Vol 2 Eco-Degradation or Regeneration The Climate Crucial Role of Regenerative Agriculture. 23-03-23

Preprint · March 2023

DOI: 10.13140/RG.2.2.18213.17120

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‘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”

PREPRINT.

BY ROBERT ANDREW BROWN – MCCARRISON SOCIETY.

FIRST SHARED DRAFT - AT COP27 - 12 NOVEMBER 2022. SECOND SHARED 9TH DECEMBER. THE BOOK IS NOW MORE OR LESS HOPEFULLY IN FINAL FORM, AND BEING SHARED AS A PREPRINT TO, IF FELT RELEVANT, ASSIST AND INFORM, RELATED POLICY FORMATION, DUE TO THE ARGUABLE URGENCY OF THESE ISSUES, AND TIME IT CAN TAKE TO ACHIEVE PUBLICATION.

THE AIM OF THE VOLUMES IN THEIR CURRENT FORM IS EDUCATIONAL, RATHER THAN PUBLICATION FOR PROFIT. OFFERS OF PUBLICATION WOULD BE WELCOMED.

THE AUTHOR HAS NO CONFLICTS OF INTEREST, AND IN NO WAY REPRESENTS OR WORKS FOR ANY OF THOSE PARTIES CITED, WHO HAVE COMMERCIAL INTERESTS. THE BOOK HAS BEEN ENTIRELY SELF FUNDED. THE OTHER VOLUMES ARE LARGELY WRITTEN AND WILL FOLLOW.

PLEASE EXCUSE TYPOGRAPHICAL ERRORS ETC. YES, ALWAYS ROOM FOR IMPROVEMENT BUT NOT ENOUGH HOURS OR LIFE YEARS; COMMENTS AND CORRECTIONS ARE WELCOMED

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AN OVERVIEW

This set of books is by its nature an overview. It will comprise three volumes, respectively considering 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, and much time, to write.

- SEWAGE Volume 1 – current Victorian technologies for collection and remediation of human and animal sewage are both, wasteful, and polluting, thus unsustainable at many levels. Resources including; carbon, phosphates, minerals and water are wasted. We continue to strive to install ever greater numbers of, water demanding, intensive, wasteful and polluting, 'flush and forget' WC sewage systems, with inadequate, and often no, water treatment, often primarily for the convenience of the better off. By doing so, we are introducing huge quantities of pharmaceuticals, and other pollutants including microplastics, into the oceans and wider environment with unforeseeable consequences; including on human development in utero, and intellect, as well as for wider life-time individual health. By mixing faeces and urine into the wider waste stream, we make their adequate treatment and recycling almost impossible. There are potential solutions such as vacuum WC systems, separation and treatment of grey water, as well as reduction of micro-plastic emissions with washing machine filters. Current treatment technologies are very inefficient, failing to remediate many toxic pollutants including pharmaceuticals; spreading antibiotic resistance; as well as a range of pollutants; and damage human, livestock and plant health. Agricultural sewage is also massively wasteful and polluting. Sewage pollution causes eutrophication and deoxygenation of waterways and oceans, damage to soils and the wider environment. Untreated discharge causes even greater environmental and health damage. This volume considers alternative potential strategies, including vacuum WC technology, and hyperthermophilic composting, for integrating sewage into a circular sustainable economy.

- REGENERATIVE AGRICULTURE Volume 2 – soil carbon storage, through the synergistic interaction between plants and the soil biome, is part of the evolved planetary regulatory ecosystem for partition of oxygen and carbon dioxide, between; the atmosphere, oceans, soil, and living organisms. 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, terrestrial soil based, and oceanic, photosynthetic organisms, and their wider bacterial and fungal symbionts, are central obligate 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; production of the complex carbon-dioxide derived, carbon-based organic molecules that underlie our very existence; incorporation of mineral elements; and other processes and resources absolutely central to and underlying most terrestrial life, and all 'sophisticated' life. We humans, by taking agricultural control of billions of hectares of formerly natural green spaces and related eco-services, have substituted ourselves for crucial aspects of the evolved Gaian system, without understanding the implications and consequent responsibilities, this places upon us. The '**F**ertiliser-**A**grochemical-**T**illage-**B**are-soil-**A**gricultural-**S**ystem' hereinafter (FATBAS), takes no account of the obligate need for maintenance of planetary ecosystem health, including the central necessity to optimise the photosynthetic light energy capture potential of plants, by maximising soil carbon and life in the soil biome, which is essential to plant health and productivity, thus life itself. Incident sunlight energy, that powers the planetary ecosystem through plants, is ultimately a finite resource, which can build life, or destroy it by heating bare soils. Fertiliser-agrochemical-tillage bare-soil, based farming, FATBAS, by failing to recognise the role of soils and plants as essential parts of our planetary ecosystem, is unthinkingly inevitably damaging soil biology and health, reducing; soil carbon, water infiltration-penetration and storage, increasing; flooding and erosion, drying crusting and heating of bare soils; killing biology; adding energy to atmospheric heat domes, contributing to drought, degrading regional hydrology, and more widely contributing to and accelerating, the planetary ecosystem service degradation we call 'climate change'. Further, FATBAS fertiliser-and-agrochemical-based farming, contributes to pollution including eutrophication, thus river and ocean deoxygenation, ultimately adding to risk of ocean sulphidication and major Anthropocene extinction event. FATBAS, also, reduces the nutritional value of food, contributing to human and livestock ill-health, and degraded human intellect, empathy, co-operation and behaviour, which if unaddressed, will ultimately lead to species devolution, further increasing risk of Anthropocene self-extinction.

- WATER AND HEALTH Volume 3 – '*Water is life*', as Bedouin appositely observe, yet we are, at pace, polluting; rivers, aquifers, and oceans, globally. Through FATBAS we compact and crust our soils, destroying soil life that otherwise ceaselessly burrows through, mixes and aerates vast volumes of soil, collectively massively reducing rain infiltration rates, from eleven and more inches an hour, to, often less than one inch an hour; in consequence rain is not recharging water tables, increasing risk of water shortages and drought. The unwarranted run-off causes; flooding, erosion, and related downstream damage, as well as ocean eutrophication. Through FATBAS we are drying our climate, increasing the risk of heat domes and fires, reducing inland ocean airflow current derived rainfall, yet at the same time, through temperature increases, and consequent augmented moisture holding capacity of air, the magnitude of rainfall events. We allow large scale industrial and wider, including sewage, pollution, of rivers, water bodies aquifers and oceans. Reduced ground water means, to grow crops, we are forced; to draw down natural 'fossil water', depleting aquifers, and to use polluted urban and sewage water for irrigation. Regenerative agriculture greatly improves water infiltration rates and regional hydrology, reduces need of pharmaceuticals for livestock, and allows natural distributions and dispersion of livestock urine and faeces. Sponge cities can capture water for reuse. 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 mind-set, to one that is 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 of carbon sequestration; reduction in wider environmental including marine pollution; better water management; flood avoidance, pollution minimisation, thus 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.

These issues at their heart have relatively simple achievable solutions; but which, due to their wider economic impact on existing industries, and the adaptation required, will require widespread public education and understanding; as well as government acceptance of the urgent need for change, and consequent major 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.

Hopefully, this review, a journey over many years through multiple interconnected issues, whilst of necessity only providing a brief dip into the many constituent topics, is sufficiently robust and well-referenced, bringing together adequate diverse interlinked threads, to provide, a thought-provoking, compelling, convincing overview and starting point. The author, and those who have assisted with editing, content and notes, do not have the life years required to become, and do not claim to be, specialists in the huge number of individual interlinking complex topics covered, but are published in related areas.

Thus, where material is clear, concise, and difficult to better, I have in italics and parentheses quoted with attribution and thanks, limited passages directly from sources, rather than trying to paraphrase, which risks; loss of clarity and accuracy, and failure to properly acknowledge the prescient contribution of others. For the same reasons, images of lecture slides have been used and credited where possible. To save confusion and space, references within quoted texts are generally removed; readers, where interested, are referred to the original texts and video lectures, for full context and cited references. The majority of quoted texts and video lectures, are free online, and linked in the bibliography.

Unattributed images are rights paid Adobe images, with thanks to them and the image authors. Other images have been attributed with thanks, on the basis this document is currently produced, at my own expense, for educational purposes on a not-for-profit basis. I sincerely apologise for any omissions or oversights.

I acknowledge, with huge thanks, those who have directly helped with; editing earlier versions, notes, structure, and comments; and more widely those that have researched, written, and lectured online, producing a diverse mass of excellent, reviews, articles, videos and reports, which are drawn on, and without which, this exercise would not have been possible. On the dietary, nutritional, and mental health side, I take the opportunity to commend and recognise the lifetimes of unceasing struggle, of Professor Michael Crawford, Simon House who sadly recently passed, and David E. Marsh, and those than preceded them, Including Sir Robert McCarrison, to educate and achieve change, including through the McCarrison Society, which hangs on by a thread.

Robert Brown. Dated 23-03-23.

REGENERATIVE AGRICULTURE – WHAT IS IT?

WHY AGRICULTURE IS A CLIMATE ISSUE OF FUNDAMENTAL IMPORTANCE

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; pathways, towards self-destruction or salvation. As sentient 'controllers' and consumers, the choices are ours.

The soil biome is an essential part of 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.

In what is the dawning of a new technological age, including AI and manipulation of DNA, we have by dint of fate, without fully realising it, taken on nascent responsibility as evolutionary controllers. Plant growth, and related soil biome function are part of earth's climate regulatory systems. We have ousted and taken on natures mantle, by taking agricultural control and responsibility for a huge proportion of the productive soil acreages of the world. Thus, we humans are now direct custodians and controllers responsible for terrestrial biological soil biome health, mass and diversity, upon which the Gaian ecosystem earth's biological function and health depends. It is within our power and choice, to destroy or support the soil biome, upon which the current Gaian climate regulatory system depends. The choice, responsibility to posterity, and the future of homo sapiens and many of the species we share earth with, is ours - to be or not to be? - that is the question.

We can continue to support current soil biome destructive; **F**ertiliser, **A**grochemical, **T**illage **B**are-ground, **A**gricultural **S**ystem 'FATBAS', or move to more sustainable regenerative agriculture practices, that have the capacity to sequester carbon, maintain soil diversity, reduce artificial inputs and the consequential pollution they cause; increase crop quality; improve: water infiltration-penetration and soil water content; drought resistance; regional and wider hydrology including mitigating flooding, and reduce temperatures. We have a choice whether to mitigate the risk of heat domes though reduction of bare ground, as well as improving regional and wider micro climates. These decisions, will ultimately decide if we will succeed or fail in significantly mitigating climate change including warming, and the consequent potential risks of system tipping points and extinction events, such as oceans becoming anoxic and sulphidic, with potential catastrophic hydrogen sulphide damage to the ozone layer.

Natures evolutionary ‘damage mitigation’ climate regulation systems, including carbon dioxide capture and sequestration into soil biomes, and related temperature regulation technology, is simple in principle yet immensely complex and sophisticated, free, proven, ‘oven-ready’. ‘Natures’ sophisticated technology, with simple cheap techniques, human will and determination, is easily widely implementable.

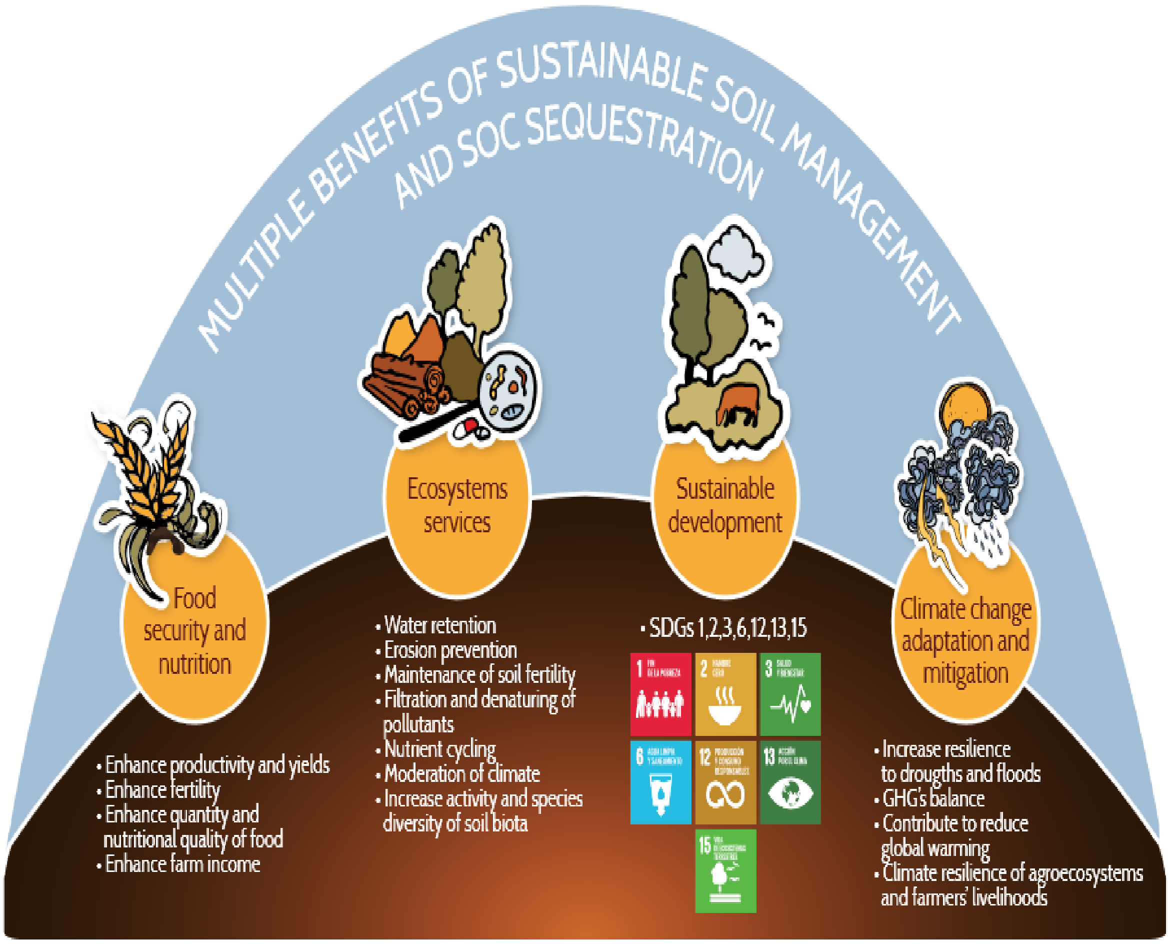


Figure 3. Multiple benefits provided by sustainable soil management practices based on SOC.

Fig. 1. 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.)

We have no other available technology that can begin to match the sophistication and interconnected synergies, that nature offers. Adopting a regenerative approach to our soils, may not fully mitigate the effects of carbon dioxide emitted from fossil fuel combustion, and may reduce in size of effect over time, but it can certainly help in a big way, and is logically essential, if climate mitigation is to be successfully implemented. Indeed, I believe in time, we will marvel at the extent of nature’s capacity, once harnessed, to help remediate many current climate issues.

Agriculture now covers a large amount of the earth's terrestrial surface, that was once occupied by natural year-round productive growing green ecological systems. We just do not think about FATBAS, fertiliser tillage agrochemical dependent bare-ground agriculture, significantly negatively impacting crucial terrestrial biosphere climate regulatory systems, including as a significant contributor of the greenhouse gases, carbon dioxide, nitrous oxide and methane.

In seeking, through global extensive non-sustainable FATBAS, to dominate, rather than work with nature, we have inadvertently broken part of the fundamental planetary climate and carbon Gaian regulatory system.

The carbon storing soil biome comprising, fungi, bacteria, and other life forms; in their dark underground world; in conjunction with their sunlight symbiotes, soil dependent photosynthetic carbon fixing plants; are together crucial and central components of the 'Gaian' regulatory system, which made, and makes, the earth habitable. The interaction of, the soil biome, plants, the atmosphere, oceans, and water cycling, significantly regulates the earth's biosphere, climate and ocean habitability. It also controls, and balances, the creation of oxygen and carbon dioxide, via photosynthetic splitting of carbon dioxide into oxygen and carbon, and thus the partition of carbon and oxygen, between, the earth's crust, atmosphere, oceans, soils, and life forms. Plants, using sunlight energy, make complex carbon molecules from air, which are the basis of life; beautiful simplicity made possible by enormous complexity.

These fundamental Gaian regulatory components of the terrestrial biosphere are inextricably interconnected and interdependent. The carbon energy sources that run the lightless soil biome, and allow creation of organic carbon containing molecules, are sunlight powered photosynthetic carbon sugars, produced by plants from the carbon dioxide in the atmosphere, and shared with the soil biome.

In their dark world, the subterranean denizens of the soil biome, are one way or other utterly dependent on plants for energy, in the form of their sugar exudate 'lunch'; and absent a sugar exudate 'lunch', are obliged to cannibalise themselves, and once they have eaten themselves out of existence, sadly must expire, leaving soils bereft of significant life or soil carbon.

Plants exchange photosynthetically fixed carbon, with the soil biome, for; minerals mined by soil biome, soil biome produced nitrates, and other support services, including provisions 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 negative human intervention, the soil biome, in conjunction with plants, provides feedback mechanisms, through carbon storage in soils, and carbon respiration, that respond to, thus eco-regulate atmospheric carbon dioxide and oxygen levels, and related climate factors including temperature.

Before human intervention, as atmospheric carbon dioxide rose due for example to fires or greater than usual volcanic activity, plant growth increased, accelerating return of the carbon in carbon-dioxide to soil and deeper carboniferous stores, and into ocean floor detritus ultimately subducted into magma, simultaneously reducing atmospheric and oceanic carbon-dioxide, and at the same time adding to, and regulating atmospheric and oceanic oxygen. 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, given fungi and mycorrhizal systems need plant delivered photosynthesis-derived energy to survive, in the absence of fresh carbon supplied through photosynthesis by growing plants, denizens of the soil biome are obliged to draw down on stored soil carbon to survive.

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.

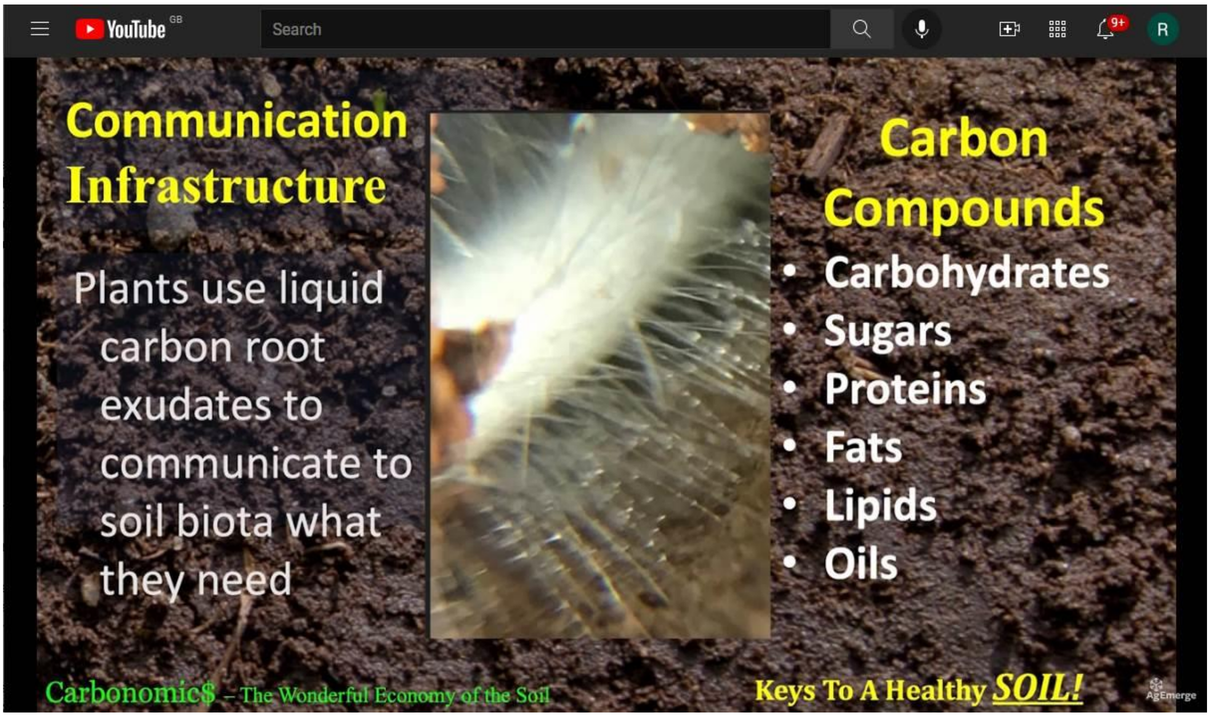


Fig. 2. Carbonomics - AgEmerge Breakout Session with Keith Berns – an allegory of soil carbon as an economy – a concise and thought-provoking presentation – photo of root exudates visible in a soil tubule made by a worm. Note the drops of exudate on the root hairs. With very many thanks to the authors. (Berns, 2020)

Soils in equilibrium seek to rid themselves of nitrate fertiliser not taken up by plants by metabolising it into nitrous oxide, which is a potent greenhouse gas. Methane, another greenhouse gas is released into the atmosphere through human activity, such as flaring, rice production and feedlot farming, which all can be reduced or improved.

Further in bare soils, exposed silicates absorb a proportion of incident visible and ultraviolet light, and retransmit their energy as infra-red, heating the atmosphere, at the same time desiccating and crusting soils, reducing the capacity of rain to infiltrate soils, and raising surface soil temperature sufficiently to kill their biology, together, reducing water tables, degrading regional climates, and facilitating flooding after heavy rain. Consequent heat radiation, moisture loss, and convection, contribute to heat domes, which in turn prevent circulation of ocean-derived moisture into the interior of land masses, creating drought fire and self-reinforcing heatwaves.

In contrast, green plant covered land, through photosynthesis, uses the energy in visible light to produce organic molecular matter, and evaporate water, rather than creating heat. Plants also use a variety of mechanisms to absorb UV and wider energy as part of that process. At the same time, both, growing plants, as part of their ‘energy producing’ respiration process, and living organisms in the soil, respire cooling water vapour, and cycle carbon dioxide, that will enter the atmosphere, water vapour returning at some point as rain. Some of that sunlight energy is captured in both the huge variety of soil-based life forms, and in complex carbon residue-molecules, carbon which, absent human intervention, is both, continuingly cycled in the form of life, and stored as residues, in soils, ocean depths, and the earth’s mantle.

It is of crucial and underappreciated importance, that plants, soil bacteria and fungi, like humans, produce water as part of the process of turning stored photosynthetically produced carbon sugars, into energy. Leave a sealed bag of celery in the fridge for a few months, and bacterial respiration, will leave you with a bag of water, containing dissolved minerals and organic matter; but if not adequately sealed, will result in a very messy fridge!

We often forget, not only is a large portion of what makes up living things water, but as above, that in the chemical process of producing energy from oxygen and carbon by breaking down organic molecules, water and carbon dioxide is produced. Thus, the greater the organic content of soils, the greater the amount of water present; as stored water suspended in interstices, in gels, as water incorporated into living structures, and as organic carbon molecules that can be respired to make water. Thus, the water retention capacity of soils is largely proportional to their organic carbon content.

In terms of environmental change, we generally currently are focusing in large part on carbon dioxide. Whilst focus on atmospheric carbon dioxide is important, we also need to keep oxygen in view. Photosynthesising plants split carbon dioxide releasing oxygen, and making carbon molecules. The atmosphere exchanges oxygen and carbon dioxide with the ocean, based on gas / liquid exchange laws. Fossil fuel combustion, as well as producing carbon dioxide, utilises atmospheric oxygen. Arguably and logically, the impact of reduction of oxygen in the atmosphere, 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 million GT) (Brown R., 2021e).

The decrease in atmospheric oxygen (Maybe say 40GT per annum, albeit only a tiny proportion of atmospheric oxygen, may represent as much as one percent – a significant amount - of the oxygen in the upper ocean layers) will logically ultimately lead to reduced oceanic oxygen, facilitated by the tendency for movement of 'excess' dissolved gases to the surface of liquids, and obliged by the immovable physical laws of gas exchange. Thus, logically, consequent on the laws of gas exchange, an oxygen loss, due to fossil fuel combustion, that is insignificant in terms of the total amount in the atmosphere, will nonetheless, ultimately over time, lead to oceanic oxygen depletion, that is significant in terms of total oceanic oxygen content, and more so in relation to oxygenation of the upper layers of the ocean. This process may explain, at least in part, the significant but unaccounted for observed depletion in oceanic oxygen (Brown R., 2021e).

Conversely, there is much more carbon dioxide in the ocean than atmosphere, because carbon dioxide is much more easily dissolved in the oceans than oxygen. Thus, increased atmospheric carbon dioxide, will by the same principles of gas exchange, increase the amount of carbon dioxide dissolved in the ocean, with consequent acidification of oceans.

The impact of increases in atmospheric carbon dioxide due to depletion of soil carbon, related reduction in atmospheric oxygen, and linked oceanic acidification and deoxygenation, are underappreciated, and under-researched, albeit evidence increasingly suggests, ocean deoxygenation and acidification are significant linked factors in 'climate change'. Longer term, oxygen depletion related ocean sulphidication and consequent hydrogen sulphide release, through damage to the ozone layer may by allowing surface life inhibiting UVC incidence, have contributed to major historic extinction events, and be a future Anthropocene extinction risk (Brown R., 2021e).

In contrast, A global move to regenerative agriculture that; does not allow 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; and maximises soil carbon storage and content; by maximising the photosynthetic potential of every acre, minimising soil heating effects, optimising diversity, and the health and size of the soil biome, reducing carbon dioxide and increasing oxygen, will bring a host of benefits, including to our climate 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 below.

Implementation of regenerative agriculture will help mend the planet, mitigate climate change, including drought and related damage, by reducing; water run-off and floods; regional degradation of hydrology, disruption of flows inland of moisture in oceanic air; soil heating; heat domes; as well as ocean deoxygenation and acidification.

As a bonus, as well as improving soils and climate, regenerative agriculture, brings us better and more nutritious food; and reduces agricultural pollution including agro-chemical damage and eutrophication of oceans by fertiliser run-off, helping secure terrestrial and ocean food resource availability, thus a happier healthier future for the human species. We are after all what we eat and drink, and there are a great many of us.

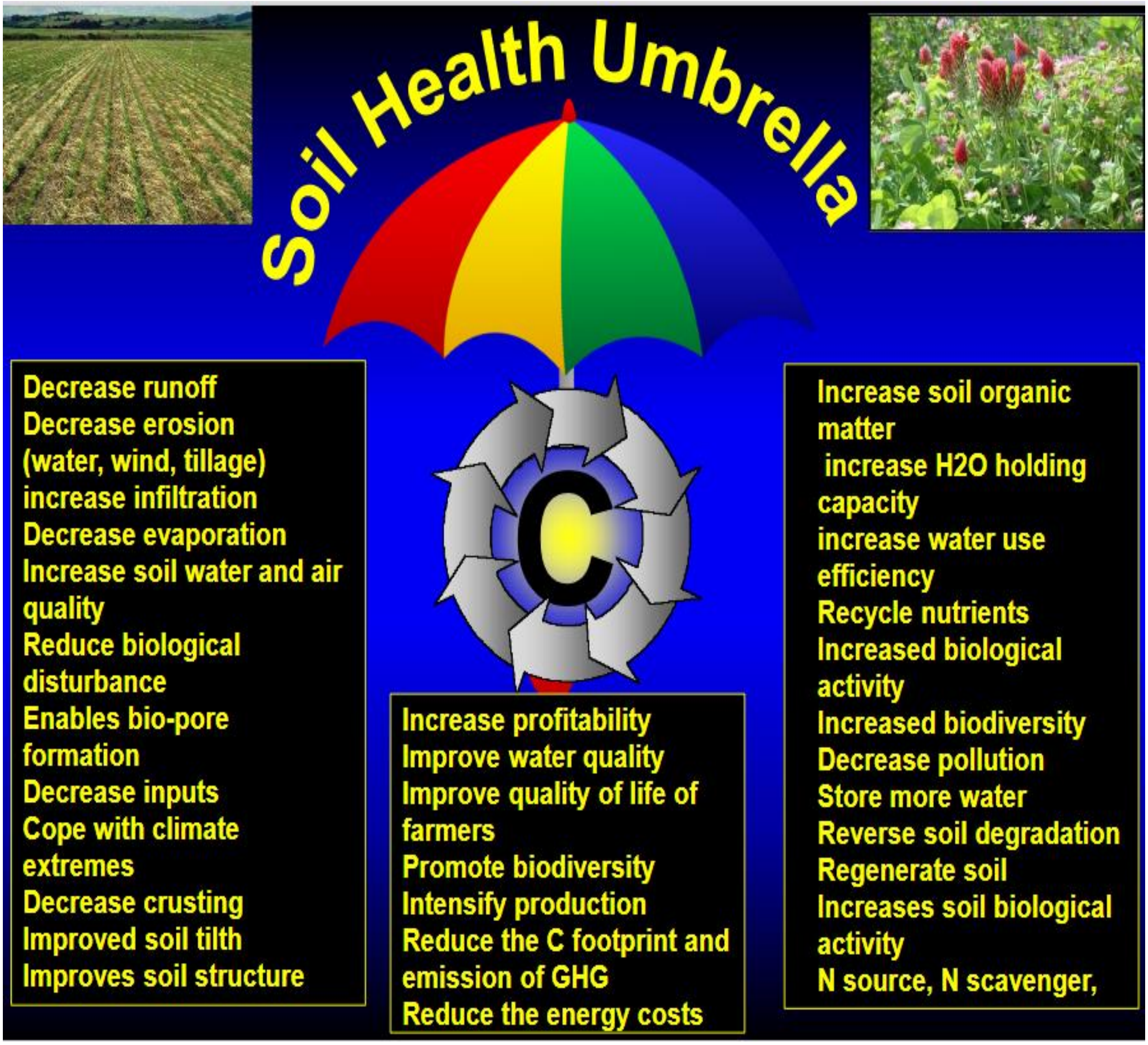


Fig. 3. Lecture slide AGVISE Seminars and Don Reicosky '*Tillage and Carbon Management: Nutrient Re-Cycling Synergies'* North Central Soil Conservation Research, with very many thanks to the authors. (Reicosky, 2014)

The mechanism for exchange of nitrogen and phosphates, for photosynthetic carbon sugar exudate, between the soil biome and plants, has evolved supply regulation systems, based on a mutually beneficial trading system, with nitrogen and phosphates being used as exchange 'currency', so to speak, for sugar exudate. Supply to plants of 'artificial' nitrates and phosphates in fertilisers, by humans 'for free', breaks that trading relationship, thus inhibits the supply of photosynthetic plant carbon exudates to the soil biome, forcing the biome to consume stored carbon, leading to downward spiralling soil carbon levels. Respiration of carbon soil reserves, thus output of historically stored soil carbon in a negative downward carbon spiral, as carbon dioxide, into the atmosphere, by a variety of mechanisms including drying, degrading and decertifying soils, does immense damage, including, significantly exacerbating 'climate change' related extreme weather events and global warming.

Artificial fertilisers and agrochemicals cause further, wider, and growing environmental damage through pollution, including eutrophication of rivers lakes and oceans, which leads to deoxygenation, marine die-offs, ocean biological degradation, and wider more visible issues, such as the seaweed inundation seen on Mexican beaches due to fertiliser run-off into the Amazon.

Further artificial fertilisers, and increased atmospheric carbon dioxide, both individually and jointly, reduce crop nutrient density, so food and feedstock quality. 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).

Using FATBAS we have converted vast areas of the planet's surface from year-round, photosynthesising, green growing, carbon dioxide capturing, sugar exudate producing, organic material covered 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, subject to soil life reducing agrochemicals and NPK, leading to downward spiralling soil carbon and incrementally increasingly degraded biomes.

It is the soil biomes that enhance plant growth, because it is in their own interest to do so, to optime 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).

Gabe Brown a regenerative farmer and campaigner, winner of the 2021 Senator Heinz Award for the Environment, has used the honour to introduce even more consumers and policy makers to the hope in healthy soil. He succinctly sums up the future for bare ground, agrochemical fertiliser dependent 'FATBAS' 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)

If we, as 'de facto' self-appointed environmental controllers, are 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, thus sustainability of current living systems, it is essential we start to respect, emulate, maximise natural soil biology, rather than seeking to dominate and destroy it. It is imperative we recognise the soil biome's role as a key carbon store, an integral working part of evolutionary Gaian, terrestrial oceanic carbon oxygen partition, and wider 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.

Fig. 4. 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)

We need to regenerate, not degenerate, nurture not 'nuke', soil biome health: failure to do so will result in accelerated destabilisation of the climate. Whilst the key climate change focus is on fossil fuel use reduction, it is very unlikely that alone will be successful; we also must regenerate the life, diversity, carbon content, water infiltration-penetration and holding capacity of our soils, that in turn regulate crucial aspects of climate.

DEFINING REGENERATIVE AGRICULTURE – A REALISTIC PROFITABLE OPTION?

'Regenerative agriculture' expands on the wisdoms of four millennia of Chinese farmers, as reflected in the experiences and recommendations made in the 1930s and 40s, of renowned agronomists including Sir Albert Howard and Albrecht. Howard, primary agricultural adviser in India, on small scale agriculture, was a very early proponent of the value of composts, and importance of focus on soil quality, in improving land sustainability, crop yields, quality, nutritional and keeping qualities, livestock and human health, without the need for 'artificials', 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 is farmers need to be profitable and productive. Regenerative agriculture can to be tailored to individual circumstances aims and aspirations, and allows farmers to find their own road. 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. Debate in the field of regenerative agriculture around optimal techniques most suited to soil types climates and crop types, is vigorous, but the long-term central importance of maintaining healthy soil biology, minimising pollution and environmental damage, is agreed by all.

The term regenerative agriculture, at its core means farming techniques that are 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 is good - by using; plant diversity, cover-crops, bio-stimulants including compost teas, low till, integrated livestock grazing where appropriate, no artificial fertiliser, and minimal agrochemicals.

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 use of insect killing ‘de-wormers’, helps maintain soil fertility, distribute biology including via earth conditioning worms and beetles, manure the land, spread seed for perennial pastures, reduce bare areas of soil, and ensure that landscapes do not desertify due to accumulation of dead oxidised organic material on the soil surface.

As explained in more detail above, and in later sections, sequestered soil carbon, both in the form of soil life, and sequestered complexes such as humic acids, is central to life on our planet, and Gaian planetary climate regulation. Healthy soil biomes are obligatory for the maintenance of soil carbon levels. Maintenance of soil carbon, atmospheric oxygen, and sustainable atmospheric carbon dioxide levels, in turn ultimately depends on green lands, healthy plant systems, and functioning ocean ecosystems. Plants cannot flourish long term without healthy soil ecosystems.

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, who has had a regenerative farming epiphany. The video presentation is ‘impassioned’ in tone, but bear with it, as the information and related images are deeply thought provoking. Images of regenerated deserts, seasonal changes in atmospheric carbon dioxide, bare soils, biology in soils, regenerative farming economics, strongly make the point there is another way.

Gabe Brown, a former hands-on farmer, now educator, who focuses particularly on livestock integration, provides practical advice, based on personal experience, on regenerative farming, in simple direct and informative terms, and as part of an 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 use of mixed cover crops, incorporation of livestock where possible, with use of biologically rich compost and extracts to speed initial development of biology. Others such as Dr Elaine Ingham, who focuses particularly 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. The beauty of the regenerative movement is it allows for diversity and individual development according to personal aims and circumstances, whilst maintaining common aims, of eschewing 'artificials', agrochemicals and artificial fertilisers, and crucially improving soil quality, life, diversity and carbon content. Time will help define and improve techniques, but all agree, it is essential to maintain diverse healthy soil biology, and plant cover throughout the year.

There is arguably more than enough evidence, that artificial fertiliser dependent, bare ground based, agriculture, is destroying soil, and should be phased out. Conversely and importantly, a growing number of farmers, are seeing a sufficiently wide range of benefits, including increased profitability, from photosynthesis and soil optimising regenerative agriculture, to attract significant interest from major international corporate food producers.

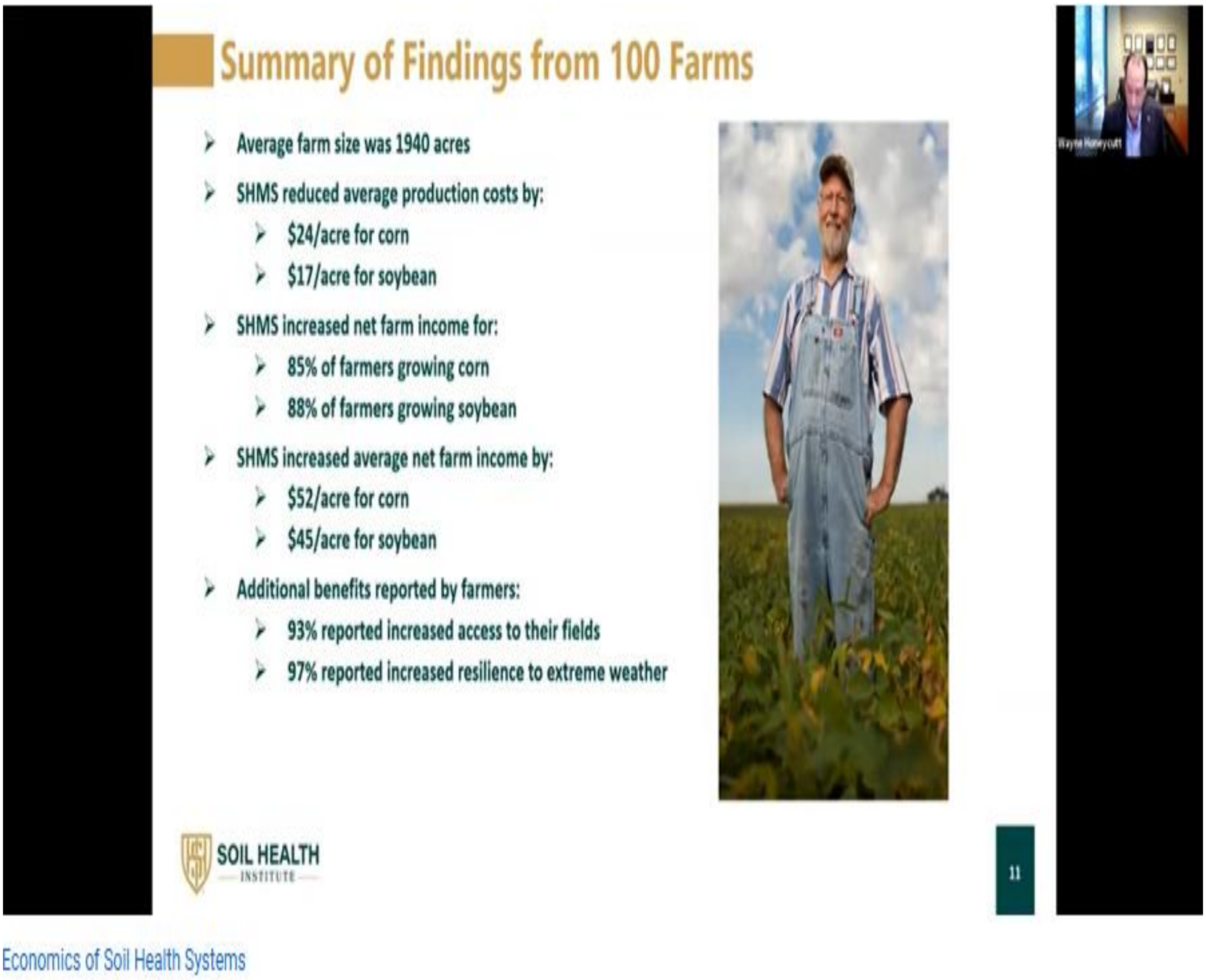


Fig. 5. Slide from Wayne Honeycutt Ph. D UTube lecture titled '*Economics of Soil Health on 100 Farms*' - Soil Health Institute – with very many thanks to the author. (Honeycutt, 2021)

For example, on the positive side, and very importantly, increasing numbers of farmers in online webinars, such as, the Haggertys, Gabe Brown, Rick Clarke and others, as well as a research project farmers funded by Cargill (see slide above), 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.

Yes, short term, fertiliser, and agrochemical reliant, bare ground-based agriculture will support plants, but is only a short-term option, because it creates a downward spiral of; fertiliser and agrochemicals driving down soil ecosystem fertility, and related soil carbon levels. Loss of soil carbon, soil biome health, and related water retention capacity, as well as degrading future productivity, has a much greater than appreciated, role in negative climate change, heating, fires, flood and drought.

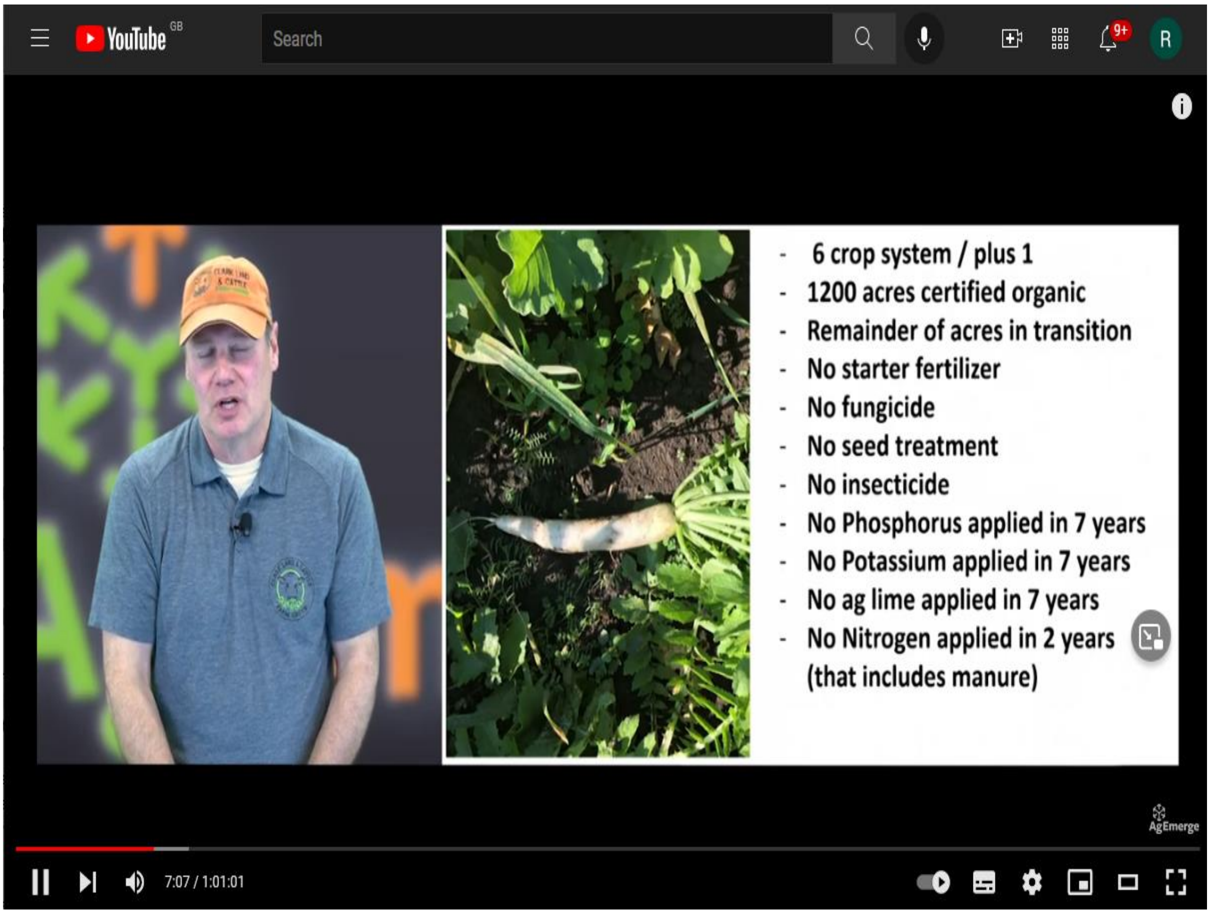


Fig. 6. Slide from AgEmerge Breakout Session with Rick Clarke - Farmers making money in real life with Reg Gen Ag with very many thanks to the Author: practicalities, and benefits of green fertiliser, agrochemical free 'regenerative' agriculture. (Clarke, 2021)

It is inherent in human nature that those that derive incomes from the agricultural status quo, will often be resistant to change for a variety of reasons, such as habit, fear, lack of time and energy, sometimes simply circumstance and sheer economic or wider necessity. Sadly, there is no guarantee that regenerative agriculture will be well received by the agricultural industry, and particularly so, given 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)*.*

However, the fact many large international food corporations, including companies as diverse as Nestle and Pepsi, are increasingly and proactively recognising regenerative farmers, such as Rick Clarke above, 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.

Albeit, it is important, 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 rely on artificial inputs to some extent (McCain, *n.d.*; Robinson, 2021). But pragmatically one can only welcome defined rewarded supported strategies over prescribed timelines, including research and education, to introduce regenerative agricultural practices. Ona can only hope that over time, success in reducing inputs, will lead to improved practice and ultimately true 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

REGENERATIVE ≠ ORGANIC – THE SRI LANKAN 'ORGANIC' EXPERIENCE

Whilst regenerative agriculture and organic agriculture share similarities, they differ in emphasis. Regenerative agriculture focuses on the ground, restoring soil health, a process that can be quickly started, but that takes time to achieve. Organic agriculture focuses on the exclusion or artificial inputs, which can be achieved at the stroke of a ministerial pen, but may fail, as in Sri Lanka, because in its obsession to exclude 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.

Total absence of artificial inputs, including particularly agrochemicals and artificial fertilisers, will enhance regenerative agriculture, but regenerative agriculture might initially or very occasionally require artificial inputs, to achieve wider gains, and allow farmers the space and mental confidence, that they are there if needed, thus assist them at a practical level to make the transition to regenerative agriculture. The reality is, farmers transitioning to regenerative agriculture, report they very rarely need to resort to agrochemicals; due to the better balance of prey and predator, and disease suppression by healthier plants. Indeed, for the crop losses involved, is not economically worth their while to do so (Noggle, 2019). Albeit, as mentioned above, some do find they need to use herbicides to kill cover crops, but are increasingly finding alternatives such as roller crimping.

Most farmers moving to regenerative agriculture find they are more profitable, and achieving equivalent or better yields than under FATBAS fertiliser agrochemicals bare ground agriculture. Although the prices they receive for their crops are not significantly higher, albeit some carry a premium because the nutrient value is higher, or where certified organic, regenerative agriculture is more profitable. Thus, food should remain available and affordable, with the benefit of being more nutrient dense and a generally healthier option.

Conversely implementation of 'artificials' free, organic agriculture, without soil improvement, will not achieve good sustainable yields, healthy nutrient dense plants, or all the benefits and ecoservices that accompany healthier soils.

The weakness of the organic agricultural system, is evidenced by the negative outcome on yields seen in Sri Lanka, where 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 soil.

Farmers transitioning to regenerative soil focused agriculture, need to do so within their means, ideally with the assistance of those with relevant experience, and possibly initially limiting change to a limited area. As discussed, there are multiple examples of excellent yields being achieved with regenerative agriculture, within a variety of time frames, but experts emphasise transition requires flexibility, taking into account local conditions, understanding of the underlying principles of focus on soil health, advance education and planning, ideally risk insurance, attention to detail, flexibility, record keeping, confidence of farmers, and at least a growing season to start the process.

SIKKIM – THE WORLD'S ONLY ORGANIC 'STATE'

Sikkim, an Indian State sitting in the mountainous Himalaya region shares its border with China, Nepal and Bhutan. It has been 'organic' since 2003, which has invaluable wider benefit, given Sikkim is an ecological hotspot of the lower Himalayas, with a wide climatic range, and ecosystems ranging from tropical forest to tundra (ARTE, 2022). Their organic status also should have wider public health benefits, which in the absence of a control, will be difficult to quantify.

Agriculture is a big sector of the Sikkim economy, which functions well. Sikkim GDP continues to rise. There are a wide range of benefits from being an 'organic' state, and there is a growing focus on soils and organic fertilisers. But arguably as a consequence of focus on organic rather than regenerative core principles, it is acknowledged that official 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 possible consideration of mineral foliar sprays, subject to acceptance and suitability, should be able to achieve better yields, whilst remaining organic. Indeed, the Sikkim Government observes "*This yield could be increased by and effective implementation of special food grain production programme (SFPP) and special rice development programme (SRPP)*." (Sikkim, *n.d.*)

EDUCATE, PREPARE, UNDERSTAND AND IMPLEMENT

The need for education including at, farmer, industry, public and government level cannot be overstated. An aspiration to move to regenerative agriculture is a quantum change, requiring massive industrial refocusing and change in agricultural support subsidies and industries. 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 clearly 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".*

Sikkim Government support included finance and legislation, as well as ongoing education and technical support. Clearly it is for every Government to develop their own policy, but this is an example of a clear long-term vision and policy producing tangible results.

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

CLIMATE CHANGE

WE, THE 'CONTROLLER'

Vast human-managed agricultural land areas have displaced what were once natural 'green' ecosystems, forming long-standing elements of the wider natural evolved Gaian climate regulatory system. Crucially humans, rather than Gaian self-regulation and natural evolutionary competition, have now become the 'masters', the 'ecological system controllers', of these once natural, now agricultural lands.

The process of photosynthetic carbon dioxide conversion to oxygen and soil carbon, is part of the earth's evolved cycling biosphere regulatory system, which partitions oxygen and carbon, and thus also carbon dioxide, between the earth's crust, atmosphere, soil, ocean and living things.

