www.youtube.com/watch?v=OTSGF1KQ1UQ>

The Water Cup 2018 Journey (Hindi) | Paani Foundation

<https://www.youtube.com/watch?v=-8nqnOcoLqE>

India's Water Revolution #1: Solving the Crisis in 45 days with the Paani Foundation

<https://www.youtube.com/watch?v=jDMnbeW3F8A>

India's Water Revolution #2: The Biggest Permaculture Project on Earth! with the Paani Foundation

<https://www.youtube.com/watch?v=KhoV-vBAyFI>

India's Water Revolution #4: Permaculture for Wastelands at Aranya Farm - there are more examples

Africa

<https://www.youtube.com/watch?v=WxXy9IsiUPM> - Uganda's New Forests

Cattle - 'Soil Carbon Cowboys'

<https://www.youtube.com/watch?v=MDoUDLbg8tg>

Soil carbon cowboys

<https://www.youtube.com/watch?v=EBTINtTcBbE>

Herd impact

<https://www.youtube.com/watch?v=wXlwUfuu9A>

A fence and an owner

Fungi role in evolution and capacity for remediation

<https://www.youtube.com/watch?v=XI5frPV58tY>

6 ways mushrooms can save the world | Paul Stamets

Somewhat random but very thought provoking and again highlighting the often as yet understood roles of soil fungi, including in possible remediation of residual pollutants in compost

Fungi - The complexity of the environment

<https://www.youtube.com/watch?v=KYunPJQWZ1o>

Stephen Axford: How fungi changed my view of the world - Amazing photos of fruiting fungi - set within the perspective of an ex-computer programmer as to the complexity of the environment.

What is regenerative agriculture

<https://www.youtube.com/watch?v=rllu71l-YE>

Charles Massy - What is Regenerative Agriculture and why do we need it?

Further videos added 01 Nov 2022

2021 AgEmerge Breakout Session with Rick Clarke

<https://www.youtube.com/watch?v=c9sm7I86hfA>

Carbonomics - AgEmerge Breakout Session with Keith Berns – an allegory of soil carbon as an economy – concise and thought provoking <https://www.youtube.com/watch?v=sFowLIYjRCI>

Regenerative Agriculture Healing The World – and ex NPK proponent who worked as USDA – impassioned – a wider overview - By Ray Archuleta @ Carbon Summit
<https://www.youtube.com/watch?v=QNW0ZN0XCpg>

Dr David Johnson – microbial scientist – excellent overview – a soil inoculation perspective
https://www.youtube.com/watch?v=aGjIt6e_ggQ

David Brandt, Dan DeSutter, David Kleinschmidt hosted by Gabe Brown – talk and Q and A Take it to the bank Increasing profitability in a corn soy rotation -useful practical background
https://www.youtube.com/watch?v=loyvV_aqoK0

Gabe Brown – Senator Heinz Award - Working With Nature Regenerative Farming, Living Soil and the Future of Our Food – *“As the winner of the 2021 Heinz Award for the Environment, SHA and UA co-founder, Gabe Brown, has used the honor to introduce even more consumers and policy makers to the hope in healthy soil.”* <https://www.youtube.com/watch?v=XPfNWeM7W4>

Can Regenerative Agriculture Reverse Climate Change and Chronic Disease? Dr Mark Hyman talks to Dr A Williams <https://www.youtube.com/watch?v=pEmnPmttoSo>

Natural sequence farming: How Peter Andrews rejuvenates drought-struck land | Australian Story – An inspiring example of land regeneration and improving hydrology
<https://www.youtube.com/watch?v=-4OBcRHX1Bc>

<https://www.youtube.com/watch?v=c05v2VaXv7U>

Building Resiliency: Farm and Ranch Profitability with Burke Teichert 12-1-21

Dr David Johnson – the Beam approach
<https://www.youtube.com/watch?v=wpF4b54l2T4> David Brandt Webinar

From Dirt to Soil: The Guys Get To Know Gabe Brown
<https://www.youtube.com/watch?v=q2aRtKNA7GE>

Adaptive Grazing Webinar: Gabe Brown
https://www.youtube.com/watch?v=ILnVNr0_rbg

Living Soil Film Soil Health Institute
<https://www.youtube.com/watch?v=ntJouJhLM48>

The Soil Solution to Climate Change Film - SustainableWorld
<https://www.youtube.com/watch?v=BxiXJnZraxk>

Changing Paradigms | Regenerative Agriculture: a Solution to our Global Crisis? | Full Documentary
<https://www.youtube.com/watch?v=V6m-XlPnqxl>
(‘Probe: Pharmaceuticals In Drinking Water’, CBS News, n.d.),