The figures are enormous, thus significant. For example, it is estimated that normal growing season respiration of carbon in soils, cycles "*more than 60 Gt of C to the atmosphere annually as carbon dioxide (CO_2), seven times more than the amount of CO_2 released from fossil fuel burning* (Ghimire, Bista, & Machado, 2019) citing IPCC (Solomon, *et al*., 2007).

Thus, by creating a regenerative agriculture scenario where net plant uptake of carbon dioxide, and consequent provision of photosynthetic carbon exudates to the soil biome, and sequestration of it in soils, is greater than soil respiration of carbon in the form of atmospheric carbon dioxide emissions, there is capacity to sequester significant carbon dioxide into soils, in quantities that could impact atmospheric carbon dioxide levels, thus 'global warming'.

In contrast, continuation of FATBAS; NPK, agrochemical, bare ground paradigms; will through multiple mechanisms, including a scenario of self-propelling rising soil temperatures, increase the respiration of stored soil carbon, and thus soil carbon loss, by emission of even more carbon dioxide into the atmosphere, and oceans, greatly contributing to, and accelerating, fossil fuel combustion induced climate change.

Because we have FATBAS agriculturalized, massive acreages of formerly wild self-regulating ecosystems, we have assumed custodial responsibility for those plant, soil biome, and related soil carbon, oxygen, atmospheric carbon dioxide, hydrological and climate, ecosystem regulation mechanisms.

How we farm and curate those soils, for better or worse, strongly impacts on the world's climate and wider 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)

GLOBAL ENERGY BALANCE - SUNLIGHT AND OTHER ENERGY SOURCES

Sunlight contains a significant amount of energy. Sunlight is arguably the most influential energy source in terms of the evolution of life, providing the direct energy for plant photosynthesis from atmospheric carbon dioxide, of the carbon molecules that form and power life, as well as diurnal planetary heating. Sunlight has much greater influence on life than the atomic reactions that maintain the earths molten core, some of which energy will provide 'stable' background heat to the earth's crust and atmosphere, maintaining surface and ocean planetary temperature ranges necessary for life.

The energy in light significantly diminishes as wavelength lengthens (UVB 4.43eV to 1.65eV for visible red light, falling to 4.14 10^{-5}eV for infrared). Considerable sunlight energy is absorbed, and much reemitted, by the atmosphere and terrestrial surface. The relative amounts absorbed by the atmosphere, are governed by the way the atmosphere functions, including reflectivity of clouds, and quantities present of gases with molecular structures that absorb the relevant light wavelengths. Fortuitously different molecular structures absorb different wavelengths. Nitrogen and oxygen absorb short wavelengths, which do not significantly penetrate the earth's magnetic field and outer atmosphere. Carbon dioxide, methane, and nitrous oxide, so called 'climate gasses', are each made of three atoms, V shaped structures that absorb energy in the range of light wave lengths that penetrates the atmosphere, which is why they factor in climate warming.

The amount of energy arriving at the outer surface of the atmosphere is around 1366Wm^2. The amount of light that arrives at the terrestrial surface will be impacted by a range of factors including season, latitude, clouds, dust, moisture, and altitude, and is reduced to between 800 to 1000Wsqm, which will reduce with cloud, latitude, and seasonally vary.

The global energy use and disposal budget for sunlight energy is immensely complex. Much is reflected into space in various ways. Some is absorbed when converted by photosynthesis into carbon products, and cycled back; some is used to heat ocean water; oceans and land masses heat and cool, ice comes and goes, and at times some energy is retained in complex carbon molecules, such as in the carboniferous era when coal and oil deposits were created.

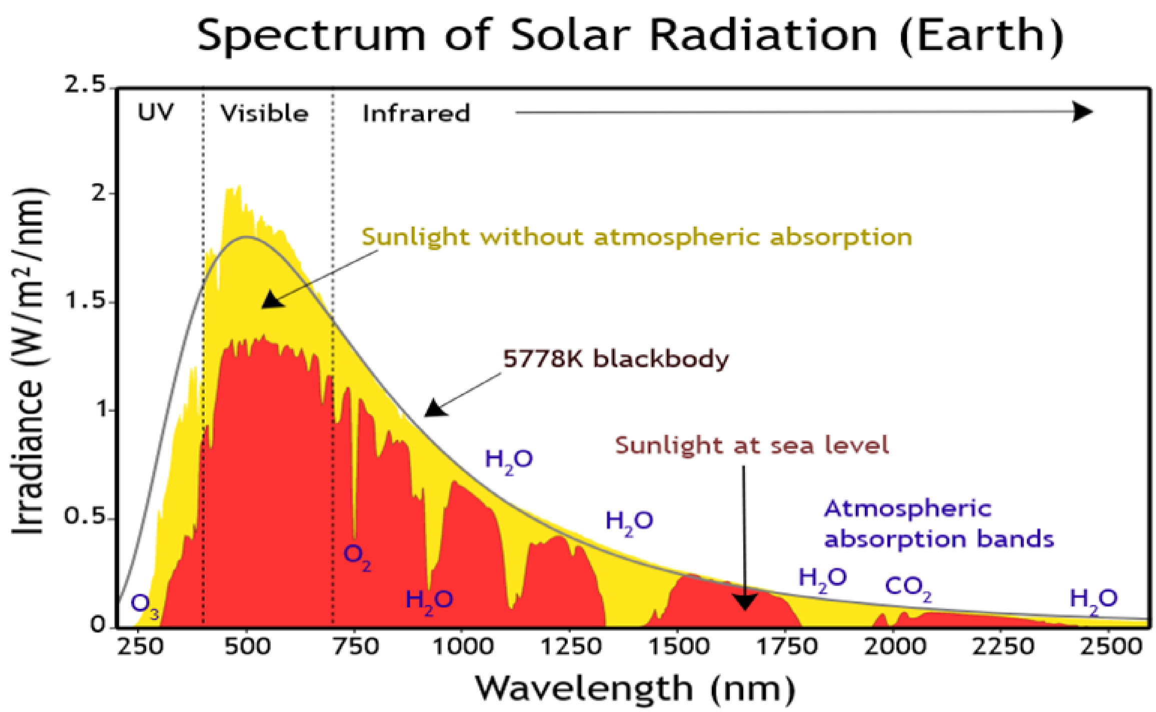


Fig. 7. Spectrum of solar radiation on earth, with very many thanks to Wikipedia, Robert Rohde and authors of the original. (Wikipedia, 2022b)

Alternatively, there is a net release of the stored energy in historically photo-synthetically produced buried carbon, into the atmosphere, as seen in the current era, due to excavation and combustions of that historically stored photosynthetic carbon in coal and oil. This heats the earth and its atmospheric envelope, directly, and indirectly through the breakdown of such products into absorbent atmospheric climate gases. including carbon dioxide, which absorb infrared light energy. The increase of bare ground due to FATBAS, creates a further mechanism for planetary heating and climate disruption, through related mechanisms.

Absent human fertilised based bare ground dependent agriculture; 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. The net gain or reduction in terrestrial surface and ocean, and atmospheric retained, solar energy, and how and where it is retained, impacts climate. We have broken that regulatory mechanism.

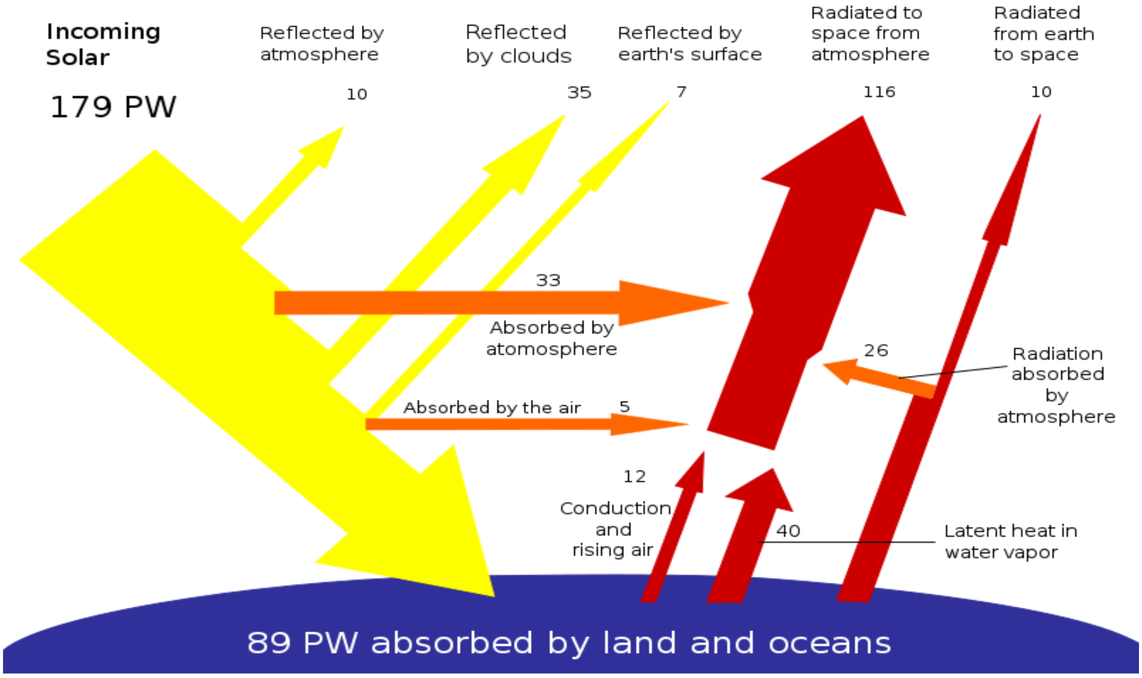


Fig. 8. Solar incidence and reemission with very many thanks to the original Authors. (Kim, 2018) (Original source not known)

PHOTOSYNTHESIS COOLS THE PLANET

A portion of light energy incident on living plants, will be used for photosynthesis, rather than reflected. Surplus light, and the energy it contains, will also be absorbed by a range of plant-based biological molecules that divert the energy in sunlight, including in; UVA, UVB, visible light and infrared, to non-destructive, energy absorbing pathways, including evaporative transpiration of water, as well as antioxidant and related energy dissipation mechanisms.

Plants 'redirect' absorbed sunlight energy by shunting electrons around, and creating or destroying molecules, including for the creation of and transmutation of organic matter, locking up / utilising sunlight energy, until such future time as the material is subsequently broken down. Clearly these strategies are effective, as living and dead plants are rarely in any sense warm to the touch, and living plants create new molecular structures from air and sunlight, which may last in soils for thousands of years, as did coal, oil and gas deposits.

In respect of dead plant material, sunlight degrades the organic molecules it is made of, absorbing energy in the process, "*Solar radiation is a fundamental ecosystem modulator (Wetzel and Tuchmann 2005). In particular, UV-radiation accelerates the degradation of organic matter either by photolysis or by oxidation of organic compounds to CO_2, often followed by enhancing the bio-availability of complex organic substrates to microbes.*" (Brandt *et al*., 2010; Paul *et al*., 2012).

Bacteria feed off the released carbon and other nutrients, producing moisture in the process, thus again diverting heat to other to non-heating pathways, which is why neither living nor dead plant material accumulates significant heat. The energy plants accumulate in the biologic molecules of which they are made, is evident when plants material is set on fire.

Further, importantly and often forgotten, living plants, and the soil biome, further regulate their temperature though transpiring the 'metabolic' water, which they make in biological processes including respiration, cooling themselves and their environment, and supporting growth during low rainfall.

Carbon sequestered into soils feeds the soil biome, including bacteria, fungi, and living creature, which respire some of that organic carbon for energy, providing the by-product, metabolic water, to plants. In times of dry weather, plants cool themselves and the wider environment, by transpiring 'metabolic water'. Living and dead plants also shade the ground preventing heat build-up in the soil, further helping to retain moisture.

Carbon sequestered into soils represents a transfer of sunlight energy into storage, as well as reducing atmospheric carbon dioxide. Conversely, burning of fossil fuels represents the addition of energy to the atmosphere.

The first law of thermodynamics says: "***Energy can neither be created nor be destroyed****, it can only be transferred from one form to another.*" – The sunlight energy incident on dead and living plant material is used to supply energy for renewal, storage of carbon, or destruction of organic molecules.

In contrast, sunlight falling on desiccated soils - ground up rock – is partially reflected, but a significant portion is absorbed by silicates, some remitted as heat, and a small portion stored, over the long-term raising soil temperatures, as seen in defrosting of artic tundra. Bare soil heating also contributes to local atmospheric heating as seen in thermals, potentially heat domes, and drying regional hydrology and microclimates, thus ultimately global warming and wider climate destabilisation.

BARE SOILS HEAT THE PLANET

We happily leave vast areas of cropland soil bare of life, for significant portions of the year. We leave barren soils naked to the elements, bereft of moisture, to be baked by the sun, killing soil bacteria, creating crusted surfaces impenetrable to rain, prone to flooding and erosion, in the belief that we are benefiting from short-term gains in crop yields. Importantly, and generally not taken into account, infra-red light, as well as arriving in sunlight, is also produced and reemitted consequent on the incidence of ultraviolet and visible light on silicate, and likely other minerals, that are the dusty core component of soils.

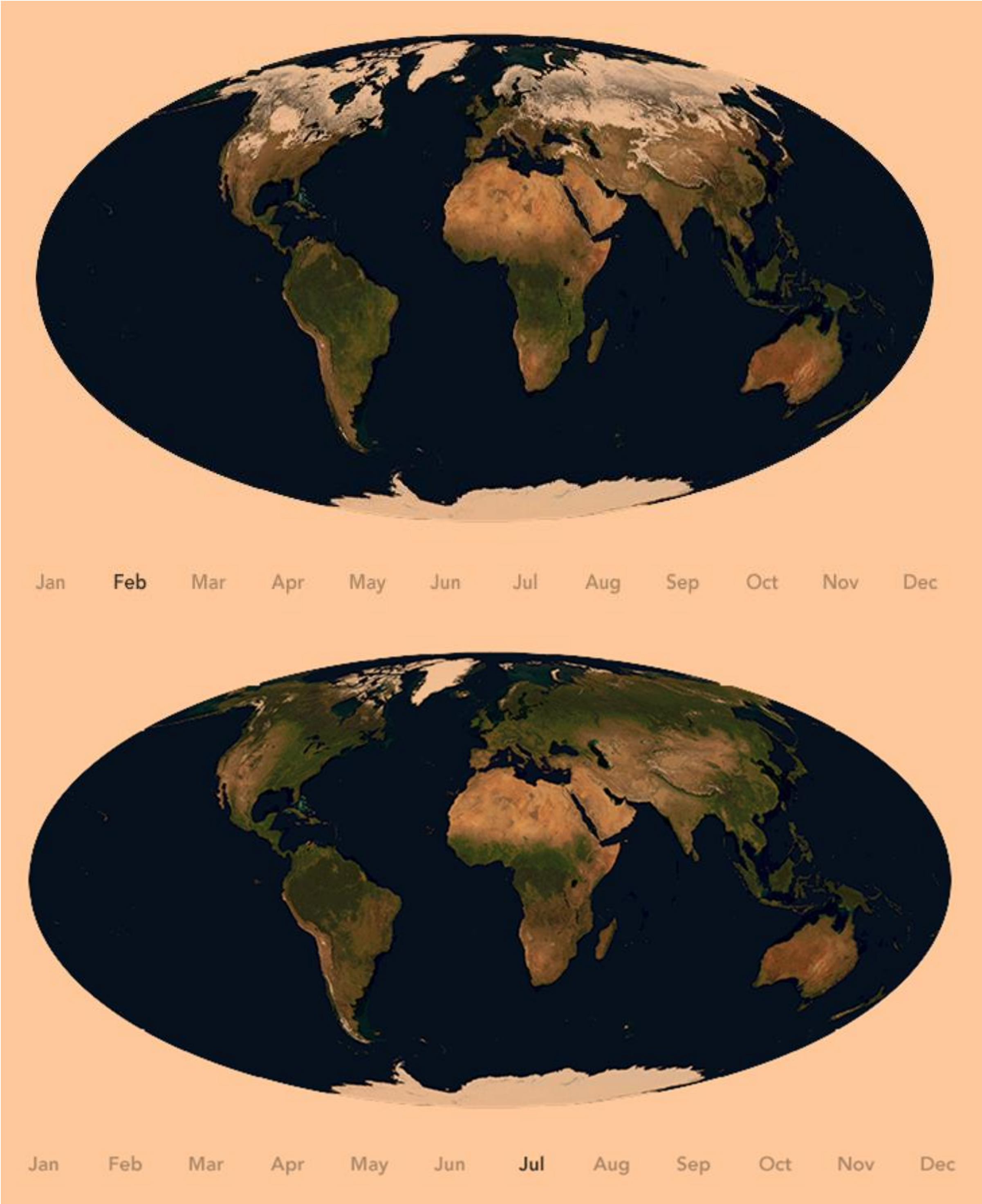


Fig. 9. NASA Earth Observatory images showing seasonal changes, **February** and **July** images, by Joshua Stevens, using NASA's Blue Marble data with many thanks to the Authors.

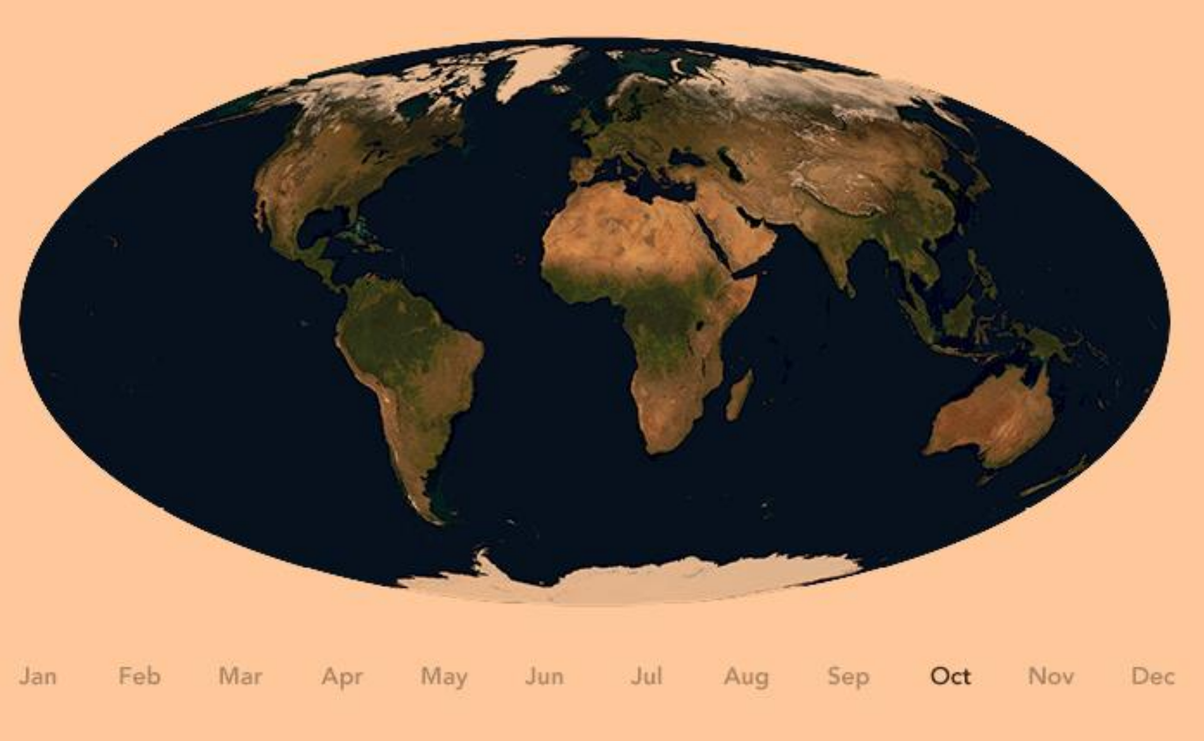


Fig. 10. NASA Earth Observatory images showing seasonal changes, **October** image, by Joshua Stevens, using NASA's Blue Marble data with many thanks to the Authors.

The NASA images above show the green, brown bare, ice and frozen, seasonal (Feb. Jul. Oct.) lands 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, with use of seasonal cover crops, could be green, or at least covered and protected, through the whole year, reducing evaporation, erosion, flooding, eutrophication, as well as moderating the capacity for soil heating. The amount of 'bare' land on the planet is shocking.

Of crucial importance and relevance, and very obvious when you alight on the idea for a moment, but rarely considered in climate change discussion, as discussed, incident sunlight on dry ground, bare of living or dead plants, heats the planet by a number of different mechanisms including;

- heating of soil by sunlight energy;
- re-irradiation of soil incident UV and visible light as infra-red through electron shifts in soil minerals;
- absorption of soil emissions of infra-red by climate-change gases such as carbon dioxide and methane;
- warmer soil indirectly forces denizens of the soil biome to increase their metabolic rate, using stored soil carbon for respiration faster, accelerating soil carbon depletion, and release of carbon dioxide by soil stored carbon respiration;
- rapid loss of soil moisture over a short time frame leading to soil desiccation.
- convection of heat thermals from bare sunlit soil to the atmosphere;

- creation of heat domes, leading to blocking of movement of oceanic moisture inland, drought, fires, destruction of plant life, and thus climate change.

What is also often forgotten, albeit again obvious once thought about, is that soil geology is inert, and relatively stable against degradation by light, which means that the non-reflected energy in light, incident on ground up rock, can only be used to desiccate soil, then heat it. Incident sunlight energy not immediately reflected or re-emitted as infrared, will be stored as heat energy in the mineral content of soil, and released over time into the atmosphere.

Sunlight energy incident on dry bare soil cannot not just disappear – a little is re-radiated into space, and no matter how the rest is divided up, what is not re-radiated into space can only heat the land mass and atmosphere of the planet – thus our bare soil farming, and human historically degraded landscapes, are contributing much more than we realise to the heating of our land, atmosphere and oceans, 'simples'☹: the simple mitigation strategy of keeping our agricultural lands photosynthesising, green and growing 😊, thus maximising the storage of sunlight energy sequestered into the carbon molecules in soils, is rarely considered in the climate debate.

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),

If one guessed that, on average in the hotter months of greater sunlight incidence, arable land globally is bare of a quarter of the year, and received sunlight for 5 hours a day, then 1,300,000,000 hectares (Wikipedia, 2021) times 10,000 (m.sq. per hectare), times 90 days, times 400 watts (half best incidence rate): 5 x 1.3 billion x 10,000 x 90 x 400 = 2,340,000,000 billion watts = 2,340,000 tera watts (tera = one million million), which is many times maybe 20, the global annual fossil fuel consumption of 120,000 tera watts. Yes, very much 'back of an envelope' calculations, and a portion will be re-irradiated into space, but the figures make the point bare land heating could potentially significantly contribute to global warming.

In summary, in contrast to sunlight falling on bare soils, a proportion of sunlight incident on plants dead or alive, will be used to make or break down organic matter, or storing energy through plant or microbial growth, and or directing it into driving creation of more complex molecules stored in soils, respiration and evaporation, as against infrared heat emitted by bare ground, that causes climate disturbance, including drought drying and resultant fire.

CARBON-DIOXIDE, NITROGEN, METHANE

Yes, the primary producer, of carbon dioxide, and of much methane, is fossil fuel use and production. However, agriculture is responsible for a significant proportion of the greenhouse gases (GHGs) produced annually (FAO, 2019b). Estimating the exact amounts is difficult because a good proportion of them are produced by biological processes, which have been supercharged by bare land NPK based agriculture, FATBAS, with the remainder being produced by the fossil fuel combustion needed for agriproducts, transport, tillage etc.

"The three main agricultural GHGs of concern are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which have GW Ps, respectively, of 1, 25 and 298, meaning that over 100 years, 1 kg of N_2O released to the atmosphere will retain 298 times the amount of heat retained by 1 kg of CO_2 in the atmosphere. Using this metric, 1 kg of CO2 is 25 times less carbon-polluting than releasing 1 kg of CH_4." (Gathorne-Hardy, 2013)

The main agriculturally exacerbated sources are:

- Carbon dioxide:
    - Soil carbon respiration and release as carbon dioxide, including from damage to soils, and conversion of highly organic wetland soils to agricultural use. (FAO, 2019a)
    - Fossil fuel consumption to provide energy for ammonia production; phosphate extraction transport and processing; production of agrochemicals, transport, and fuel for farm equipment.
    - Burning crop residues.
    - Burning of mature forest, as in the Amazon, for subsequent, often short term, agricultural land use.
    - (Defrosting tundra – a biological but not strictly agricultural source).
- Nitrogen based N_2O:
    - Metabolism and release from soil consequent on excess fertiliser application.
    - Metabolism and release from metabolism of available nitrates in sewage. sludges, cattle slurry etc applied as manure.
- Methane:
    - Rice production, anaerobic soils.
    - Livestock production.
    - Defrosting tundra.
    - (The other major source of methane is hydrocarbon flaring).

Natural systems are enormous in size and complexity, thus accurate figures are very difficult to estimate, but there is no question all the above are significant sources of greenhouse gases. In addition, losses from FATBAS agricultural soils due to; bare ground, agrochemical, fertiliser, based agriculture, are not generally accounted for in many annual carbon dioxide production estimates, but are likely much more significant than realised.

For example, by way of 'a wake-up alarm', 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 losses of soil carbon of this magnitude are widespread, they would represent a significant addition to the annual carbon dioxide additions budget.

Further, and crucially, but often lost sight of, much carbon dioxide is absorbed by the oceans, meaning the annual rises in atmospheric carbon dioxide are unlikely to tell, and may even disguise, the full extent of carbon dioxide emissions. Nitrous oxide and methane also dissolve into sea water, but research to date on the impact of atmospheric concentration changes, on oceans concentrations, and vice versa, is limited.

HUMAN HUBRIS – NATURE RULES – DESTRUCTIVE SHORT-TERMISM WILL FAIL

There is growing recognition by the food industry, farming and environmental groups, reinforced by rising financial, raw material, and manufacture, 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.

Whilst requiring major adaptation and refocus of the agro-farming–fertiliser–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, rather than seeking to optimise immensely sophisticated biological proven and free natural technology, evolved over millions of years, which is 'oven-ready', and primed and ready for use. Humans just need to find the wisdom and long-term vision to optimise and work with nature, rather against it.

By trying to dominate nature, without fully understanding the implications of our actions, global ecological equilibriums have been disturbed. Consequentially we now face mounting evidence of changes in natural cycles, including diminished soils carbon sequestration, and storage, which increases oceanic and atmospheric carbon dioxide. We have further exacerbated system imbalances, in atmospheric, soil, and ocean carbon stores, by mining and burning eons old accreted soil carbon in the form of 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, increased atmospheric carbon dioxide, desertification, deforestation, erosion, ocean acidification and wider 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, including of IQ, empathy and abstract thought capacity.

As discussed in the Sewage volume, addressing the need to deal with faeces and urine in a more intelligent way, has a host of potential benefits, including economically and for environmental sustainability at many levels.

More worryingly, whilst our head continues to remain blinkered in the sand, we risk major 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, UVC penetration of the atmosphere, UVC damage to living system and a consequential risk of extinction events (Brown R., 2021e). A review worryingly observed most major historic extinction events were connection to ocean anoxia Consistent with this, ocean sulphidication leads to hydrogen sulphide releases, which in sufficient volume would damage the UVC blocking ozone layer, allowing UVC incidence on the terrestrial surface. Again, consistent with this posit, a recent paper noted that pollen at the most recent major extinction event, appears to have increased UV self-protection, and have been damaged by UV (Liu, *et al.*, 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 sulphidication, and hydrogen sulphide release events are already observed from time to time in Namibia.

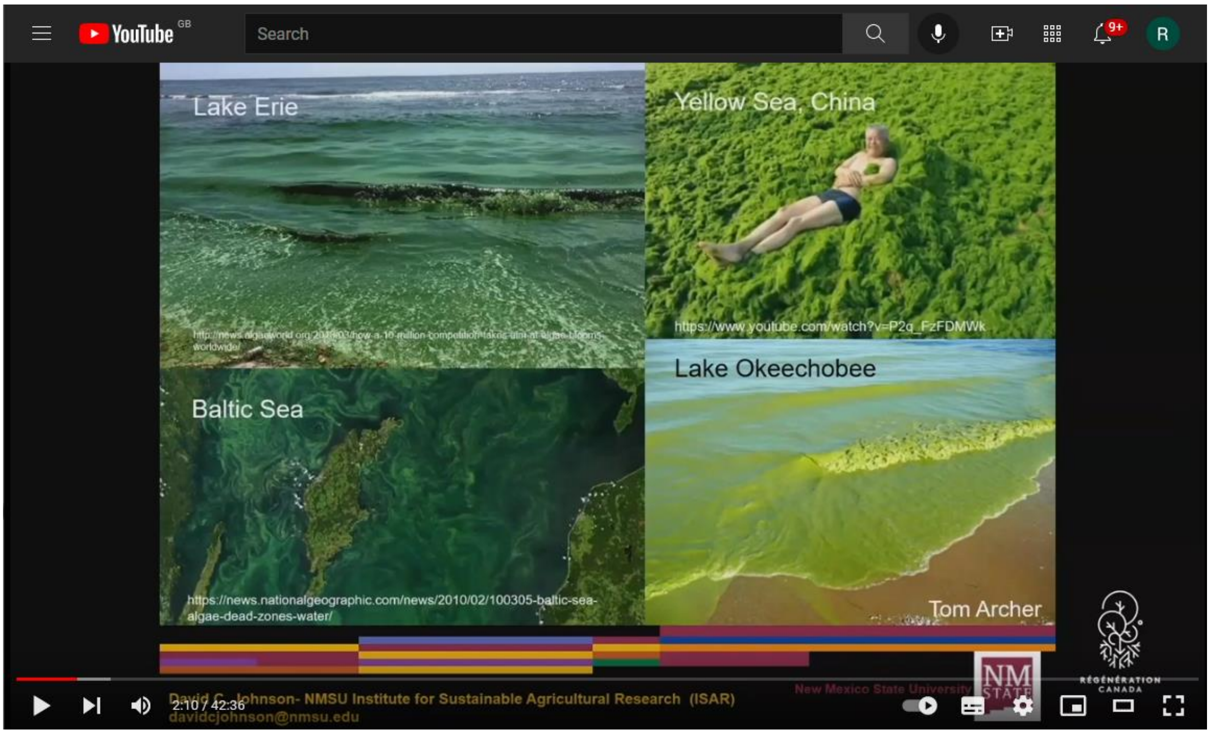


Fig. 12. From video lecture by Dr David Johnson, using the ‘*The BEAM (Biologically Enhanced Agricultural Management’) Approach*” illustrating the effect of washout of excess phosphate application on rivers and oceans, to which could be added many other examples, including the Sargasso Sea; very many thanks to the Author. (Johnson, 2017)

As well as adding to risk of an Anthropocene extinction event, in the more immediate term, pollution and degraded nutrition must, and indeed is evidenced as, impacting on, human health, behaviour, and cerebral capacity, 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 skill and capacity, that defines and differentiates us as humans. If we are to survive and prosper as a species and find our destiny in this universe, in a resource-pressured world, we need to be the healthiest, best, most intelligent, empathetic, cooperative, abstract and complex thought capable, humans, we can be. (Brown, R. a-d) (Authors copy PDFs on ResearchGate)

It is essential we do not to lose sight of the bigger picture – the evolutionary miracle of, our existence, and emergence as highly sentient, immensely complex life form – or that the choice of our future 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, fair, or beneficial, in favour of often imperfect short-term fixes, as long as they immediate offer, profit for shareholder, kudos, access to resources, a sense if being cutting edge research with financial prospects, and employment or wider financial reward. This has arguably happened in both farming and health. Simple ways to make a difference rarely get the attention they deserve.

For example, trying to fix dietary nutrient imbalance induced illnesses, with complex pharmaceutical preparations is never going to provide an optimal solution, yet is constantly pursued in preference to fixing the obvious 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 an evolutionary essential deficient nutrient with multiple, interlinked pleiotropic physiologic effects – the pathways involved are simply too complex. Food and pharmaceuticals both have their place, but generally there is little focus on the impacts of nutrient imbalances, which ultimately determine our basal health profile, to which basal potential, modern wondrous surgery and pharmacy, is an undoubted bonus. The above are examples of us, as a species 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 huge range of system services for free. Leaving land bare, wastes the opportunity of using sunlight energy to capture atmospheric carbon, which behaviour is arguably deeply irrational.

Our technological advancement including in, travel, communication, medicine, and urbanisation, have been miraculous, yet at the same time, we failed to recognise the importance healthy soils, including for human and livestock nutrition. As well as revelling in new human produced, profit rendering amazing new technology, humans need to recognise nature's immense sophistication and resilience. Nature's technology is still, in many respects, beyond the current reach of human understanding and science. Soil carbon sequestration is an essential non-negotiable, irreplaceable, parts of the evolutionary planetary 'Gaian' climate regulatory systems. Yet we hinder, rather than help nature to function optimally. On order to feed ourselves, optimise our health, behaviour and neurological capacity, 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, deeply illogical.

THE BIGGER ECOSYSTEM PICTURE

Life exists on earth because we have won the life lottery. Earths 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 universe.

The existence of life on earth depends on the interaction of innumerable pathways in a way that creates the planetary conditions required for the emergence of abiotic RNA, then life. We are governed by the laws of atomic physics, and the way 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).

GAIAN PLANETARY REGULATION

Thus, as discussed, plants, and the mycorrhizal and bacterial soil biome, are crucial interdependent parts of the evolved wider Gaian supportive planetary regulatory systems. The soil biome, plant health and growth are totally interdependent. Upsetting these regulatory processes facilitates and accelerates the system dysregulation caused by human combustion of long stored carbons, including, coal, oil, and gas.

THE CARBON CYCLE

Carbon is central to life. The recycling of carbon from carbon dioxide, to organic molecules supporting life, and back to carbon dioxide, including through subduction back into the earth's mantle, and release via volcanoes, is called the 'Carbon Cycle'. Because carbon along with oxygen, forms the atmospheric gas carbon dioxide, as a component of that gas, it is easily and widely available and accessible, to life forms.

The atomic structure and properties of carbon, make it uniquely capable of being a molecular structural backbone, that is also sufficiently chemically reactive to support multiple structural forms, including those that; conduct switched and non-switched charge; absorb and remit photons; facilitate energy production; store energy; and act as structural molecular building blocks, including of membranes.

Oxygen based reactions supply sufficient energy to power more complex life, other mechanisms do not. Thus, sophisticated high energy dependent life, requires available oxygen, for energy creation through respiration. Carbon, the other component of carbon dioxide, is the basis of all living cellular structures. Plants capable of photosynthesis use sunlight energy to turn carbon dioxide and water, into carbon containing molecules, and oxygen, as encompassed in the formula: $6\ CO_2 + 6\ H_2O$ + light --> $C_6H_{12}O_6 + 6\ O_2$.

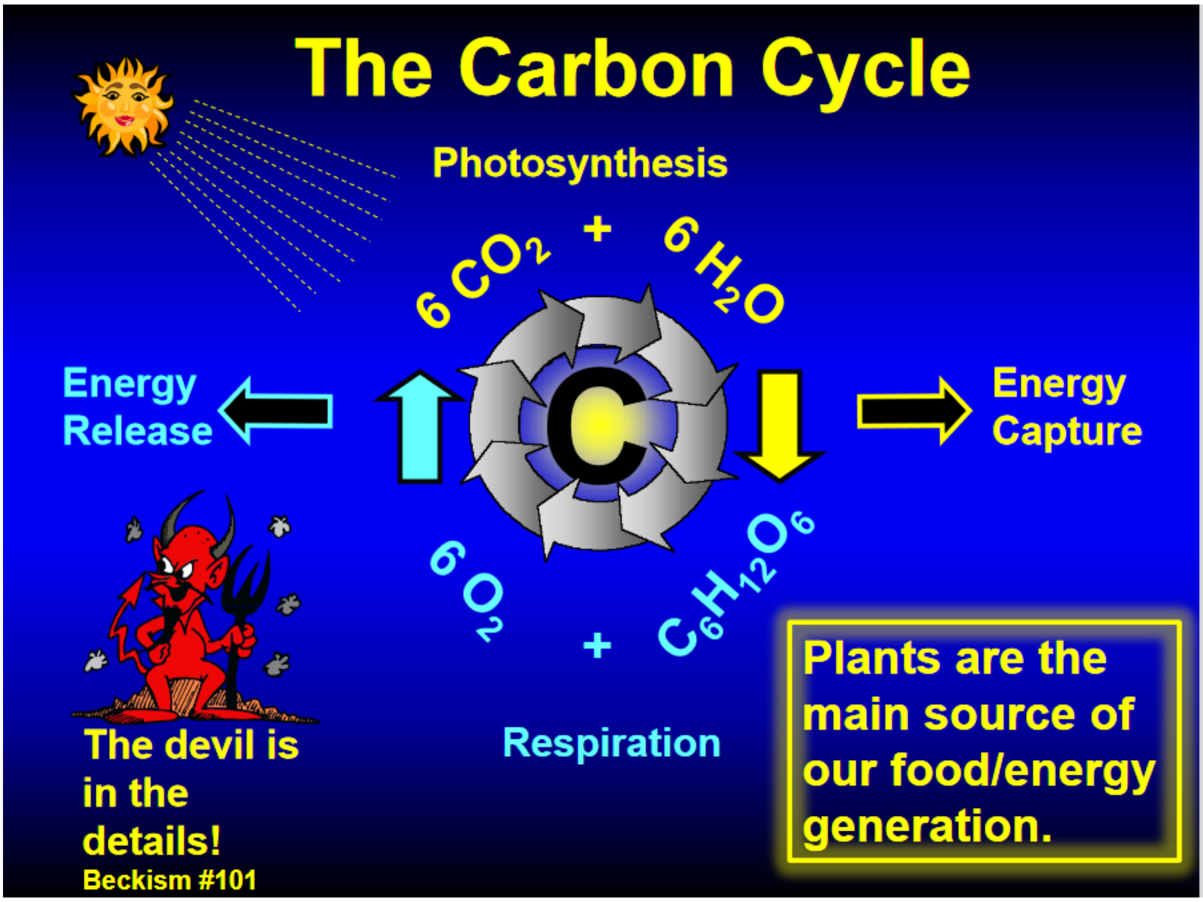


Fig 13. 'The Carbon Cycle' - Lecture slide AGVISE Seminars and Don Reicosky 'Tillage and Carbon Management: Nutrient Re-Cycling Synergies' North Central Soil Conservation Research, with very many thanks to the authors. (Reicosky, 2014)

Plants need a range of nutrient resources, to be capable of significant oxygen production. It is soil bacteria that provide them the nitrates supplying the assimilable nitrogen they require. A range of minerals needed by plants are mined largely by extensive fungal systems. Plants in return provide photosynthetic plant sugars.

The symbiosis between plants, the soil biome, and more widely ocean biology, plays significant roles, through multiple mechanisms, in regulating climate, including by determining, atmospheric oxygen, atmospheric and oceanic carbon dioxide levels, and soil carbon (FAO, 2018-b).

Humans have hubristically, massively intervened in the natural self-regulating cycles. We have taken oven huge areas, billions of acres, of natural habitat, and subjected it to FATBAS, industrial agricultural bare ground, fertiliser, agrochemical-based farming. 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 *et al*., 2022). Artificial fertiliser also increases the metabolism of stored carbon by the soil biome, further depleting carbon stores, shifting the biological soil profile from, carbon-rich mycorrhizal to nitrogen-rich bacterial, dominated soil. Agrochemicals kill soil life; ploughing and bare land further magnifies the damage, accelerating reduction of soil biomes and stored soil carbon.

In consequence, over the last 50 years primarily, soil carbon has dropped massively, from 8% or more, to in some cases 2-3% or less, 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.

Christine Jones, agronomist, reports for example, 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% to 5% at the lowest with an average of 3.72% carbon per hectare.

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

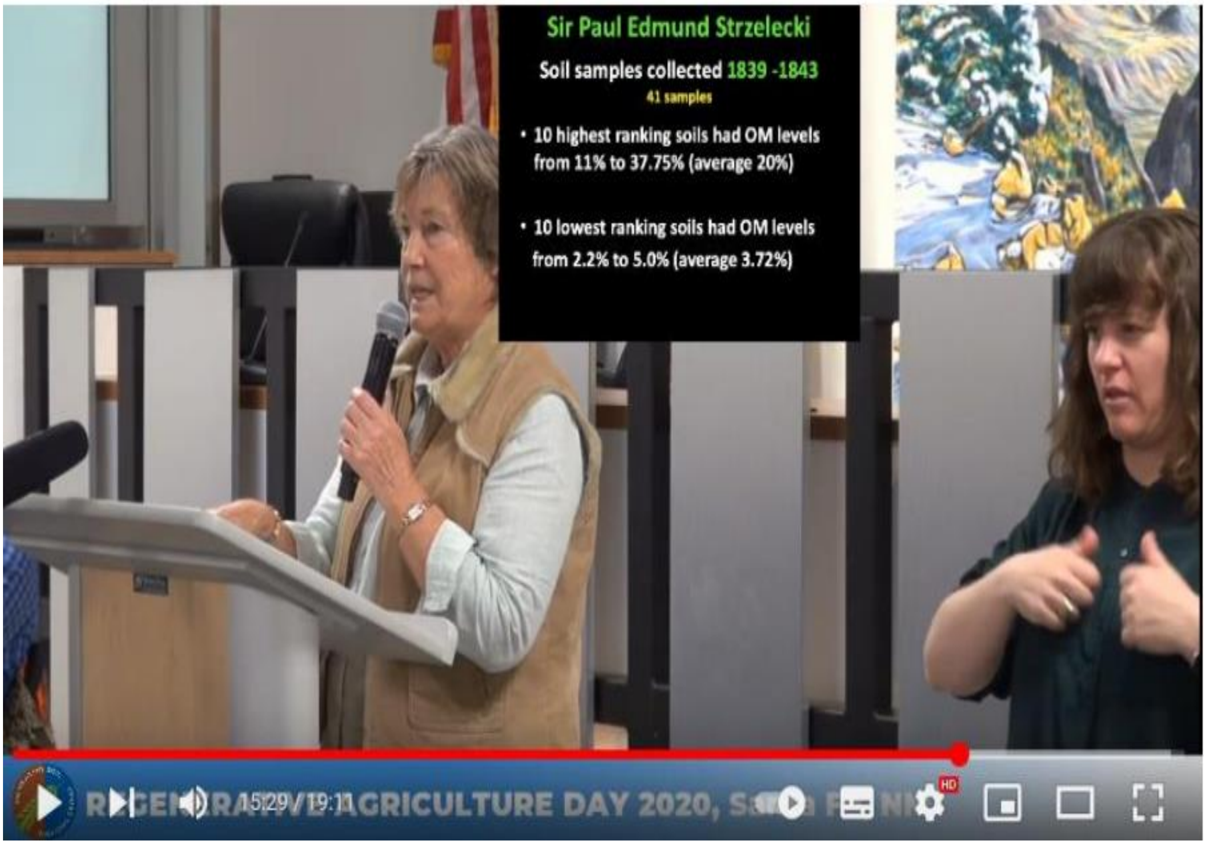


Fig. 14. Dr. Christine Jones from her UTube lecture *'Soil health and water security (DATA 1830 Australian Soils from Kew highest organic matter 11-37.5%!)'* (Jones, 2021)

This and other diverse data gathered in other sections of this volume, indicates, both the degree to which soil carbon has been reduced, and conversely the potential to store huge amounts of carbon, if these soil losses were reversed.

Considered on a global basis, loss of several percent of carbon from carbon rich soils, due to intensive agriculture over the last 50 or so years, translates globally, over the billions of hectares now under agriculture, to potentially billions of tons of carbon dioxide having being added back to the atmosphere and oceans.

Thus, the mix of industrial agricultural techniques, artificial fertiliser, and agrochemical dependence, FATBAS, are significant additive, and accelerating and likely keystone factors, in the negative global climate changes, greatly exacerbated by the burning of fossil fuels.

Conversely, with good soil management through Regenerative Agriculture, the opportunity exists to sequester billions of tons of atmospheric carbon dioxide back into soils, and improve; soil quality, diversity, water retention, regional hydrology, and weather; at the same time reducing heat domes, pollution, eutrophication, flooding, erosion and desertification, buying us necessary time for development of truly green energy technologies.

CAPACITY TO '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 ignoring the fact 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.

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, to 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 CO_2, 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)*

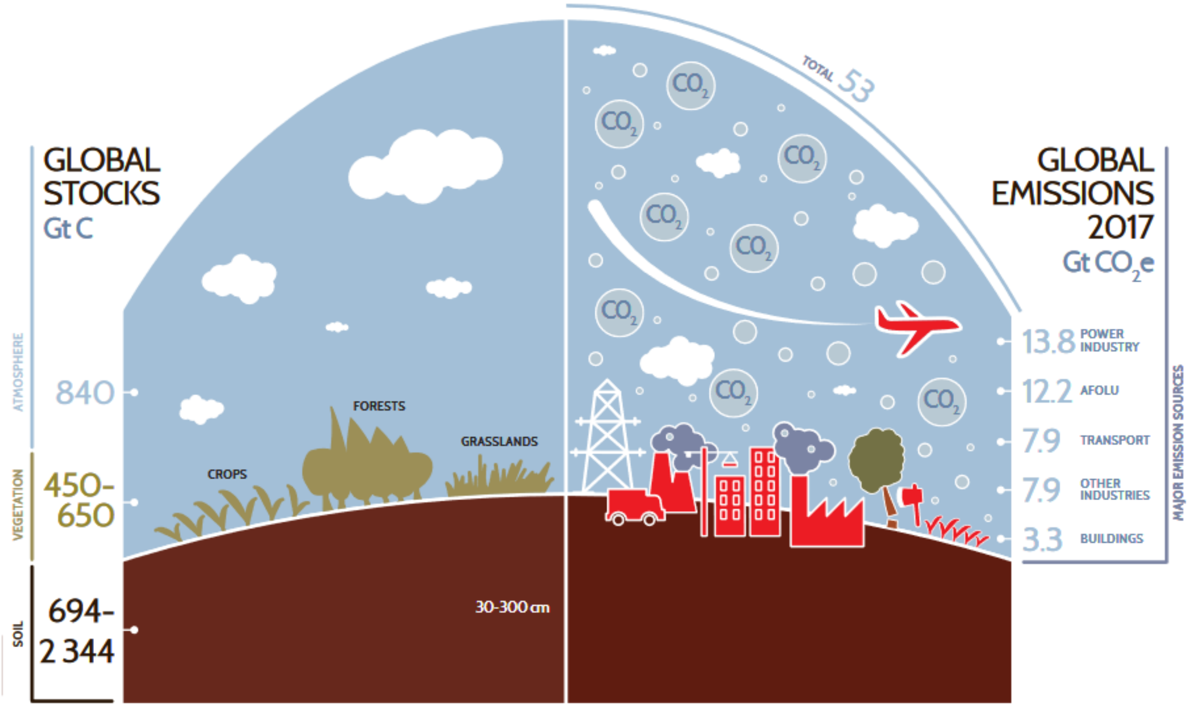


Figure 1a. Global carbon stocks and global emissions. Gt = gigatonne = 10^{15} g C = 1 petagram = billion tonnes. 1 Gt = 3.664 Gt CO_2

Fig. 15. 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.

Thus soils, given appropriate conditions, can store carbon long term; storage requires an ongoing **annual net supply** of carbon exudate by plants, to the soils, at rates exceeding the annual metabolic respiratory energy requirements of mycorrhiza. 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, but at lesser rates than carbon supplies (Johnson, 2017), leaving capacity for net carbon gains.

Thus, given the will to do so, by moving to regenerative agriculture, and away from our current model, dependent on artificial fertilisers and bare ground, we can help nature sequester large amounts of carbon into soils with multiple co-benefits.

Significantly, the FAO recognises and actively promotes the importance of soil carbon to the quality and sustainability of food supplies, and wider 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).

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).

Whilst the FAO is wholeheartedly focusing on ways to increase soil carbon, the use of traditional artificial NPK fertiliser remains a part of part of the FAO package, whereas the author and others argue, long term, the general use of NPK fertilisers is part of the problem rather than solution, and the need for a fertiliser industry move to organic plant growth promoters must be explained, facilitated, financed and enabled.

Independently, at the grass roots 'sharp-end', consistent with these observations, hands on financially and ecologically successful regenerative farmers, including Gabe Brown and the Haggertys, are organising measurement of soil carbon sequestration, and reporting biologically enhanced regenerative farming, is capturing significant amounts of soil carbon, much larger than those captured by other agricultural systems.

Further the food industry is recognising the potential of regenerative agriculture to improve crop quality, sustainability, profitability of farmers, with wider environmental benefits, and supporting expansion of regenerative agriculture through multiple mechanisms, including through significant financial support, training, and research funding.

Ultimately everything comes back to the need to optimise natural systems, and in particular the value of, and need to maximise, the energy value of incident sunlight through photosynthetic plant energy production. We rightly spend large sums creating technology to use light energy to make solar electricity to offset climate change, and are looking at mechanical and or chemical, but energy demanding, ways to capture carbon, yet at the same time we fail to recognise what is under our noses, literally – natures oven-ready proven free fully developed carbon sequestration technology – photosynthesising plants.

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 optimises 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, and a social, economic and ecological pariah.

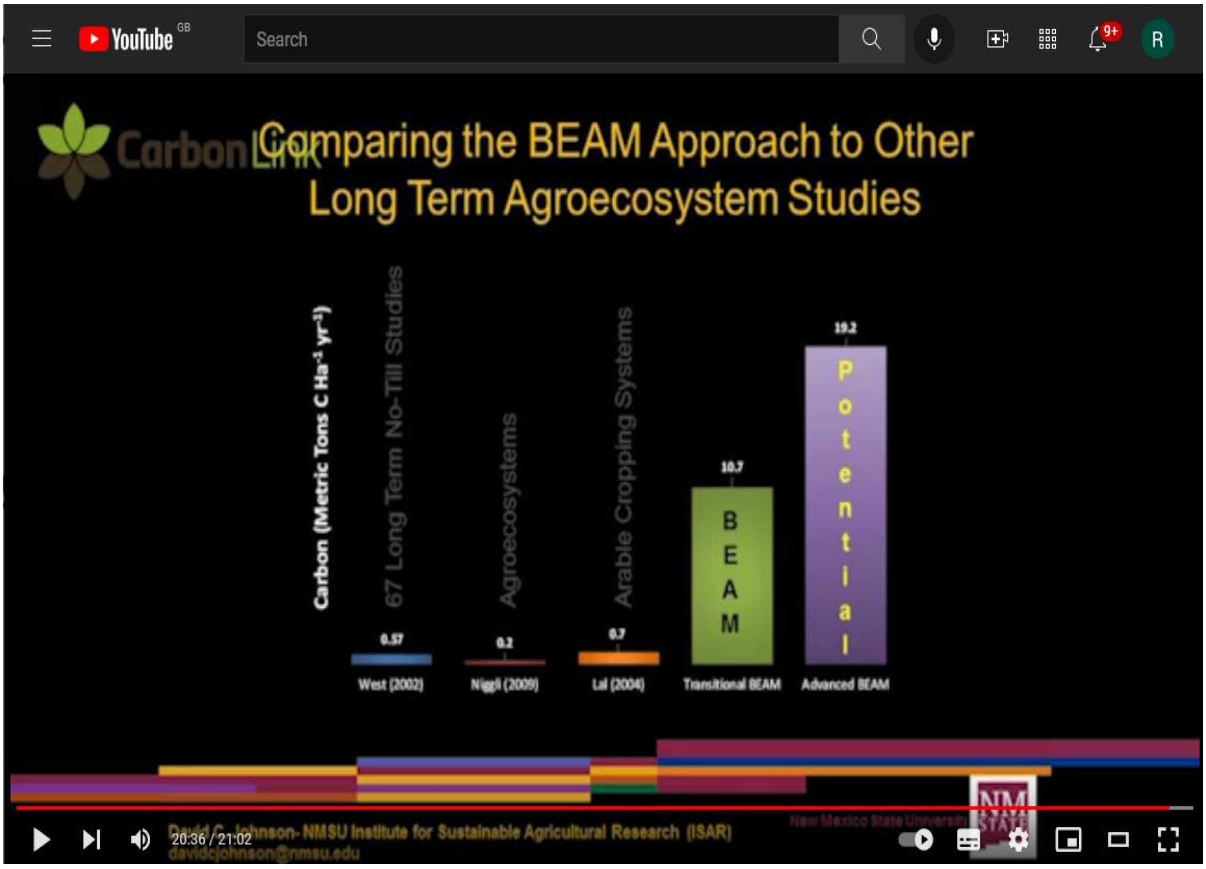


Fig. 16. The use of compost teas, as seed soaks, drips and foliar sprays, biologically rich mediums containing a wide range of bacteria, and fungal spores, particularly on degraded land, greatly increase plant health and growth, and thus soil carbon sequestration rates. David Johnson calls this *'Biologically 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).

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 the amazing sophisticated role of plants maximising the potential of energy in light. Plants, with the assistance of enzymes – molecule machines, photon-capturing molecules, proteins, water and minerals, turn the carbon dioxide in 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, thus helping maintain the planets regulatory systems, by maximising the potential of a free proven sophisticated mature natural technology.

OPTIMISING SUNLIGHT POTENTIAL OF EVERY ACRE

In practice, maximising the photosynthetic potential of each acre, means ensuring mycorrhizal biomes and their symbiotes, plants, photosynthesise, thus flourish, for as much of the year as is biologically possible under applicable weather and regional light constraints.

In the absence of NPK provision, which inhibits carbon sugar supply to the soil biome, plants when provided with biologically rich environments, will flourish, and optimally supply sugar exudates to the soil biome; and in exchange the bacteria and fungi in the soil biome will supply the plants with metabolic water, nitrates and minerals.

Plants signal needs for specific nutrients; and in return for carbon sugars the soil biome meets specific nitrate, mineral and wider 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 inter cropping to optimise seasonal sunlight growing potential, thus maximising provision of carbon to the soil biome, at the same time minimising mycorrhizal draw-down of stored soil carbon to meet energy needs, thus 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 plant / 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 use of nitrogen and synthetic fertilisers on soils (except where soils are measured as definitely 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), maybe a more efficient way to address mineral deficiency issues.
- **Minimal agrochemicals**: - avoiding use of 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. (Cattle should not be given anti-parasitic products as discussed later,

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 biology soils with well matured compost, or compost tea inoculant's / soil injection, optimising seed access at germination and 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 through improved immediate access to bacteria and fungi that assist germination, and 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.

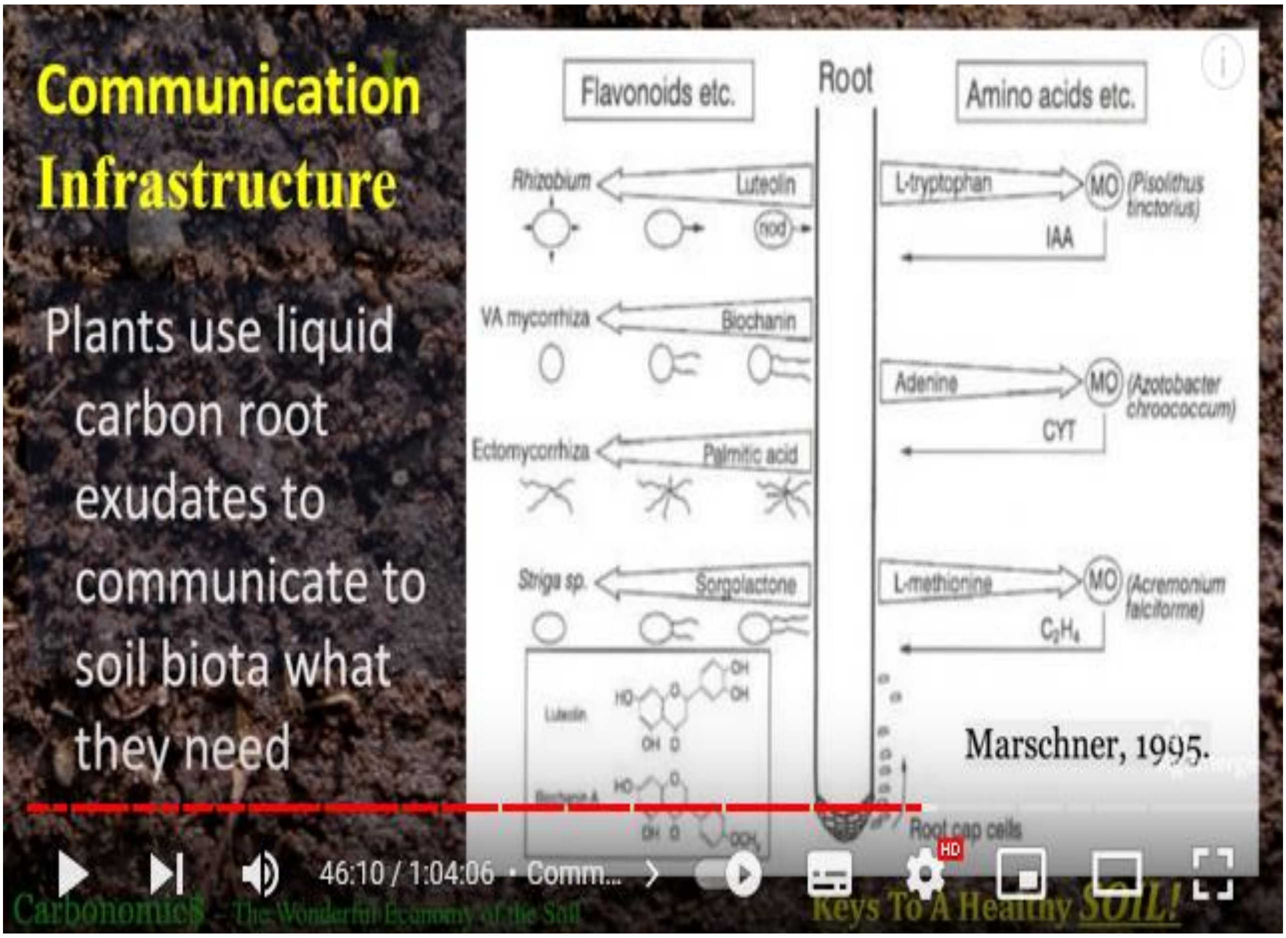


Fig. 17. Plants use organic compounds to signal their needs to the soil biome. UTube video slide '*AgEmerge Breakout Session with Keith Berns*' 2020 with many thanks to the Author and Ag Solutions Network (Berns, 2020)

Fig. 18. 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 soil based, and above soil, lifeform, including insect, diversity.
- Crop health, nutrient content, and productivity.
- Livestock health were fed on regenerative pastures, and through better quality feed.
- Soil carbon retention to respiration rate ratios.
- Metabolic production of water.
- Water retention in the soil, regional hydrology, transpiration rates, and plant formation and stromal release, of cloud seeding bacteria.
- Supply of minerals and nitrates by mycorrhiza to their plant symbiotes.
- Soil carbon sequestration, reducing atmospheric and oceanic carbon dioxide levels, thus moderating, climate change.
- Oxygenation of the atmosphere and oceans.
- Reduction in; heating of bare soils, soil desiccation, crusting, and in re-emission of absorbed heat, related heat dissipating thermals, and consequent heat-dome production.
- Immediate microclimate by regulating water transpiration, improving soil water retention, local hydrology, reducing soil heating, thus moderating climate change including temperature rises, drought, heat domes, and related extreme climate events, including flooding and related soil and nutrient loss relative erosion.

- Energy efficiency of farming.
- Farming profits.
- Sustainability including through reduced eutrophication and agrichemical pollutants.

KEEP IT GREEN LONGER

Green growing plants are of necessity photosynthesising. The longer the growing season of a single, or multiple crops, the more carbon sugar exudate that will be supplied to soils, increasing fertility and water retention; the more solar energy that will be used to moderate climate, rather than being absorbed by bare land, and causing climate degradation by a variety of mechanisms.

On grazing land, use of cattle at appropriate times of the year will encourage new and more growth, by a number of mechanisms. Cattle spread bacterial biology, nutrients in saliva, as well as nitrates and minerals in manure and urine.

Fig. 19. 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)

On arable land, most crops are optimally photosynthetically active for around 70 days, with a longer time for the subsequent ripening of grains. A grain crop cycle may take between 90 and 120 days to grow and for the seed to mature. Inter-row crops can be used to help optimise the photosynthetic capacity of arable land throughout the growing season.

In contrast, as discussed, bare land generates no carbon sugars, and contributes to; flooding, soil erosion, land degradation, soil heating, risk of drought, soils-carbon loss, rising atmospheric and oceanic carbon dioxide, and climate change generally.

Fig. 20. 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)

METABOLIC WATER

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, 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 fats and proteins. The issue is considered in more detail in a separate section below, but raised here as an overview, due to the importance, and lack of appreciation of the topic, even in agricultural circles. 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, which carbon in turn, in the darkness of the soil, they respire to supply the energy soil residents need to exist. Respiration by bacteria, mycorrhiza, and other soil life in turn 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 photo-synthetically 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 is enormous. Thus, the amounts of metabolic water produced must be vast, given 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 net 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 and water tied up in deceased or dying organic living structures, including humans.

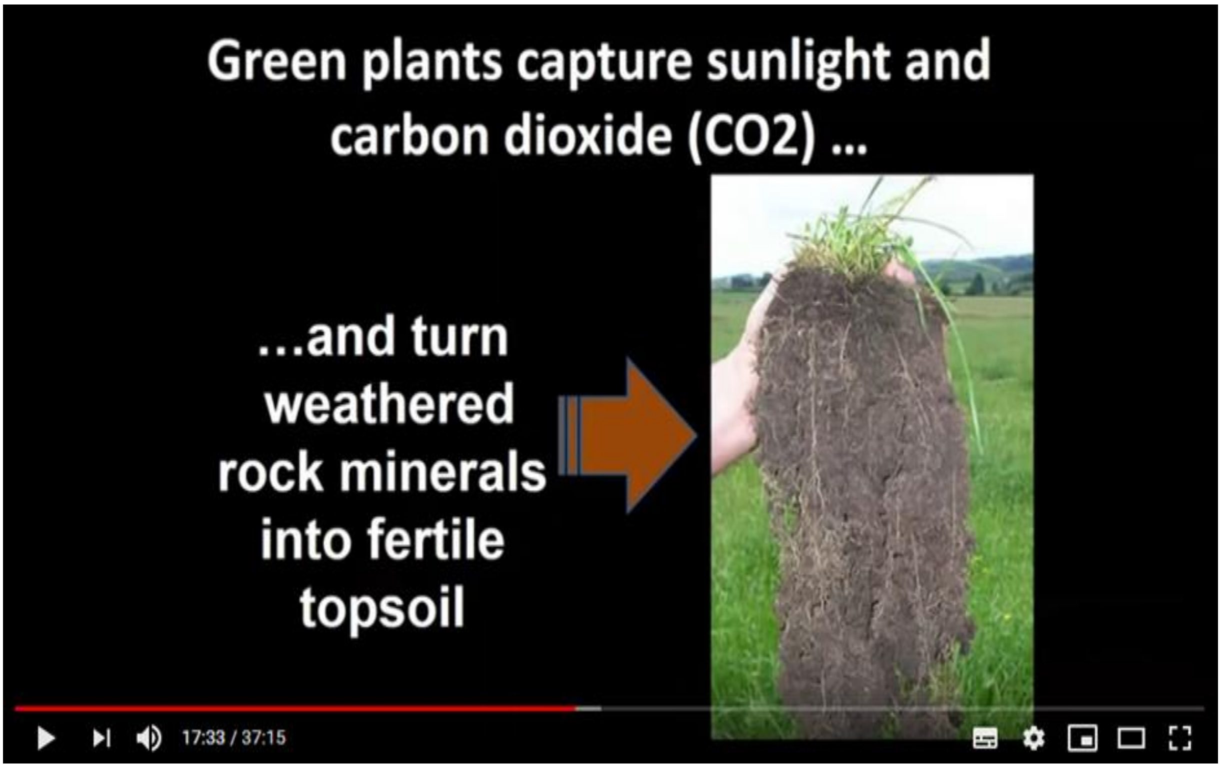
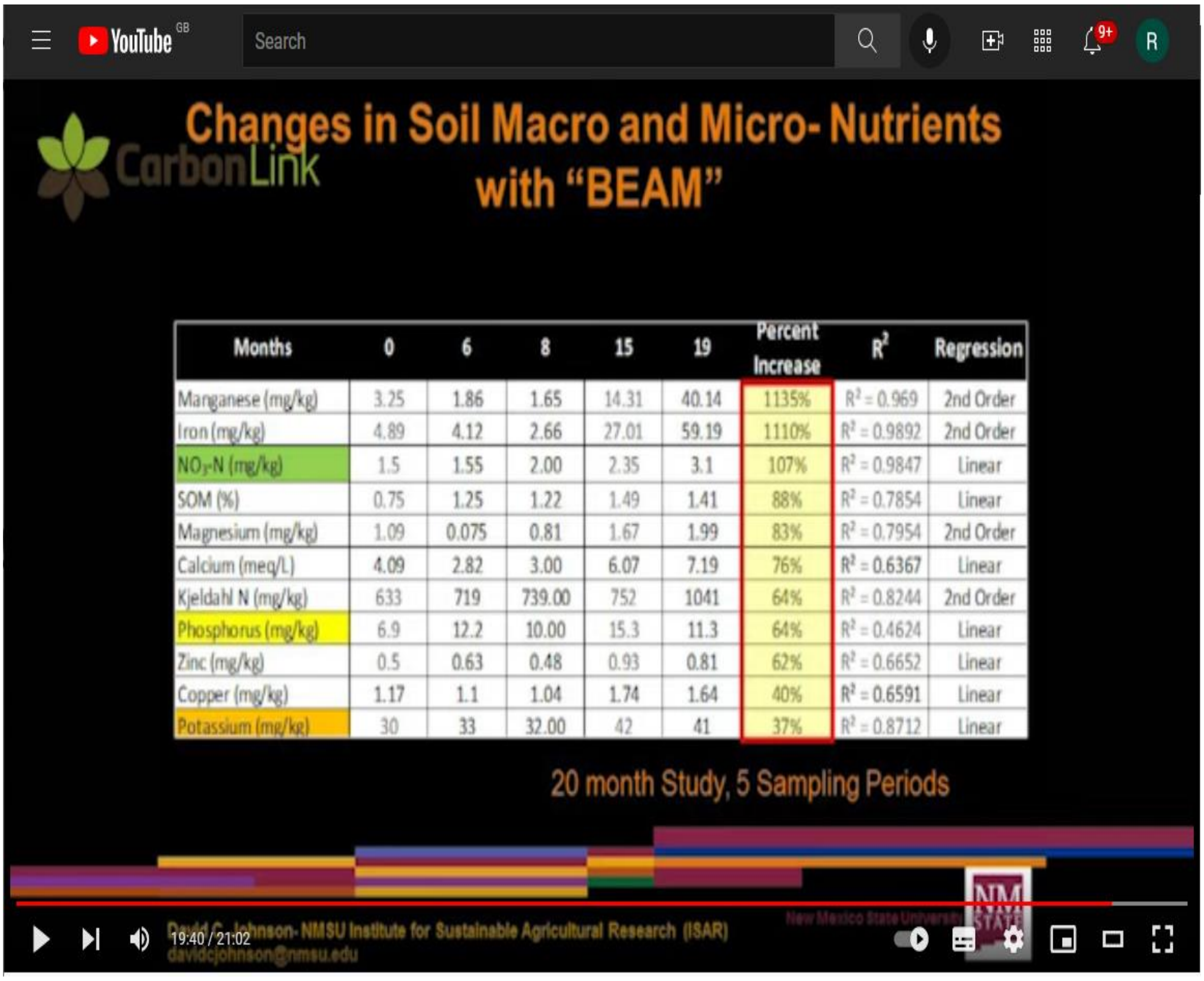


Fig. 21. Dr Christine Jones – '*Building New Topsoil Through The Liquid Carbon Pathway*', with very many thanks to the author. (Jones, n. d.-a)

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 grass lands, 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.

IMPROVED PLANT HEALTH, GROWTH, AND MINERAL AVAILABILITY, THROUGH PROVISION OF ASSISTIVE, BIOLOGY RICH, COMPOST EXTRACT

Importantly, both soil carbon, and atmospheric oxygen, originated from photosynthetic metabolism of carbon dioxide. Thus, whilst the Earth's Gaian biosphere is intact and functioning, carbon dioxide, oxygen, and molecular carbon in, plants, bacterial, fungi, and related life forms, will continue to be cycled, supporting and enabling the essential Gaian life sustaining ecosystem in the process.



Months	0	6	8	15	19	Percent Increase	R^2	Regression
Manganese (mg/kg)	3.25	1.86	1.65	14.31	40.14	1135%	R^2 = 0.969	2nd Order
Iron (mg/kg)	4.89	4.12	2.66	27.01	59.19	1110%	R^2 = 0.9892	2nd Order
NO_3-N (mg/kg)	1.5	1.55	2.00	2.35	3.1	107%	R^2 = 0.9847	Linear
SOM (%)	0.75	1.25	1.22	1.49	1.41	88%	R^2 = 0.7854	Linear
Magnesium (mg/kg)	1.09	0.075	0.81	1.67	1.99	83%	R^2 = 0.7954	2nd Order
Calcium (meq/L)	4.09	2.82	3.00	6.07	7.19	76%	R^2 = 0.6367	Linear
Kjeldahl N (mg/kg)	633	719	739.00	752	1041	64%	R^2 = 0.8244	2nd Order
Phosphorus (mg/kg)	6.9	12.2	10.00	15.3	11.3	64%	R^2 = 0.4624	Linear
Zinc (mg/kg)	0.5	0.63	0.48	0.93	0.81	62%	R^2 = 0.6652	Linear
Copper (mg/kg)	1.17	1.1	1.04	1.74	1.64	40%	R^2 = 0.6591	Linear
Potassium (mg/kg)	30	33	32.00	42	41	37%	R^2 = 0.8712	Linear

Fig. 22. 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).

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 Michael Howard in the 1930s, who found that application of modest amounts of quality compost (The Indore Process) greatly improved plant health and yields.

RECLAIMING DESERTS

Fig. 23. 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 details in later sections, tremendous opportunities exist to reclaim degraded farm lands including deserts, by adding the use of suitable microbiome inoculants to basic water capture and retention techniques, with in addition, inclusion of livestock where appropriate, managed using short term 'mob-grazing techniques.

EROSION AND SOIL DEGRADATION

Bare carbon depleted soils are, and always have been, very prone to erosion. Humans through ignorance and greed, have first agriculturalised, and then 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 have not learnt the lessons, still 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)

POLLUTION

Fig. 24. 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)

Industrial agrochemical-based farming is resulting in pollution and environmental damage at many levels, as discussed in more detail in the first and last sections. Run off of nitrates and phosphates is resulting in eutrophication, and in addition is wasteful of resources, including the carbon energy needed for fertiliser and agrochemical manufacture. Further, application of fertiliser produced from rock phosphates results in 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 salination is another consequence of bare land fertiliser dependent farming.

Further under the current agricultural model, chemical use is widespread. Some of the applied agrochemicals, including pesticide and herbicides remain in soils, and some end up in run off, thus waterways aquifers and oceans. In the short-term, agrochemicals kill thus damage the soil biome to varying extents, and are clearly a part of the processes degrading soil biology, sustainability and carbon levels. They also reduce biodiversity including, pollinators, soil cultivators and conditioners, beneficial prey species, and food sources for animals up the food chain, thus threaten the long-term stability of the ecosystem.

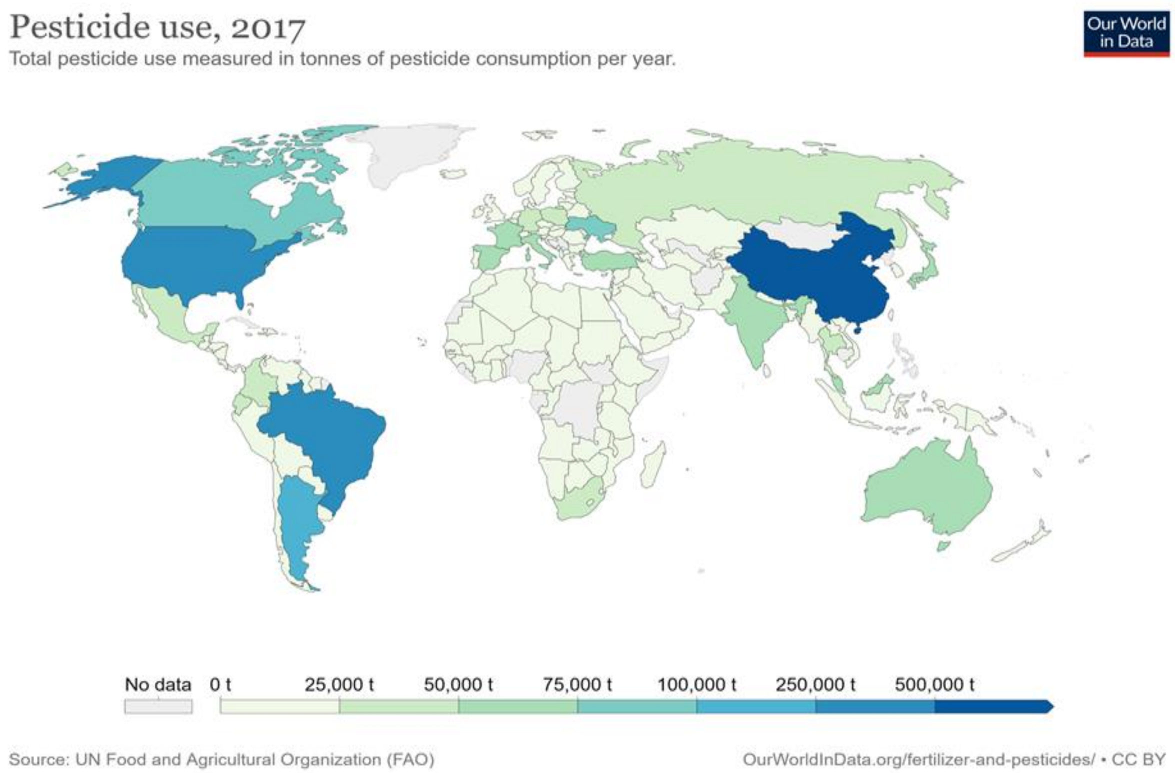


Fig. 25. FAOSTAT ANALYTICAL BRIEF 16, Pesticides use Global, regional and country trends 1990–2018, with many thanks to the authors. (FAO, 2021)

The wider longer-term implications of agrochemical pollution of the land environment, as well as on oceans, and living creatures including humans, are not clear, but are clearly not beneficial. The good news is that regenerative farmers are achieving equivalent average yields, better profits, improved biodiversity, reducing pollution, and finding they rarely need to use agrochemicals.

DRAW DOWN 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 over grazing, 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 agriculture is reliant on historic stored water in aquifers. Draw down of ancient acquirers is a problem globally. Many of these deep ancient sources are not significantly replenished by natural systems, so capable of use only once. Thus, it makes great sense to optimise natural water cycles, including metabolic water production by growing plants, by working with, as against, nature including by adopting soil health centric regenerative agriculture.

Fig, 26. 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 region. The Great Manmade River is the world's largest irrigation project with abstraction estimated at 2.4 km^3 per year. With many thanks to Jaap Berk.

FOOD PRODUCTION ENERGY EFFICIENCY IS NEGATIVE

Whilst estimates vary greatly, the calorie input required to farm and process 1 calorie of food, is between 3 to 10 times greater than the actual calorie value of the food. Meat will have an even higher input ratio. Transport and processing, add further significant calorie cost. Thus, it takes many external energy calories, to produce 1 calorie on the plate, part of which is 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 7 calories, (Heinberg & Bomford, 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 for fuel, as well as in nitrogen and rock phosphate-based fertiliser production costs.

Wider reduction of food energy inputs including for livestock related products, will require social debate and significant change. Energy and wider environmental considerations for livestock raised on marginal land, and where integrated into regenerative agriculture, are more complex and nuanced than for livestock raised on industrial facilities. Nutrient value, also needs factoring into environmental related food debates, including for those with particular diets such as vegetarians and vegans.

Vegans on a wide and varied nutrient rich, minimally processed diet, grown on healthy soils, such as available to historic Jains, were a healthy and greatly respected civil group. Sadly however, there are frequent reports of vegetarians and vegans, and their children, suffering from insufficiencies or deficiencies of one or a range of essential nutrients. Artificial highly processed modern diets, including meat substitutes, are not nutritionally equivalent, to those of the Jains, and 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;) particularly when used as staples, and may not optimally supply all necessary nutrients

RURAL POPULATIONS, SOCIETAL IMPACTS AND URBANISATION

There is a real danger of further decline of rural communities (Parton, Gutmann, & Ojima, 2007). Regenerative agriculture has the capacity to encourage and support the retention of small farms, 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 important for a host of reasons.

ESSENTIAL TO MITIGATING CLIMATE CHANGE

Without adoption of a regenerative agriculture approach to soils, as part of the climate package, we are very unlikely to be able to halt climate change. Human hubris, reluctance to keep an open mind, 'corruptibility', sometimes lemming-like tendencies, our need to belong, so 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 wider 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 basic resources including food and water.

Realistically, there is considerable economic capital, employment, income generation potential, and human 'pride', 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. Albeit a move to regenerative agriculture is essential if we are to have any realistic hope of addressing the climate change issues that face us.

There is an alternative to possible extinction; a global move to regenerative agriculture, but it will take considerable leadership, wisdom, and corporate foresight, to drive the very necessary, not always straightforward, but relatively simple and painless, change to regenerative agriculture, with its multiple planetary ecosystem and human health benefits.

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 the opportunity to determine our own evolutionary, including cyborg future, we remain, and unavoidably are part of, and currently ultimately totally dependent on; an enormously complex web, that facilitates a life supporting biosphere. However, we rarely sufficiently consider the impact of our actions on the wider ecological 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 interlinked processes, are all fundamental to 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 planet functioned, but we no longer have that excuse.

More widely, adoption of better farming methods, are central to the long-term sustainability of commercial agriculture, as well as to improving the nutrient density and quality of foods, and thus ultimately the neurological and wider heath of those that depend on those food nutrients. Cells have evolved in the presence and availability of a basket of essential nutrients, and thus insufficiency of any one of those nutrients inevitably compromises cellular thus human function.

Given 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, has fundamental implications for our biosphere, including, and crucially, factoring in regulation of: biodiversity, climate change including, warming, drought, and extreme weather events. We ignore the functional parameters of the earth’s natural Gaian regulatory systems, required for maintenance of a healthy biosphere, at our peril.

IT’S ALL IN THE SOIL – Geology + Biology + Atmosphere = Soil

‘SOIL BIOME’ = MYCORRHIZA + BACTERIA + LIFE FORMS

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.

Ultimately, without; the minerals that make up ‘geology’; biology; and air between soil particles; there is no soil, or more importantly no soil biome, or dependent plants, to help regulate; planetary atmospheric carbon dioxide, oxygen levels, rain fall, and climate including temperature, and manufacture the photosynthetic carbon sugars that underlie sophisticated life.

Yes, plants can grow without soil in human created hydroponic, all essential nutrient providing, including nitrates, media, but hydroponic solutions and delivery systems do not exist in nature.

In nature, soil biomes interact with root structures, and mineral dust, together binding and forming water retentive structures, helping preventing; erosion, run off and flooding, as well as improving; drought resistance, local microclimates, regional hydrology and weather.

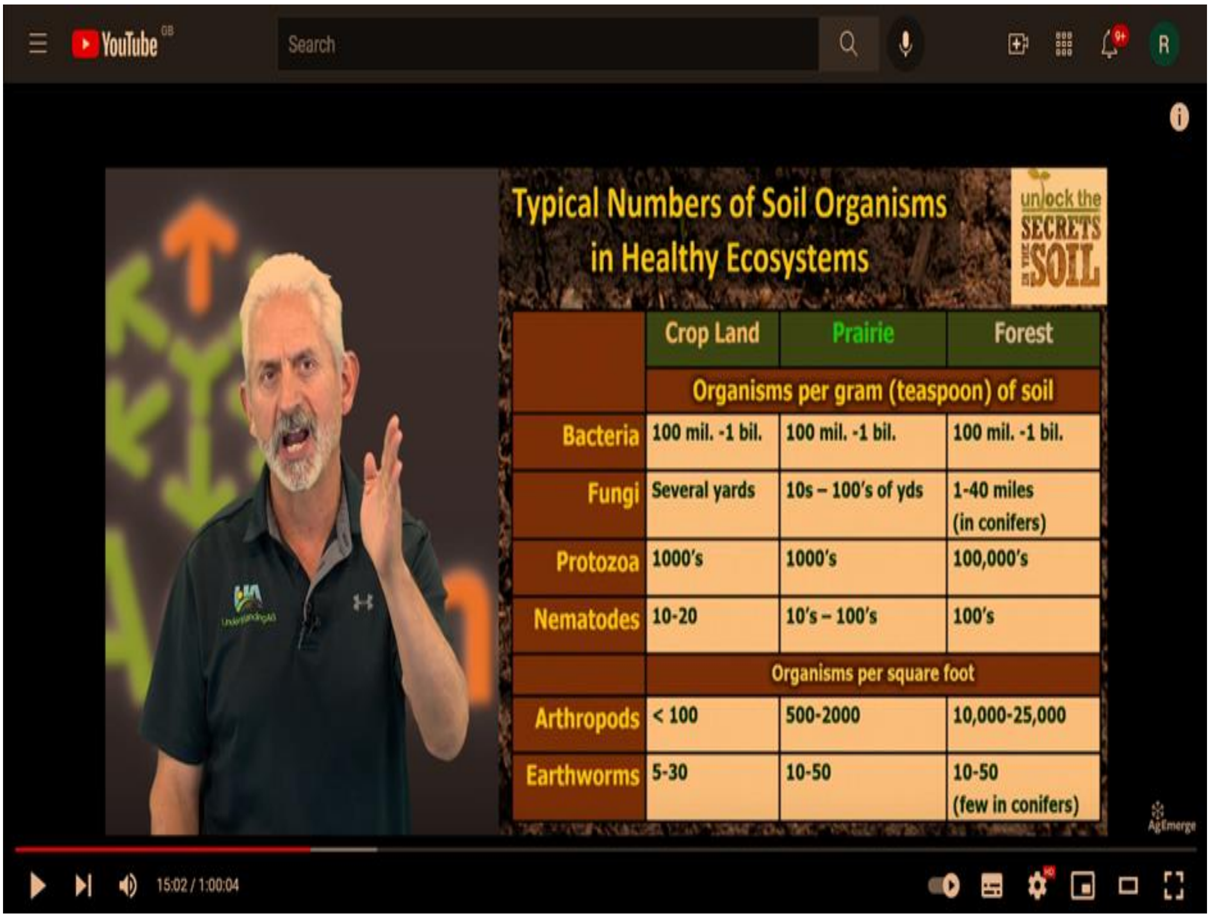
Soil biome metabolic water production, decaying and dead matter, plus layered, living and dead plant growth on the soil surface, together create both a microclimate, and physical barrier, that protect soils including against; excess heat, water loss, and crusting due to rain compaction.

Living plant material shades, shelters, and respires 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, and the carbon and other nutrients are recycled. Thus, soil life forms assist recycling and redistribution, as well as breaking up soils, and at the same time creating passages for water, air, roots, and soil life generally.

Whilst dead plant material supplies some soil carbon, the primary source of carbon in soils, is plant supplied photosynthetic sunlight derived carbon sugar 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. Soil stored carbon, through continued soil biome respiration, and consequent metabolic water production, helps symbiotically ensure, both plants and their soil symbionts flourish as best they can, even in difficult growing conditions.

Importantly and often not appreciated, absent human intervention with fertilisers, plants are, and always have been, totally dependent on nitrates supplied by soil bacteria, and in large part on minerals mined and transported by fungal networks. The role of mycorrhiza in mineral transport is experimentally evidenced. For example, it was shown plants receive very different amounts of radioactive labelled phosphates, from a compartment outside the root zone, depending on the variety of fungus present. "*The hyphal uptake of 32P* (Radiolabelled phosphate) *from the HC* (lateral root-free compartment) *increased as follows –S. calospora ≥ Glomus sp. ≥G. caledonium. The uptake of 32P from the HC was equivalent to 7, 21 and 109 % of the uptake of 33P from the RHC* (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 & Jackobsen, 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 diversity of soil life that we are only at the beginning of understanding as to how soils function. What is clear is that diversity greatly improves soil function and capacity to support plants.



	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. 27. A slide from the UTube video '2021 AgEmerge Breakout Session with Ray Archuleta, with very many thanks to the authors. (Archuleta, 2021a)

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, which includes ones we rely on for food. Fungi and bacteria are both essential for healthy plant growth, through overlapping but different ratios of fungal and bacterial soil services. Fungi require more carbon and bacteria more nitrogen, thus as the fungal bacterial ratio changes. so does the soil's capacity to support plants with different nutrient demands.

Thus, healthy plants require a healthy soil biome and visa-versa. Further wider soil life, such as worms and dung beetles, provide a huge range of free eco-services, including soil rotation, aeration, and fertilisation, often involving moving huge tonnages of soil per hectare. Maintaining healthy agricultural plants and soils requires diversity, with human comprehension, understanding and respect, for the fundamental importance of its sophisticated biology.

SOIL CREATURES

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 useful to plants; and 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. 28. 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)

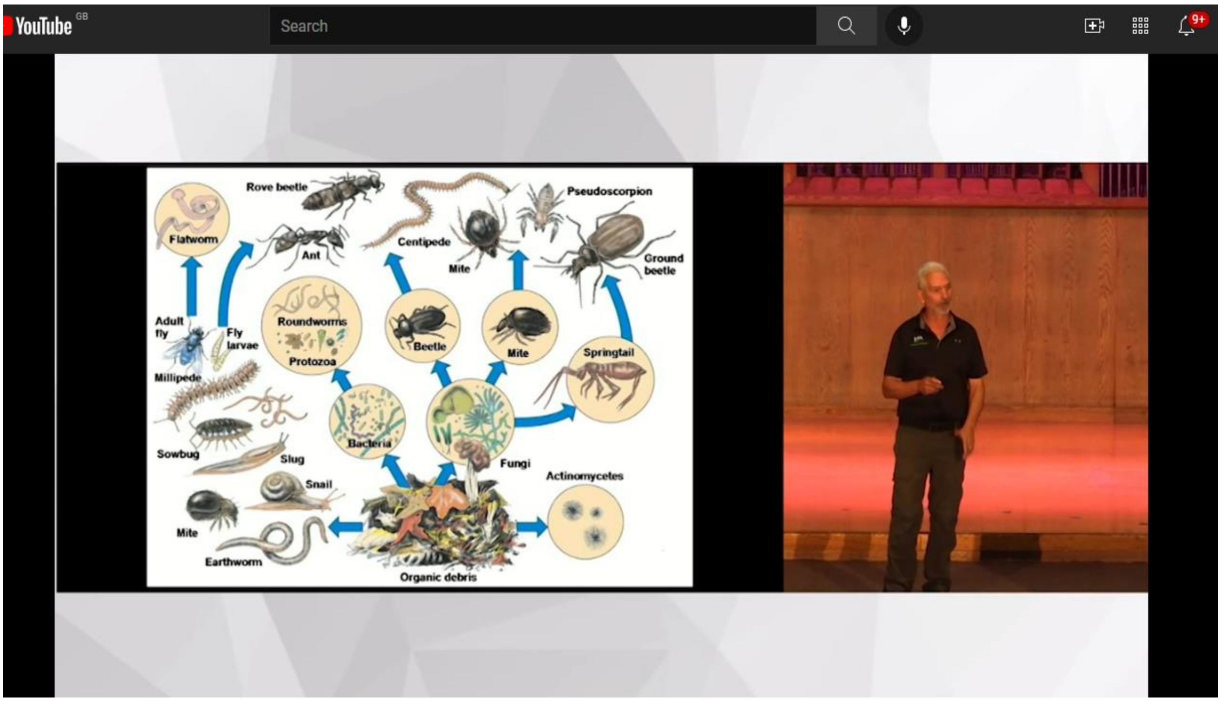


Fig. 29. A slide from the UTube lecture '*Regenerative Agriculture Healing The World*' - By Ray Archuleta @ Carbon Summit: Importance of "*oneness and connectedness*" with very many thanks to the authors. (Archuleta, 2021b)

DEFINING SOIL CARBON

Given there is no one accepted term I am aware of, to describe conglomerate soil biology, I often use the term 'soil biome' to encompass all soil biology including, mycorrhiza, bacteria, and other soil life forms. In terms of an overview of wider soil function and health, the elements of the 'soil biome' are intimately bound and connected, that it makes no sense to constantly refer to them all separately, albeit at a more detailed level soil biology varies greatly.

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, Jones, & Cutler, 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, Jones, & Cutler, 2021)

Organic matter will be added to the soil biome in a number of 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 soil, and
- Human, livestock, and wildlife application of organic matter and manures.

'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 – referred to as 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).

Albeit the report also makes the point 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).

The importance of carbon sugar exudates, in-soil growth, and the soil biome is made by the fact 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, Jones, & Cutler, 2021), which again brings us back to the fundamental role of the carbon in plant sugar exudates to; the creation of the soil biome structure; the provision of the energy substrates that support of the soil biome, and the consequent capacity of in-soil carbon sources to contribute to soil carbon stocks to a greater extent than above ground biomass.

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 not an easy task, and is further complicated by a host of factors, including a lack of consistent use of comparative descriptive terminology.

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 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 at 0-30cm, to 2,300 at a soil depth tranche of 0-300cm (FAO, 2017). The wide range of outcomes, makes the point it is important to be mindful of the need for definition of the basis of measurement, and the uncertainties, when considering reports and debates on soil carbon.

A key problem is the very loose definition and use of the term soil carbon, when in general use, and even where defined, is difficult to measure. Further, soil carbon is also measured by reference to a variety of soil depth profiles. As a result, depending on the criteria used, soil surveys, even of the same regions, can produce very different figures. It is thus difficult to even establish with certainty, regional base-line figures for soil carbon, and even more difficult to estimate global carbon stocks.

To organic carbon can be added inorganic carbon, including for examples carbonates. Inorganic carbon can be removed by acids. Organic carbon can be removed by combustion. The percentage of carbon by soil weight will vary based on the moisture content of the soil, thus to provide greater consistency of results, for some tests, the soils are dried before testing. Thus, acid and combustion (with or without soil desiccation) can be used to determine the amounts of the inorganic and organic carbon in a soil test core sample, which test samples may be anything from 10cm to a meter deep, with some looking 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, to accelerate and make measurement easier, but which are likely to pose their own issues.

Issues in; defining, measuring, and comparing, soil carbon levels include:

- Differing soil core depths are used, varying between 10cm 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. Drying of soils produces different percentages to consideration of undried soils.
- Types of carbon included vary; some include all undecomposed organic detritus; some restrict according to size. Some include bound carbon such as soil carbonates.
- Soils types and composition will vary, including the density, granularity and size of particles present, such as gravel and rocks etc, altering the interstitial capacity to integrate organic matter.

In thinking about what soil carbon figures, tonnages per unit area, or percentages, represent, it is helpful to be aware of 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 – 2,000 tons. Thus, an acre to the depth of 90cm (36 inches) contains around 6,000 – 12,000 tons of material.

A proportion of this will be water and soil organic matter. Water content will be dependent on the water infiltration and carbon-related water retention capacity of the soil, as well as the amount of rain received and how recent.

Based on the above figures, an acre of soil to a depth of 90cm containing one percent carbon will therefor contain between 60 and 120 tons of carbon. Soil carbon percentage vary greatly. Pre FATBAS some suggest agricultural lands may have contained 10% carbon – 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. It is unquestionable that soil carbon has fallen, and loss of just a percentage or two per acre, globally, represents a huge amount; 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 calculation of those estimates.

Thus, there is significant opportunity to sequester carbon by both using regenerative agriculture techniques and optimising the photosynthetic potential of every acre of land. A successful crop can generate several tons of organic matter, when the roots, stems and leaves, and crop seeds are taken into account. In addition, during the growing of the crop the subsoil biome likely increased its mass as well. By growing more than one crop, and in particular cover crops, the carbon returned to the soil, compared to mono-crops and bare ground, is greatly increased, thus it would appear entirely feasible to sequester a ton or more of soil carbon per acre per year, which if achieved globally, would significantly contribute to mitigating annual atmospheric carbon dioxide increase due to fossil fuels (around 10GT annually of carbon, which is about 37GT of carbon dioxide – oxygen is heavier than carbon, and each carbon dioxide molecule contains two oxygen)

FACTORS IMPACTING SOIL CARBON ACCRETION

Factors impacting soil carbon accretion, are dealt with in greater detail in other sections, but in summary include;

- Sunlight is required for photosynthesis, which impacts plant growth, and sugar exudate production rate capacity. Hours and energy in incident sunlight changes with latitude and altitude. Plants only photosynthesise a portion of incident sunlight, which capacity likely varies between species.
- Seasonal weather including sunlight rain and temperature, species of crops grown, and timing of agricultural cycles of, planting, growth, harvest and fallow periods.
- The current health and related structure, including drainage, and carbon status thus moisture and metabolic water capacity, of the soil will impact its capacity to accrete carbon, including by impacting plant growth via accessibility to water, fungal and bacterial mined essential minerals including phosphates, bacterial produced nitrates, and assistive plant soil biome interactions and wider exchanges, including modification of epigenetics.

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 provision of carbon sugar exudate to soils by plants and speeds soil metabolism of soil carbon.
- Agrochemical use – kills soil life.
- Tillage – kills soil life, destroys water and air channels, creates soil pans.
- Failure to return organic matter – reduces soil organic matter.
- Bare soils – fails to maximise photosynthetic potential of land, causes crusting, inhibits water penetration, increases soil heating.
- Erosion – carbon and other resources are washed away.
- Temperature rises – increases soil metabolism of stored carbon, and at higher levels kills biology.

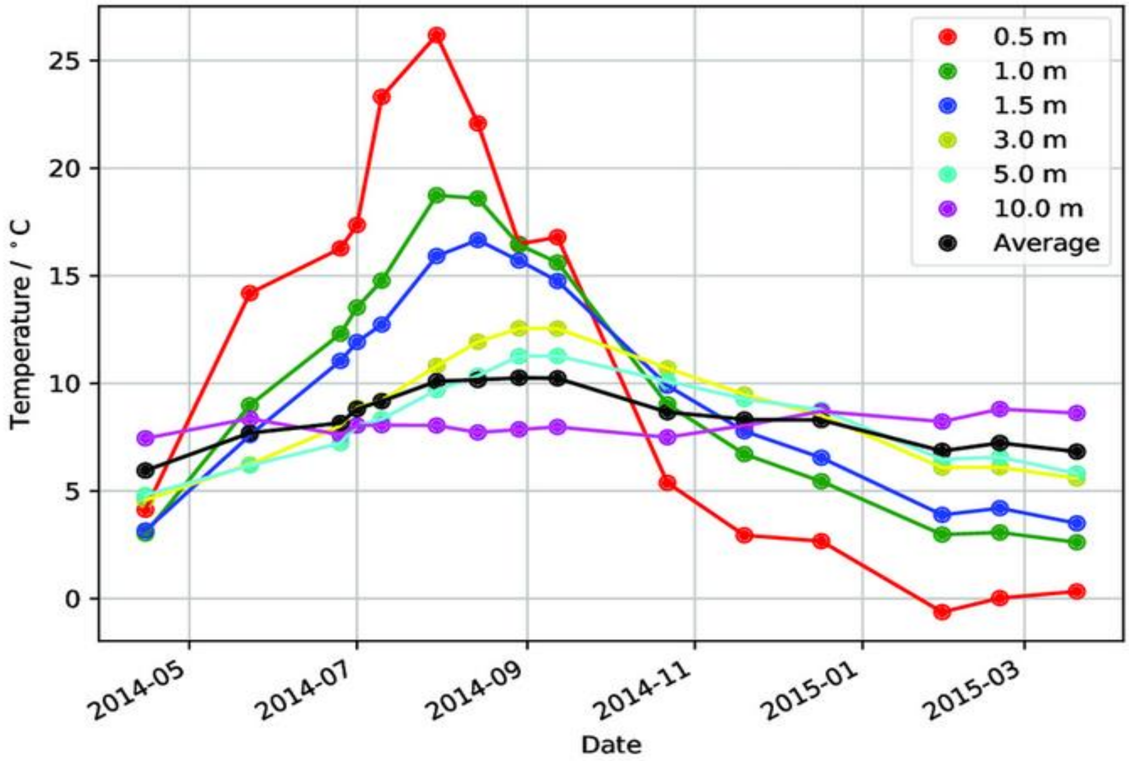
TEMPERATURE – IMPACT ON SOIL LIFE AND CARBON

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℃-35.6℃ for their activities. At a soil temperature range of 10℃-24℃, 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℃, soil macro-organisms die."* (Onwuka & Mang, 2018) The optimal growth temperatures levels will vary as community species balances change. Artic research suggested optimal temperatures for bacterial activity were between "*23.4 ± 0.5 and 34.1 ± 3.7 C*" (Rijkers *et al*., 2022). Temperature also indirectly impacts pH and soil structure (Barros, 2021). More widely, clearly a host of factors, including nutrients availability, will also impact the relative presence of particular bacterial communities.

Interestingly "*Bacterial communities in Arctic soils have a structure similar to those found in soil environments elsewhere*" (Schostag *et al*., 2015). In artic soils and related scenarios, it is suggested that bacteria can remain active well below freezing (Gadkari *et al*., 2020), and observed that relative abundance of species changed over the season: temperature, directly and indirectly, will certainly be a factor in that 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 own structural carbon content, and carbon sugar exudates, as well as 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 thus bacterial respiration, further supporting growth of carbon soil stocks. Thus, the presence of carbon in the form of soil life and plant material, and 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. 30. 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 *et al*., 2021), including particularly deep rooting plants, even more important in the quest to sequester carbon into soils for long time frames, and may help explain why very old carbon is seen in prairies where native plants and grasses can reach down several meters.

OPTIMAL GERMINATION

It is fungi and bacteria that provide the essential nutrients necessary for efficient plant growth, including mined minerals and bacterial produced nitrogen. Fungi and bacteria provide these services via the roots, in exchange, for plant produced photosynthetic carbon. Plants provided, photosynthetic sunlight energy derived carbon sugars, are the major energy substrates for the subterranean mycorrhiza, bacteria and other biology, that comprises the root enclosing, dreadlock like, ryzosheath, that in turn interact with the wider fungal bacterial soil web biome.

Most plant life starts with a seed. Access by seeds to diverse healthy fungal and bacterial biology, contained, within or on the seed, and in soil, and or applied as a biologically rich compost tea extract, give sprouting seeds early access to the fugal and bacterial biology, necessary for promoting rapid early germination, growth of a robust root system and ryzosheath, thus accelerating onward growth.

Fig. 31. *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)

This includes providing low oxygen zones necessary for nitrate production; supporting bacterial and fungal extraction of minerals; and helping both, respiratory based metabolic water production, and retention of rainwater and dew.

METABOLISED HISTORIC STORED SOIL CARBON INCREASES ATMOSPHERIC CARBON DIOXIDE

When plants are given artificial fertilisers, they reduce supply of photosynthetic sugars to soils. Bare soils self-evidently supply no photosynthetic sugars. When deprived of adequate supplies of plant supplied photosynthetic carbon sugars, by bare ground, tillage and agrochemicals, soil bacteria and fungi, are obliged to dial-down reproductive activity, and forced to 'respire' longstanding 'old' stored soil carbon 'reserves', which includes themselves, cannibalising their communities, to meet their energy needs.

Respiration of historically stored carbon, depletes the carbon-based soil biome population, and fuels production of carbon dioxide, which in turn increases atmospheric and oceanic carbon dioxide, adding to that produced by fossil fuel combustion, thus contributing further to 'climate change'.

It is not widely appreciated or understood that artificial fertilisers, agrochemicals, and bare ground dependent agriculture are contributing significantly to climate change. The magnitude of the contribution of 20th century related carbon loss from soils, to atmospheric and oceanic levels of carbon dioxide, and its impact on climate change, is likely very much larger than appreciated, as discussed in more detail in later sections.

ARTIFICIAL FERTILISER DRIVES SOIL CARBON LOSS

The advent of artificial fertilisers, in an emerging era of scientific discovery and advance, led us to naively believe the power and sophistication of our science was greater than that of nature. Despite the fact 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 synergies, that allows 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, is very bad news for the soil biome, which is easily killed by soil disturbance including ploughing, through; exposure to heat and light, desiccation, as well as by physical damage to their environment. In addition, the use of agrochemicals kills life in soils, thus further inhibiting carbon accretion.

Further and crucially, the use of NPK (nitrogen phosphorous potassium fertiliser) reduces plant supply of root exudates to the soil biome, thus likely reduces 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, thus further diminishing soil carbon content, in an inevitable downward self-reinforcing spiral, as detailed in later sections.

BARE GROUND = NO PHOTOSYNTHESIS AND NO CARBON SEQUESTRATION

As referenced above (FAO 2011) suggest arable land cover in the order of 13,963,743 square kilometres (FAO, 2011). A square kilometre is 100 hectares, thus arable land may be around 1.3 billion hectares. Approximately 50 per cent of the world's cropland is bare during any twelve-month period ('*Building New Topsoil Through The Liquid Carbon Pathway*' (Jones, n.d.-a). Thus, a substantial area of land is bare every year.

Further, but of great importance, bare ground is stark-staringly, self-evidently, devoid of plants. Thus, bare soil has no capacity to utilise incident free sunlight energy to supply photosynthetic carbon exudates to the soil biome. Instead that energy is turned into heat, drying soils and ultimately contributing to global warming.

Bare ground also results in erosion, desiccation, crusting thus reduced water infiltration-penetration, contributes to heat domes by conversion of visible and UV to infrared light and re-emission as 'heat', as well as degrading local hydrology, and increasing risk of flooding.

We recognise the dark inorganic surfaces of cities absorb light and reradiate it as heat. Hard dark mineral surfaces convert much more heat from visible light and UV, than a green landscape would emit, but for reasons that are unclear, we do not think about vast amounts of energy absorbing heat readmitting dark ground created annually by FATBAS agriculture.

This is a human-made environmentally damaging phenomenon – nature does not leave watered fertile green spaces bare. Yes, global warming is complex, but surely this is just 'common sense', within what we understand about the planetary heating mechanism, in the same way we accept sooty snow reflects less heat. (Berkley.edu nd). Ergo, FATBAS based annual between-crop bare soil, by diverting light energy that could be put into biological preocesses, into bare-soil-based infra red heat production, over billions of hecatares, is contributing to global warming.

Our love of 'tidy' bare land between crops, thus failure to optimise plant capture of incident sunlight energy for photosynthetic processing of carbon dioxide into organic carbon molecules, as well as heating the planet contributing to climate change by multiple mechanisms, leaves soil mycorrhiza, in their dark world, hungry. To meet daily energy requirements for survival, entombed soil biomes to survive, are forced to drawdown on their soil carbon reserves, and ultimately in effect eat themselves, which, together with damage by tillage, consequent light exposure, drying, soil structure disruption, and death by agrochemicals, creates a downward spiral, of; reducing soil carbon, organic matter, lower water retention, increased atmospheric and ocean carbon dioxide levels, degrading regional climates, thus ultimately significantly contributing to the patchwork of global warming climate change events.

BARE SOIL – HEATING – HEAT DOMES

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 soils 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.

Devastating wild fires were seen in 2021/2022. Undoubtedly, the heating effects of bare soils, diminished soil water storage, reduced hydrological flows, absence on bare ground of plant and soil biome transpiration, reduced soil rain infiltration, flooding, and consequent regional drying, will have contributed to these events, as considered in greater detail below.

Regenerative agriculture, crucially helps provide living and dead plant material coverings that shelter the soil surface, and lower subterranean home temperatures, for, bacteria, fungi and other life forms, which continue to be the predominant, albeit significantly diminished, lifeforms on planet Earth, despite, the albeit unintentional considerable human industrial and technological investments in destroying them.

Fig. 32. 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).

REGENERATIVE AGRICULTURE SEQUESTERS CARBON

Conversely, on the positive side, 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 conversion to heat by bare soils, and working with, rather than seeking to dominate and destroy nature, presents significant opportunities to sequester giga-tons atmospheric carbon dioxide back into soils, thus buying possibly several 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, a number of regenerative farmers, as in the graph below, 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. Soils carbon sequestration at this level over global acreages, would buy us more time to develop green energy sources, as discussed in later sections.

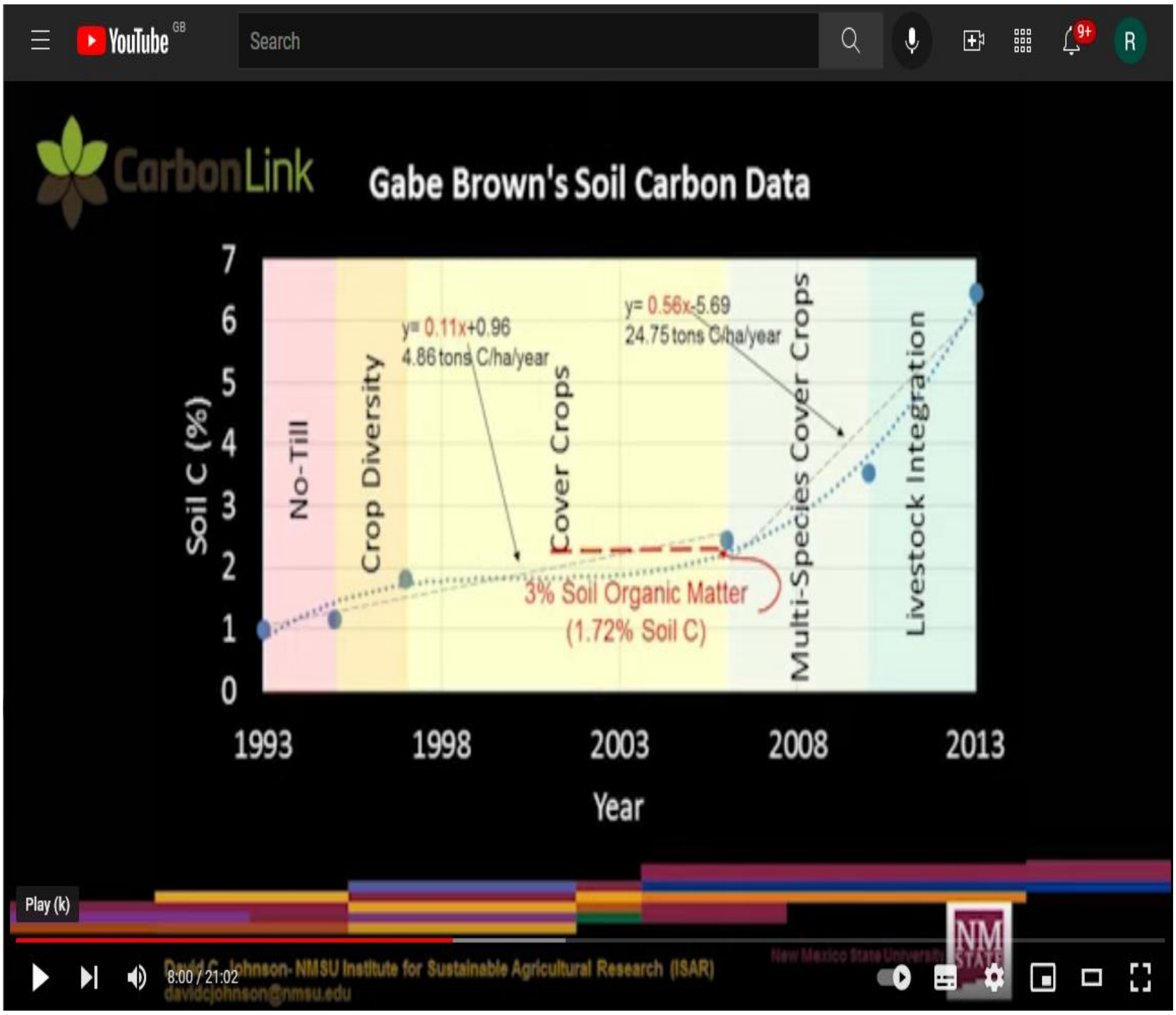


Fig.33. From video lecture by Dr David Johnson, citing independent soil carbon data history following the transition of Gabe Brown to regenerative agriculture. From *'The BEAM (Biologically Enhanced Agricultural Management') Approach*" with very many thanks to the Authors. (Johnson, 2017)

PRODUCTIVITY, AND CAPACITY TO FEED WORLD – UNITED NATIONS SUPPORT

Clearly in addition to being sustainable and profitable, any agricultural methodology adopted, must be capable of feeding the world. It was, and still is regularly stated, that without artificial fertilisers and agrochemicals, economically productive 'organic' farming, was not possible. Until recently, it was commonly portrayed that 'green' 'organic' agricultural 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.

By way of explanation, historically organic farming, focused more on avoidance of additives and agrochemicals, whilst retaining 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 capable of equalling or improving on average regional fertiliser farming based yields, by focusing on optimising soil health and biology, whilst at the same time pragmatically accepting very occasional use of agrochemicals may be, but often is not, necessary.

Regenerative farmers have, without artificial fertilisers or significant agrochemicals, achieved equivalent yields to regional averages, at the same time; producing crops with higher mineral and protein content; sequestering soil carbon; improving hydrology, and achieving multiple other benefits, as well as being more profitable, as detailed later.

Fig. 34. 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 as summarised in the slide above, cattle farmers have increased; milk yields, quality, reduced exposure of cattle to nitrates, doubled land carrying capacity, improved livestock health, and achieve premium prices for their milk and meat.

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

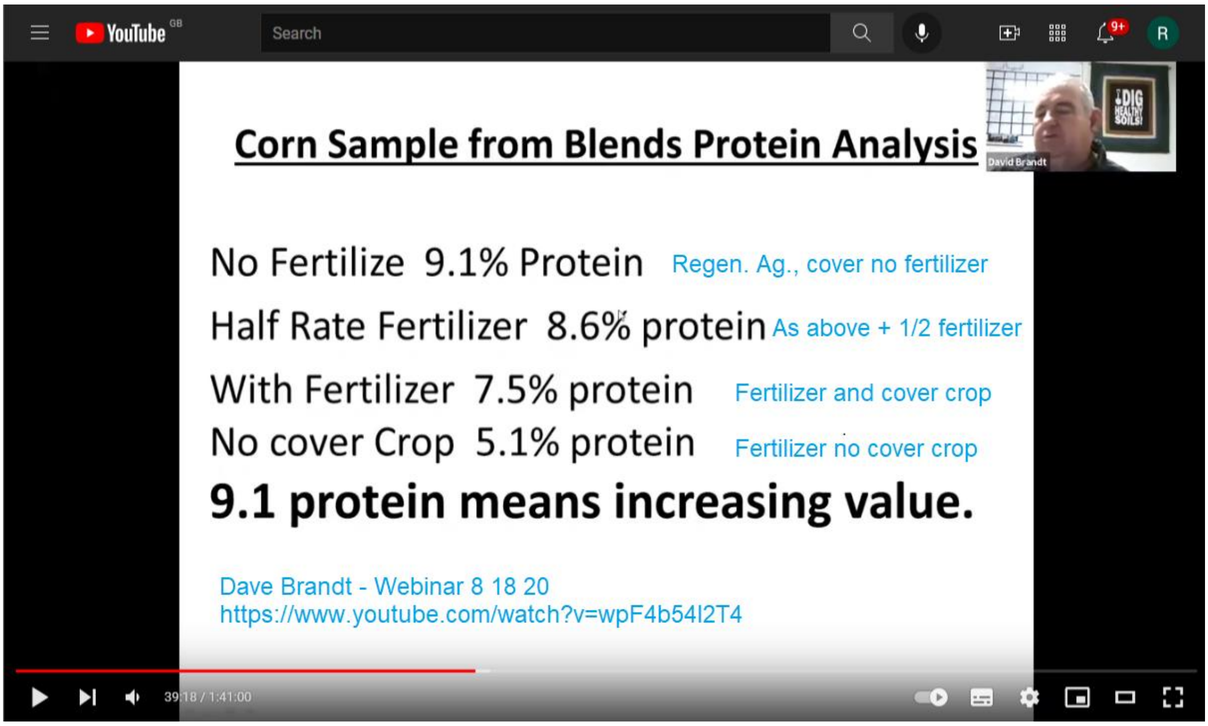


Fig. 35a. A slide from the David Brandt Webinar titled *'40 years of regenerative agriculture*' with very many thanks to the authors. (Brandt, 2020)

Moving away from the FATBAS agricultural models, and no longer restricted to the sometimes-fluffy exhortations of the woolly hated, 'organic' purists, idealists and dreamers, pragmatic regenerative agriculture has had real benefits. The include including equivalent crop yields and greater sustainability, are recognised at high level, including by the UN, but 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".*

"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 get better:

the global food demand is expected to increase by 50 percent by 2050 with 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 security and that any greatest opportunity to address our planetary crises.
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, et al. 2021)

FARMERS REPORT INCREASED PROFITS

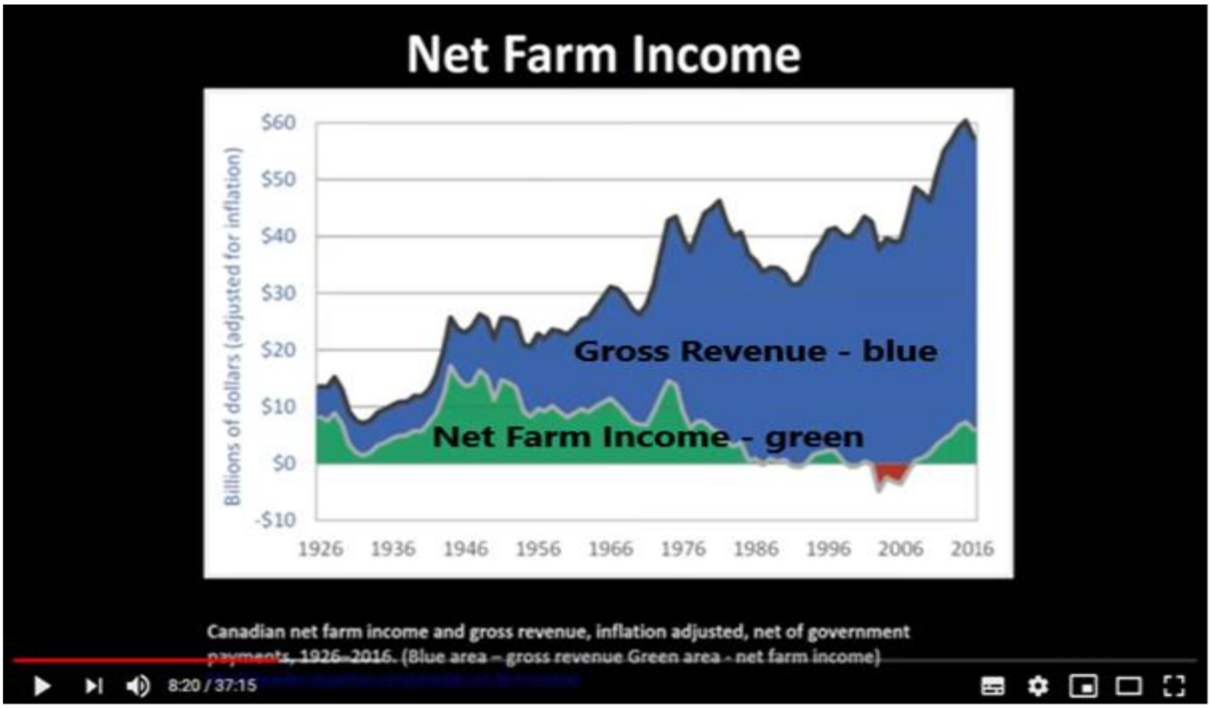


Fig. 35b. Annotated slide from lecture by Dr Christine Jones – '*Building New Topsoil Through The Liquid Carbon Pathway*' (@7.20) Conservation Tillage and Technology Conference 2019 with many thanks to the author. (Jones, n.d.-a)

Self-evidently farmers need to make a profit. FATBAS NPK / agrochemical technology dependent farming profits, are in long term decline as demonstrated by the graph above. The health of farmers is suffering, suicide levels are high, and the capacity for farms to be passed down generations is impaired. FATBAS is no longer an attractive career. Soils are being degraded, which in turn is contributing to global warming, water shortages and climate disruption. Regenerative farming addresses many of these issues but is it profitable?

The good news is regenerative 'soil-carbon-centric-farming' 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 techniques.

Farmers moving to more 'soil-carbon-centric-farming' are reporting better soils, yields, reduced inputs, diminished erosion and runoff, and crucially greater profitability. By way of examples, as set out in some of the referenced videos, Gabe Brown is making profits 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. The Cargill study, as discussed, reports many such cases of sizable farms achieving equivalent or better yields and greater profits.

In 2019, the British Magazine 'Farmers Weekly', reported '*Grower slashes inputs with focus on soils and variety blends*' (Impey, 2019). '*Farmers Weekly*' (Allison, 2019) in an article titled '*Three Canadian farmers reveal their secrets to soil health*', reported on Canadian farmers using a variety of low till cover crop farming variants. These farmers have increased yields above the regional average. Exact detail as to agrochemical and fertiliser use in not given. Yields achieved by the above Canadian farmers, are reported in the '*Farmers Weekly*' article (Allison, 2019), and have been abstracted and tabulated below. **Table. 1.**

	Denys J. t/ha	**Barlow J. t/ha**	**Brock S, and M. t/ha**	**Average Ontario t/ha**
Maize	12	8.4-9.4	12.6	10.4
Wheat	6.7	6.8	6.7	5.6
Soy	3.4	2.7	3.4	
Soil	Mostly clay loam	Heavy clay	Mostly clay loam	
Livestock	7000 pigs		600 Ewes	
Cover crop	7 species		12 species	
Manure	Manure		Manure	
Organic carbon soil condition	Better soils		3-5% since 2006 better soil	
Rotation	Cover crop after wheat	Clover intercropping with wheat	Cover crop after winter wheat	
Strips	Yes		Yes	
Other	Crops less stressed - little rain late July to the end of August.	20% yield increase with greater soil focus	Yield increase – "excess water, there are very dry spells too"	
Costs	Reduced fuel and labour £77.35 ha			
Under cultivation	800ha	1,700ha	650ha	

Conditions are stated to be; *Spring and autumn are particularly wet, which is why tile drainage is so vital for winter wheat growing. But there are periods of drought, so soil water conservation is also important.*" "*Compaction is not the only challenge – some soils are prone to water erosion and some areas near the Lake Huron can also suffer wind erosion*"

As an additional benefit, as might be expected, no till systems are reducing erosion "*Back in 1981, one-third of the cropped area in Ontario was deemed to be at high risk of soil loss. By 2017, the area had nearly halved (17%)*" (Allison, 2019).

LARGE CORPORATIONS INCREASINGLY COMMIT TO REGENERATIVE AGRICULTURE

In the last year or so, large food corporations, including millers, coffee growers, potato farmers, rice farmers and dairy companies, have committed to regenerative farming, recognising it has multi-layered potential benefits, including possible value in soil sequestered carbon, 'carbon credits', and pledged very large investments to accelerate the capability of farmers to transition to regenerative practices.

The article by Tania Strauss, (Strauss, 2023) Head, Strategy and Global Projects, Food Systems Initiative, World Economic Forum & 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. In the EU, a new Forum report on farmer-first climate strategies found that greenhouse gas (GHG) emissions could be lowered immediately by 6% a year if just one-fifth of EU farmers were supported to transition to net zero, boosting soil health and incomes by €2-9 billion." (Strauss, 2023)

There remains a lack of understanding that evidence, and on the ground experience of regenerative agriculture farmers, suggests traditional fertilisers are part of the problem rather than the solution, albeit things are clearly slowly moving forward.

Major international corporations that have committed to varying extents to regenerative agriculture, a few examples of many, not in any particular order, and at the date of this preprint, none of which I have had any relevant contact with, the recent addition of **Irish Distillers and Heineken Ireland** (Ahern 2023) include:

- **General Mills** (Mannette, 2021).
- **Cargill** – interest and aspiration (Klein, 2021a).
- **Danone** (Askew, 2021).
- **Nestle** $US 1.29 billion (Ho, 2021).

- **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).
- **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).
- **PepsiCo** (Trémolet *et al*., 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).
- **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)
- **RePlant** Capital $US 2 billion (Marquis, 2021).
- **Carlsberg** – "*Carlsberg Group plans expanded regenerative barley usage across brands in the UK, Finland and France*". (Carlsberg, 2023)

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 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.*

The announcement of intention to invest in regenerative agriculture by large international food companies, strongly signals it provides economically and technologically viable solutions capable of meeting the above challenges, including feeding the world. Governments, agroindustries, and the wider public, need on this occasion to actively support and follow the food industry, and take regenerative agriculture more seriously.

SOIL: SUMMARY

Through agriculture we have taken environmental custodial responsibility for huge amounts of the earth's most biologically productive soils. The key to optimising agriculture, and minimising its negative environmental impact, is to realise the fundamental importance of the biology of the soil, aka the 'soil biome', to plant health, better quality food; carbon sequestration, improved soil moisture retention thus; regional hydrology; temperature regulation; mitigation of heat dome risks, more widely the potential for positive climate change impact, and thus ultimately a more biodiverse sustainable future for the species.

At first sight these statements might appear overly bold, simplistic even, but this symbiotic relationship between plants and soil micro-organisms, is not only beneficial for both parties, but actually a vital regulator of ecological equilibrium of the carbon cycle (creation sequestration and respiration of organic matter), which in turn, through a number of interconnected pathways, influences hydrology, atmospherics, temperature and more widely weather, including extreme events such as drought and heat-dome-related fire risk. Effects are significant, because a huge amount of the global biomass, thus naturally accessible stored organic carbon, is to be found in the soil.

The consequences of our use of 20th-century farming methods, FATBAS, reliant on artificial fertilisers, common place use of destructive agrichemicals, and creation of bare soils between crops - without full understanding of the biological consequences - are badly degrading soil biome systems, with a raft of further negative impacts on the current, human supporting, planetary ecosystem equilibrium. Ultimately, bare soils, NPK, and agrochemical use, drive down soil carbon, degrade soil biology by multiple mechanisms, increase atmospheric carbon dioxide, and inevitably contribute to disruption of Earth's climate regulations systems, 'climate change': aka planetary ecosystem disruption.

Conversely, the use of regenerative agriculture principles, as well as maintaining fertile healthy soils, helps us produce; nutrient dense, food, feed, and healthy livestock, in an environmentally more sustainable way. Having regard to the evolutionary conditions in which plants prospered, also improves yields. Self-evidently, but in the excitement of development of 20th century technology largely hubristically ignored, working with immensely sophisticated, long-lived, and productive natural systems has to be a more rational approach, than seeking to overwhelm and work against them.

DIVERSITY AND COOPERATION IS KEY

The vast diversity of life forms in the soil biome is a crucial part of the regulation of earth's biosphere ecosystems. The mycorrhizal, bacterial, soil biome family, plays a variety of 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, normally provided by soil mycorrhizal systems, are delivered directly by human provided systems, to their roots at saturation levels, in easily 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 assistance of mycorrhizal systems.

Soil biomes are immensely complex interactive systems. Not only are mycorrhizal systems diverse, they are overall, cooperative and interconnected, yet competitive. The phrase the '*world-wood web*' has been coined, to try and 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.

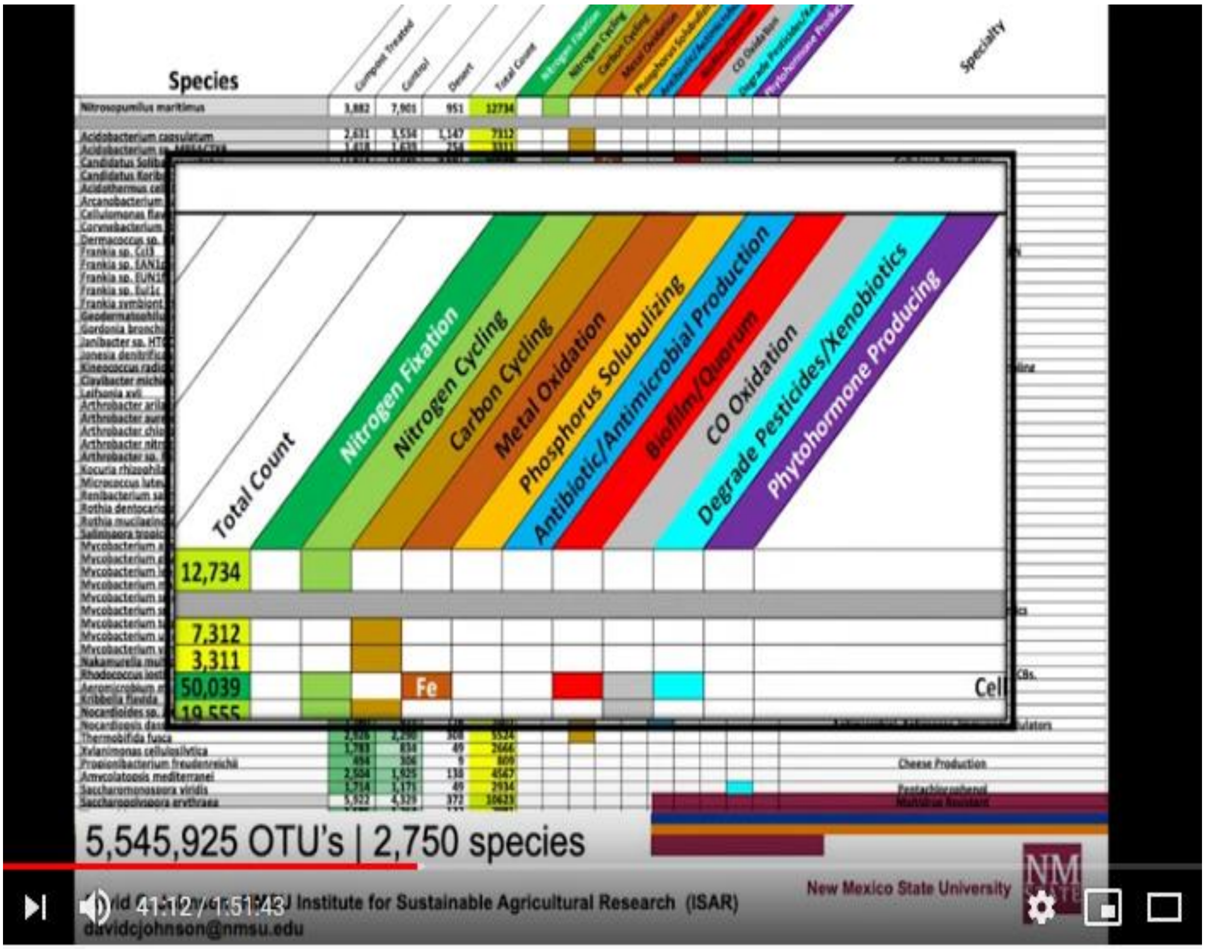


Fig. 36. Mycorrhizal systems have multiple functions, and particular microbes have their own specialities, from the UTube lecture titled '*Dr David and Hui Chun Su Composting*'. with many thanks to the authors. (Johnson & Su, 2019)

Particular species have evolved their own preferred bacterial and mycorrhizal systems, and vice versa. Plants also interact act 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, exchange of nutrients, information, interlinked soil carbon sequestration potential, the common need for, the formation of 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.

Further, species and functional diversity improves soil carbon sequestration, hydrology, and plant health and resilience generally. Consistent with this, field trials have clearly demonstrated that multi-species crops are much more drought resistant, which is logically due to increased soil carbon related water retention, and soil respiration related production of metabolic water.

Indeed, observational evidence suggests improving soil carbon content, plant cover, and diversity, will improve; crop health, disease and pest resistance, maintain yields, and improve nutritional value, including; protein, mineral, and wider biological including antioxidant value. These issues are considered in more depth in later sections.

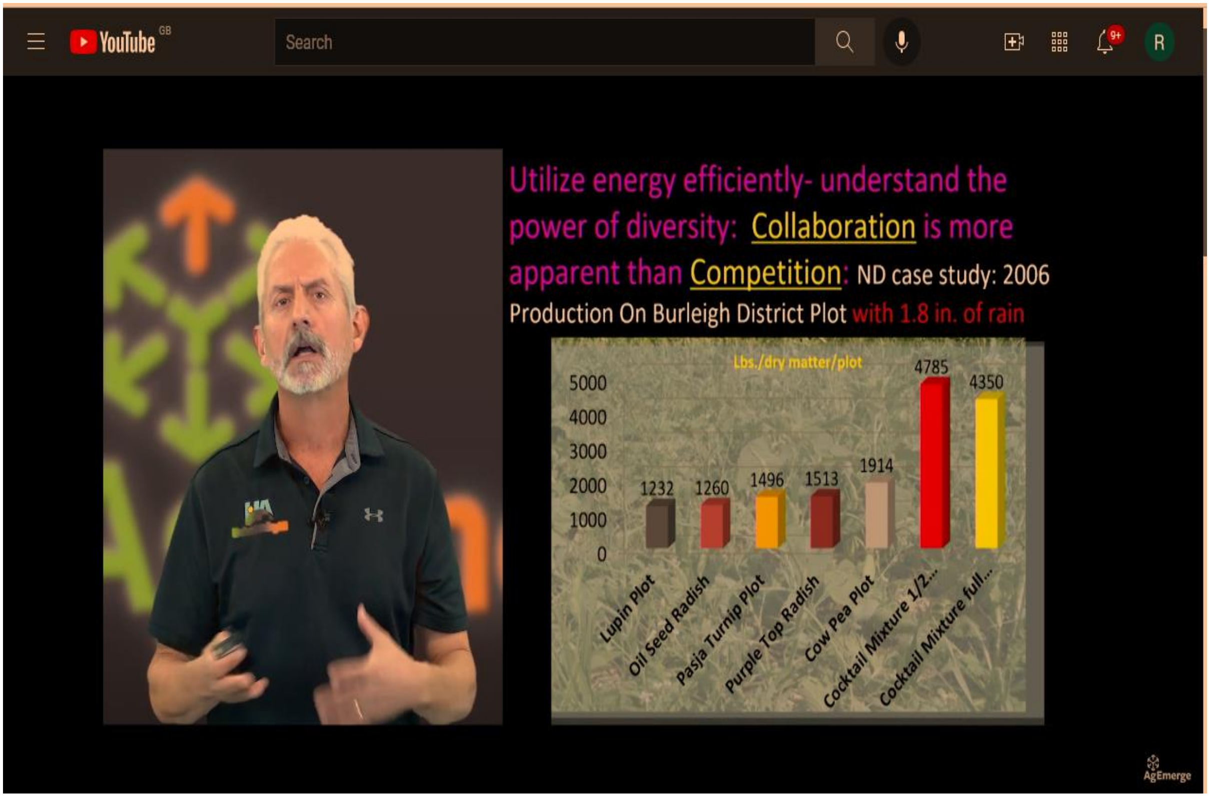


Fig. 37. Relative productivity with increasing species diversity. A slide from the UTube lecture '*Regenerative Agriculture Healing the World*' - By Ray Archuleta @ Carbon Summit, with very many thanks to the author. (Archuleta, 2021b)

Part of the reason that plant diversity in cover crops, pastures and wider environment is important to soil health, is seeds come equipped with their own species and environment related biome, to give them the best start possible in life. This in turn brings external, thus further microbial diversity to that already present in soils, and plant ecosystems. The use of bio-fertilisers, composts, and compost teas, can add further biological diversity. Conversely, agrochemicals degrade ecological diversity.

Fig. 38. 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)

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 competitive evolved optimal functioning of highly complex and sophisticated evolutionary self-regulating systems.

Diverse soil microbiomes have evolved a complex sub soil web, that have 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.

IMPORTANCE OF THE SOIL BIOME

The reasons for the importance of soil biome systems are so simple, and very obvious once grasped, but of crucial and fundamental importance. Soil biome systems, like all living things, must have access to an energy source to survive and prosper. They live in the dark, and even if they had access to light like humans, similarly cannot directly use sunlight to make molecular energy sources; thus, are reliant on plants using sunlight energy to enzymatically transform carbon dioxide into biological energy substrates including sugars (carbohydrates) and fats (including the essential polyunsaturated omega 3 and 6 fatty acids linoleic and linolenic acid).

Whilst the primary currency of the bacterial fungal / plant, carbon-trade 'market' is in plant sugars, recent research points to an important 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 fungi are getting at least some of the lipids they need from plants or plant material (Wang *et al*., 2017). This concept is supported by the presence of significant amounts of essential fatty acids in soil fungi (Kühn, Schweitzer & Ruess, 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, carbon dioxide is extracted from the atmosphere by plants, turned into organic carbon products, including plant sugars, some are used to meet the structural and energy needs of plants, and some 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 soils.

Eons 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 over millions of years developed immensely sophisticated interlinked systems to optimise their chances of survival, which includes 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 for their existence on plants for sunlight-derived carbon-based energy, lipids, carbohydrates, and wider nutrients.

Crucially, the bacteria in the soil biome also makes 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', biologic chemicals, to optimise plant health and survival, and to thus optimise mutual capacity to survive in times of limited water supply, and wider environmental stress. (Surprisingly soil microbial systems supplied the basis of many of our antibiotics.)

More simply these soil biome, phosphate miners, nitrate factories, and self-extending organised nutrient transport systems, also capable of bi-directional communication and supply regulation, could be characterised as guardian angels to plants, giving them the nutrients and medicines, they need to survive and then thrive. By 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 building understanding of 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]

'GREE~~D~~N' IS GOOD – BARE SOIL WASTES SUNLIGHT AND CANNOT 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 as far as possible keeping land green, thus, optimising photosynthesis, helps maintain and heal, rather than degrade earth's planetary ecosystems. As discussed, but worthy of restatement, when land is green, plants are using sunlight energy for photosynthesis; energy is absorbed; carbon is being sequestered; and cooling, life supporting, water is being produced. The planet's carbon regulatory systems including for; soil-moisture, atmospheric carbon dioxide-oxygen balances, temperature and weather, are functioning within the relatively stable parameters that permits life as we know it.

In contrast, - bare soil is bad. In changing natural year-round functioning ecosystems into vast areas of agricultural land, farmed using bare soil fertiliser paradigms, we render huge areas of soils bare for much of the year. As discussed, when sunlight energy falls on bare ground, soil silicates convert visible and UV light to infra-red heat, and by a variety of mechanisms that energy heats the planet. Soils are desiccated eroded and desertified. Drought, heat domes, fire and flood become more frequent and damaging.

ROLE OF SOIL FUNGI

The often-underrated importance of mycorrhizal fungal systems, to plant stress alleviation, (Diagne *et al*., 2020) including drought adaptation, to healthy productive plant growth, is more technically set out below. I quote from others, both; to fully recognise their contributions, and as pointless to try and paraphrase concise detailed specialist explanations by experts in the field.

The review '*Role of Arbuscular Mycorrhizal Fungi (AMF) in Plant Growth Regulation: Implications in Abiotic Stress Tolerance*' observes "*The fungal mycelium colonizes roots of many plants even if they belong to different species, resulting into a common mycorrhizal*

[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).

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.

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 *et al*., 2019)

Another useful summary of the importance of soil fungi, which of course are intimately linked to soil bacteria, is to be found in the review '*Role of Arbuscular Mycorrhizal Fungi in Plant Growth Regulation: Implications in Abiotic Stress Tolerance*'. "*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 *et al*., 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 et al., 2019)

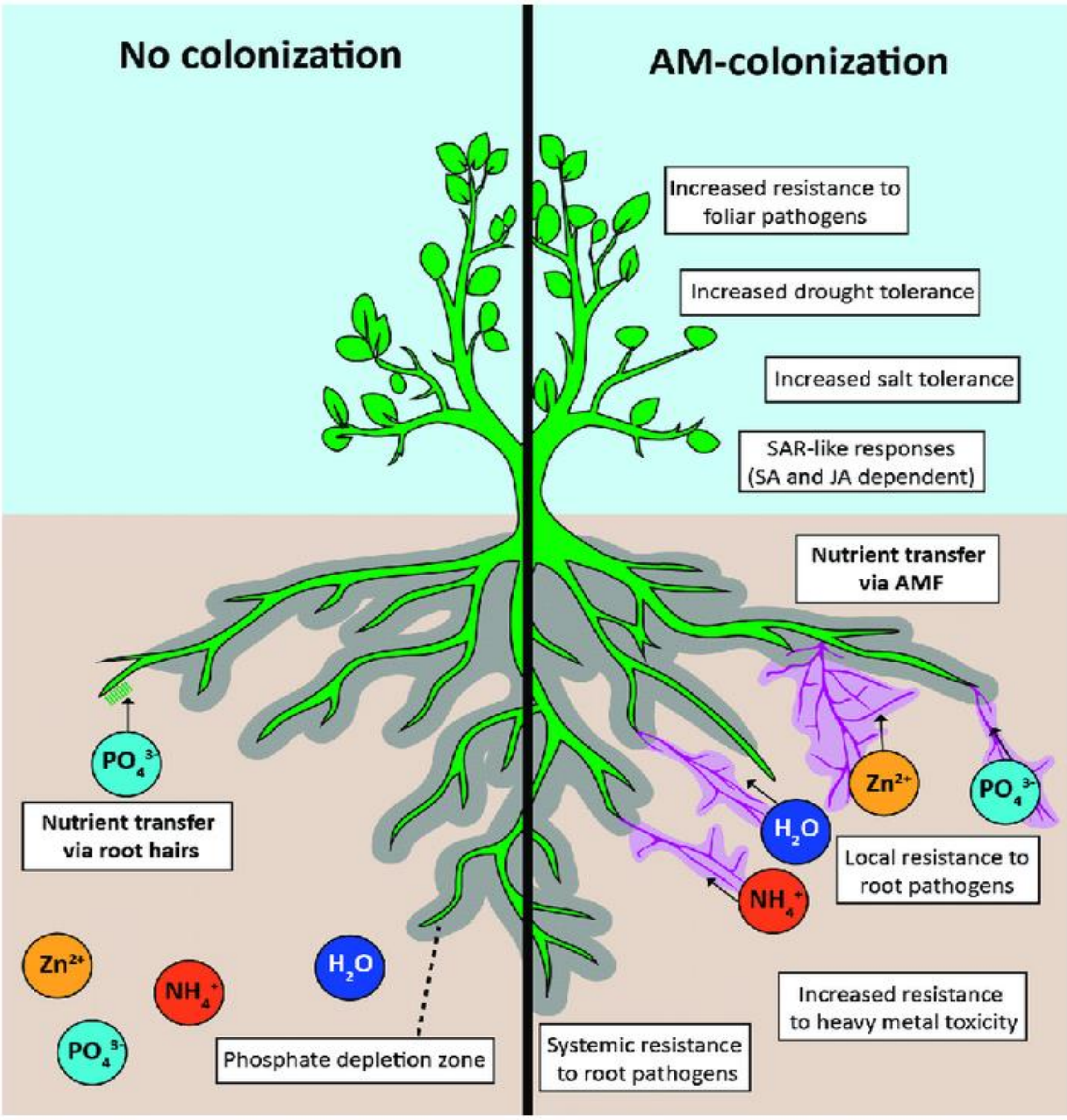


Fig. 39. A representation of mycorrhizal symbioses with, and eco-services provided to, plants in return for services, and particularly the provision of photosynthetic carbon sugar exudates by plants, with very many thanks to the authors. (Jacott, Murray & Ridout, 2017)

Ultimately, mycorrhizal interactions were key to 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, Liepold & Ambilwade, 2012).

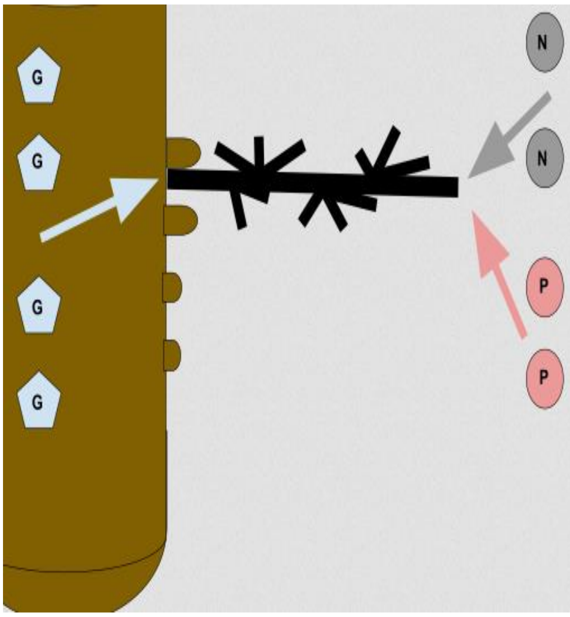


Fig. 40. *"Mutualistic Relationship Between Plants and Mycorrhiza.svg"* With many thanks to Wikimedia and author Ussyprne18. (Wikipedia 2023a)

"*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)

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 wider 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 exchange of bacteria between plant tissues and the soil biome. Bacteria can modify epigenetic responses, including in plants in response to drought. Bacteria, and fungal spores, on and in seed, prepare them for expected growing conditions, and help provide them with the biology needed to germinate. Use of biocides inhibits the function of these important evolutionary survival pathways.

KILLING OF THE SOIL BIOME IS NO WAY FORWARD

Near ubiquitous global use of artificial fertilisers and agrochemicals, is both killing soil biomes, and accelerating mycorrhizal metabolism of stored soil carbon, by deregulating plant soil biome nitrate mineral / carbon sugar exudate exchange mechanisms, with devastating unsustainable consequences. The soil biome, left without supplies of carbon sugars, inevitably must draw down stored soil carbon, creating a downward spiral of drying, less fertile and productive, soils.

The video by farmer Gabe Brown '*Treating the Farm as an Ecosystem with Gabe Brown Part 1, The 5 Tenets of Soil Health*' (Brown, 2017b) provides a forthright and prescient perspective on current artificial fertiliser dependent farming, he observes, "*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, 2017b)

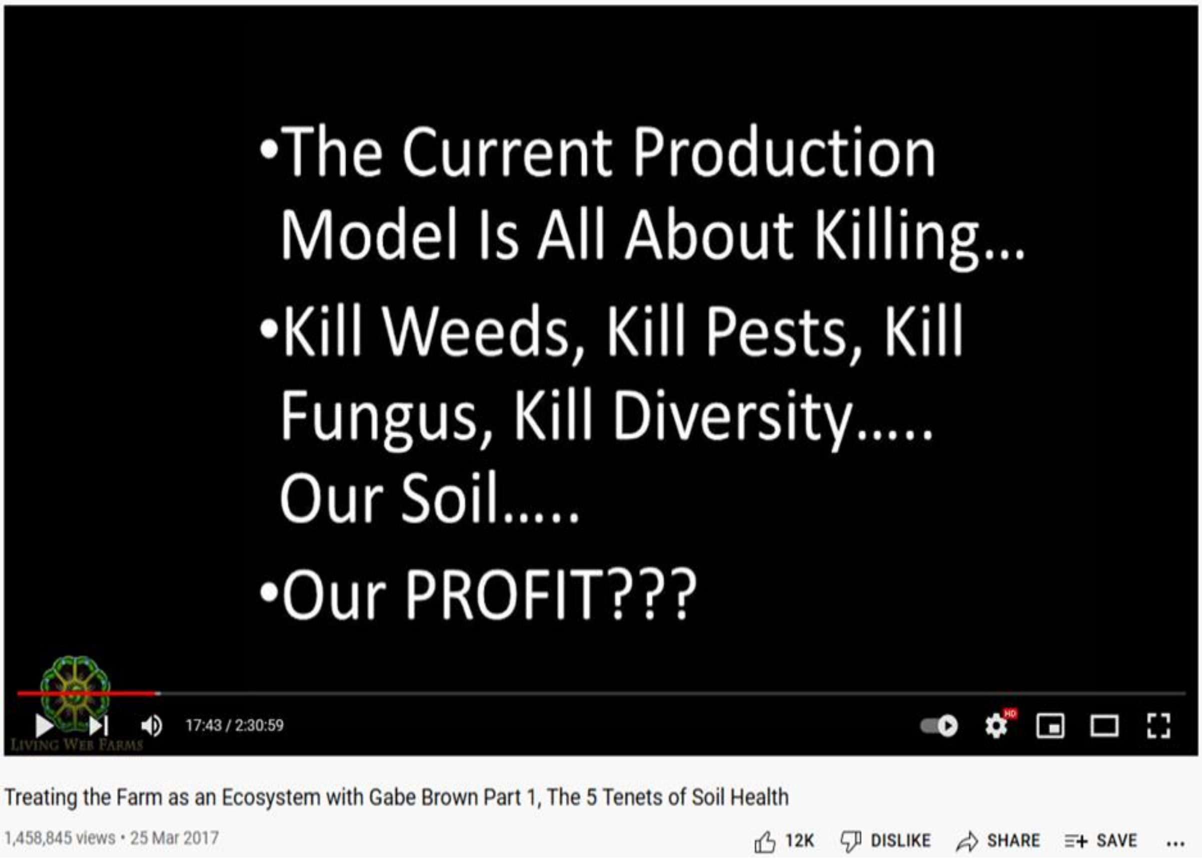


Fig. 41. From the UTube video '*Treating the Farm as an Ecosystem with Gabe Brown Part 1, The 5 Tenets of Soil Health*' by Gabe Brown with very many thanks to the author. (Brown, 2017b)

In the words of the FAO, *Soils* (the whole – author's addition) *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).

Without plant photosynthesis, and resource exchange between plants and the soil biome, soil biome systems 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, accelerating climate change, including adverse weather events, that cause erosion and run off, degraded soils, and enhanced ocean eutrophication.

Destruction, almost always due to human intervention, of fertile soil biome systems, results in 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, and more generally support plant life.

Without soil biome systems, 'soils' become just dry ground-up-rock-detritus, that re emit heat from the sun, helping fuel droughts and extreme climate events including heat domes and fires, with greatly diminished capacity to support mycorrhizae, or bacteria, thus plants.

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.''*

NPK FERTILISER - PLANT MYCORRHIZAL CARBON EXCHANGE

The discovery of industrial processes to make nitrate, and extract phosphate, thus produce fertilisers, were perceived as a new miraculous agricultural revolution, offering a brighter better future, helping farmers to cost-effectively bring 'worn-out' land back into production.

Despite encouraging early results, longer-term NPK application damages soil sustainability, carbon levels, plant productivity and health, requiring ever greater inputs including agrochemicals, and improved breeds, to try and 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, was not generally understood. In the hubristic excitement of technological discovery, and commercial rush for profitable new industries, those agronomists that 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, that is slowly being more widely understood and accepted. The problem is, 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. Reduced supply of carbon sugar exudates leads to degradation of soil biome systems, loss of interaction with plants, and reduced supply by the soil biome to plants biome of, nitrates, minerals, metabolic water and wider plant bio-support systems. Ploughing, bare soil, and 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).

There is no question phosphates and nitrates are essential to plant growth, and indeed healthy biomes have over aeons evolved to supply adequate nitrates to plants, and phosphates too, in return for plant sugars. The ground up rocks in soils, and subsoils, contain a range of minerals in varying mixes and amounts. Most soils contain adequate phosphate to last many, even hundreds or more years.

Fig. 42. 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 phosphates are an essential mineral resource, and known economic minable reserves are limited. Optimising use of supplies of phosphates for a huge variety of uses including products such as washing liquids and powders is important, and implementing regenerative soil biome optimisation farming practices, would significantly reduce immediate agricultural requirements, because healthy soil biomes are very efficient at finding, extracting, solubilising and supplying bound phosphates in soils, to plants.

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 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, nitrogen is essential to life.

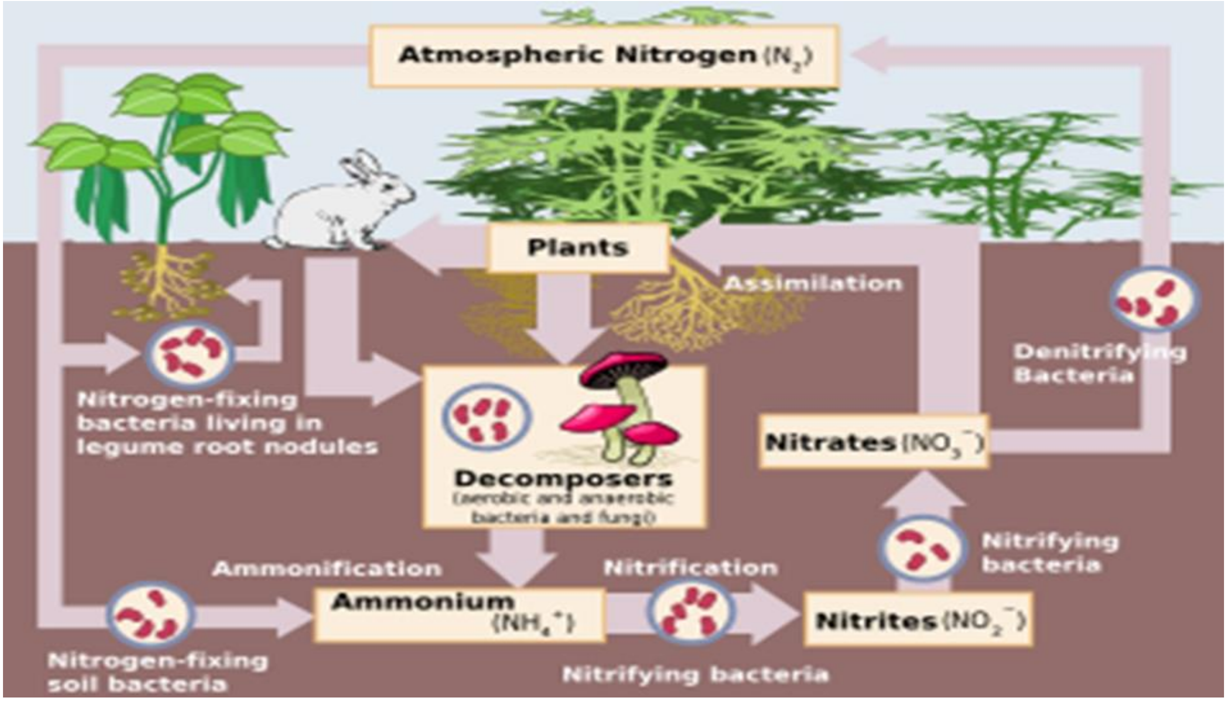


Fig. 43. Schematic representation of the nitrogen cycle. Abiotic nitrogen fixation has been omitted. With very many thanks to Wikipedia and image author Dreo J. (Wikipedia, 2022a)

Assimilable nitrogen is available from (Wagner, 2011):

- Conversion of atmospheric nitrogen by lightening (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 microbia and wider life.
- Human supply of industrially supplied 'artificial' nitrogen fertilisers.

For the avoidance of doubt, contrary to often cited 'wisdom', not only brassicas that can fix nitrogen, "*Many heterotrophic bacteria live in the soil and fix significant levels of nitrogen without the direct interaction with other organisms.*" (Wagner, S. 2011) given a low oxygen home in the mycorrhizal sheath, and a plant produced energy source of fats and sugars.

Importantly, the natural creation of nitrogen products by bacteria can only occur 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.

Thus, the creation of nitrogen products by plants and seeds (non-brassica), incapable of forming root nodules, requires both; healthy seeds and soils rich in biodiversity (and or microbial inoculation of seeds and soil, with biologically rich compost extract); and that the plants are not given artificial fertilisers, thus assisted to make rhizosheaths, and obliged to trade sugar exudates for nitrates, and minerals. As discussed, 'artificial' soluble nitrates and phosphates, switch down supply of root sugar and fat exudates by plants, to mycorrhiza.

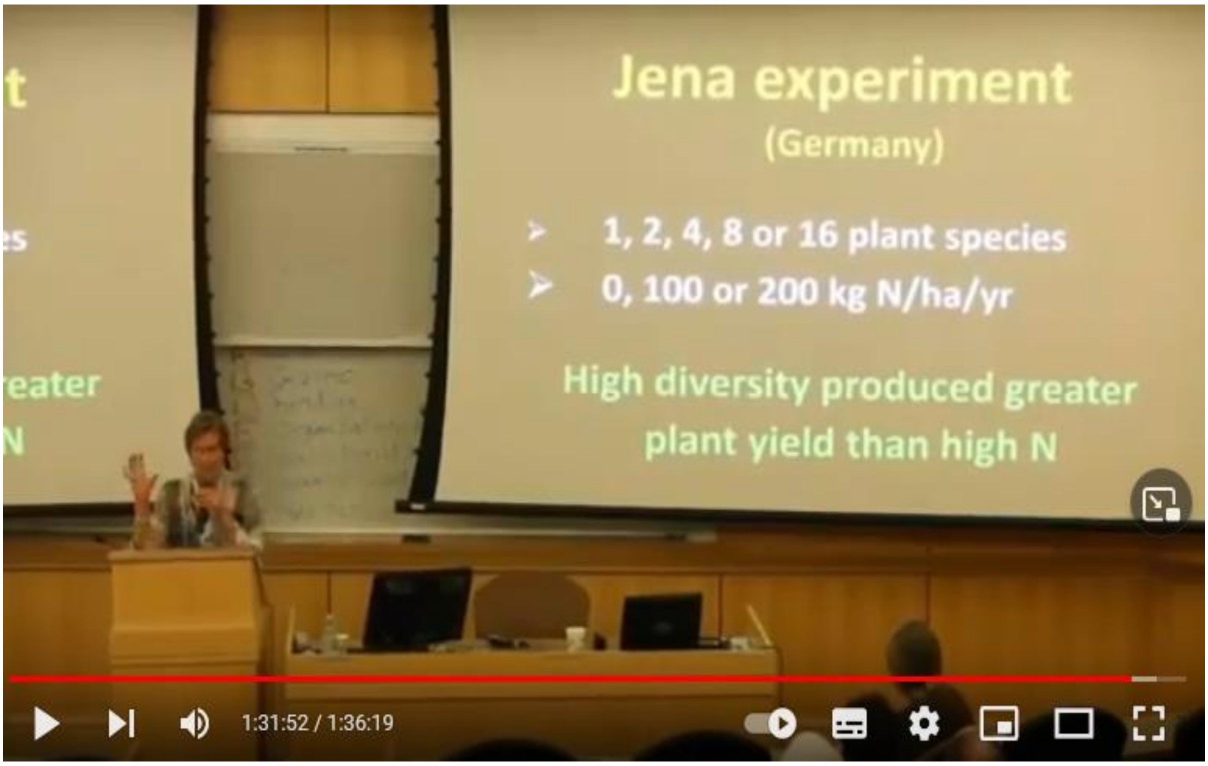


Fig. 44. Jones, PhD, Founder of '*Amazing Carbon*' (Australia) and soil ecologist – '*Nitrogen: The double-edged sword*' – With many thanks. (Jones, n.d.-b, Jones, 2018b)

Plant functional and species diversity, which contributes to the formation of healthy soil biomes, increases nitrogen fixation to nitrates. The Jena study, reported that nitrogen production increased as numbers of cover plant species rose; one species making little difference; but 16 species when combined, resulted in greatly increased nitrate productivity.

Sixteen species with no nitrogen addition, in terms of growth, outperformed addition of 0kg, 100kg or 200kg nitrogen per hectare per year with 0, 1 or 2 plant species. Dr Christine Jones in the lecture video stresses "***Species richness was the most important factor for soil carbon sequestration***" (Authors bold).

As might be expected from the relevance of a healthy soil biome, soil carbon levels are also important 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) In nature, when soil carbon is increased, it is accompanied by increased nitrogen processing capacity; both are symbiotically interlinked.

Conversely as discussed, 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 & Cotrufo, 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 & Cotrufo, 2016)

Fig. 45. 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)

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 major trading currencies if you like; between the mycorrhiza and plants. Phosphates, nitrates and magnesium, and other minerals are exchanged for plant photosynthetically produced carbon-based sugars and fats.

Nature tends to optimise resources by simplifying core systems, and until humans intervened with artificial fertilizers, 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, other minerals, as well as wider factors that support plant health.

Fig. 46. 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 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 Pi and N by plant hosts from soil. In turn, Pi and N regulate AM symbiosis.*" (Wang *et al*., 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 *et al*., 2018).

Interestingly, applications of fertilisers, to longstanding natural pastures that have achieved a natural ecological niche species balance, may upset natural plant species balances, reducing the number of plant varieties, as well as impacting the soil biome.

The paper '*Direct and indirect influences of 8 yr of nitrogen and phosphorus fertilization on Glomeromycota in an alpine meadow ecosystem*' (Liu *et al*., 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 *et al*., 2012)

Conversely application of solutions containing a wide mix of fungal spores and bacteria, as well as increasing fertility, has been observed to result in reappearance of native species in 'natural', grasslands.

MYCORRHIZA SHEATH CENTRAL TO EFFICIENT NUTRIENT EXCHANGE

The soil volume accessible by roots through which to take up soluble phosphates is limited; thus, without mycorrhizal assistance, plants rapidly deplete the area accessible to their roots of soluble phosphorous. Further surface supply of 'artificial' phosphates and nitrates, prior to seeding, and during growth, encourages shallow surface root formation to optimise uptake. Shallow roots increase reliance on external supply of nitrates and phosphates throughout the growing season, reduces access of the deeper soil biome to root supplied sugar exudates, and in addition reduces drought tolerance.

Thus, efficient abstraction, and supply to plants, of phosphorous from wider areas of soils by mycorrhizal systems is important. Whilst it is a 'relatively' 'scare' mineral in the earth's crust, "*When compared to other essential macronutrients, P* (Phosphorous) *is <u>one of the less-abundant elements in the lithosphere (0.1% of the total)</u>.* (Campos *et al*., 2018) (Authors' underline). The relative amount of phosphorous in the earth's crust, and 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 *et al*., 2018).

The extensive reach of healthy mycorrhizal systems; capacity of them 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, plants may grow better when provided with a broad based foliar mineral spray (including for example sea weed extract or possibly sea salt extraction residue).

Most Abundant Elements of Earth's Crust	Approximate % by weight	Oxide	Approximate % oxide by weight
O	46.6		
Si	27.7	SiO_2	60.6
Al	8.1	Al_2O_3	15.9
Fe	5.0	Fe as FeO	6.7
Ca	3.7	CaO	6.4
Na	2.7	Na_2O	3.1
K	2.6	K_2O	1.8
Mg	1.5	MgO	4.7
Ti	0.44	TiO_2	0.7
P	0.10	P_2O_5	0.1

Table. 2. Approximate minerals composition of the earth's crust – with thanks to the authors and Wikipedia. (Wikipedia, 2022)

Phosphates 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, Johnston & Curtin., 2008):

- *"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 not subject to run-off, 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 can be efficiently accessed by mycorrhizal systems.

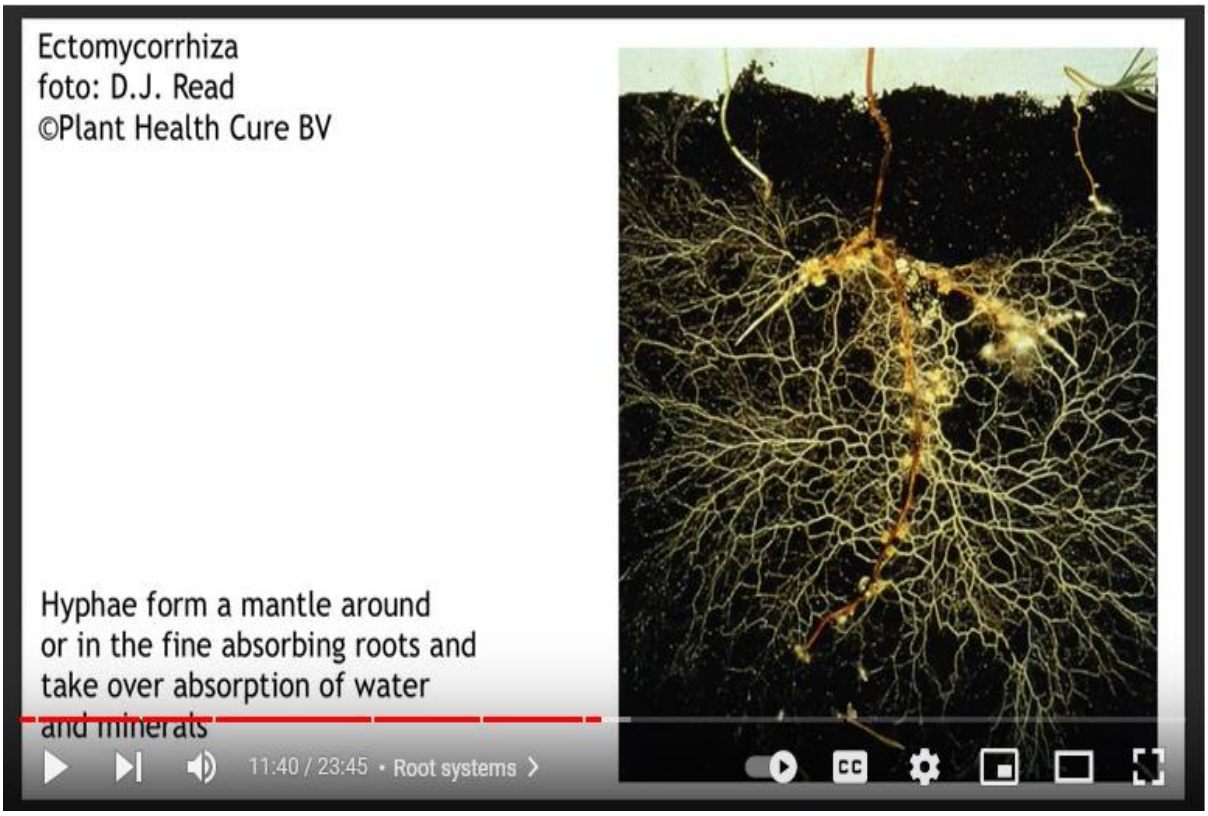


Fig. 47. Young seedling plant roots (dark brown) quickly develop mycorrhizal symbiotes (light brown) to optimise nutrient supply, helping explain why compost tea seed treatments and drip, and foliar sprays, optimise plant germination, health, and subsequent growth in poor soils. With very many thanks to the authors – UTube lecture "*The long term effect of chemical fertilizers on soil health*" ('*Plant Health Cure'*, 2019)

The bottom line is, mycorrhiza are phosphorous extraction and transport experts, with capacity to create extensive underground networks to mine, move, and make it 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 absent human applied soluble fertiliser, are normally 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 *et al*., 2012).

"*Between 1-50% of soil bacteria and about 0.5-0.1% of soil fungi can be classified as P-solubilizing microorganisms*" (*Campos et al*., 2018). Mycorrhiza and accompanying bacteria, improve the efficiency of phosphorous abstraction, usage, and uptake, by plants from soils, by a number of 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 spanning much greater soil volumes than plants roots.

Phosphorous also symbiotically helps regulate mycorrhizal root colonisation, so transport and wider 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 growing vigorously, 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.

The processes between plants and mycorrhiza are symbiotic, both parties seeking to enhance their own existence by promoting and optimising the growth of the other, to best suit their own 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 *et al*., 2018).

Fig. 48. *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)

Healthy plants work with the mycorrhizal systems to create a mycorrhizal sheath, of soil particles, fungi, bacteria, root exudates and bacterial films, that create micro environments, mini factories, for specialised biology to take place, including low oxygen spaces that allow creation of nitrates. The mycorrhizal sheaths area is also referred to as 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 *et al*., 2018)

Mycorrhiza are capable of extraction from a much wider soil area than plant roots, so able to concentrate more dilute amounts of phosphates in soils, and overcome phosphate depletion zones, caused by plants root activity.

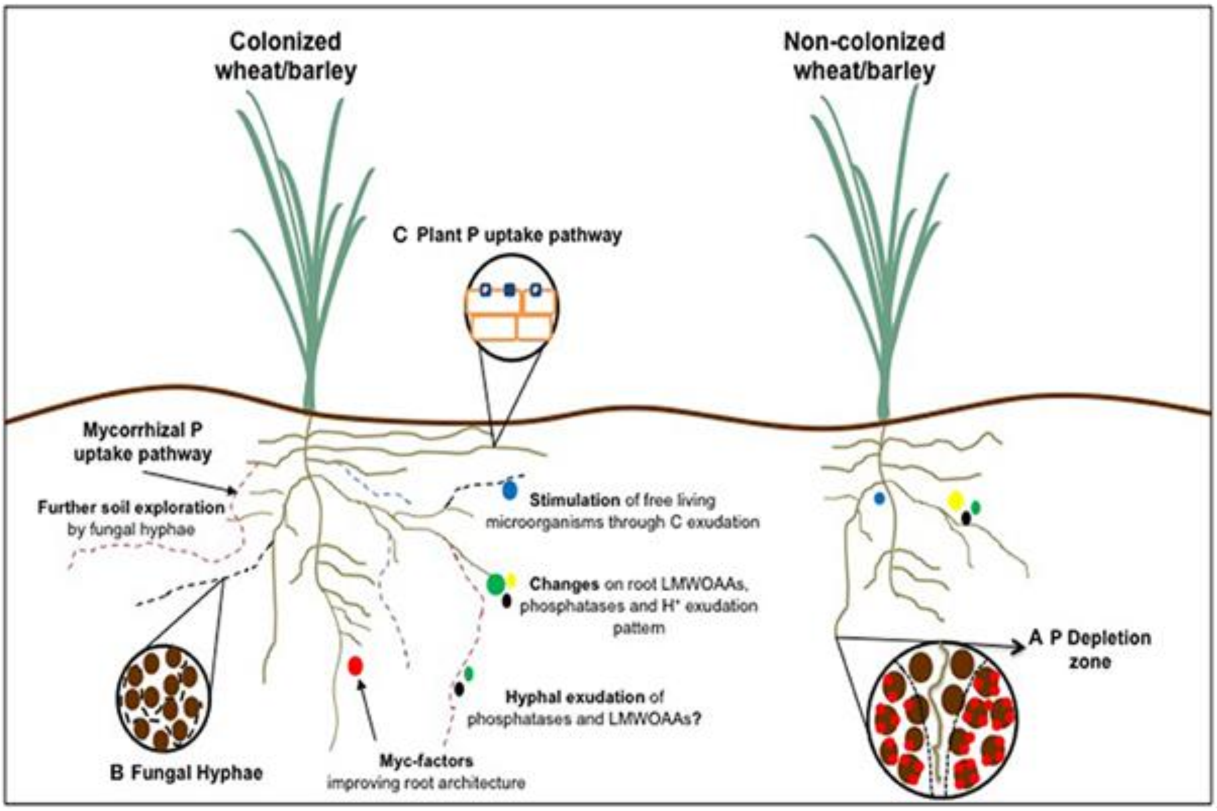


Fig. 49. From '*Phosphorus Acquisition Efficiency Related to Root Traits: Is Mycorrhizal Symbiosis a Key Factor to Wheat and Barley Cropping?*' (Campos *et al*., 2018) *"Phosphorus acquisition efficiency related traits of wheat and barley roots affected by arbuscular mycorrhizal symbiosis in comparison 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)

Phosphorous 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 *et al*., 2018)

As well as phosphorous, a range of minerals, are crucial to cellular function, because one or more of them are selectively incorporated in most enzymes, where they act as electron donors and acceptors. Plants accumulate "essential" metals including; Ca, Co, K, Mo, Na, Mg, Mn, Ni, Se, Cu, Fe, V and Zn) from soil. 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 phosphorous pool) is limited in soils, and soils might, over the very long term, become depleted of phosphorous, hence it makes sense to develop systems, including through greater use of composting of faeces and urine collected at source, to close the phosphorous cycle by returning the phosphates mined in crops, which is exported in food, including grain, to city conurbations and livestock facilities.

MAGNESIUM SUPPLY REGULATION

Mycorrhiza also provide magnesium, as well as other minerals, to plants (Zare-Maivan, Khanpour-Ardestani & Ghanati, 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 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 *et al*., 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 optimal provision of magnesium.

WATER HYDROLOGY, WEATHER AND CLIMATE IMPACT

Fresh water, cycled via plant transpiration, wider evaporation, producing atmospheric moisture and rain, is fundamental to many forms of terrestrial life, and crucial to maintenance of the global biome. Plants and soil biome systems provide crucial system ecowater-services, including metabolic water creation, transpiration, bacterial cloud seeding, and provision of the carbon that facilitates the soil biome.

As intimated above, but well worth reiteration and further examination: rain water retention by soil systems; soil biome metabolic water production in soils; and release of both into streams and rivers improves: local and regional hydrology; drought resistance; and transpiration of water into the atmosphere, thus reducing temperatures and regulating rain fall.

Soil biome systems, as well as creating metabolic water, will retain and access water even bound to very small, mineralised rock particles, and also 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.

Ensuring diverse plant ground cover is retained, thus healthy mycorrhizal systems, combined with landscape-based water management, will regenerate water catchment areas, ensuring river flows are maintained, and thus ameliorate regional, and wider climate.

The capacity to restore ecosystems has been convincingly demonstrated in many places including in; the Yellow River catchment in China, and the Nile catchment in Ethiopia, and in regions in India. The re-greening of these area with appropriate management can also sequester carbon. Water issues and desert reclamation are examined in more depth below and in volume 3.

METABOLIC WATER - MYCORRHIZAL RESPIRATION

The production of metabolic water due to respiration, by plants and denizens of the soil biome, once pointed out, is self-evident, but not widely appreciated. The metabolism of carbon-based molecules for energy including heat, including via mitochondrion and peroxisomes, and other cellular molecular reactions, produce 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

However, whilst there is limited research into the topic, in relation to agriculture, metabolic water is rarely mentioned, as a relevant, but unquantified, mechanism for the supply to and retention of water in soils, and wider hydrological systems, and logical explanation for the observed greater drought resistance of multi-species crops, growing in healthy diverse soil biomes.

Net metabolic water production supplies living organisms from humans to bacteria with varying amounts of water, over and above their water intake. The amount of metabolic water produced and retained, depends on species wider physiology, but to some extent will contribute 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 (1), 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 *et al*., 2016)

Metabolic water is produced both by mitochondrial and peroxisomal pathways. Whilst most have heard of mitochondria, the importance of peroxisome, including in metabolic pathways is under appreciated. Peroxisomes, small multifunctional organelles, with roles including in provision of energy substrate, and as a by-product produce peroxide, which will then be converted to water, and that peroxisomal water may have greater roles in plants than generally appreciated. Uprating peroxisomal and related linked antioxidant function, through metabolism of stored fats, during periods of shortage of sugar exudate supply, would result in increased peroxide production, thus increased available metabolic water. Peroxisome activity appears to increase during drought at least in some plant species (Sanad et al., 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.

Indeed, creatures such as migrating birds during long flights. with no chance to drink or eat, polar bears during long swims in salt water, 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.

Pathways are complex and include mechanisms that are not widely known such as peroxisomal respiration referred to above. Respiration in mitochondria will also produce water. Some body processes produce water, and others use water, thus equations, such as that for metabolism of glucose for energy, points to, rather than tells the whole story.

$C_6H_{12}O_6$	+	$6O_2$	-->	$6CO_2$	+	$6H_2O$	+	30ATP
(reductant)		(oxidant)						(energy)

Given differing individual metabolisms, and the complexity of biological systems, a precise answer as to how much water any species actually produces is difficult; but amounts are not insignificant, "*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 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 is exceptionally difficult to determine, but crucially represents very large amount, which as discussed helps explain better drought resistance in crops grown using regenerative farming techniques.

Consideration of the relatively modest surface accumulation of organic matter over eons, points to the important amount of metabolic water produced: all the vegetation produced over millions of years (unless buried in anoxic environments forming oil and coal etc.) effectively largely disappears, because much of it is converted back to carbon dioxide and water, by various life forms.

Thus, microbiome respiratory processes will maintain production of, and access to, at least some water, by drawing down on stored 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 sugar exudate by plants, in a beneficial circular cycle that helps support the entire plant and soil biome community.

Thus, keeping plants growing on land even during low rainfall periods, facilitates a self-supporting system; a combination of plant and soil biome respiration, helping both plants and the soil biome to better survive and remain hydrated, whilst carbon dioxide exhaled is recycled back to the atmosphere, and reused for photosynthesis.

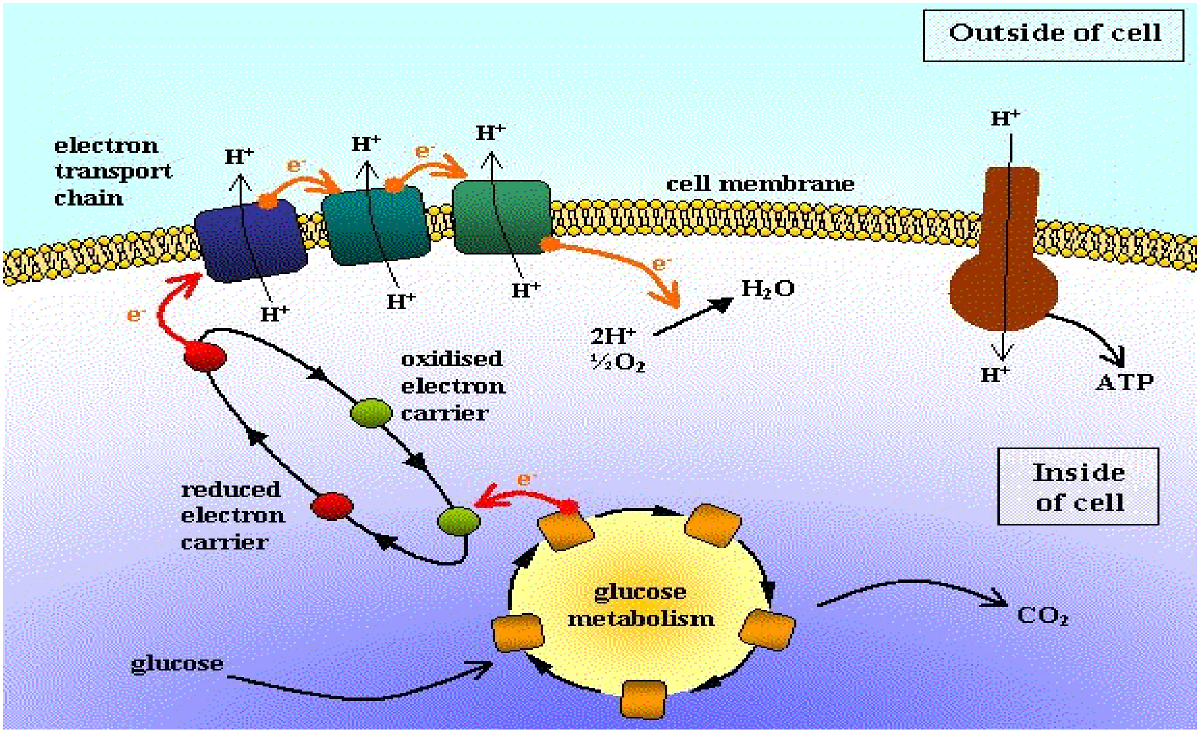


Fig. 50. Glucose metabolism and the electron transport chain, within mitochondria, from '*Sparks of Life*', with thanks to the author Lewis Dartnell. (Dartnell, n.d.)

Additionally, the presence of plants helps protect the soil surface, limiting subsoil water transpiration, and soil heating, thus the water will be more effectively retained within the soil biome, and also available to plant roots.

Thus, we must not lose sight of the sophistication that eons of evolution have conferred on the level of integration in these natural cycles, in order to optimise survival chances in adverse conditions, by manipulation of local and wider hydrological and atmospheric conditions.

These Gaian systems have been repeatedly disrupted by human interventions. Artificial fertilisers, agrochemicals, bare soils, tillage and overgrazing, lead to denuded, overheated, compacted, low biome carbon, soils, which then fail to absorb rain fall, and are further degraded by erosion. Such soils, increasingly devoid of soil carbon rich mycorrhizal biome plant support systems, become ever more incapable of supporting significant plant life.

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?

IMPORTANCE OF WATER TO AGRICULTURE

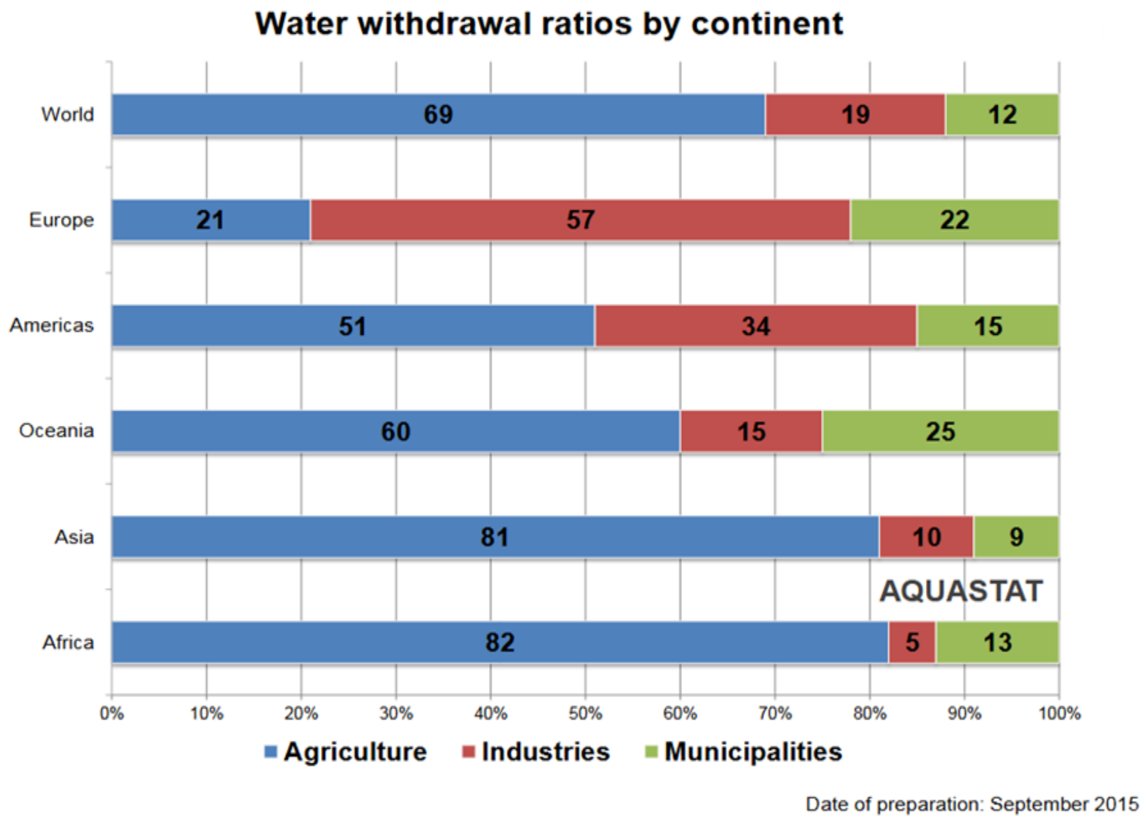


Fig. 51. Surprisingly agriculture is a very major user of water in most of the world, underlining the importance of water retention in soils, and optimal water efficiency use during the growing process. The Food and Agricultural Organization of the United Nations AQUASAT data chart "*shows global water 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 major portion of water use globally is used to support agriculture. Water globally is becoming increasingly polluted, and supplies are diminishing. It is clearly imperative, to both minimise pollution of agricultural water supplies, and to optimise, water use efficiency and retention in soils, as well as to prevent erosive, polluting, and wasteful run off during heavy rains.

Water infiltration-penetration, and retention in soils increases dramatically with greater soil biome carbon content. Thus, improvement of water retention in soils, and efficiency of water use by crops, through improved farming techniques that sequester soil carbon, warrants significant research effort, and focus.

DEGRADATION OF WATER QUALITY AND QUANTITY– "THE INVISIBLE WATER CRISIS"

The World Bank group report '*Quality Unknown: The Invisible Water Crisis*' (Damania *et al*., 2019) expresses deep concerns as to diminishing water supplies, and 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 *et al*., 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 *et al*., 2019)

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

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

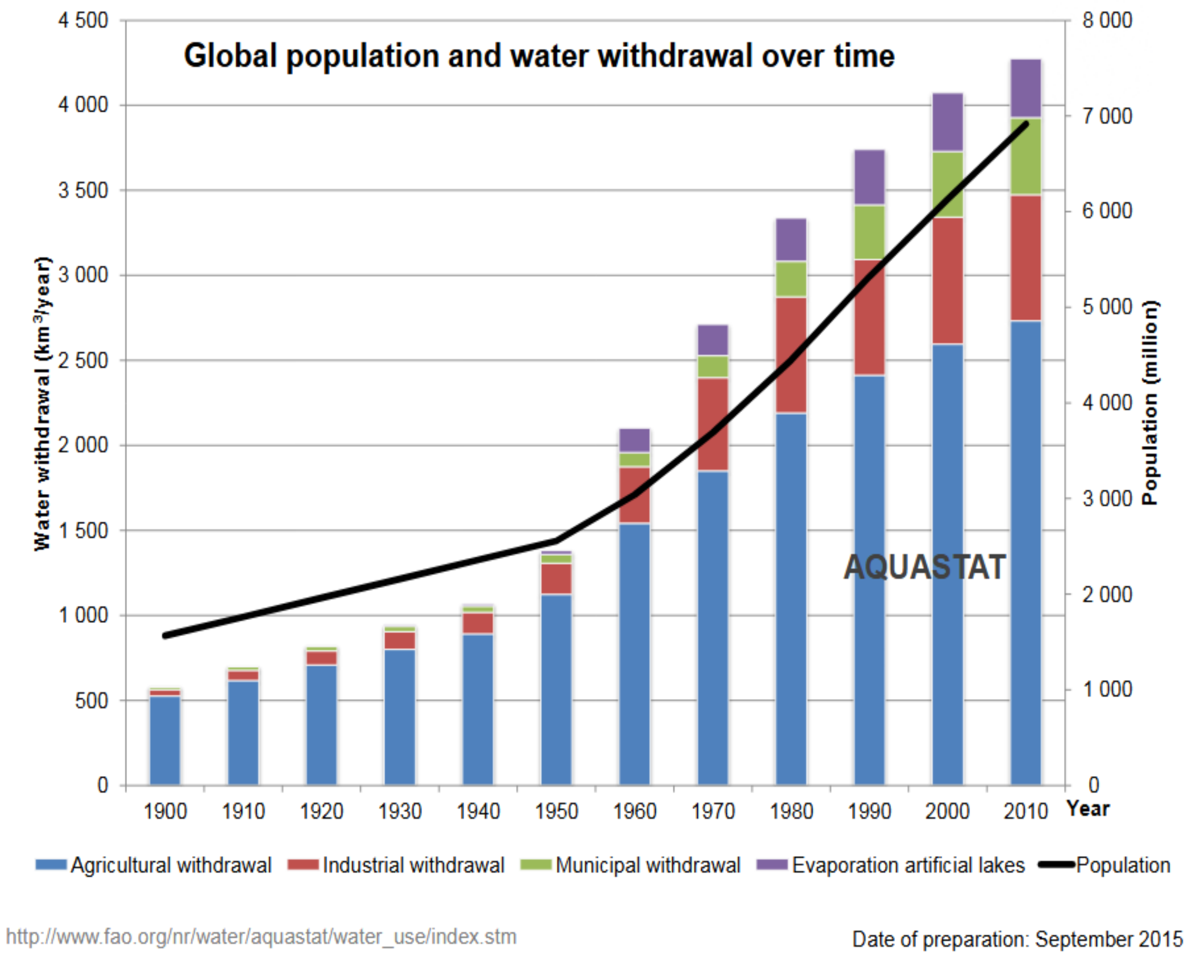


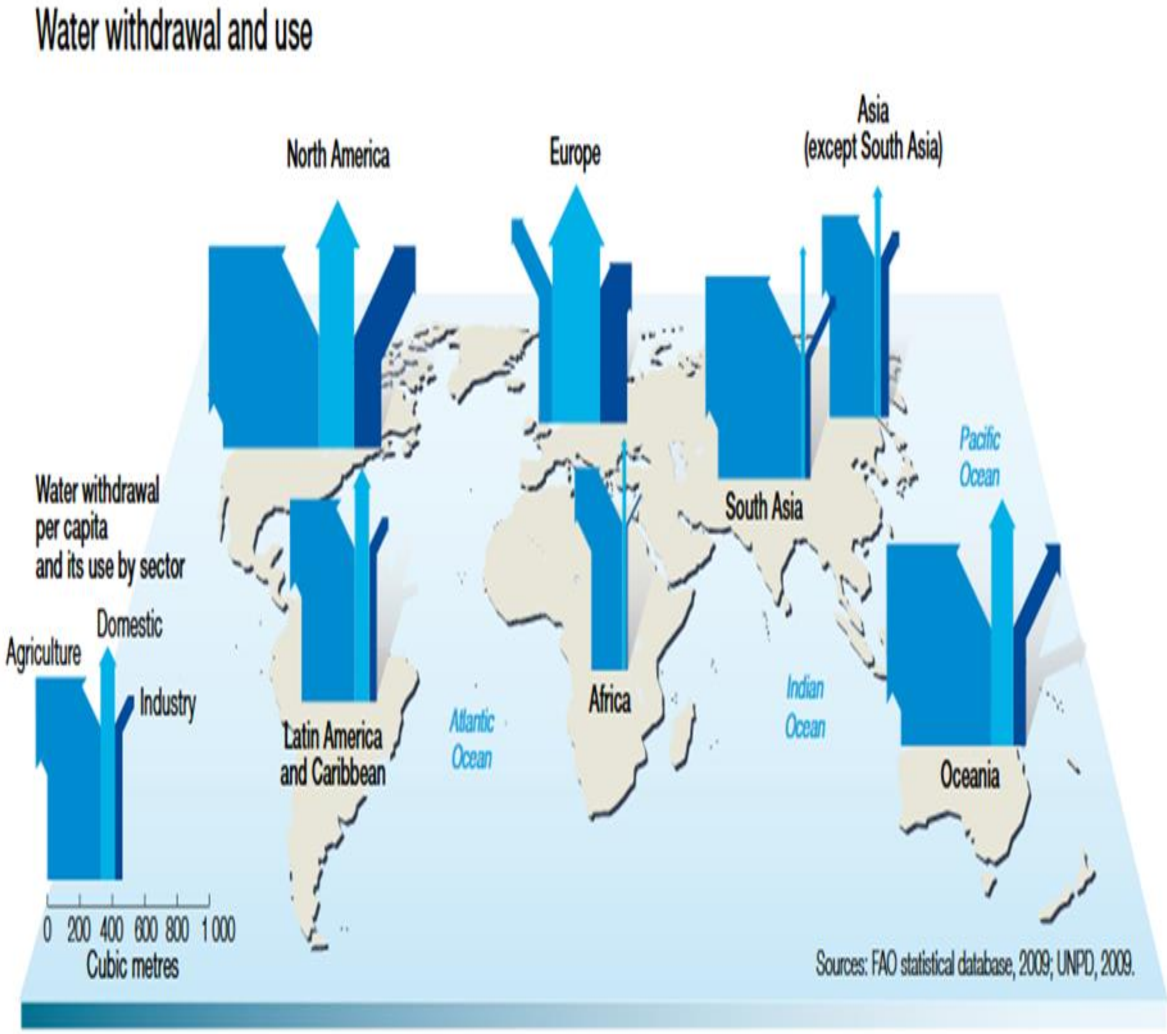
Fig. 52. *"Global population and water withdrawal over time"* with thanks to the authors

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

Global water demand for domestic use and agriculture is rising, driven by; increasing global population, rising individual water usage, demand for flush WCs, and growing agricultural demand for a variety of reasons including; degraded soils, reduced water retention and increased runoff. Improving soil carbon levels through regenerative agricultural practices, would, as discussed, improve water retention and local and wider hydrologies.

Reduction in pollution of water sources by sewage would similarly bring huge benefits. Huge 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 lake and marine environments.

Fig. 53. 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; and limit pollution of water due to sewage incorporation, fertiliser run off, and downstream pollution of water-courses, and sources; as well as to protect the marine environment, are urgent. The issues of water are considered in greater detail in the next volume.

Fig. 54. "*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)

DEGRADATION OF LAND

Through our actions of displacing natural ecosystems for agricultural purposes we have taken on the responsibility for, and appointed ourselves custodians and controllers of Gaian planetary regulatory systems and eco-services that the natural systems normally provide and regulate. By failing to respect the need for the green cover, carbon sequestration, and the need to maintain downstream hydrological and meteorological stability, we have upset climactic stability, which we have magnified by burning of fossil fuels and industrial pollution.

The worldwide areas of underused agricultural land are vast, millions upon millions of acres of degraded land, added to by unbelievably massive acreages of seasonally bare fields: as discussed 50 per cent of the world's cropland is bare during any twelve-month period ('*Building New Topsoil Through The Liquid Carbon Pathway*' (Jones, n.d.-a).

When land is bare and or degraded, the opportunity for plants to photosynthesise carbon to feed the soil biome, thus improve water hydrology, soil quality and food yields, and sequester carbon, is self-evidently lost

The consequent cost to humanity in terms of lost potential for ecosystem improvement including; better hydrology, moderation of weather, sequestration of carbon, improvement of soils, reduced pollution, increased food supply and stability, as well as improving the lives of millions, is huge.

Compared to the quality of unfarmed soils, the current base line 'health' of soils is low. Dr Christine Jones, PhD, Founder of '*Amazing Carbon*', on her web site, succinctly and powerfully sets out the impact of degradation of soils, including as to soil carbon. In a paper titled, '*Light Farming: Restoring carbon, organic nitrogen and biodiversity to agricultural soils*' Jones not*es, "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)

Further, vast areas of land globally are hugely degraded, thus lost to agriculture. "*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 et al., 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 Organization 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) (Authors' 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).

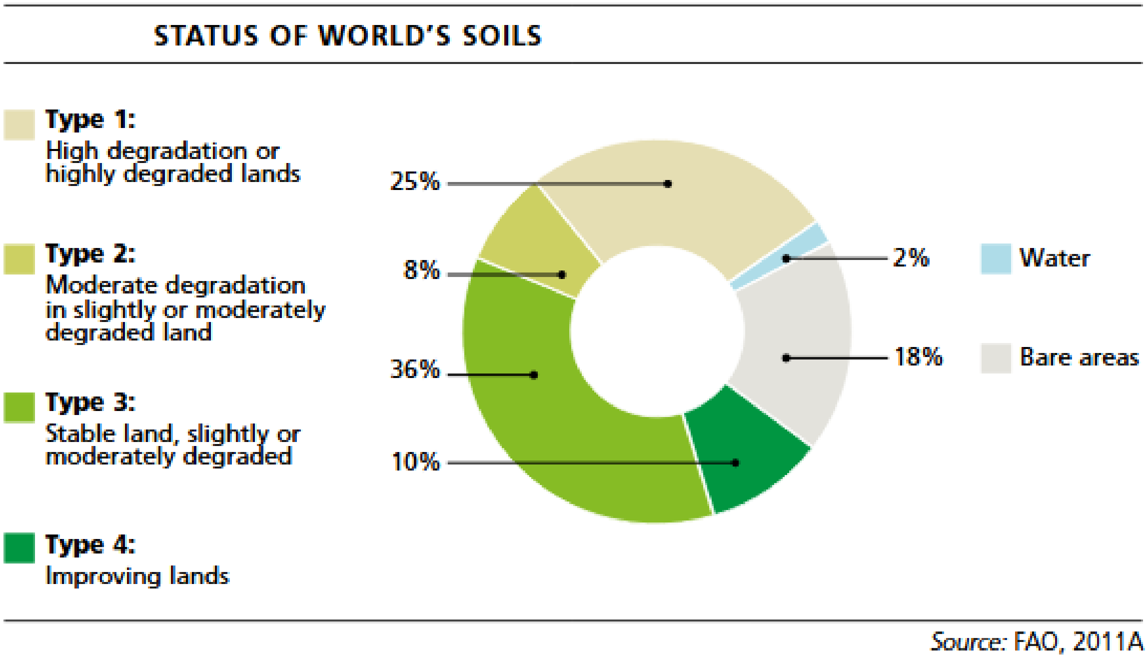


Fig. 55a. Status of the world's soils from The Food and Agriculture Organization of the United Nations report, 2018, '*Nitrogen Inputs to agricultural soils from livestock manure*' with very many thanks to the authors. (FAO, 2018-a)

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 put it '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).

Heathy soils are central to the wellbeing and health of populations. Marginal agricultural land in low rainfall low-income countries, is particularly at risk; a critical environmental, climate change related, issue. Destruction of forest and scrub, degradation of soils, and use of bare ground NPK based farming, will lead to changes in hydrology, and atmospherics, reducing rain fall and exacerbating the impact of climate change on the whole region, including remaining adjacent forests.

Southern Madagascar, the Sahel, and Cerrado in Brazil, are arguably examples of the slow long-term degradation of land and hydrology, caused by bare-ground, mono-crop, 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, which can be further enhanced by regenerative agricultural practices.

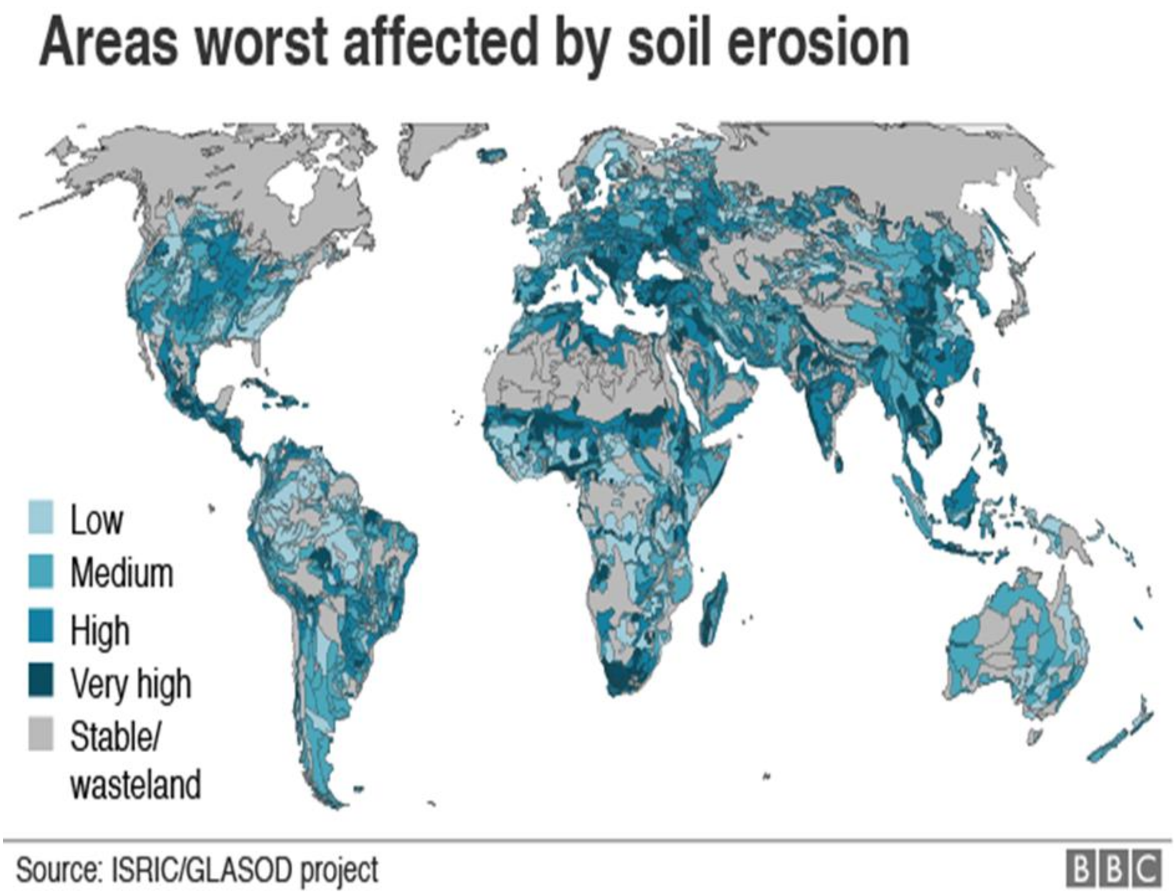


Fig. 55b. From the BBC report 'Climate change being fuelled by soil damage, with many thanks to the Author and BBC – report' (Harrabin, 2019)

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 using simple technologies, including water capture and or regenerative agriculture, where severely degraded land has been restored to fertility, and hydrology restored, and as a result those affected can once again earn livings producing and selling nutritious food.

SOIL DEGRADATION LESSONS OF HISTORY

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 agricultural nations.

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, completely dependent on 'artificial' inputs of fertiliser and agro-chemicals.

Fig. 56. "*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)

In the middle of the last century books on agriculture and soils, were written, that remain very relevant and prescient, including by; Rodale, Howard, Albrecht, and King (Albrecht, W. A. 1958; King, F. H. 1911; Howard, "*The Soil and Health*," n.d.) Their message, as to the importance to all civilisations, of nutrient dense food, and the need for the maintenance of productive soils, remains an enduring and fundamental truth.

Historically, soils have been repeatedly exploited for short-term yields, and profits, including by absentee landlords, whose primary concern was short term profitability, as seen in the Roman era. Many civilisations, including the Romans, in consequence ultimately destroyed large areas of fertile lands; human nature and behaviour it seems remains stubbornly consistent, but needs to change, becoming more focused on the greater good and long term, if we are to henceforward prosper as a species.

Dr W C Lowdermilk, was commissioned by the U.S. Soil Conservation Service in the late 1930s to tour Europe and the Middle East, looking at 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 very many agricultural empires, which through land degradation, including soil erosion, literally crumbled, disappearing with the dust erosion they had created.

He observes, 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 over-exploited, the soil's stored resources, to meet commercial demand for export of food to the cities, often in other lands; for example, North Africa supplying Rome. The consequent agricultural 'graveyards', include areas of the Middle East, North Africa, and the forests of Lebanon, and Mesopotamia.

Fig. 57. 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).

'*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).

Historically, in the mid-1930s, huge 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 what were ploughed prairies, and farmsteads, that, after exposure to drought and wind had become dust bowls.

Fig. 58. "*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)

The Europeans, similarly mined soils of nutrients including carbon, but 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 et al., 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, and would arguably, economically and environmentally, benefit from doing so. As below parts of Estonia are no longer farmed due to degradation in soil quality.

Further, 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 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 et al., 2016). The implication is land is not economically productive if the artificial fertiliser agrochemical model of farming is considered. However regenerative agriculture would logically allow this land to be brought back into economic production.

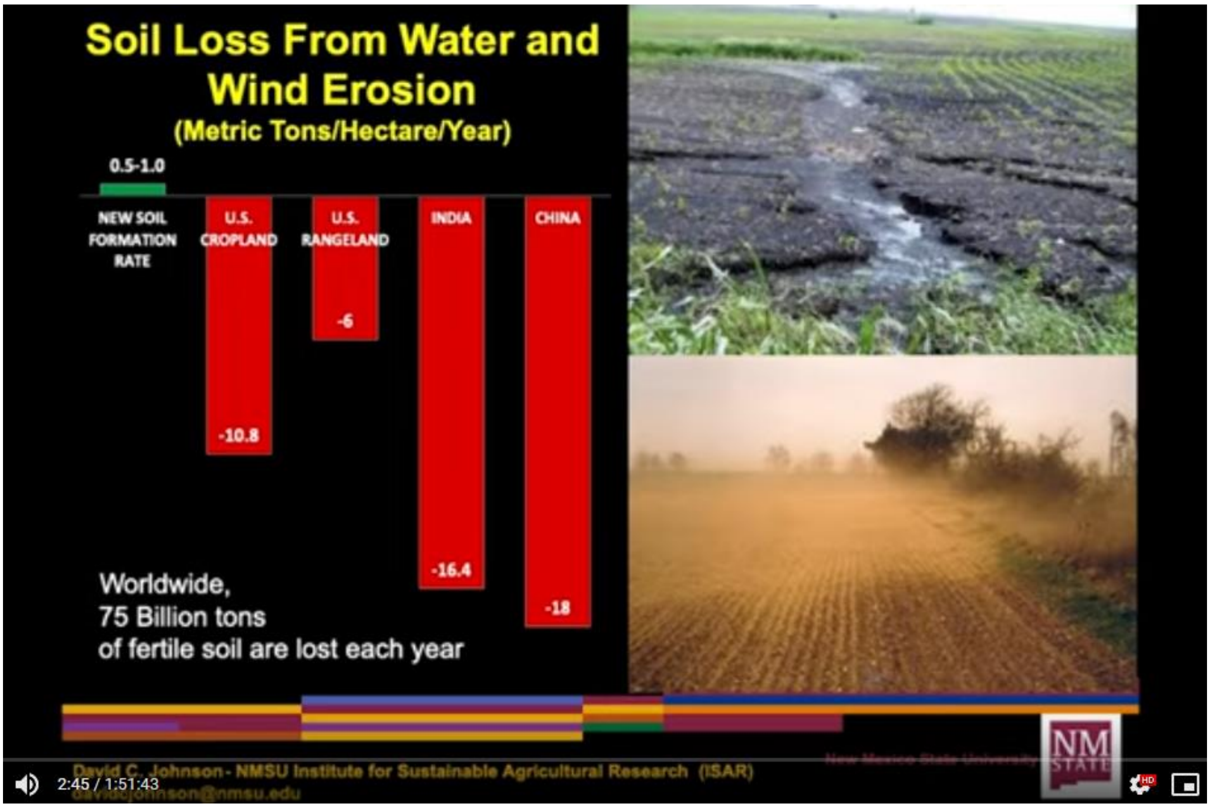


Fig. 59. Soil erosion continues as evidence by the slide from the UTube lecture titled '*Dr David and Hui Chun Su Composting'* with very many thanks to the authors. (Johnson & Su, 2019)

Less economically well-off countries, in warmer areas, with less certain rainfall, are much 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 a number of years, with unsustainable bare ground farming practices, the soils eventually became incapable of supporting crops. The annual cost of land and wider degradation in Ethiopia is estimated at $4.3 billion (Gashaw, 2014; Gebreselassie, Kirui, & Mirzabaev, 2015).

We are becoming more aware of soil erosion, but it continues, including: windborne erosion of friable soils lacking the organic matter that traditionally has bound it; and water-based erosion due to lower permeability and absorbency of damaged soils, thus run off of fine particulates.

Wider 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 improve water retention, and reduce erosion, becomes ever more pressing.

LAND DEGRADATION IN ADVANCED ECONOMIC COUNTRIES

Erosion is not limited to emerging economies, for example in the UK, '*Fen blow*', a name given to wind erosion of soils in the English fen lands (often reclaimed marshes, so recognised historically as quality soils): has been reported by the BBC. 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. 60. "*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 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)

"*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*

Fig. 61. Soil erosion in a wheat field near Pullman USA with thanks to Wikipedia and the author Jack Dykinga. (Wikipedia, 2019b)

"*"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)

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 facing the need to recognise the value of natural resources, and issues of 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).

Fig. 62. 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 NOA.

SOIL DESTRUCTION = NEEDLESS DEPRIVATION AND POVERTY

We are utterly reliant on our soils for food. More widely soils and the green and varied life they support, are a key part of the biosphere, that enables and regulates life on the planet earth. Land degradation, the inevitable consequence of destruction of soil biology, erosion of geology, and damage to hydrology, is an age old human induced phenomenon, which results in food shortages, conflict and ultimately breakdown of civilisations: the difference is we now have no excuses, as we understand the causes of soil degradation.

Lowdermilk in 1939 in his book powerfully conveyed his concerns as to 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 it is not only desirable, but imperative, that we act on Lowdermilk's enjoinder that we look after our soils, as they not only feed us, but help regulate our atmosphere thus our climate. It is imperative we use 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. Very sadly, wider society still has not come to understand this reality.

Regenerative agriculture should also include closing the nutrient cycle. The recycling through composting of human and livestock waste, so organic matter, other nutrients, minerals, including nitrates and phosphates, was a central and integral part of the maintenance of productive use of land for centuries. Today millions of tons of waste containing nutrients and minerals, including phosphate rich material, are sent to land fill, 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 wider organic waste), and return it to the land; or properly 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 historic 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, return of all organic matter to the soil, good practice including 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 from farms, that with regenerative agriculture, including; multispecies-variety cover-crops, half-height-grazing, and low till technology; with no input of artificial fertilisers, carbon-soil-centric farmers are producing, equivalent or better cash crop yields, of better quality, than those that are fertiliser dependent, with lower costs so greater profits; reducing pollution, increasing diversity, at the same time improving hydrology, and helping sequester carbon, thus helping ensure future human habitability by respecting the sophistication of the planetary Gaian biosphere that nourishes us.

SOIL CARBON LOSS – CLIMATE CHANGE - HOW MUCH

The potential of regenerative agriculture to reverse soil carbon loss, and sequester carbon into soils, presents a significant opportunity, as a part of global plans to mitigate increasing atmospheric carbon dioxide. 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.).

However, there is a lack of accurate cheap practical technologies and protocols for measurement of soil carbon levels, and particularly so at greater depths (measurement techniques and protocols are still being developed – an industry in its infancy), and this deficit is compounded by insufficient understanding of the role of soil carbon in regulation of atmospheric carbon dioxide levels.

The common position is that increasing carbon dioxide in the atmosphere is predominately due to fossil fuel combustion, as moderated by absorption of carbon dioxide by the oceans, with little consideration given to the contribution to atmospheric carbon dioxide, of historic and ongoing loss of soil carbon, which is likely to be a significant amount. Similarly little focus is put the impact of modern farming on climate change more widely.

The BP Energy Outlook 2020, suggests total fossil fuel carbon dioxide emissions in 2018 of 33.9 gigatons, which is equivalent to approximately 9.3 gigatons of carbon. That figure can be adjusted for estimated land use gains from tree planting, losses from; deforestation, and fires including, forests, tundra and stubble burn off. However, loss of agricultural soil carbon is generally not included, and plant / tree absorption figures may be optimistic for a number of reasons.

For example, a report by '*Carbon Brief Clear on Climate*' 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) - 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.

Agriculture related loss of soil carbon is not mentioned in the above analysis. However, it entirely possible that there is higher absorption by oceans than estimated, masking release of carbon dioxide from agricultural soils, as well as from thawing arctic tundra, and drying peat bogs.

We know agricultural soils and soil hydrology are unquestionably degrading, which points to net carbon loss, rather than sequestration of carbon in soils. Raised carbon dioxide does increase plant metabolism, but any carbon sequestration benefits in the natural environment, are likely far outweighed by ongoing degradation in existing, and new agricultural soils taken from natural ecosystems – yes more data needed - but the general changes we are seeing in climate events, including drought and fire, is surely telling us we should not ignore what land soil health change is telling us.

In effect, the uncertainties in data, and necessity for estimation based on wide criteria, allow great latitude for us to see in the guestimate variables, what we wish to see. The reality could be much worse and more urgent, but estimators of such figures, politicians and many climate groups, simply do not wish to see that possible eventuality.

More widely, the FAO recognise that agriculture overall may contribute a third of greenhouse gases. The FAO observes, *"It is estimated that land-use conversion and soil cultivation are still responsible for about one-third of GHG emissions . . . 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.)

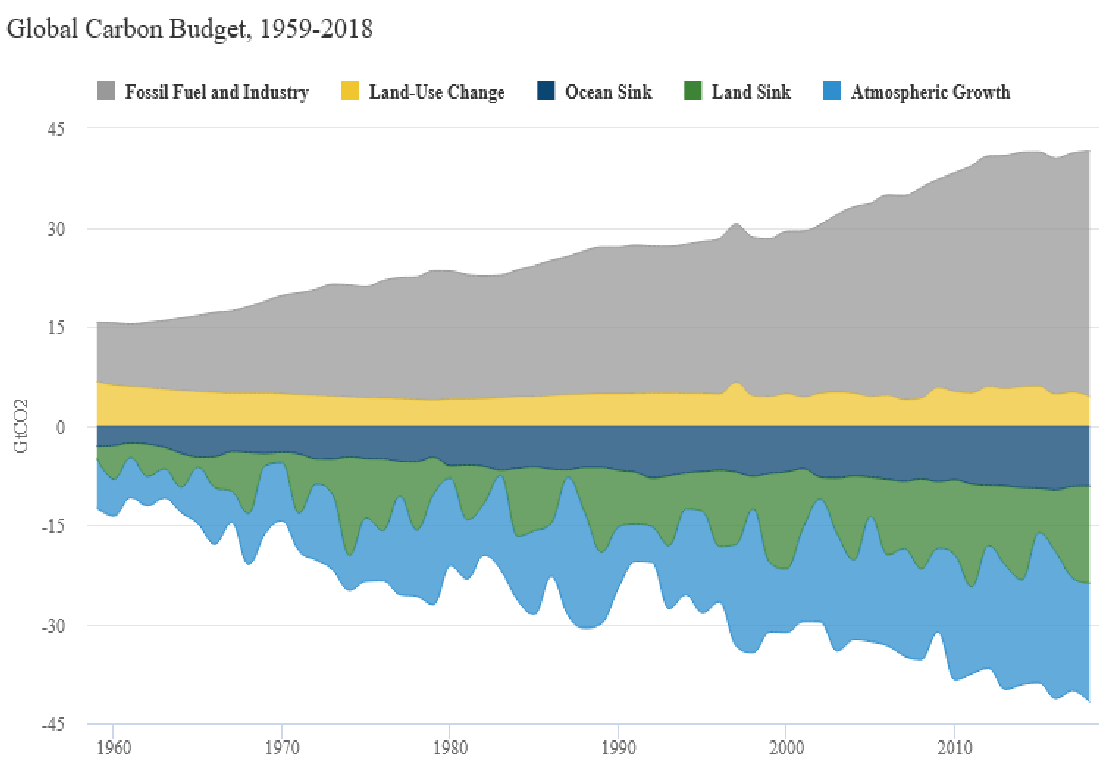


Fig. 63. *"Annual global carbon budget of sources and sinks from 1959-2018. Note that the budget does not fully balance every year due to remaining uncertainties, particularly in sinks. 2018 numbers are preliminary estimates. Data from the Global Carbon Project; chart by Carbon Brief using Highcharts."* 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)

On the positive side there is potential to store huge amounts of carbon in soils. Exact agricultural soil losses are not known, but 'guesstimated' by some at 1 billion gigatons a year, others such as the FAO suggest larger figures. 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) The 2007 FAO report concluded total soil carbon in the 0 - 30cm range with some reporting to 1 metre, is significantly lower 504 -1267 peta-grams. (FAO, 2018b)

Estimates of global soil carbon, and related data vary greatly for the reasons set out earlier, including lack and variety of data, as well as difficulties, differences, and complexities of assay and computation. Thus, there is huge uncertainty, in respect of global carbon budgets, and partitioning, and better data collection is urgently needed. The only certainties are, the global figures are massive, and moving to regenerative agriculture offers significant potential, to not only sequester atmospheric carbon, but also to mitigate the carbon footprint of farming, by reducing the need for energy intensive artificial fertilisers, agrochemicals, and energy for ploughing etc. as well as improving species diversity, hydrology, regional climate, and reducing pollution and eutrophication. Thus, adoption of regenerative agriculture could help buy us time to find and implement non-carbon using energy sources.

MODERN EXTRACTIVE AGRICULTURE DEPLETES SOIL CARBON

The farming paradigms adopted in the 20th century are resulting in carbon loss for soils. It is suggested "*In general, cultivated soils normally contain 50-75 percent of the original SOC* (Soil Organic Carbon)" Others estimate and observe greater losses. As discussed,

- Use of artificial nitrogen, phosphates, impedes supply of plant produced photosynthetic sugar exudate and fats, thus reduces 'soil-carbon' substrate flows to soil biome systems.
- Agrochemicals, variously kill or inhibit the fungi, bacteria, and life forms in the soil biome.
- Extensive 20th century, plough-based, bare fallow land, centric; NPK dependent farming; has resulted in further significant loss of soil carbon.

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 et al., 2018).

The review '*Global Sequestration Potential of Increased Organic Carbon in Cropland Soils*' (Zomer et al., 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 et al., 2017)

The review '*Greenhouse gas mitigation in agriculture*' (Smith et al., 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 et al., 2008) Estimates of annual loss of carbon from soils vary, are estimated using modelling. (2006) ("*Global Carbon Emissions*," n.d.) Thus, large uncertainties exist, and more so given the report below of New Zealand grasslands loosing approximately a ton per hectare per year, which if representative could mean global soil carbon losses of 1 to 4 giga-tons a year.

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).

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 representative globally, even at the lowest estimates, they would represent the equivalent of many years of carbon fossil emissions. The only relative certainty is, soils are losing carbon, and reversal of loss could significantly contribute to mitigating climate change.

With thanks to Adobe Stock

In conclusion, biology, strong observational evidence, and as yet limited research data, suggest soils farmed with artificial fertiliser, will experience falling stored soil carbon levels. Consequently, soils farmed under protocols using significant amounts of agrochemicals, and regular fertiliser application, are likely to be a significant net atmospheric carbon source, rather than sink.

LOSS OF SOIL CARBON IS UNCERTAIN, UNAPPRECIATED AND UNDER-REPRESENTED

Loss of soil carbon to the atmosphere is an underappreciated, and underestimated, potential contributor to, atmospheric carbon dioxide related global warming. In addition, degraded soil cover, soil carbon, plant respiration, including reduced metabolic water production, thus diminished soil and regional hydrology, must exacerbate wider climate change, including increasing risks of heat domes, consequent fires, floods, erosion, and wider environmental damage.

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 carbons, via carbon dioxide emission to the atmosphere,
- increased bare soil surface temperatures, causing faster drying, damage to soil biological systems and increased planetary heating,
- reduction of rain infiltration-penetration and retention – including due to reduced; soil carbon related aggregates and gels, soil life responsible for soil aeration, loss of organic matter soil cover, bare soil crusting, and compaction,
- reduction in metabolic water production,

- reduction in transpiration,
- reduced atmospheric moisture in dry seasons,
- reduced opportunity for formation of mists and dew,
- reduction in emission of bacteria and moisture 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 forms the basis of rain, due to blocking of inward moisture flow movement by heat domes,
- desertification,
- contribution to extreme climate events including flooding,
- silt run off, eutrophication and damage to marine ecosystems including reefs,
- erosion, causing soil degradation, loss, and related soil carbon loss.

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

With thanks to Adobe Stock

Reversing the loss of life in the soil biome, thus soil carbon, by moving to more carbon-soil-centric practices, and thus facilitating plants natural evolutionary tendencies to optimise mycorrhizal bacterial and wider soil populations, so soil carbon levels, could have significant wider beneficial effects in mediating climate change, including flood and drought. This would not be a solution to our current dependence on fossil fuels, but would provide more time for a transition to a zero carbon and oxygen combustion economy, as well as providing many wider 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 very useful 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.

SOILS AS A CARBON SINK

The photosynthetic energy potential for more efficient sequestration of atmospheric carbon dioxide into soil is significant. It complements the carbon-saving benefits from alternative emerging technologies such as photovoltaic cells or carbon capture, not because it is more efficient at capturing light energy, but because of the vast areas of agriculture involved, and the comparatively limited input resources needed to make regenerative agriculture work.

Yes, we need power, but we cannot coat the world with solar panels, but we can globally optimise the capacity of plants to photosynthetically capture carbon, feed soil biomes, and create organic matter. Both dead and living organic material divert sunlight energy into creation and dismantling of molecules, rather than resulting in desiccation of bare soils, and related light energy re-radiation by soils, including through conversion and re-radiation of visible incident light as infra-red heat. Regeneratively grown plants are a lot easier, greener, and less demanding of fossil fuels, to produce, manage, and replace, than solar panels, or industrial carbon capture installations. Yes, we do need to optimise the use of all options

As discussed, there is significant potential using regenerative agriculture, by maximising photosynthetic land capacity, and by excluding artificial fertilisers, for farmed soils to become long term carbon sinks for atmospheric carbon dioxide, and climate change mitigators through variety of mechanisms.

Fig. 64. Adapted from the UNFAO document 'Global Soil Organic Carbon Map' V1 ("*Global Soil Organic Carbon Map, Version 1.0,*" 2017).

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 accumulated historic, 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 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 et al., 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 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 et al. 2018) number of 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.).

The primary mechanism for soil carbon sequestration, is plant photosynthetically produced liquid carbon supplied to the soil biome, rather than the incorporation of organic matter. Whilst organic matter is not the primary source of sequestered soil carbon, it does protect, 'armour' soil, reduces soil temperatures and evaporation, provides biology, and returns some carbon, and other nutrients to the soil, as well as providing food for some of the denizens of the soil such as earth worms.

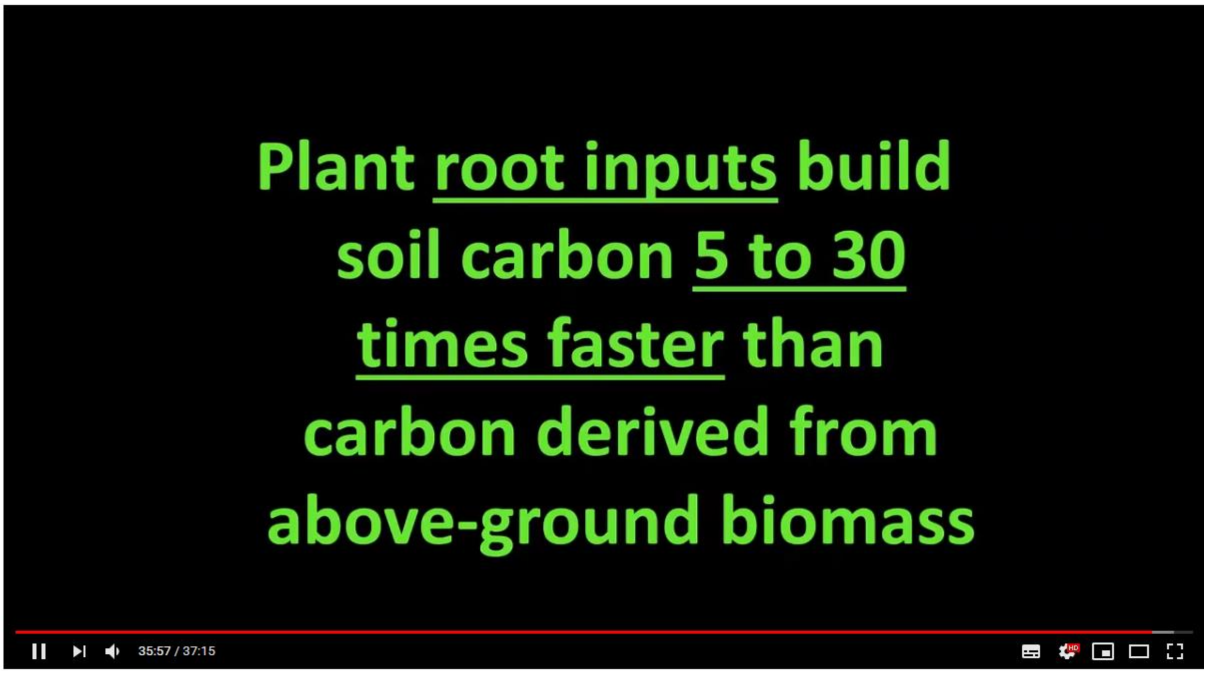


Fig. 65. Dr Christine Jones – '*Building New Topsoil Through the Liquid Carbon Pathway*' - a Conservation Tillage and Technology Conference, with very many thanks to the author. (Jones, n.d.-a)

Thought provokingly, soil carbon sequestration 'back-of-envelope' calculations, based on the global area under agriculture, using FAO estimates of land usage, applying the rates of carbon sequestration seen by the best regenerative farmers, suggest significant amounts of atmospheric carbon form carbon dioxide could be sequestered into soils.

The amounts of land under production in 2011 were estimated by the FAO:

- *Arable land:* *13,963,743 square kilometres (5,391,431 square miles);*
- *Permanent pastures:* *33,585,676 square kilometres (12,967,502 square miles);*
- *Permanent crops:* *1,537,338 square kilometres (593,570 square miles);*
- **Sum of above** ***49,116,227*** *square kilometres (18,963,881 square miles);*

(FAO, 2011) (Wikipedia, 2021). A square kilometre is 100 hectares, giving 4.9 billion hectares based on the above estimates. Figures vary between sources and over time with usage change.

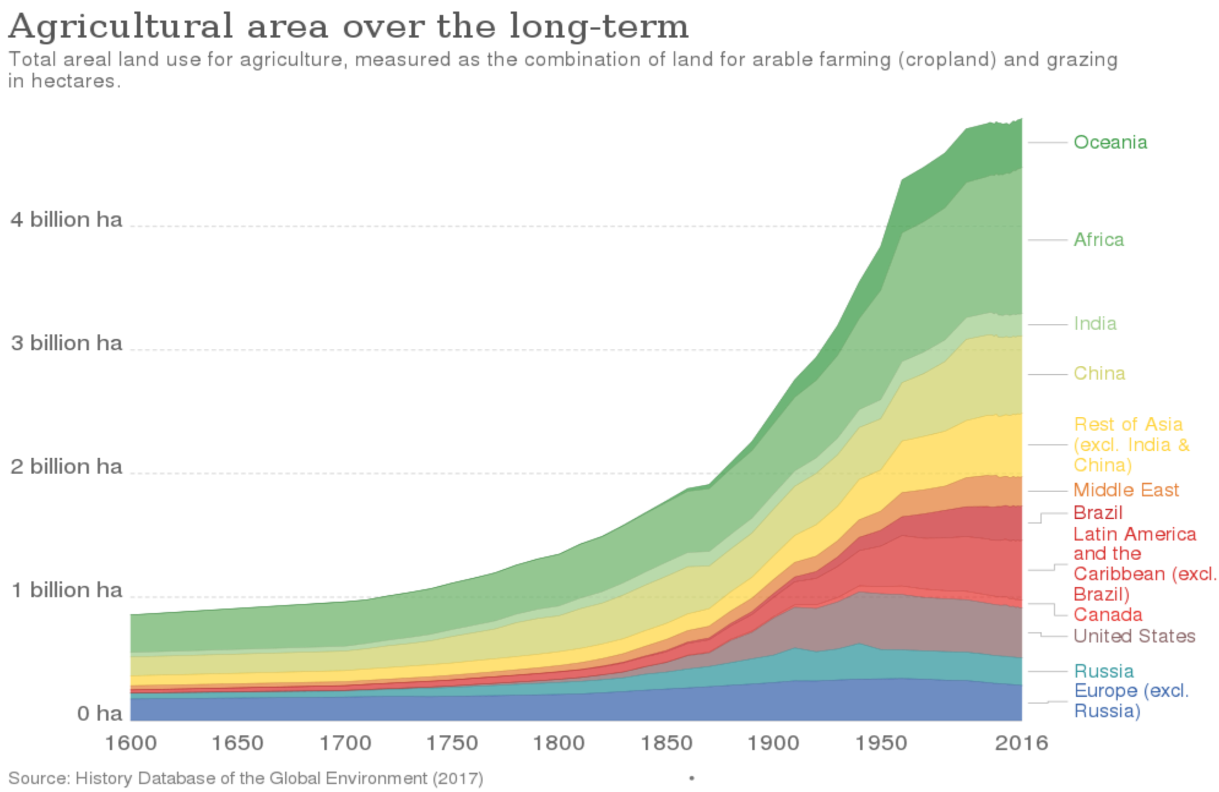


Fig. 66. With thanks to Wikipedia and Our World in Data for the figure (Wikipedia, 2021)

The point is very large areas are involved. Thus, sequestering a ton or two of carbon per annum hectare for a few years, would amount to five to ten gigatons per annum in total, which even for a short time frame, 10 – 20 years, could make a useful dent in net accumulating carbon dioxide emissions due to fossil fuel emissions, the most optimistic scenarios even exceeding annual emissions, as well as having huge wider environmental, hydrological and climate mitigation benefits.

Of course, it is not possible to turn all farm land globally to regenerative agriculture instantly, but the carbon sequestration possibilities, and the potential wider incremental climate mitigation benefits, are nonetheless hugely thought provoking.

Soil carbon sequestration capacity would likely diminish over time as soils become more saturated, but the strategy could buy valuable time to find greener alternative energy sources. Yes, more evidence and action are needed, but surely, we cannot afford to ignore, and fail to set a course to optimise, such enormous possible potential to both sequester carbon, and mitigate weather related climate change effects.

With sufficient will, motivation and energy, such changes could be achieved in a short time span, a few years, thus arguably representing the only meaningful immediate 'oven-ready' action humanity can take to mitigate climate change, whilst we improve and find new options for truly green energy production. No other current options offer anything near these potential benefits.

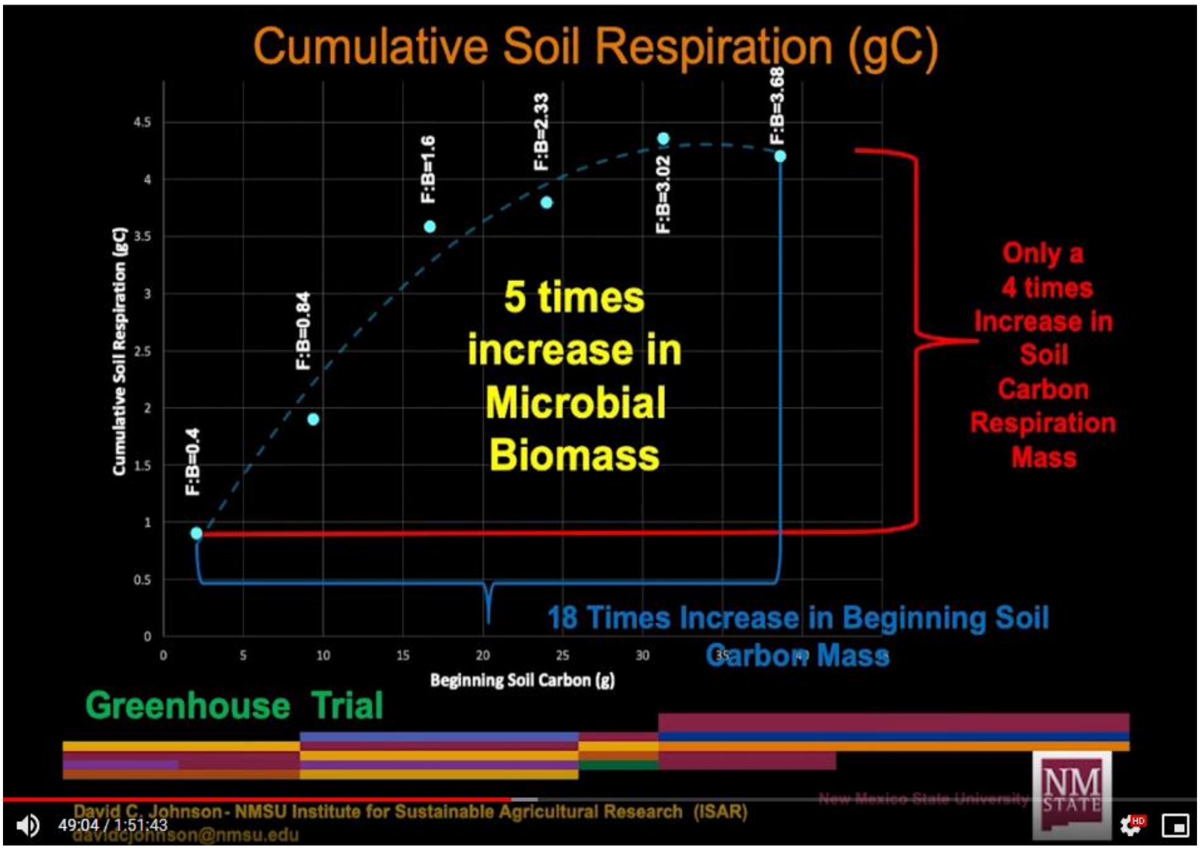
This strategy as well as reducing atmospheric carbon dioxide would:

- improve the hydrology cycle,
- improve rainfall and reduce drought,
- cut global temperature increases,
- cut localised temperature gains so the risk of fires,
- increase food quality and supplies,
- reduce pressure for new agricultural land acquisition from existing forest stocks,
- reduce fossil fuel requirements for production and transport of artificial fertilisers . . . nitrates and phosphates, and agrochemicals,
- reduce river and ocean eutrophication and related environmental pollution,
- add oxygen back to the atmosphere and oceans.

Optimisation of capacity to sequester carbon into soils, relies on soils having a healthy diverse sub ground mycorrhizal population. Farmers all round the world using regenerative agricultural practices are reporting increased carbon sequestration in soils. For example, New Mexico State University data suggests farmers eschewing artificial fertilisers, using low-till multispecies cover crop, are remarkably seeing significant increases in soil carbon, in the order of 6-7 per cent over 20 years.

More optimistic estimates than those of CGIAR, suggest even higher rates of carbon could be sequestered into soils. Dr David Johnson, in his YouTube presentation '*The BEAM Approach*', states that his own 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 historic data, 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 carbon can be sequestered into soils (Paredes et al., 1996), as do reports by, Gabe Brown, Dr Christine Jones, David Johnson and others.



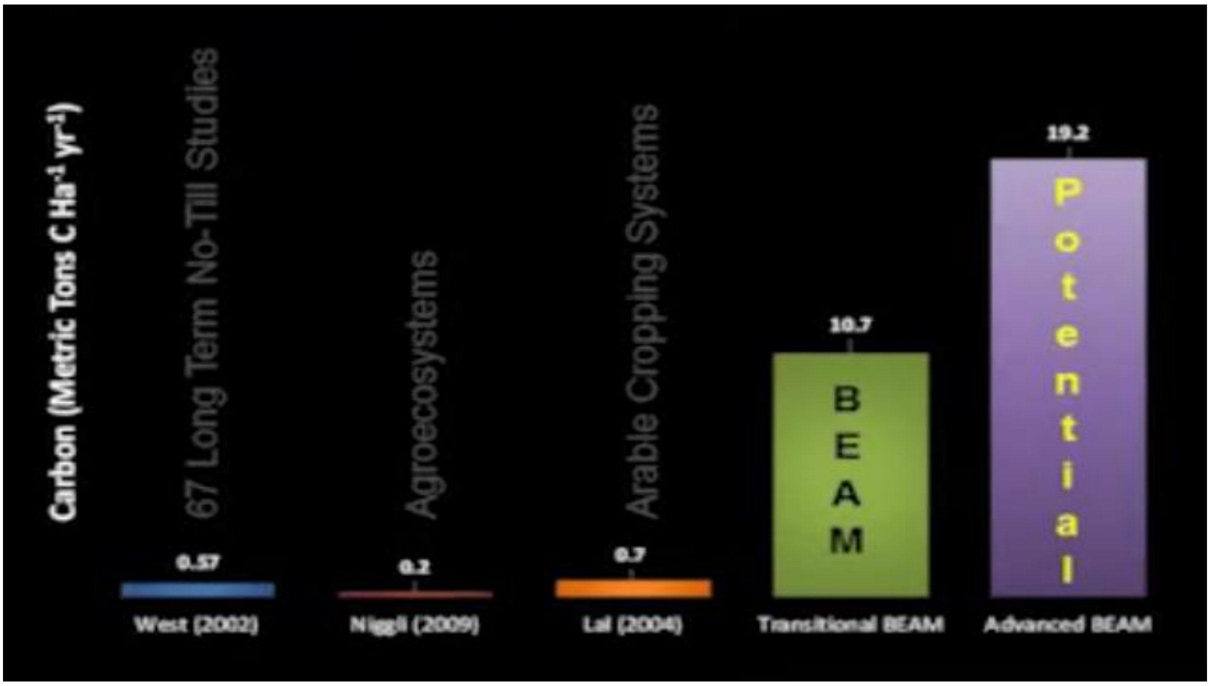


Fig. 67 a & b. In optimal circumstances, the rate of soil carbon sequestration exceeds that consumed by increased soil respiration rates, from the YouTube lecture 'Dr David and Hui Chun Su Composting', with many thanks to the authors. (Johnson & Su, 2019)

Carbon can be stored in soils for very large timeframes. Radiolabelling 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, Paul & Leavitt (n.d.)) [this author's bold and underline].

As a carbon sink, soils logically have a maximum capacity, which differs with their depth and type, so it is not clear how long regenerative agriculture soil carbon accumulation would continue to increase - only time will tell. Whilst the capacity for storage of soil carbon may over time flatten, it is aruably a 'no brainer' for us as a species, to optimise the utilisation of photosyntheis by plants, a free existing proven and working technology, to capture carbon.

Soil carbon capture will not mitigate our use of fossil fuels, but will help in a meaningful way; by buying us time, and at the same time will improve; soil quality, water retention and crop nutrient density, and likely mitigate climate effects including heating, heat domes, droughts and fires, reducing flooding, as well as improving hydrology and regional weather - thus warrants serious consideration and research.

TREES AS A CARBON SINK – AGRICULTURAL SOIL MAY OFFER 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 whole range of much valued eco-services, including fire wood, shade, cooling and food, to small communities living on marginal land.

However, the subject of contribution of trees, including mono-crop plantations, to carbon sequestration is complex. In determining the level of carbon sequestration by trees it is necessary to also consider their wider environmental impact, including on soil carbon levels. For example, in some instances, trees planted on carbon-rich soils may fuel growth in significant part, by drawing on soil resources including the carbon beneath them, providing 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 take-up 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 net calculation of changes in soil carbon, and tree growth-related carbon. Forest soils vary in depth, but are often not very deep - though very old and established mixed broadleaf forests tend to be exceptions. Soil carbon levels of tree plantations, surprisingly can be below those of agricultural land.

Also, the speed at which carbon can be sequestered into agricultural soils may be faster as well, than sequestering carbon into trees, albeit there are clearly good reasons to do both as part of creation of sustainable landscapes. '*Global Sequestration Potential of Increased Organic Carbon in Cropland Soils*' (Zomer *et al.*, 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 *et al.,* 2017)

Further the carbon trees contain will also be released when; they die and degrade in situ, are used as fuel, or other ultimately disposable purposes. Whereas agricultural soil carbon can potentially be sequestered at depth, for longer time frames with greater certainty, providing; 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 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 sources of; very useful 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 real value of simply planting mono-crop trees en-masse on agricultural soils, for the purposes of carbon credit related sequestration, instead of sequestering carbon into continuously productive cropping agricultural soils through environmentally sensitive, regenerative, approaches to farming, with use of trees as an integrated part of that strategy.

RECYCLING OF STORED SOIL CARBON

High carbon demand by above ground growth, and below ground roots, by high production crops such as maize at peak growth, as well using photosynthetically fixed carbon from carbon dioxide, likely draws down carbon from the soil to build root and wider structure, another factor that would make extensive soil carbon essential to high yields. Where the plants drawing soil carbon for root growth were long lived, or grown repeatedly in succession, this process may reduce available soil carbon, and help further explain 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, but 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 *et al.*, 2019).

In another labelling study, (Yamamuro *et al*., 2002) in poor soil, using labelled manure on corn, "*The final uptake rates of l3C and l5N 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 soil. The figures for rice were much lower. In rice most of the carbon uptake was present in the roots. More research is required to better determine the dynamics of soil carbons in the growth of fast-growing plants.

ARTIFICIAL FERTILISERS LIKELY 'FRUSTRATE' CARBON SEQUESTRATION BY SOILS

That artificial nitrogen leads, to deleted soil carbon, was first observed by agronomists as long ago as the early 1900s. It was further reported, based on soil trials, that where nitrogen is applied, depletion was observed to occur even where large amounts of organic matter were annually incorporated into soils.

It appears nitrogen addition, changes bacterial and fungal metabolism and balance, and in absence of adequate available soil carbon, results in draw down of stored soil carbon. The science is very complex. A number of more recent papers also point in this direction (Weng *et al*., 2022), but the suggestion fertilisers damage soils has been around over one hundred years.

A miller, Hensel writing about '*Stone Meal as a Fertilzer*' (Hensel, 1894), in the book '*Bread From Stones*' (Hensel, 1894) (see section on 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 personal observations, but noted highly experienced then leading agronomists, Albrecht, Howard and others, in the 1920s-40s also had observed 'artificials' 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 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, Khan & Ellsworth, 2009). (References in italics are available in original, and have been left in the text body on this occasion, given the importance and contentious nature of the subject matter).

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. Artificial 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 top soil layers with nitrate use; wider 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, Mulvaney & Boast, 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 both essential components of the organic matter that comprises soil carbon, 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 may be a consequence of reduced organic matter availability. Falling total soil nitrogen points to falling soil carbon.

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 et al., 2018).

As might be expected there is significant opposition to the idea artificial fertilisers inhibit soil carbon supply and sequestration, both from the agro-fertiliser industry, and from many agricultural advisers who have promoted fertiliser intensive farming for decades. Whilst the direction of travel is arguably clear, 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, it makes huge sense to promote the rapid adoption of regenerative agriculture, thus discontinuance of NPK use, combined with reclamation of degraded land, globally.

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, results in soil compaction, crusting, 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 exchange of gas including nitrogen necessary for nitrate formation, encourages waterlogging and disease, and more widely makes the plant soil biome interactions necessary to life very difficult.

COMPACTION, DESTRUCTION OF SOIL STRUCTURE, REDUCED WATER PENETRATION INFILTRATION RETENTION, INCREASED FLOODING AND EROSION RISK

Fig. 68. 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)

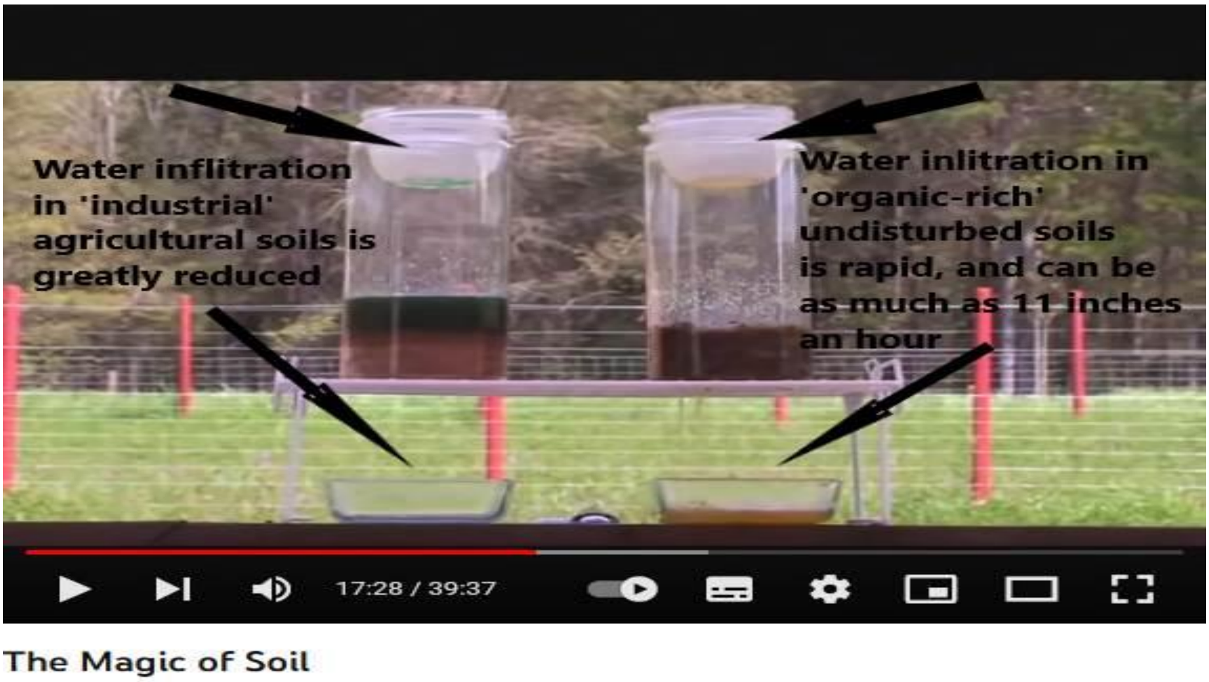


Fig. 69. Annotated and with very many thanks to '*Magic of Soil*' and '*Soil health lessons in a minute: soil stability test'* - NRCS Agronomist Ray Archuleta (Archuleta, 2012b; Gregory, 2017).

Fig. 70. 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. 71. 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)

Simple but visually powerful demonstrations, of the loss of water infiltration-penetrability of soils by Ray Archuleta, are referred to in the video the '*Magic of Soil*'. The slides above compare, infiltration rates. As can be seen the water rapidly penetrates and infiltrates the undisturbed soil, but sits on, and is unable to rapidly infiltrate or penetrate, the industrially farmed soils.

The second experiment demonstrates how, where an industrially farmed soil, and a biologically rich undisturbed soil are 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, the biologically rich soil remains largely intact.

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, was greater than that of nature, and that we could afford to both go to war with nature, ignoring the aeons of evolutionary synergies, which had allowed life to self-perpetuate and prosper.

Fig. 72. "*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)

Most of the energy that powers the production of structured carbon-based molecular elements, and energy required for cellular respiration, of surface terrestrial life comes from sunlight. Humans, through FATBAS farming, have taken responsibility for much of earths productive photo-synthesising lands thus are now the custodians of the natural light carbon and water cycles, that are our planetary Gaian regulatory systems. With hubristic lack of comprehension, due to lack of public understanding, we humans happily leave vast areas of agricultural land barren of life, for significant portions of the year, naked to the elements, in the mistaken belief such practices assist crop yields. We further kill plants and soil biology with agrochemicals just to be more certain the land remains bare. The vast majority of us have no understanding that it is these systems that ultimately support the biosphere, that supports our ongoing existence.

By leaving land bare between crops, and allowing degradation of land through poor agricultural practice, including over grazing, 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; earth's crust, soils; atmosphere; oceans and living things.

SOIL WATER RETENTION, IS PROPORTIONAL TO SOIL CARBON

This section looks in more detail at the relationship between soil carbon and water retention. As discussed, when living creatures, including mycorrhizal systems respire, dependent on respiration and water reuse rates, and their wider 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 in consequence soil carbon content, opportunity exists to significantly improve soil water retention, soil moisture content, plant water use efficiency, and crop productivity.

Conversely reduction in soil biome life, thus soil carbon, will result in 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, Stewart, & Sainju, 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, Stewart, & Sainju, 2015)

From the graph below it is plain to see, increasing soil carbon levels could have massive beneficial downstream hydrological implications for wider ecosystems, as well as on the ability of farmers to grow the crops, needed to meet the dietary needs of ever-growing populations, including in increasingly arid scenarios

Whilst exact results as to the impact of soil carbon on water retention greatly differ, data, including that provided by Dr Johnson, and observational experience of regenerative farmers, consistently, supports the importance of soil carbon, in water retention and infiltration.

Loss of soil carbon proportionately reduces soil water retention capacity, thus reduces soil and plant health, soil cover, and respiration capacity, due to,

- less stored soil water available for plant and soil transpiration 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 transpiration, and reduced mycorrhizal supply of nutrients to plants,
- reduced plant growth reduces supply of sugar exudates to mycorrhizal biome,
- agricultural soils containing no growing plants further reduce transpiration,
- bare soils speed initial water evaporation of water stored in soils, adding to the impact of dry season droughts
- bare soil facilitates; water runoff, erosion rather than soil penetration, and through absorption of UV and visible light, and their reemission as infrared, leads to soil heating, thus heat domes, which in turn inhibit movement of ocean moisture circulation in land, and thus reduce rain fall.
- greater plant cover, dead or alive, of soil, protects the surface of the soil from; rain drop impact compaction, heating, 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 related presence of cloud seeding bacteria, negatively affect 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 about 50% of natural microorganisms can be adversely affected via practices such as use of fungicide for seed coating (Wang & Cernava, 2020).

Further and thinking more widely, use of biocides may kill or alter populations of rain seeding bacteria pseudomonas syringae emitted by plants, which could potentially influence cloud seeding, thus rain fall (more research required), reminding us how interconnected with potential unforeseen consequences our action can be.

Loss of soil carbon also increases 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, Stewart, & Sainju, 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.

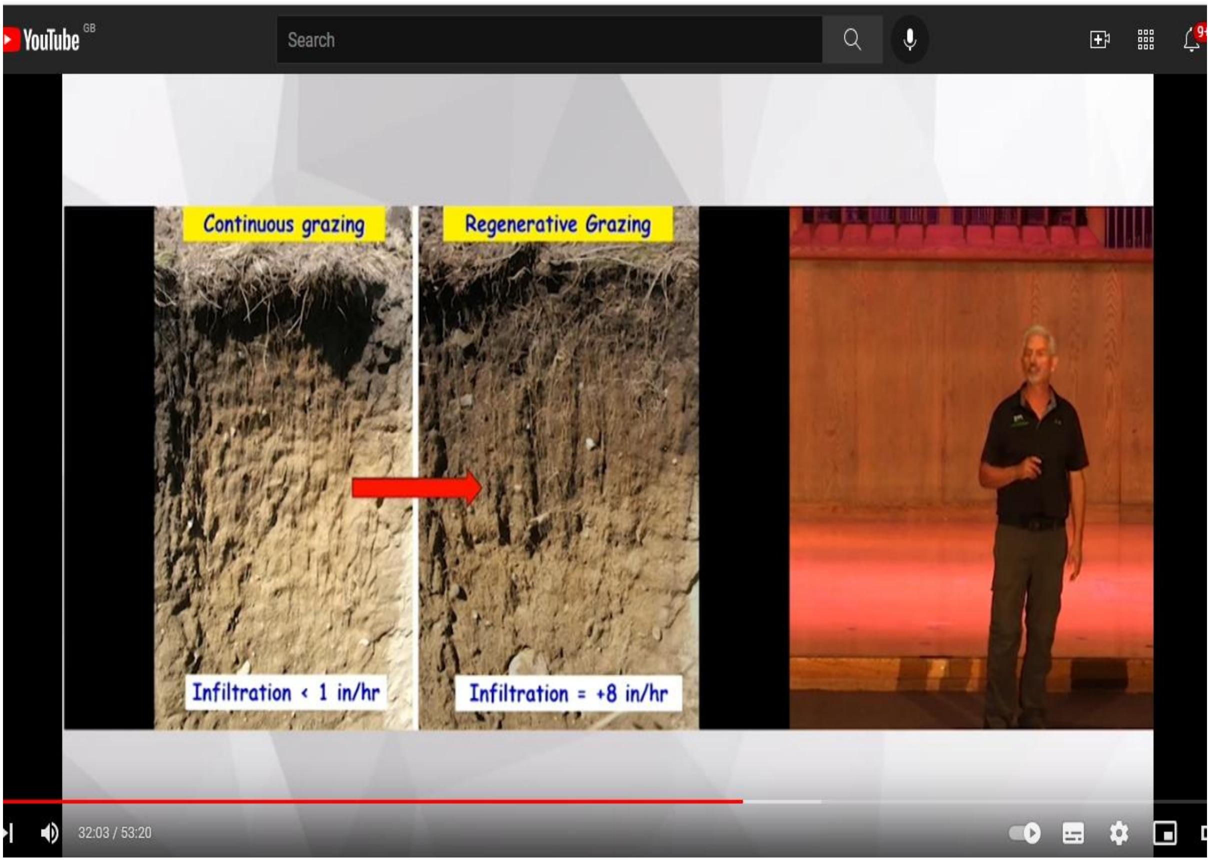


Fig. 73. '*Regenerative Agriculture Healing the World - By Ray Archuleta @ Carbon Summit*' –Capacity of farming techniques to improve water penetration. Elsewhere, Gabe Brown reports measure rates of 11 inches and more per hour in his farm, a vast improvement from the original rate of 1 inch per year. (Archuleta, 2021b)

Soil carbon, and related diverse fungal, abacterial and wider life, also improves; biological remediation, filtration, and aeration, enhancing emergent water quality. Water that infiltrates will replenish local hydrology, resulting in stream flow returning, and for longer periods in the year; greater plant respiration, and cooler temperatures; positively influencing local microclimates.

WATER RETENTION HYDROLOGY AND SOIL CARBON – THE SAHEL

Perhaps it is easy to write off arid, or semi-arid land, as irredeemably unproductive, and beyond useful cultivation, but 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 soils, depleted of carbon and thus soil biome biology. The loss of soil plant cover, increases erosion, raises soil temperature, speeds soil water respiration; and precludes any photosynthesis of sunlight into the carbon organic molecules, which ultimately 'fuel' the subsoil system. Loss of soil organic life, including root systems, and burrowing lifeforms, limits water penetration, retention, and diminishes metabolic water production through soil biome respiration.

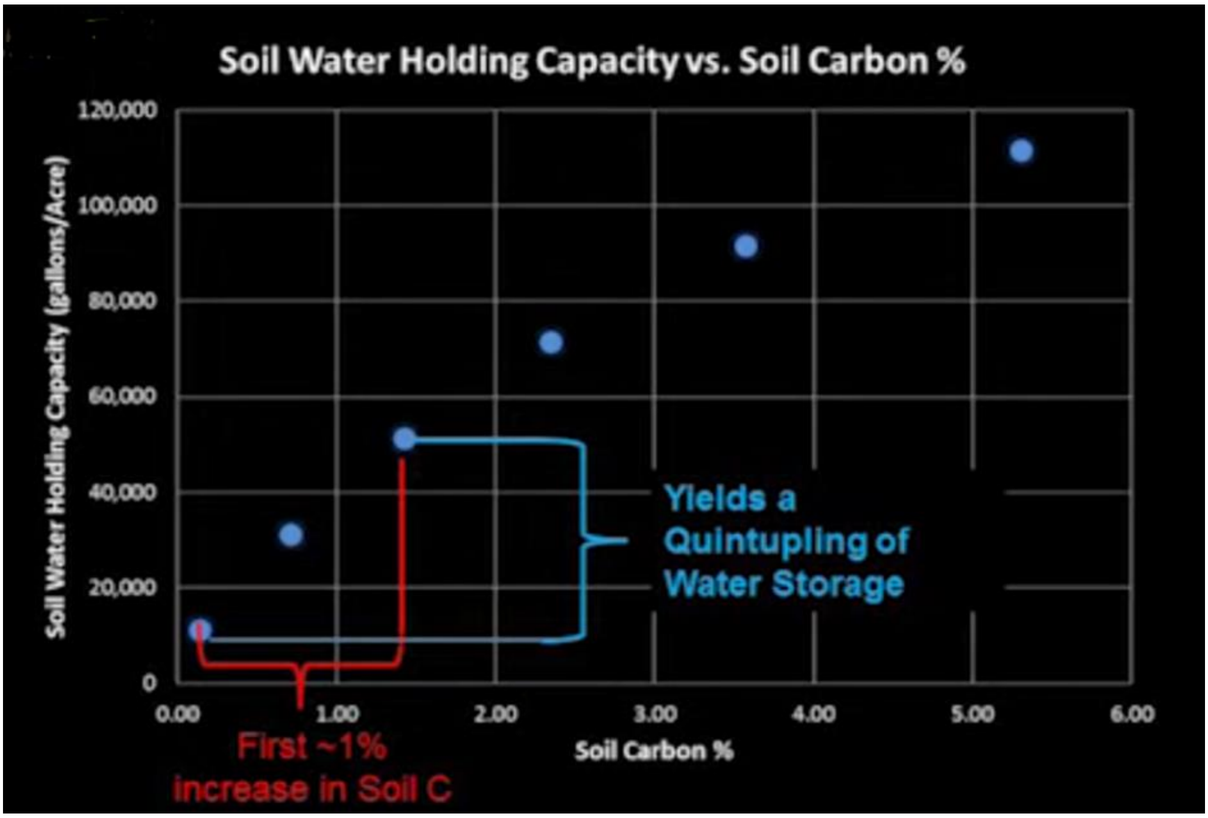


Fig. 74. Soil water holding capacity of soils with increased carbon content from the UTube presentation *'The BEAM Approach'* by Dr D Johnson, with many thanks to the author (Johnson, 2017).

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 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 areas with relatively extreme climates, recovery of degraded land is possible though improvement of soil. 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, where used, increase; metabolic water production, rain penetration, and retention. Permanent ground cover, 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 de-desertification.

PLOUGHING, SOIL DAMAGE AND CARBON LOSS

Ploughing both creates increased bare surface soil area, and further exposes soil biology to light and heat, which will kill many fungal and bacterial elements, and impair 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.

Once the mycorrhiza below the plough cut, become socially isolated, they can no longer cycle metabolic water above the cut point, and gravity will drain retained water downwards, drying the soil below the plough cut layer. Interestingly, it was historically observed and recorded, that shallow ploughing restricted soil moisture to the upper layer.

Further, it is logical ploughing also severs nitrogen and oxygen, soil gaseous pore transport channels, which are directionally disturbed and overlayered with the turned surface biology. The horizontal cut layer, will impair; downward penetration of; plant sugars, rain, as well as dew, oxygen and nitrogen; thus, below the cut layer, inhibiting; mycorrhizal, bacterial, and wider life form 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.

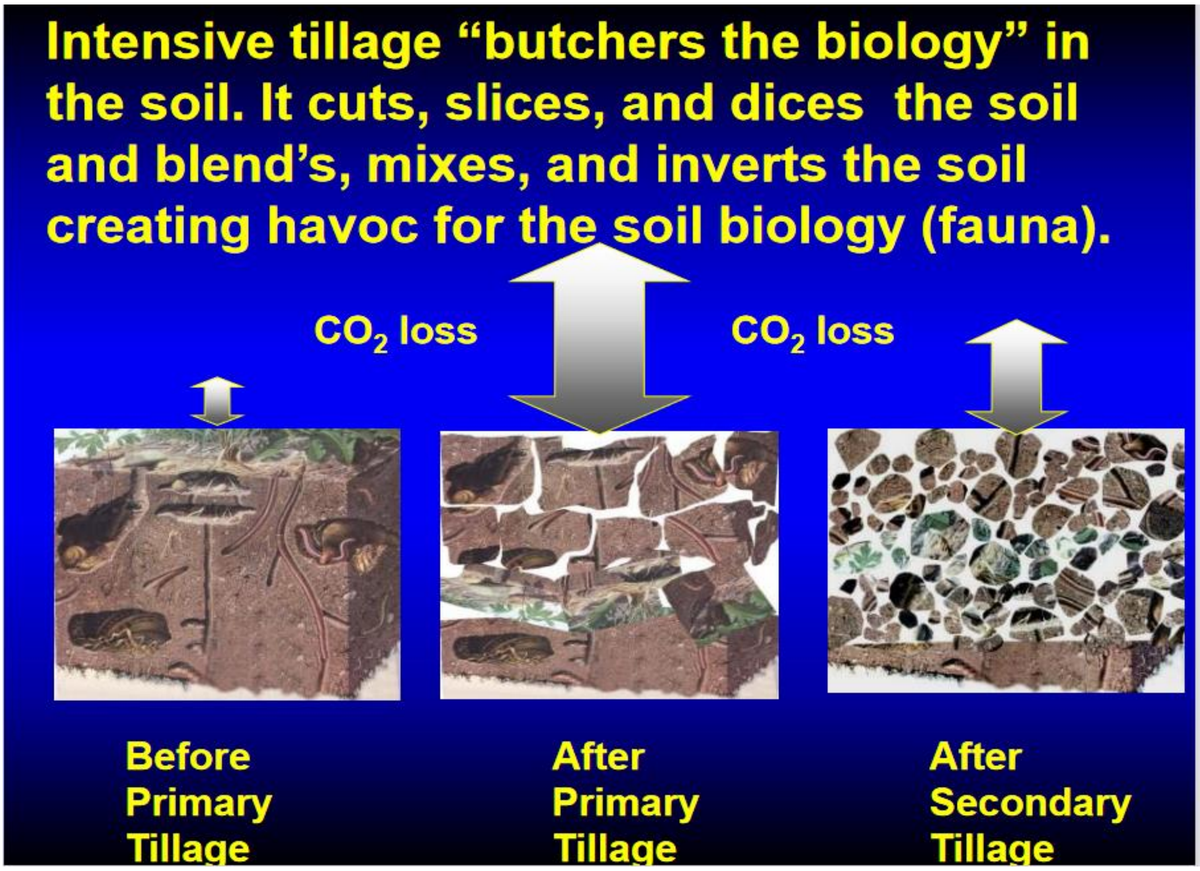


Fig. 75. Lecture slide AGVISE Seminars and Don Reicosky '*Tillage and Carbon Management: Nutrient Re-Cycling Synergies*' North Central Soil Conservation Research, with very many thanks to the authors. (Reicosky, 2014)

In addition, newly planted seeds (absent pre-treatment with soil biology), in a UV exposed wind and light desiccated upper 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 death, and destruction of soil life, which is then respired in an ever-diminishing annual downward spiral to each year support diminishing remaining soil life, with loss of soil carbon, which exits the soil as carbon dioxide. The stored carbon from dying soil biome life forms, is metabolised, because consequent on tillage, and bare ground, thus 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.

Fig. 76. '*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)

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.

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.

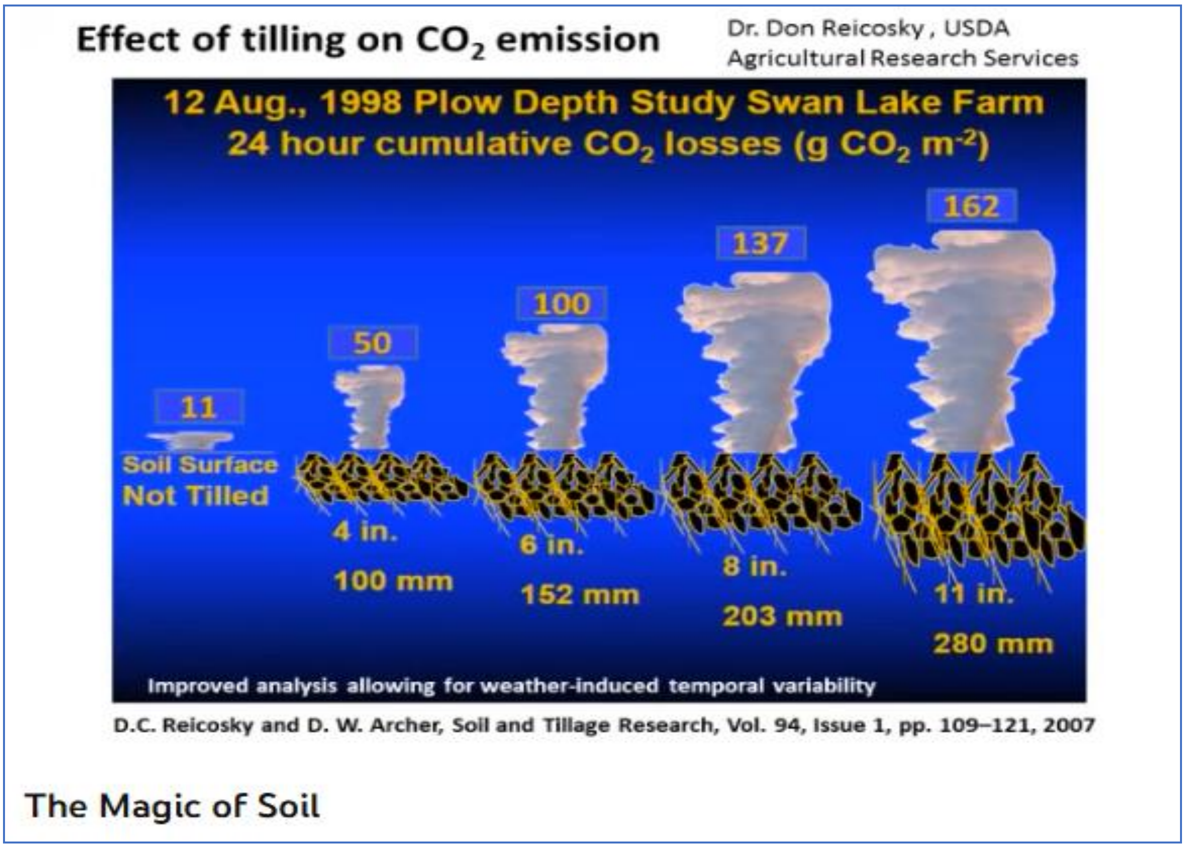


Fig. 77. '*Magic of Soil*' Philip Gregory, "*Now one acre is 4047 sq. meters which means 162 x 4047 = 655,614 grams or 656 kg of CO2 released from one acre which translates to 0.657 tonnes per acre or 0.723 U.S. tons of CO2/acre. To convert tons of CO2 to tons of carbon divide by 3.67 which yields finally 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)

OBSERVABLE SEASONAL CHANGE IN ATMOSPHERIC CARBON DIOXIDE INCLUDING LIKELY DUE TO TILLAGE

In the spring tillage season, Ray Archuleta (see annotated slides below) observed, carbon dioxide appears to increase to levels above those seen in mid-winter when home heating in increased, which whilst logical, is a wake-up call as to the amount of carbon dioxide likely released from tillage of soils. Carbon dioxide, then as might be expected, due to uptake by photosynthesising plants, reduces in the growing season.

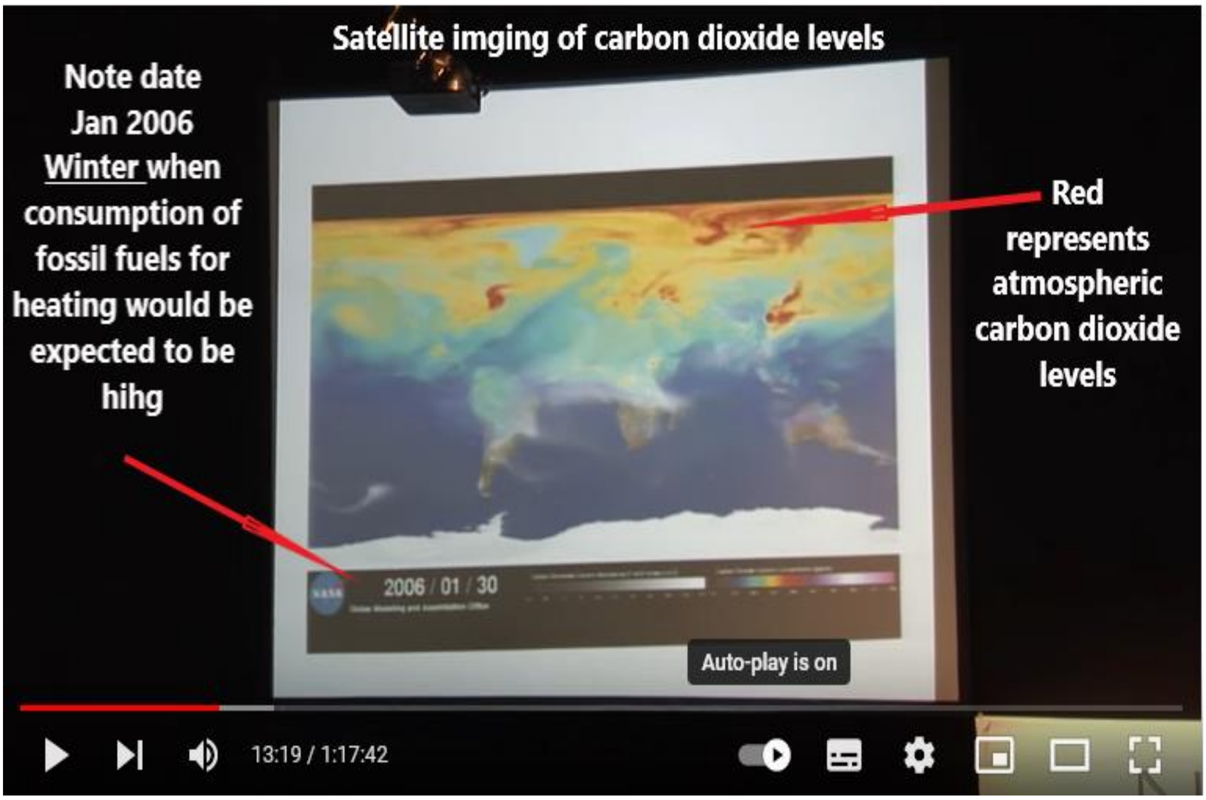


Fig. 78. Annotated and with very many thanks to *'No-till on the Plains'* by Ray Archuleta and NASA, taken from a video representation of changing annual atmospheric carbon dioxide levels (Archuleta, 2016).

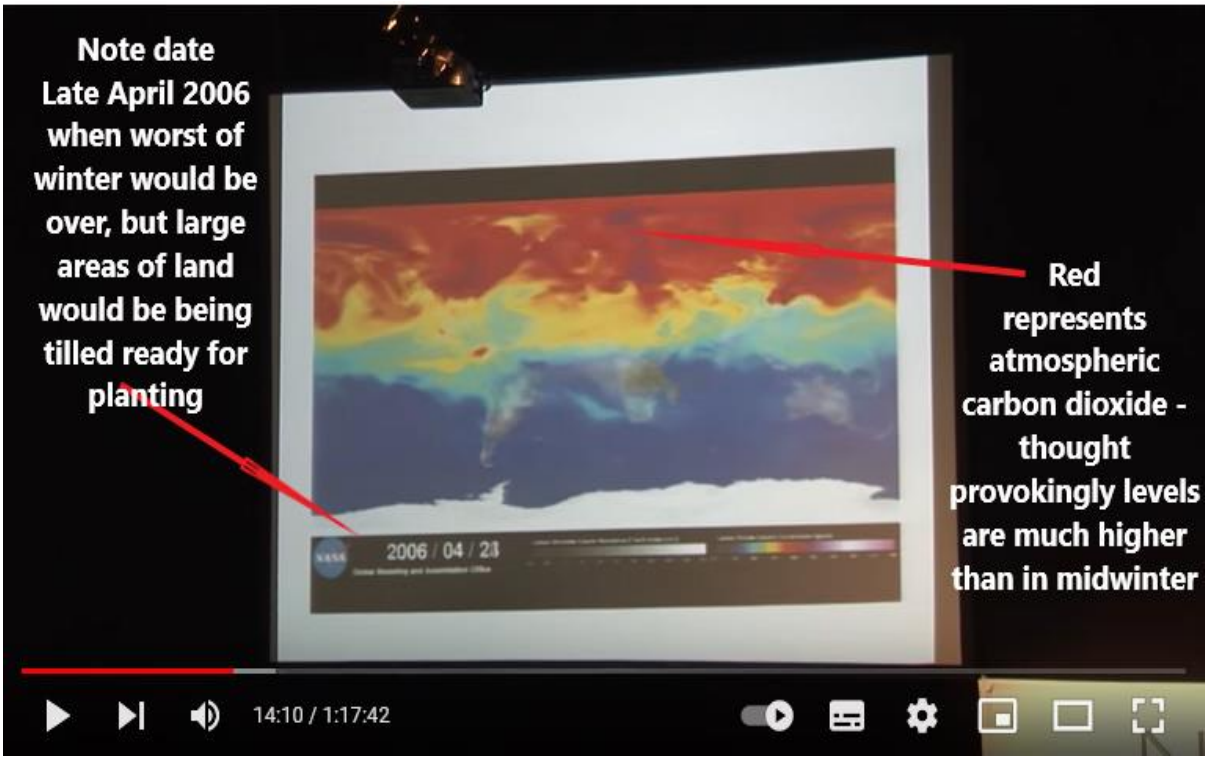


Fig. 79. Annotated and with very many thanks to *'No-till on the Plains'* by Ray Archuleta and NASA, taken from a video representation of changing annual atmospheric carbon dioxide levels (Archuleta, 2016).

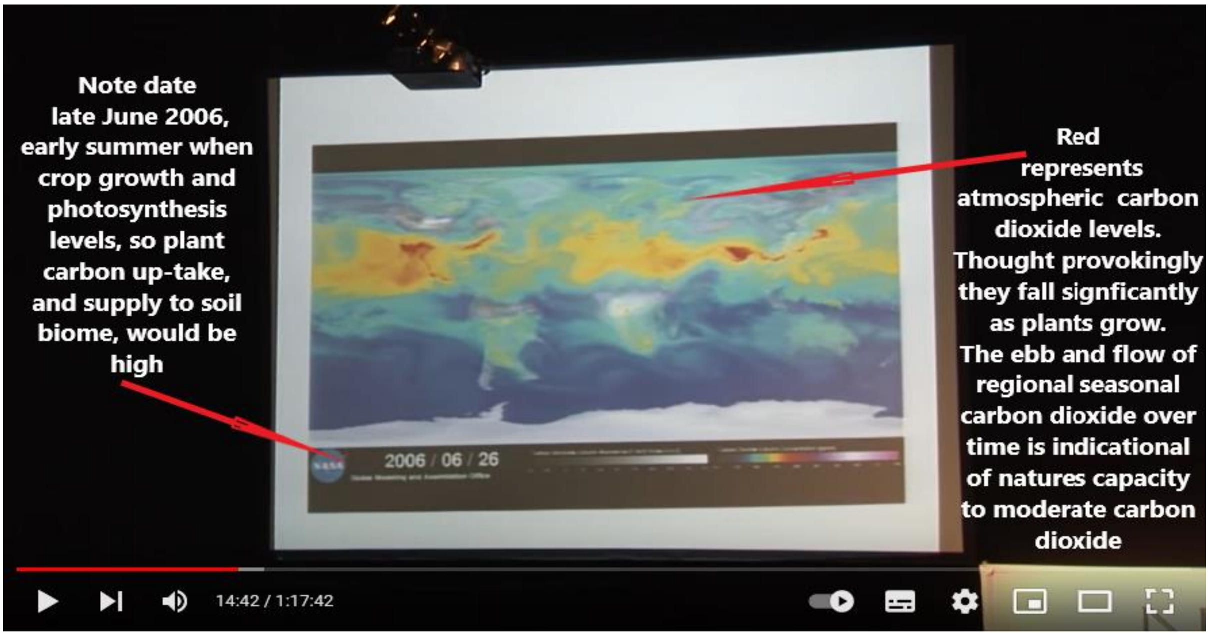


Fig. 80. Annotated and with very many thanks to *'No-till on the Plains'* by Ray Archuleta and NASA, taken from a video representation of changing annual atmospheric carbon dioxide levels. (Archuleta, 2016).

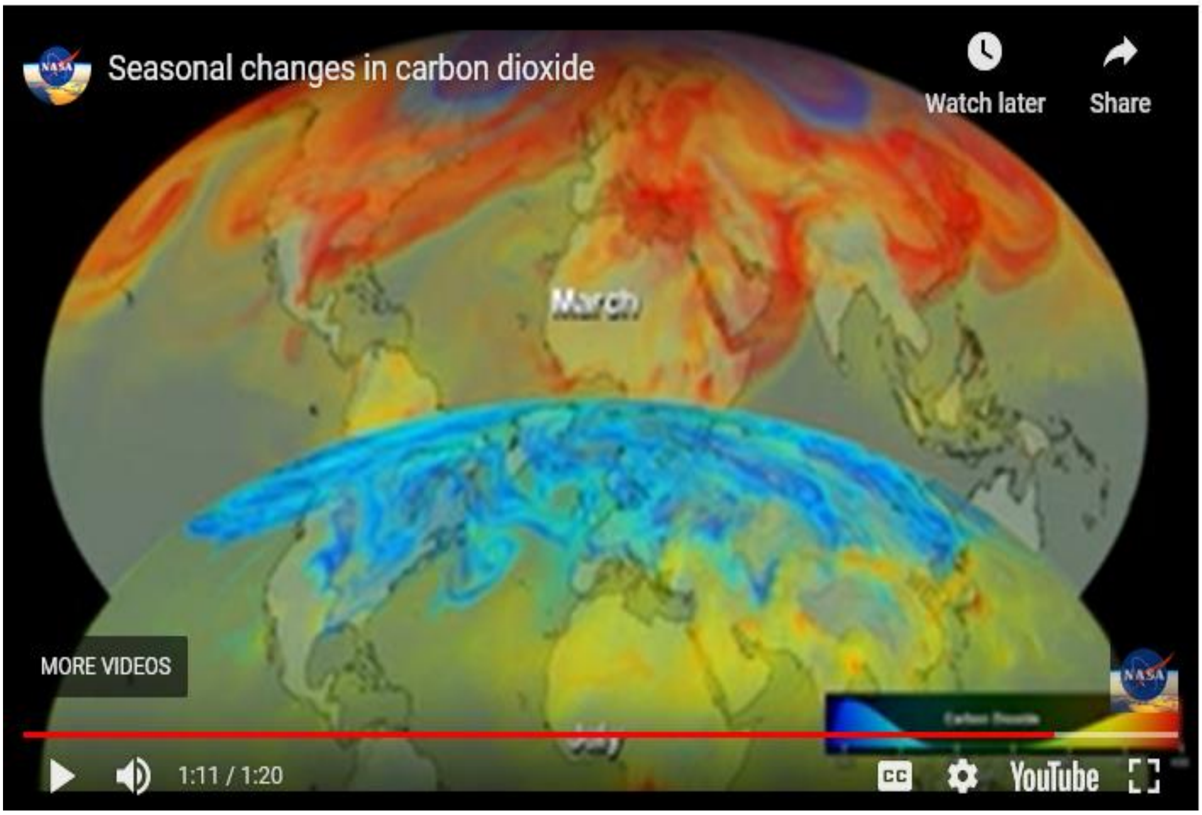


Fig. 81. With many thanks to NASA - "*This visualization provides a high-resolution, three-dimensional view of global atmospheric carbon dioxide concentrations from September 1, 2014 to August 31, 2015. The visualization was created using output from the GEOS modelling system, developed and maintained by scientists at NASA.*" ('*Video: Seasonal changes in carbon dioxide*', 2015)

The satellite images above are suggestive our agricultural practices have much greater 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, due to fossil fuel usage, buying us precious time. It would also logically reduce climate event occurrences including drought, heat domes, flooding, and eutrophication.

IMPORTANCE OF SOIL CARBON IN CLIMATOLOGY AS SEEN IN THE CERRADO

As discussed above, the water holding and production capacity of soils is proportional to the quantity of soil carbon present. Localised water absorption, retention, and release rates, by each hectare of agricultural land, have with massive down-stream hydrological implications, which in turn impacts on wider ecosystems, including atmospheric moisture, bacterial cloud seeding, rain, and downstream river flows, as seen in the Cerrado in Brazil.

The Cerrado in Brazil provides an example of the effects on soils, of replacement of 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 indeed 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, Kuepper & Piotrowksi, 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, Kuepper & Piotrowksi, 2018) Estimates of water loss vary; some estimates, as below, are much larger, but even 1.7 kilometers cubed is a large volume of water – a cubic kilometre - 1,000,000,000 cubic meters – which would make a lake 10 kilometers square by 10 meters deep.

"*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 km^3 less (-3%) water than if the land cover had been native Cerrado vegetation.*" (Spera *et. al.*, 2016)

Fig. 82. 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).

*"__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, Kuepper, & Piotrowksi, 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 (Costa & Pires 2010, Yin et al. 2014). 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. 83. Cerrado in Piaui, Brazil with very many thanks to Pedro H C Pinheiro

Ironically the dying 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, creates a large increase in the requirement for crop irrigation, whilst at the same time reducing water supply. Thought provokingly, 70% of the Cerrado's water is being used for irrigation. Local communities protested as they are at times they are deprived of water. "*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 evidences 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 movement of oceanic moisture inland. It is surely unsurprising the area is drying, and the hydrology and rainfall is changing. Such changes in local hydrology clearly have wider implications for regional hydrology, climate change related events, drought, fire, floods, and consequent run off, erosion, (Gomes *et al*., 2019) including in the wider Amazon region, with the additional effect of fertilisers in run off, via rivers, reaching and through eutrophication, and wider chemical impact, damaging marine habitats.

Fig. 84. 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)

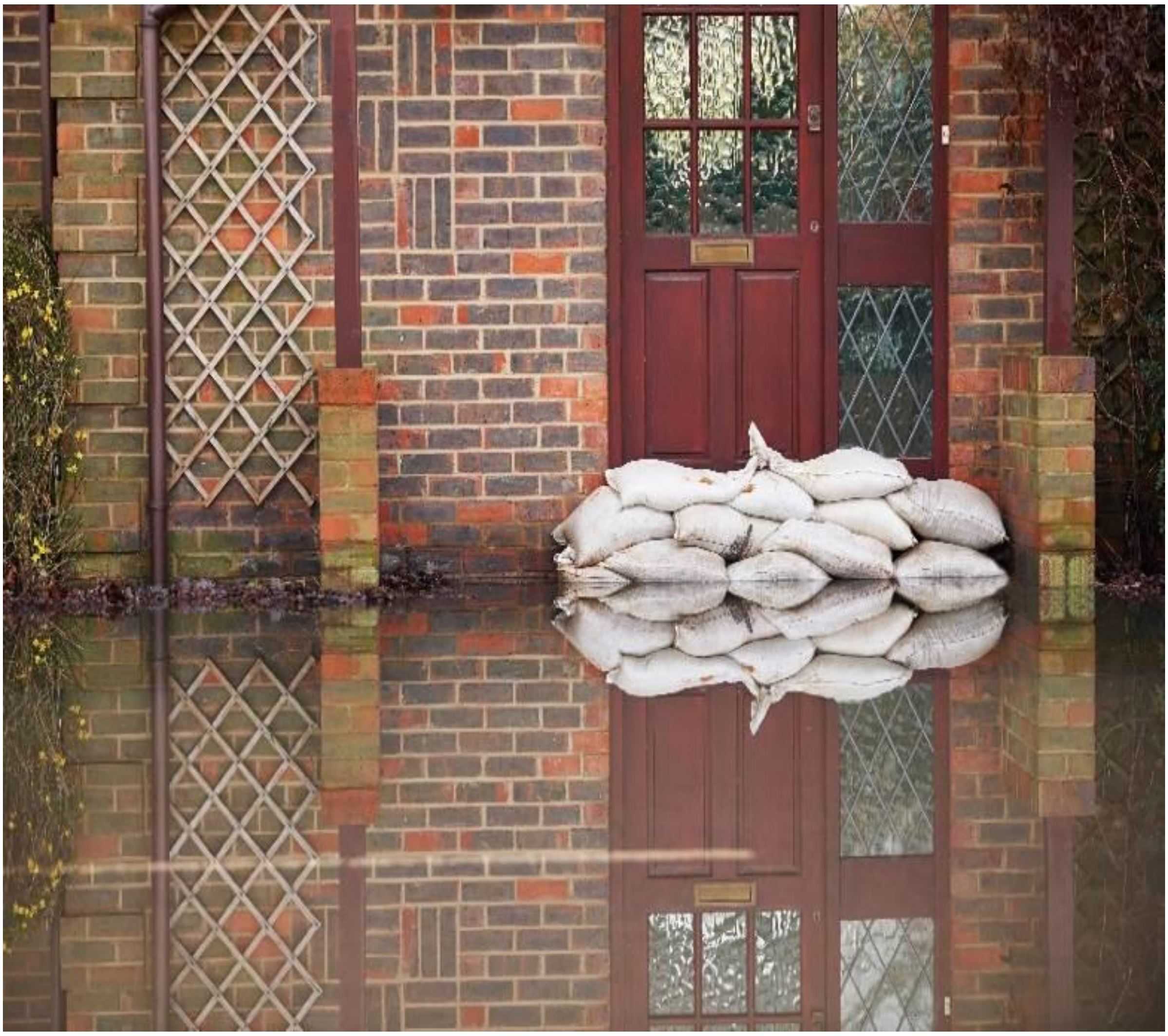
Microclimates are a recognised phenomenon. In Western Australia there are anecdotal reports of square mists forming over square areas under regenerative agriculture, but not in the surrounding areas. We all have experienced the massive regional cooling climate regulation effect of green parks in urban 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, and result in greater temperatures, including due to reflected heat from bare soils creating heat domes, they also negatively impact weather, including reducing rainfall and atmospheric moisture, and thus contributes to the risks of bush fires as seen in the Amazon, Australia, and Canada in 2020/21.

Logically, were carbon soil stocks – soil biome systems - increased through soil-centric-agriculture, a number of climate change risks could be mitigated, including, temperature rise, water availability, soil productivity, fire and flood, risks.

Wider beneficial effects of regenerative agriculture based, increased soil carbon, thus healthier more prolific soil biomes, would include; greater 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 wider climate mitigation; including likely rainfall smoothing, and flood reduction. Thus, significant potential exists to mitigate climate change trough the sequestration of carbon into soils, as set out in Jehne's paper (*Regenerate Earth*' (Jehne, n.d.)

FLOODING, EROSION AND DROUGHT



With thanks to Adobe Stock ©

Farmers, as they switch to regenerative agriculture, are reporting massive increases in measured infiltration rates of rain into soil, from less than one inch per hour to many inches an hour. Gabe Brown reporting 11 inches an hour infiltration. As a result, the fields of established regenerative farmers, after large and small rain events, are free of lying water or soil run-off, whereas their immediate neighbours with adjacent land with similar soil, using bare soil / fertiliser / agrochemical, farming techniques, suffer wet soils not accessible to farm equipment, lying water often for significant periods, and soil erosion including loss of nutrients, related carbon, nitrate and mineral loss

Whilst heavy rainfall has water and soil health implications for every farm, there are wider regional and downstream implications of erosion and run-off; including; eutrophication of rivers and oceans, and silting of rivers; increased risk of large-scale flooding, and related

property and infrastructure damage. 'Industrially' farmed, high tillage, bare-ground, low organic matter soils inhibit the infiltration of rain, resulting in run-off, which can only lead to erosion, flooding, downstream eutrophication, degradation of regional water tables, and ultimately increased drought risk, including of heat domes.

Soil health lessons in a minute: benefits of no-till farming

Fig. 85. 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)

As illustrated by the slide above, soils damaged by FATBAS greatly 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 area, and released over a long-time frame into streams and rivers, and consequentially flood events would be greatly reduced.

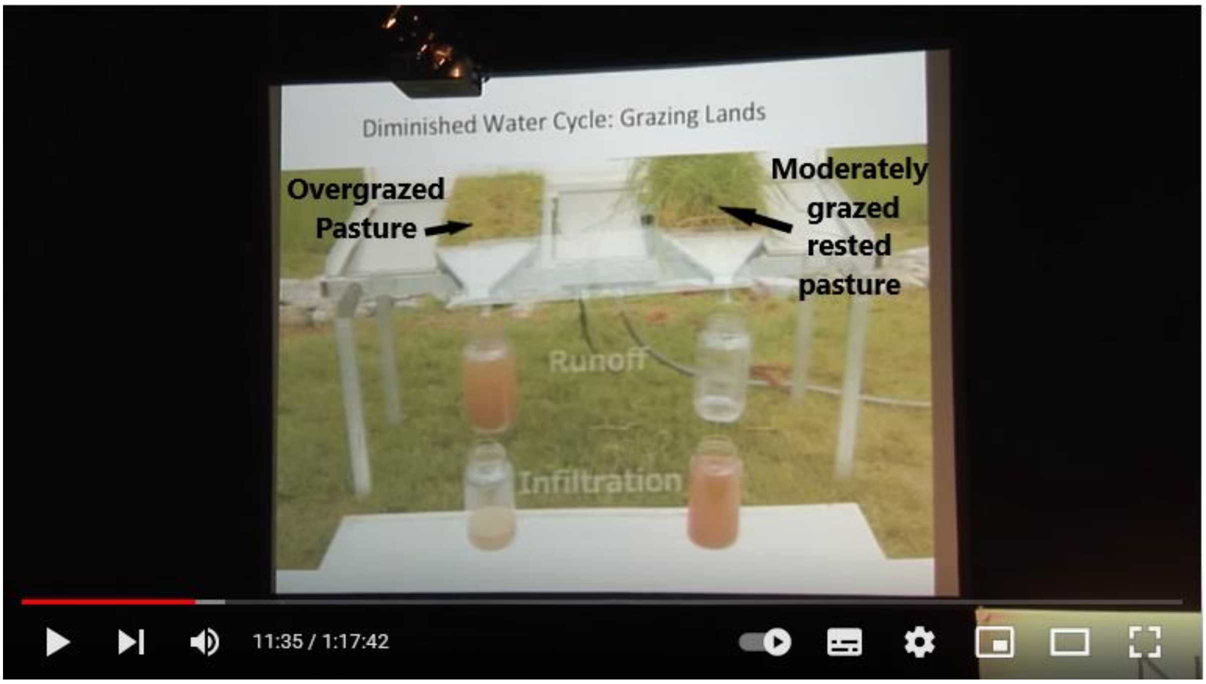
An understanding of the implications of modern agriculture on ground penetration and water retention capacity, begs the question as to the extent to which increased flooding events of increased severity, which are being seen globally, are due to increased rain fall, and how much is due to damaged soils consequent on fertiliser / agrochemical / bare ground farming?

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 and nutrient run off, erosion including of; soil carbon, agricultural applied fertilisers, (Bashagaluke et al, 2018) and mineral dust, consequent eutrophication, silting, and increased opacity and pollution generally, of otherwise clear water in rivers and ocean deltas.

With thanks to Adobe Stock ©

RUN-OFF FROM OVERGRAZED UNRESTED PASTURES

Poor infiltration and high run off, 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 greater 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.



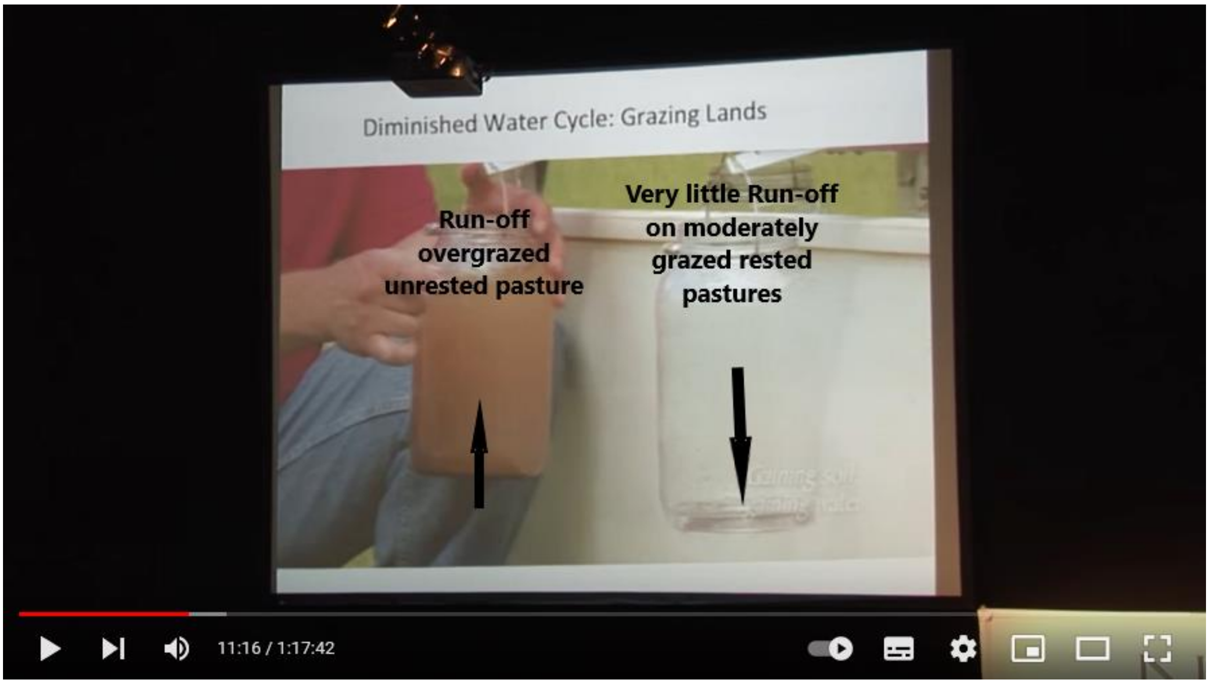


Fig. 86 a & b. Annotated slides with very many thanks to Ray Archuleta from his UTube lecture *'No-till on the Plains'* (Archuleta, 2016).

URINE AND FAECES AND CLIMATE CHANGE

Industrial raising of livestock, transport, requirement for feedstock, medication, including dealing with urine and faces, have significant environmental consequences. Livestock animals, and particularly cattle, inevitably produce large amounts of faeces and urine, which is a huge issue where animals are raised in yards. Human faeces and urine add to the issue.

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 from, during processing or storage of sewage, of 'climate warming' gases such as; ammonia, methane, carbon dioxide etc.,
- Release from treatment plants, and run off from un-composted sewage sludge and untreated sewage and manure, applied to land, of released 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, cattle slurry, by treatment outfall discharges, and sewage sludge applied to land.

The options for disposal of urine faeces and related sewage sludge, waste water discharge, and direct discharge into the environment are considered in greater detail in volumes 1 and 3, so not repeated here.

IMPACT OF CHANGING RAIN FALL AND TEMPERATURE ON CROP PRODUCTION

Clearly, to the extent that climate change results in altered rainfall and temperature, such factors will impact on crop production. Given the consensus is, and recent events suggest, that weather events will become more severe, it is clearly important that soils are maintained in optimal condition, to reduce soil albedo and heat domes, maximally absorb and retain rain, minimise erosion from water and wind, reduce flood risks and related damage, and maximise coil carbon sequestration.

ATMOSPHERIC OXYGEN 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 the other side of the equation, increased atmospheric carbon dioxide. This is because oxygen forms a relatively large portion of gases in the atmosphere above 20% - it is estimated totalling million gigatons - thus the anthropogenic removal of a 'few gigatons', maybe 30GT 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, 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 exchange of gas between liquids and gaseous environments, as moderated by production of oxygen by plants and oceanic oxygen producing photosynthetic organisms, and conversely 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, very long-standing, gas exchange equilibrium, at a very complex air water interface.

In spite of its complexities, ultimately, this surely is a system in very long-standing equilibrium, 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, which will happen as oceanic oxygen moves upward in the ocean layers to restore the surface oxygen partial pressure. Whilst not currently on the agenda of the climate change community, this it is suggested will likely prove to be a significant contributing factor to oceanic oxygen depletion.

This effect is logically very important, and the impact underappreciated, because whilst there is a 1,000,000 gigatons of oxygen in the atmosphere, it is estimated there is only about 8,000 gigatons in the oceans, of which say 4,000 gigatons is in the upper ocean layers. 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 release of oceanic oxygen, to maintain partial pressure equilibrium, could represent up to 1% of the oxygen that in the upper ocean layers. Even if annually half that or less moved from the ocean to the atmosphere, the losses in terms of ocean deoxygenation, would be significant, and may account for a portion of the significant, and not fully explained witnessed oxygen loss from oceans (Brown R, 2021e).

The distrubution of molecules comprising gases, including carbon dioxide and oxygen, between the earth's crust, ocean, atmosphere, soils and living things, forms part of a stable Gaian system that has reached stability over millenia. The partition of resources is the consequence of the laws of physics, and presence of evolutionary pathways. Stable biosystems seek to maintain the stable status quo. We may not be able to exactly explain why the distribution ratios between earth's crust, atmosphere, ocean, soil, and living matter, are what they are, but natural systems over aeons of evolution have determined it is so.

It is positied by the author, that the logical consequence of Henrys' 'Law', and the inherent self-regulating quality of bioshpere systems, is limited stores of oxygen in the upper ocean layer, will still seek to recharge depletion of atmospheric oxygen, and therby maintain the stable system status quo.

In liquids in motion, gases will tend to move over time to the surface due to pressure changes consequent on upward movements of water, and reduction on gaseous solubility. Thus, logically, the ocean will try and maintain the amount of oxygen at the surface layers, even though oxygen at depth is falling.

Loss of ocean oxygen will be further reduced by damage to oxygen producers, eutrophication, ocean warming, stratification, warming of, the poles, and thus artic waters, and consequent reduction in the Gulf Stream and related global current system oxygen subduction and transport, and likely will be further negatively impacted by pollution, and other damage to ocean biology.

The crunch issue is, whilst there are comparatively large amounts of oxygen in the atmosphere, there are much lesser amounts in the ocean, and they tend to concentrate in the upper oceanic layers. Thus, oxygen eqilibiriation; in effect repletion of the atmospeher by oceanic oxygen, by a system tied to the laws of gas exchange, trying to maintain steady partial pressues; over time, will greatly increase the risk of the oceans regionally suffering significant sized, annoxic episodes.

The risk of oceans going annoxic has massive environmental implicatons. Concerningly we are already seeing significant and partly unexplained losses of ocean oxygen, including seas in vulnerable areas, which already on occaions turn annoxic, for example off the Namibian Coast.

Anoxic oceans, where the biology becomes sulphidic, can emit hydrogen sulphide, which is a very toxic gas, fatal even at low concentration. Hydrogen sulphide kills ocean life forms; and if emitted as gas in quatity, that moved onshore, could cause mass fatality to all species in the relevant toxic gas concentation zone. We are not at that stage yet, but it would be a logical consequence of long term loss of oceanic oxygen in susceptible regions.

Looking more widely and longer term, if ocean deoygenatin continues, ultimately significant oceanic emissions of hydrogen sulphide into the atmosphere, could damage the ozone layer, resulting in surface UVC incidence, which would be very damaging to all forms of surface life including plants. Indeed, as discussed and referenced earlier, research suggests, ocean anoxia featured as an element in many of the global extinction events, and hydrogen sulfide emmissions would be a plausible causitive factor in such extinction events. Atmosperic hydrogen sulphide would further lead to extreemly damaging acid rain. Thus atmospheric oxygen loss, including through, combustion of fossil fuels, loss of soil carbon, and degradation of photosynthetic potenttial of; land though bare soil farming, and due to ocean damage, may well, though accelaeration of ocean dexoygenation, be a much bigger 'climate' issue than as yet appreciated.

Other factors likely to impact on occeanic oxygen include, acidification, eutrophication including antropogenic increases in marine phosphates due to run of feriliser applied to agricultural land, and more widely 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 mass increase of respiration, decreasing regional oceanic oxygen; in combination, over time, leading to annoxic events and mass die offs.

Thus, in considering the effects and impacts of strategies to reduce the impact of climate change, it is also arguably very necessary to consider their rarely discussed impact on atmospheric oxygen levels, because that will ultimately impact on the rate of ocean deoxygenation.

Importantly, the observed level of oceanic oxygen depletion, cannot be explained by ocean warming and related effects alone. Reabsorption of oceanic oxygen to the atmosphere, is entirely logical, inevitable as based on the laws of physics, would help explain unaccounted for oceanic oxygen depletion, and more worryingly suggests the rate of oceanic oxygen loss is greater than realised. This is possible given 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 emissions of carbon dioxide, but will not address reduction of atmospheric oxygen, and consequent ocean damage. In the face of continued use of combustion, including combustion of hydrogen to create energy or electricity, replacement of atmospheric oxygen used, will require use of atomic or other green energy to split water into hydrogen and water, with 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, movement of oxygen from oceans otherwise at risk of oxygen depletion, into the atmosphere with large oxygen reserves, is inconvenient in climate change terms, but nature is governed by the laws of the universe, not the wishes or need of humans.

Thus, when a wider ecosystem perspective is taken, that encompasses oceanic oxygen levels, arguably anthropogenic atmospheric oxygen depletion through combustion, and net respiration of soil carbon due to FATBAS agriculture, represent a 'climate' issue of equivalent or greater importance, than atmospheric carbon dioxide.

SOIL CARBON STORAGE = INCREASED OXYGEN PRODUCTION

The net production and consumption of carbon dioxide by plants and the soil biome, and oxygen production by plants, is part of the climate regaulatory system of the planet. To the extent that historically stored plant photosynthetic carbon root exudate made from carbon dioxide is respired from soils, it represents a net reduction of atmospheric oxygen. To the extent that photosynthetically derived carbon, from the splitting of carbon dioxide, into carbon and oxygen, is stored long term in soils, it represents a long term addition of oxygen to the atmosphere. Thus storage of soil carbon, photosyntetically produced from carbon dioxide, helps replace atmosperhic oxygen used in combustion or metabolism of carbon.

In summary replacement of atmosperic oxygen is important, when considered in the context of the impact of anthropogenic reduction in atmospheric oxygen content, and the logical negative impact of such reduction, on the long standing gas partial pressure equilibrium, between the atmpsheric and ocean compartments, thus ocean oxygen levels.

INCREASED CO_2 = INCREASES PLANT GROWTH – TO A POINT

Anecdotally observation, and limited studies, suggest, plant growth, and related photosynthetic supply of carbon sugar exudate to the soil biome, as expected, is increased by additional atmospheric CO_2. This would be a logical evolutionary mechanism for a self-regulating Gaian system, that has evolved to regulate 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 CO_2 concentrations for the growth of three perennial grass species*', concluded, "*All three perennial grasses featured an apparent optimal CO_2 concentration for growth. Initial increases in atmospheric CO_2 concentration substantially enhanced the plant biomass of the three perennial grasses through the CO_2 fertilization effect, but this CO_2 fertilization effect was dramatically compromised with further rising atmospheric CO_2 concentration beyond the optimum*." (Zheng *et al*., 2018) Thus if action is not taken to use regenerative practices to restore soil carbon with some degree of urgency, the task of returing carbon to the soil amy become more difficult as atmosperic carbon dioxide levels rise above the threshold at which photosynthesis becomes less efficeint.

In the meanwhile, unless any additional CO_2 promoted plant growth is linked to long-term return of additional plant carbon to the soil, through changed farming practices, increased atmospheric CO_2 above the threshold, is unlikely to result in increased sequestration of significant amounts of carbon. Further, continued application of artificial nitrogen to try and increase plant growth, may well negate sequestration, by as discussed, accelerating soil carbon respiration.

INCREASED CO_2 = REDUCED 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*'" 2018) (Reints, 2018).

Self-evidently but of enormous importance, plants are essential for human and livestock nutrient provision. Reduction in proteins and vitamins in staple crops, such as rice and wheat, due to NPK use, and raised carbon dioxide, (Weyant *et al*., 2018) exacerbated by nutrient removal and damage during excessive processing, increases the risk of nutritional deficiency in populations globally.

Most humans meet most of their protein and mineral requirements, largely 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 "*rising CO_2 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, would be a major concern, affecting future generations (Reints, 2018).

Yes, these are just estimates, and much is unknown, but the downward direction of travel of nutrient availability in food, and its consequences for human health, neurological development, and optimising behavioural outcomes, is crystal clear.

Thus, it is crucial, to the wellbeing of many species including humans, to optimise the nutrient density of plants, including through 'soil carbon centric' regenerative agriculture, and nutrient density centred breed selection. Whilst biology, and early results, suggest regenerative agriculture techniques would mitigate observed crop nutrient density depletion, depressingly the negative effects of nutrient density reduction due to increasing atmospheric carbon dioxide may negate some or all of that benefit. More research is required.

FOOD AND HEALTH – NUTRIENT DEPLETION

As discussed, food too is a central concern . . . *our* food . . . the 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, which, combined with relatively longevity, thus capacity to gain, curate and pass on knowledge, are central to human wellbeing and survival as an 'advanced' species.

Far from being controversial, it is surely the commonest sense of all, 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 the next volume, but 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'.

MINERALS IN CROPS, SOILS AND UNDERLYING ROCK STRATA

'Modern' farming, relying on artificial fertilisers and agrochemicals, by inhibiting soil biome health, 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, hydroponics often uses a limited range of minerals in their plant growing mediums. Plants grown in glass houses 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 humans, including importantly pregnant mothers, 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, or disease resistance, traits, but without any regard to the impact of selection, on nutrient content; indeed, it may be in some cases that the reason that the breeding imparts resistance, is because it has lowered levels of specific nutrients essential to those pests, fungi or bacteria being selected against – we simply do not know, but do know 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 thus density. Interestingly, limited research suggests some older tradition varieties have higher nutrient density. The nutrient density of crops clearly needs greater research focus.

Over a very long-time scale microbiome biology will mine extract and transport both bound and soluble minerals to 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. But this will take a very long time, likely millennia for most minerals.

Thus, in the immediate term, and acknowledging the geology of soils and underlying geology, varies, 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 soil may need supplementation of individual minerals, 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.

NPK - 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 less nutrients including minerals and proteins.

Plants supplied with NPK fertiliser, have reduced access to the wider range of minerals. Fertilisers contain a more limited range of nutrients than the soil. Nutrients, are best supplied from the soil by mycorrhiza and bacteria, and in consequence 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, appear to be falling, which chimes with anecdotal reports from animal feed stuff 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 *et al*., 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*"

Data produced by McCance and Widdowson (Thomas, 2003) is questioned by some, and clearly there are many variables, including as to the origin of the foods selected for assay, but their report is indicative of the scale of loss of minerals from food, in line with the general effects of NPK driven agriculture, and deeply concerning.

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 and or impedes access to a wider basket of minerals, and support mechanisms including; genetic transcription related plant adaptation prompted by the denizens of the soil biome, with the aim promoting their own wellbeing, by minimising the impact of adverse events and conditions, including drought, on their plant symbiotes.

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 nutritional values of crops have fallen (Esther & Newark, 2011).

In addition, research has shown that surface application of NPK encourages 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 more susceptible to pests and diseases, as well as being less nutrient-dense.

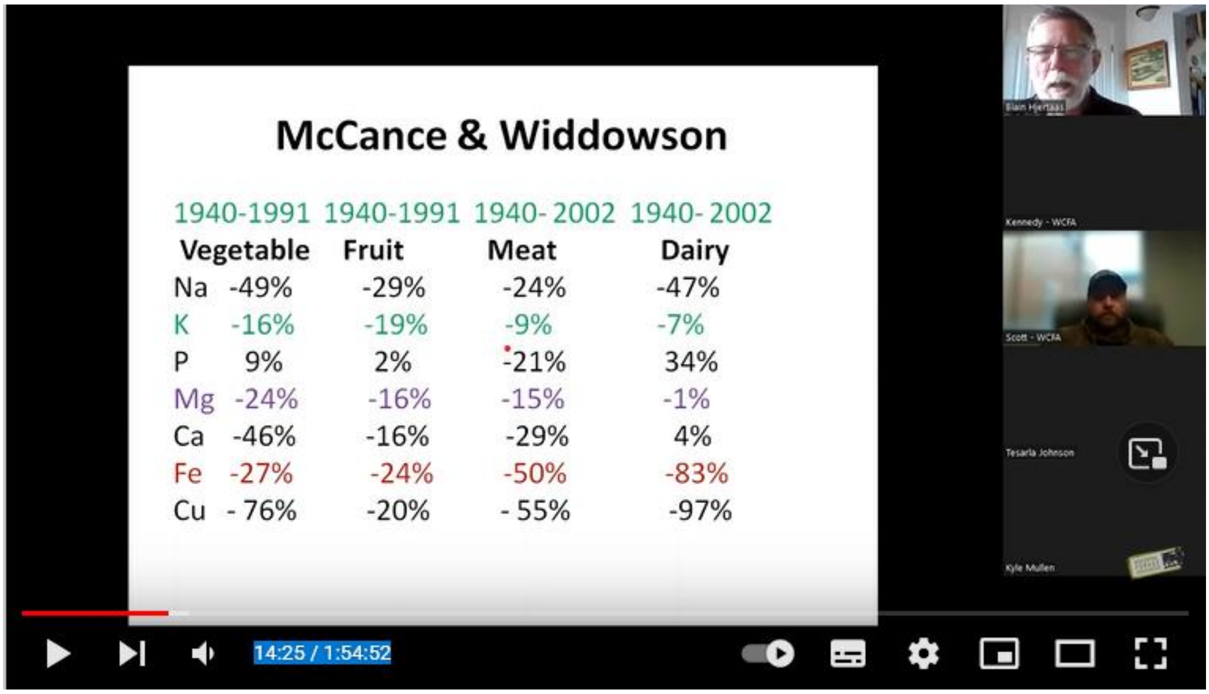


Fig. 87. A slide reporting McCance and Widdowson data (Thomas, 2003) from the UTube lecture Adaptive Grazing Webinar: by Blain Hjertaas with many thanks to the authors. (Hjertaas, 2022)

Ultimately it is in the interests of mycorrhizal and bacterial soil systems to supply their plant symbiotes, 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 *et al*., 2017) provides very useful background. Much remains to be researched, but it is clear, better understanding of the very complex, nuanced, multifaceted symbiotic relationship between plants and mycorrhizal systems, is crucial to efficient sustainable farming, and nutrient dense crop including feed-stock production.

Yes, the issue of nutrient density of crops is complex, an OECD document cited in Marles (Marles, 2017) observes "*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).

Davis in '*Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999*' also observes significant mineral variation in similar crops." (Davis, Epp & Riordan, 2004) Consistent with such variation, use of low till high variety cover crop, no bare ground, farming, using no artificial input, and biological fertiliser, has shown to enhance the nutrient and phytochemical content in plants and reduces 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 a number of regenerative farmers have reported higher crop densities. The Haggerty's regenerative farm, which comprises many thousand 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 their wheat had higher mineral and protein content, which allowed them to achieves premium prices for their grain. In addition, they sequester carbon soil, improve hydrology, and farm more profitably.

LACKING NUTRIENTS – PASTURE COWS AND DAIRY

To produce milk, cows need plant-derived minerals and polyunsaturated lipids. Dr Christine Jones observes fertiliser use on pastures of dairy farms, promotes 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. Tellingly, despite increased pasture growth, milk production from cattle eating lush nitrogen fertilized pastures, remains relatively stable, yet is lower in protein and likely other nutrients including minerals. In contrast cattle gazed on alpine pastures tend to have better nutrient and fat profile, as well as better 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, Penno & Bryant, 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 & Hood, 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 resulted in improved milk yields, cattle health, and land carry capacity.

FARMING – OTHER THINGS THAT HAVE GONE WRONG

WASTAGE OF PHOSPHATE IN ORGANIC MATTER

Because we have lost sight of the value of carbon and wider minerals in soils, as well as failing 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 also do not adequately appreciate the negative environmental consequences on rivers and oceans, of fertiliser and pollutant release, 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 wider 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, and microplastics makes safe recycling of human and animal waste extremely challenging, but as discussed in volume one, with change and research, there are opportunities to improve.

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 productive land and healthy crops; thus adequate food, and as far as feasible with then technology, 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, soils health and microbial diversity.

In the previous century, prior to understanding of the principles of regenerative agriculture, the use of mono-cropping, ploughing, and bare land, obliged the return of organic matter and biology in the form of compost, to the land, because 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).

PHOSPHATE FERTILISER FUTURE – A 'LIMITED' RESOURCE

Through regenerative agriculture, by optimising the soil biome, thus soil health and carbon content, we can maximise the capacity of plants to access non-soluble soil phosphorous, and thus minimise demand for scarce rock phosphate, prolonging availability of reserves.

In addition to the negative impact of the use of phosphate fertilisers on the soil biome, thus soil carbon levels, and wider environment, 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 & de Boer, 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 & de Boer, 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 & de Boer, 2016) As ever estimates vary.

Some phosphate from fertiliser accumulates in soil, but large amounts are washed into water ways, and ultimately oceans, where it causes eutrophication, and or ecological imbalances, as evidence 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 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, solulisable by mycorrhiza but not efficiently by plants. The Greenpeace review titled '*Phosphorus in agriculture Problems and solutions*' (Tirado & Allsopp, 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 & Allsopp, 2012) The use of regenerative agriculture supports health 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 do not have enough purchasing power to be able to afford, and use increasingly expensive phosphorus-based fertilizer, thus may not be able to continue to afford to grow crops, as in Estonia. The problem will be more acute in countries with less developed economies. Those excluded from fertiliser use by non-affordability, urgently need the educational resources and de-risking to help them make the transition to regenerative agriculture, to enable them to maximise access to non-plant-available phosphates.

Fertiliser costs are likely to rise with increasing demand, due ultimately to limited supply, including due to geopolitical uncertainties in energy markets, with costs being magnified by rising fossil fuel prices. Ultimately, the use of fossil fuels to produce artificial fertilisers is not sustainable.

Regenerative farming practices, combined with return of locally appropriately sourced collected composted faeces and urine, 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 disquiet at the idea, current status, new technologies, and how recycling of animal and human waste, might be better achieved, are discussed in volume one.

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 selective application of minerals where soils are truly deficient, but not the blanket use of phosphate fertiliser, and particularly so where total soil phosphates accessible to mycorrhiza, providing regenerative agricultural systems are used, are sufficient for plant growth.

How long we can rely on storage of many years' worth of bound phosphate from artificial fertilisers; that is accessible to mycorrhiza, is not clear, only time will tell, which is why it make sense not to waste scare phosphate resources.

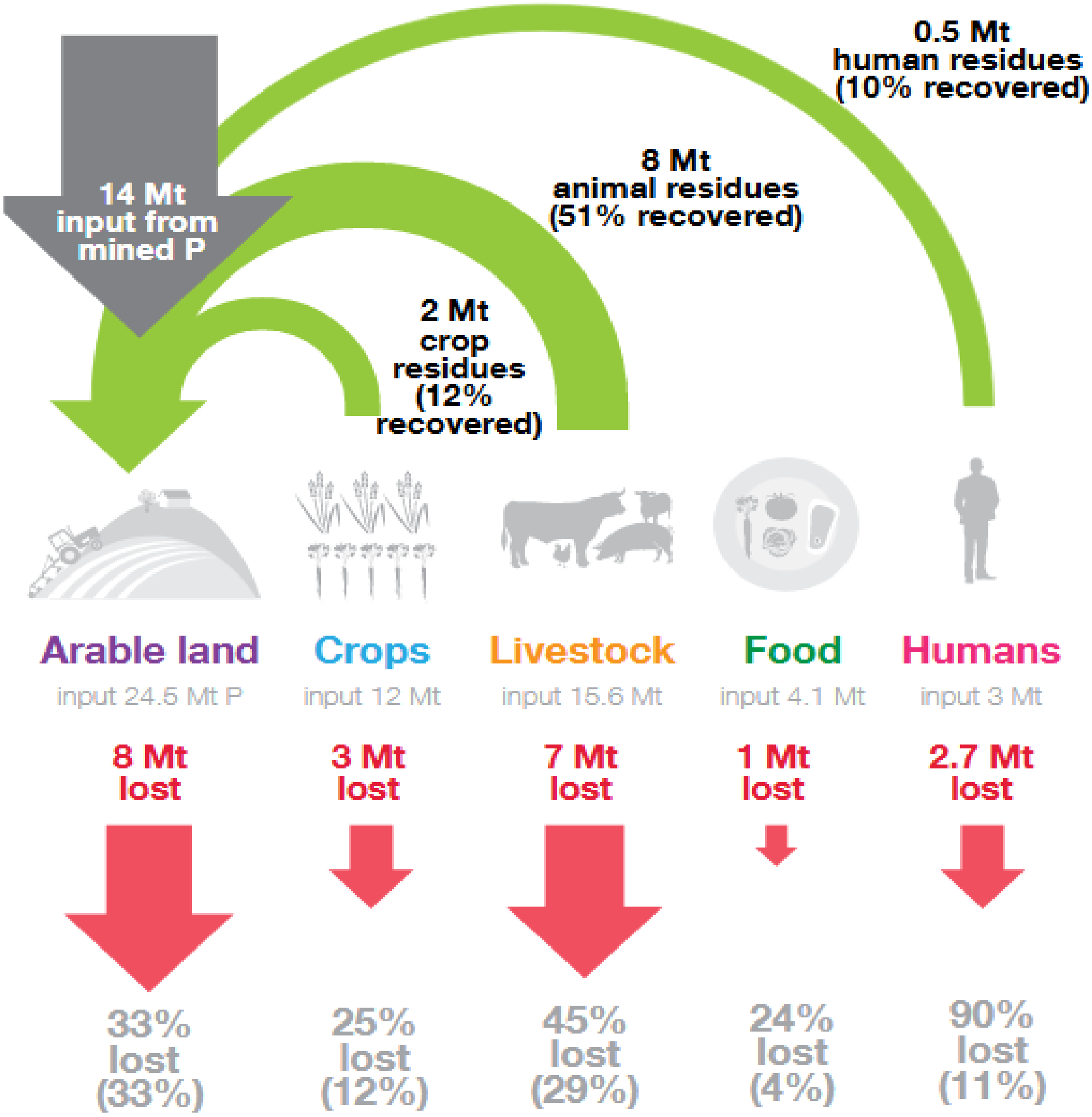


Fig. 88. "*Simplified cycle of phosphorus in agriculture based on data from Cordell et al, 2009, and Cordell et al, 2011. Red arrows represent losses into water systems ultimately, and green arrows represent current recoveries into arable land from the different subsystems. The percentages under the 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

Nitrogen a gas essential to life, is present in large quantities 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 cannot access nitrogen directly from the air, it is made available in other forms, by bacterial action, in low oxygen pockets, in enclosures generally close to plant roots, often created by mycorrhizal and bacterial biomes. Nature over eons, has produced verdant landscapes without addition of artificial nitrogen, by using these, and wider processes and synergies.

Nitrogen fixing bacteria, as do mycorrhiza, need plant sugars for energy, and bacteria in return supply nitrogen in available form, to the plant; bacteria and mycorrhiza also use nitrogen for their own growth, some of which becomes immobilised, remaining stored in soils in less soluble forms (Sadej & Przekwas, 2008).

"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.) Not only does this enrich the biome, it also allows for a longer-term regulation of nitrogen supply to roots, providing balance and stability to plant growth.

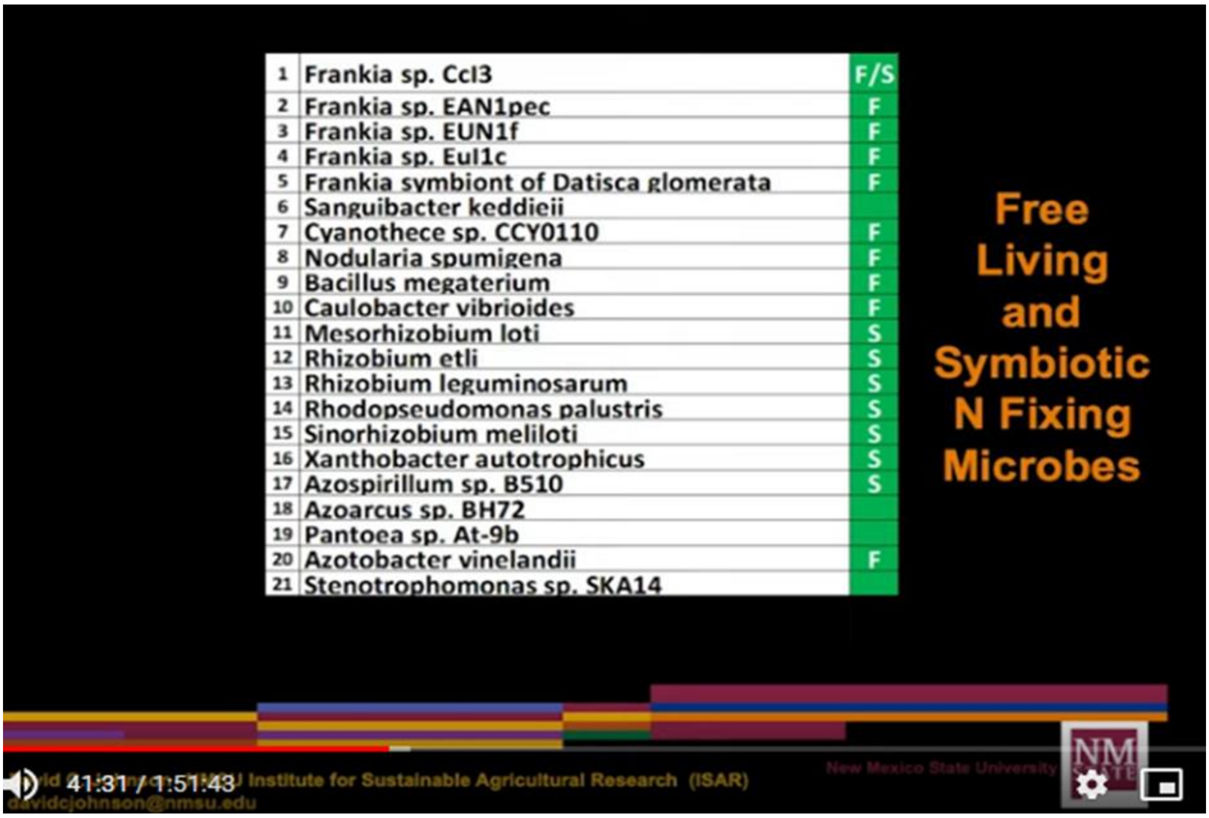


Fig. 89. '*Free Living and Symbiotic N Fixing Microbes*' from the YouTube lecture '*Dr David and Hui Chun Su Composting'*, with many thanks to the authors. (Johnson & Su, 2019)

In contrast, as discussed, application of 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'*).

Artificial nitrogen supply creates a 'double whammy', because artificial nitrogen, both appears to; stimulate carbon metabolism by the microbiome as discussed below, and reduces supply or sugar carbon exudates to the microbiome. When supplies of plant exudates are reduced, to stay alive, the bacteria, viruses and fungi in the soil, are forced to draw down stored soil carbon, accelerating soil degradation.

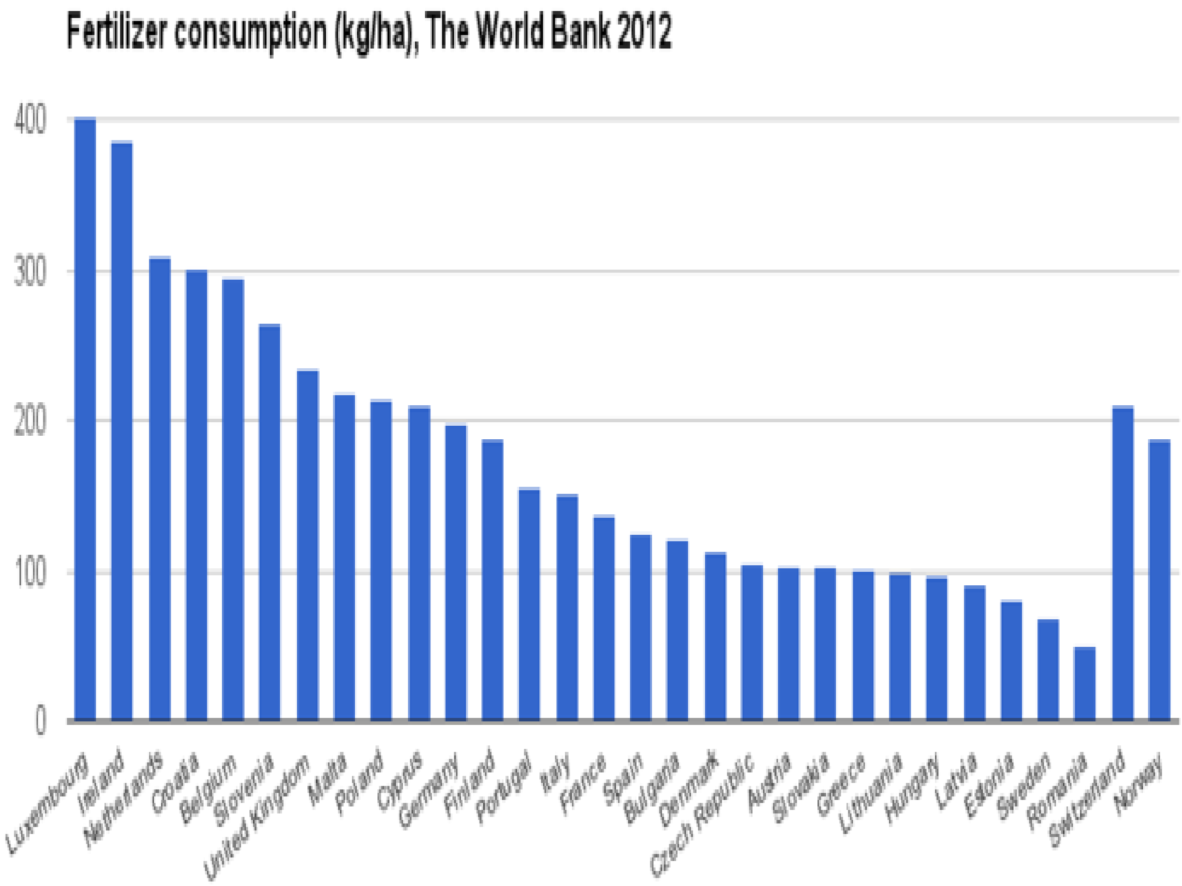


Fig. 90. NPK is a market now worth upwards of $100 billion [£710 million] a year (Jones, 2017).

RUN-OFF AND EUTROPHICATION

Where artificial fertiliser nitrogen and phosphate rich, including eroded soil and silt run-off, and or sewage sludge, washes into river and marine environments, there are multiple negative effects, including eutrophication.

Applied nitrogen in fertiliser also creates a risk of increased run off and eutrophication (Bingham & Cotrufo, 2016). Indeed, only between 10 and 40 per cent of the nitrogen applied to the earth is taken up by plants.

Fig. 91. Eutrophication of the Potomac River, US, with thanks to Alexandr Trubetskoy.

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 - and sludges less prone than mineral fertilisers (Corrêa, White & Weatherley, 2006; Sadej, Bowszys & Namiotko, 2009; Czyżyk & Rajmund, 2014). Indeed, the low content of easily-soluble nitrogen in compost, – in defiance of mainstream thinking – is arguably an advantage, as it limits the potential for run-off and helps keep carbon exudate flowing from roots into the soil.

Fig. 92. '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 as above does not leach significant nitrogen.

BLUE BABY SYNDROME

An arguably greater, but rarely discussed concern, is that excess nitrites in drinking water causes blue baby syndrome (a lack of haemoglobin in the blood of young children), and can be a factor in the risk of stunting. Many in the world do not have access to centralised treated water systems. Further processes for removal of nitrates are very costly, and more so for less well of 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 *et al*., 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).

HERBICIDES AND BIOCIDES

Biocides including fungicides, will reduce soil biome activity including of microbes and fungi, (Abd-Alla, Omar & Karanxha, 2000; Schreiner & Bethlenfalvay, 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 better and more sustainable long-term strategy to counter plant disease, than simple reliance on agro-chemicals. Consistent with this, historically, Howard and King, noted plant disease fell with good land management including composting. Howard, through composting, and appropriate management, successfully reduced a range of diseases in a variety of commercially grown crops including tobacco, sugar, cotton, coffee and potatoes. (Howard, Sir Albert, 1945)

Similarly, King (King, 1911) an experienced and respected agronomist, in the 1900s saw few occurrences of common plant disease in China. Modern regenerative farmers are also reporting, that after a number of years, plant health improves, pests and predators reach a natural balance, and find they vary rarely, if at all, have to use agrochemicals, yet achieve better quality crops, and acceptable equivalent yields, with greater net profitability.

Glyphosate – originally marketed as Roundup by manufacturer Monsanto – is the most used agricultural herbicide of all. *"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 *et. al.*, 2016). It continues to be used in huge quantities – even as part of some low-till regimes – despite a flood of US lawsuits claiming it has carcinogenic properties. In 2020, Bayer – who now owns Monsanto – agreed to a $10 billion settlement. Yes, it may well have a useful place for limited usage, but certainly not as a central agricultural pillar.

Of relevance here, and concern, glyphosate may also damage micro-organisms in the soil. '*Glyphosate reduced the mycorrhizal colonization and growth of both target and non-target grasses'* (Helander *et al*., 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 *et al.*, 2021).

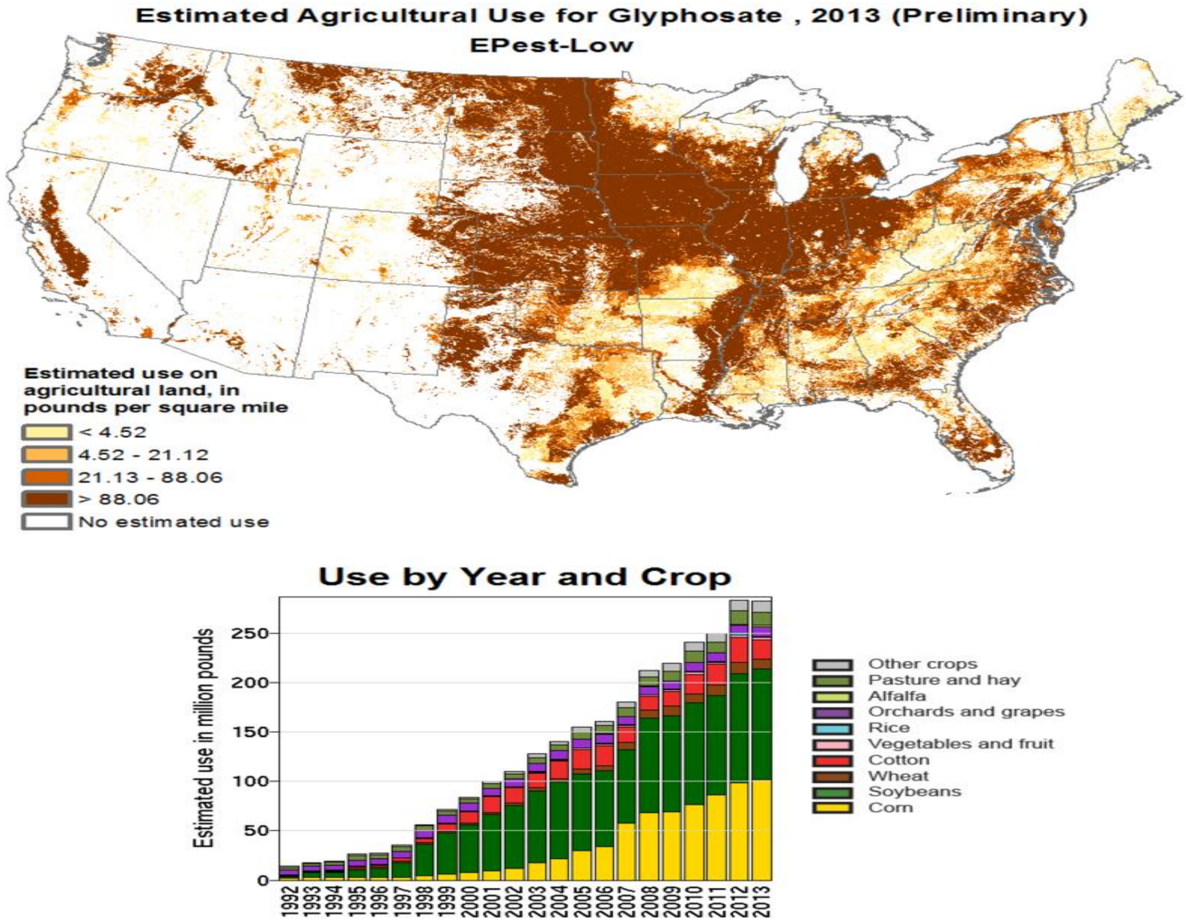


Fig. 93. '2013 Glyphosate Use Map', with many thanks to the USGS Pesticide National Synthesis Project

Some regenerative farmers do use herbicides to kill cover crops, to allow timely planting of cash crops, but alternative techniques are being developed to try and minimise their usage. It is hoped that alternatives prove more cost effective and productive, so the practice will diminish with time.

HEAVY METALS FROM FERTILISERS AND FEEDS

Once again practical experience and research suggests, regenerative agriculture, which allows for production of equivalent yields, and more profitable faming, can be achieved without the use of phosphate-based fertilisers. Cattle raised using regenerative principles are reported not to need mineral supplementation, yet remain healthy and calve annually.

Substantial reduction in the use of phosphate-based fertilisers will have a host of benefits including reducing application of heavy metals to soils, and via animal diminished need for mineral supplements. This in turn will also improve livestock and human health. It is possible some may regionally need specific scare nutrients such as iodine. Clearly the testing and mineral support industry will grow over time to assess, and more exactly meet, any 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 *et al*., 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*." (Kpomblekou-A & Tabatabai, 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 major source of toxic cadmium. Levels vary significantly between phosphate sources. Cadmium uptake and behaviour in the soil, and accumulation by crops, is 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, Longhurst & Brown, 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, Tidåker & Jönsson, 2014)

Fertilisers are also used to directly supplement feed stocks, 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, which are then fed to livestock etc. creating the risk of a negative cycle of increasing excesses or imbalances of toxic, 'heavy' metals, in the agriculture land food cycle.

Purification of the fertiliser mineral supplement is possible, but market demands for cheap food, and need of farmers to be profitable in the immediate-term, mitigate against this, as farmers are unable to meet the additional cost, thus through livestock feed add 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, in appropriate quantities, are essential to plant livestock and human metabolism, becoming toxic in excess, whereas others such as cadmium and lead are toxic even at low concentrations. This is a complex topic, but clearly reducing the addition of toxic heavy metals into soils and the wider food chain, can only be beneficial.

SEWAGE SLUDGE AND SLURRY - ANTIBIOTICS PHARMACEUTICALS AND WIDER POLLUTANTS

Sewage sludge is use as a soil conditioner in many countries, albeit some have banned the usage of them for agriculture, instead incinerating sewage sludge. The disposal of sewage sludge from current sewage systems is problematic for a number of reasons. The topic and potential alternatives are discussed in volume 1. Given the current usage of sewage sludge on agricultural land, thus direct relevance of the subject to current agricultural practice, some of the issues are outlined in section below.

Thought provokingly, many of our antibiotics were derived from molecules produced by soil related bacteria. We have very limited 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 *et al*., 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, Mrozik & Piotrowska-Seget, 2019), which potential, given the crucial role of the soil biome in natrual 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 *et al*., 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 *et al*., 2018) (Authors underline).

Another paper reported elevated levels of swine Clostridium spp in soil even a decade after receiving animal slurry (Scott *et al*., 2018). To reiterate, around 100,000 tonnes of antibiotics are used every year, approximately 70 per cent of them to treat livestock (Geetha, 2012; Gelband & Laxminarayan, 2015). A significant part of them – between 70 and 90 per cent – remain unmetabolized as they pass into the environment, via rivers, oceans, and farmland. What damage they do is unknown and research in this field is in its infancy. The presence of antimicrobial resistance 'AMR' within the wider environment is a growing and arguably underappreciated problem including in Africa. (Tadesse et al., 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 *et al*., 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 *et al*., 2019).

Surely it makes sense to collect separate urine and faeces at source, and research and optimise the most practical and applicable technologies we have, including combined anaerobic digestion and hyperthermophilic composting, to as far as possible remediate these products and related genetic material, rather than putting partially treated or untreated human and livestock faeces and urine, with the pharmaceuticals and antibiotics they contain into the environment. These options were discussed in greater detail in volume one.

As set out in the previous volume, current sewage, and farm waste, treatment methods do not remove most of these contaminants. Sewage water and sludge, as well as livestock slurry, are applied to farmland. At what point are mycorrhizal biomes so deadened by the weight of contaminants, that toxicity, sickness and degradation set in, and at what point do those effects damage soils 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?

Those following regenerative livestock production are finding their livestock remain healthy with minimal intervention. Dung and urine are naturally distributed in pasture, and incorporated in soils including by dung beetles, thus bypassing many of the issues above to the great benefit of the environment.

PAHs, PCBs. DIOXINS AND OTHER POLLUTANTS FROM SEWAGE SLUDGE

Whilst this review concentrates on directly introduced pollutants, pharmaceuticals, and personal care products; there are wider pollutants including, PCBs, PAHs, and dioxins. These pollutants comprise a very wide range of products, from a variety of sources including: industrial pollution; traffic including tyre wear; atmospheric pollution including from power plants and incinerators; motor traffic emissions; run off 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 sewage sludge component, due to their chemical characteristics, including structural charges, others in the liquid waste water component. Both on occasions are applied to agricultural land, one as an amendment, the other for irrigation. Sewage water is sometimes pragmatically applied to land where too high in pollutants, to introduce directly into sensitive aquatic zones, yet consider safe for land application, in the hope the land will provide some remediation capacity, but at the cost of adding to soil pollution, with a risk they 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 *et al*., 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 removal, so far as feasible, of such products from washing machine formulations, and new clothes. Treatment options are generally technical (Maier *et al.*, 2016), and not arguably practical for most domestic applications.

As discussed in volume 1, washing machines are also a significant source of micro-plastics, (Lamichhane, 2018). which end up in rivers and sewage sludge so in soils. 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, collection of urine and faeces at source, using vacuum WC technologies, would alleviates addition of all elements that are externally added through mixing-in of other water streams, including run-off. Removing pollutants from household products would also help alleviate pollution at source. The issues ae discussed in volume 1.

GREY WATER IRRIGATION USE– PLANT UPTAKE OF POLLUTANTS AND TOXICITY

The reuse of grey water, which excludes processed sewage water, is an area of emerging research. As discussed, plants can, and do uptake and concentrate pollutants; uptake will differ between toxicants as influenced by conditions, soils, and plant types.

Toxicity risks in the west in relation to grey water 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 product) 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 et al., 2014) (Authors' underline)

Effects may be more toxic where untreated water is used for crop irrigation, as happens in emerging economies, and more research is required to better quantify risk of food pollution. As ever results vary, and human nature is such that, where commercial interests are involved, we are often reluctant to objectively face issues.

Fig. 94. A selection of personal care product containers to help illustrate their extent and diversity. With thanks to Adobe Stock ©

WASTEWATER USAGE FOR AGRICULTURAL IRRIGATION

As previously noted, demand for water for agriculture use has led to the emptying of ancient aquifers. Countries have also turned to 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 a variety of 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 is inevitably creating 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 & Okieimen, 2011).

The problems get worse as there has been an explosion in personal care and pharmaceutical products present in skin related products, including antibiotics, and as discussed due to the growth of antibiotic-resistant bacteria and related pollutants.

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, to use reverse osmosis for treatment of water for agricultural use. 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, in the knowledge that their actions may have longer-term negative consequences. The alternative is often financial failure.

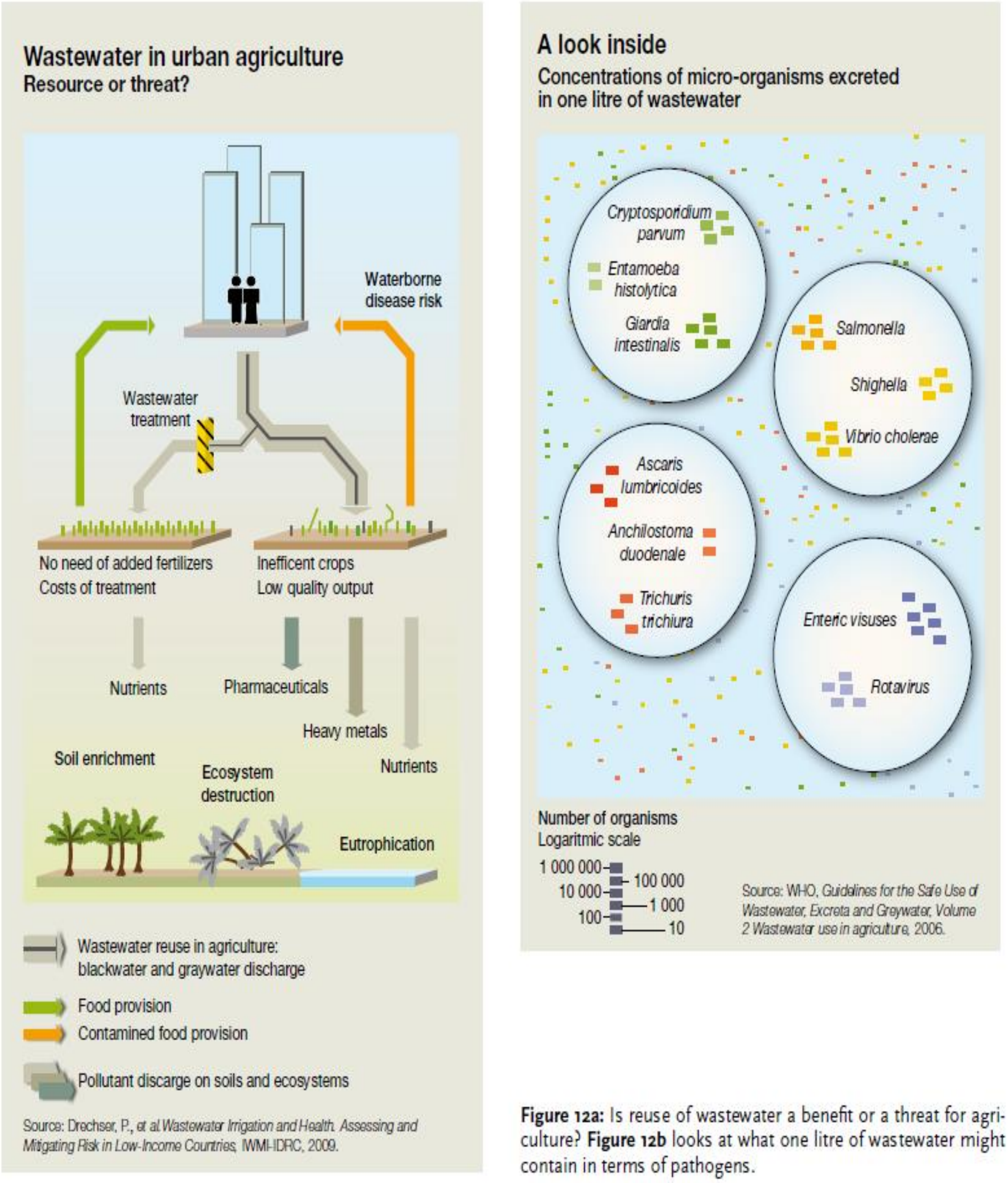


Figure 12a: Is reuse of wastewater a benefit or a threat for agriculture? **Figure 12b** looks at what one litre of wastewater might contain in terms of pathogens.

Fig. 95. With many thanks to the authors of '*Sick Water?*' (Corcoran et al, 2010).

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 et al, National Research Council, 2018).

It is often believed treated water is fit for irrigation due to *"advances in wastewater treatment technology"* (ibid), however, it is certain many contaminants including pharmaceuticals remain in sewage derived water, because the vast majority of sewage treatment plants are unable to remove them. There is 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).

With thanks to Adobe Stock ©

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 richest country in the world. Elsewhere infrastructure is not so extensive, so risks greater, water scarcity, and economic reality, requires reusage no matter what the level of treatment.

Large scale direct reuse of treated wastewater by reinjection into the water system takes place 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.*, 2018).

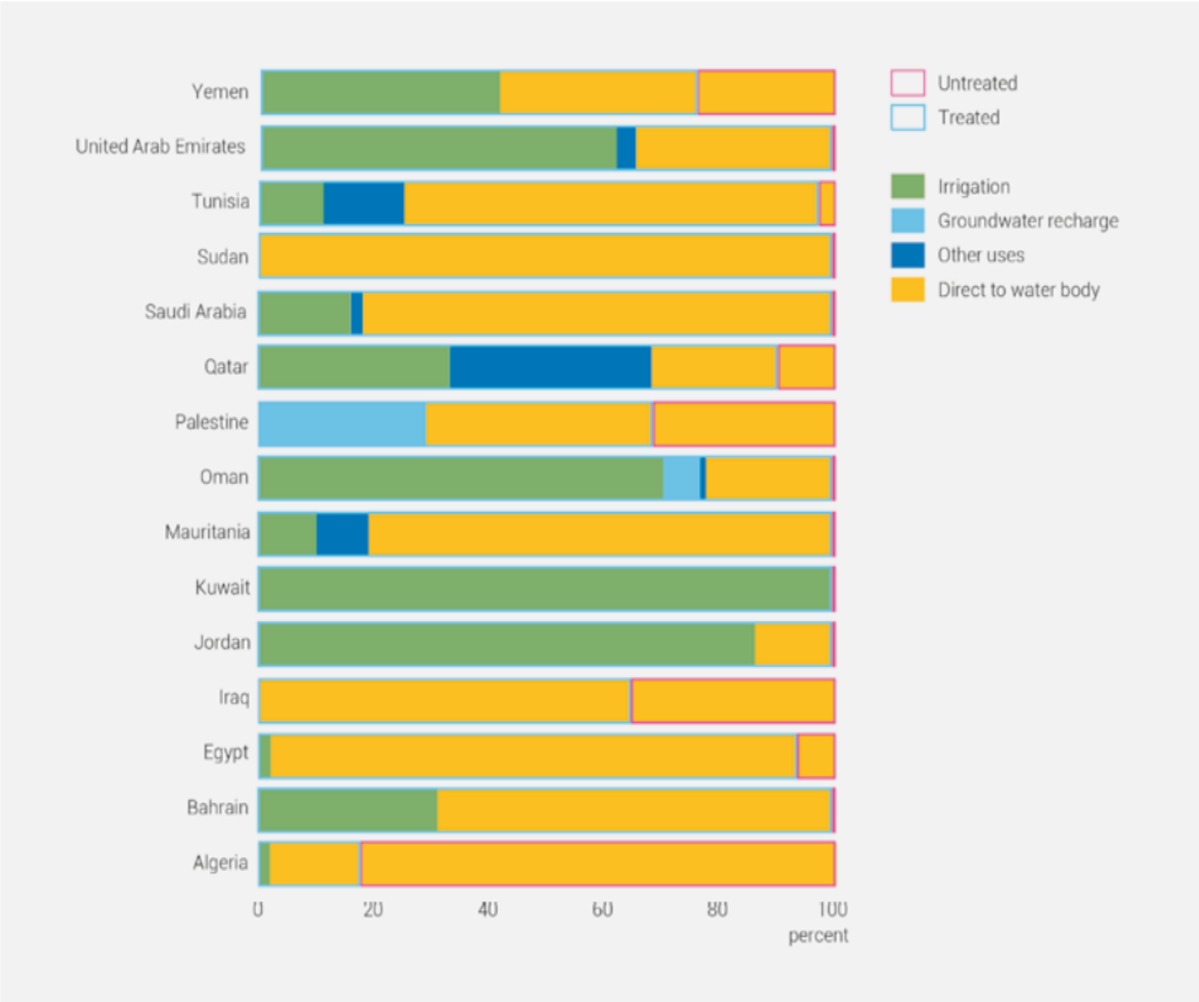


Fig. 96. Water reuse data illustrating the high reuse of untreated water, including by re-inclusion in the wider water body, with many thanks to the authors - Arab Countries Water Utilities Association (ACWUA), 2016 and Progress on Safe Treatment and Use of Wastewater (*Guidelines on Sanitation and Health. Licence: CC BY-NC-SA 3.0 IGO.*, 2018)

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.)

Water pollution and supply is considered in greater detail in volume three on water. Hopefully, it will soon be better understood that regenerative agriculture principles offer a more water efficient, environmentally sustainable, and profitable, alternative.

AGROCHEMICALS

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Monocrop, bare ground, NPK based agriculture has arguably increased the requirement for agrochemicals to maintain yields, and yes, it is acknowledged that the world needs feeding. However, regenerative practices appear able, by rebalancing pests and predators, to produce reasonable yields, comparable to existing regional averages, or better, with minimal agrochemical input.

The review '*Advances in agrochemical remediation using nanoparticles*', (Sebastian, Nangia & Prasad, 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, but clearly avoiding unnecessary use in the first place must be the preferred option. Regenerative farmers, unlike organic farmers, pragmatically, do not rule out minimal use of agrochemicals, when necessary, but generally find they rarely need to use them.

With thanks to Adobe Stock ©

INCINERATION

Incineration, be that of waste, sewage sludge or crop stubble contaminated with agrochemicals, like every solution poses its own problems. For example, the incineration process itself may result in release of 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 farm land. "*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 negative health implications.

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 et al., 2017).

In some studies, living near incineration plants has been potentially associated with health and developmental issues. Clearly risk will be dependent on the quality of gas 'scrubbing' technology used, the operation parameters applied, and materials incinerated.

CROP BURNING

On-the-spot incineration of stubble, stalks, grasses, and husks, is commonplace around the world and a significant source of pollution. The burning of agricultural waste is another practice, which not only adds to ecological problems, but also wastes resources that could be part of the solution.

A solution advanced by some companies, the use of crop stubble for biochar, also poses a number of issues, and in consequence the negatives likely outweigh any possible benefits from addition of stubble biochar as a soil amendment. Biochar is discussed in a later section.

Crop residue could be rolled to provide soil cover, so protecting soils from erosion, also reducing 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 removal results instead in bare unprotected soils, which speeds evaporation, causes crusting, reduces rain penetration, and increases run–off, thus risk of erosion and downstream flooding. Burning also releases carbon as CO_2, and other pollutants, including dioxins, both contributing to rising air pollution, and adding to global warming risk.

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). Whilst some of this carbon was that recycled by plants, that carbon could alternatively have been returned to soils. The figures are large, yet we focus almost exclusively on fossil fuel emissions, when the reality is all sources of pollutants and climate change accelerators, need focus.

The pollution problem is exacerbated by the presence of herbicide. "*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 to the soil. Significant increases in soil dioxins are seen where crops such as corn stalks have been treated with pesticides.

Fig. 97. Stubble burning in Essex, England, in 1986, with many thanks to John Roston.

The problems caused by crop burn-off are global, whilst common place in less developed countries it also happens 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)

In contrast, regenerative agriculture uses crop residue as soil protectant and source of minerals and nitrates, either directly, or through composting and subsequent return to agricultural soils.

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, as well as 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.

Bromide will also be taken up by plants. Thus, it is important to ensure livestock and humans have adequate access to iodine. Inhibition of rain by heat domes prevents transport of organic iodine compound produced by ocean evaporation, the main inland circulatory mechanism for iodine, which is highly soluble and washes out quickly. High bromide will exacerbate lack of iodine, which is important, given many in the world 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.

MINERAL 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.

The formation of mineral elements takes place in supernova; with the creation of planets, minerals become part of the surface mantle. Through, rock degradation by; glaciers, general weathering, biological action. and volcanic activity, rock dusts and particles will accumulate over time forming the geological element of soils.

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

Table. 3. 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)

The rock based mineral geological portion of soils is significant, thus mineral exhaustion will take a long while, but it can be seen from the table above those important nutritional elements, such as zinc, molybdenum and more so selenium, are already relatively limited in the earth's crust and thus soils. Minerals are essential to enzyme function, and enzyme function is central to all life forms. Thus, minerals are much more important than most realise, both to plants and soil life forms. For example, molybdenum is essential for nitrogen fixation by legumes (Udo de Haes *et al*., 2012).

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.*" Yet we pay rather more attention to malaria which is considerably less easy to resolve. (Udo de Haes *et al*., 2012)

Further, some minerals may be scarce or excessive in local soil geology, thus creating risk of insufficiency or excess. This is borne out by mineral nutrient insufficiencies, which require supplementation, for grazed pastures on both wild and managed grassland areas. Mineral excess, both due to geology, and plants that are particularly effective at accumulating particular minerals, can lead to pastures that inhibit livestock health if over-grazed on them.

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, albeit some soils will require supplementation due to regional biology. Further plants may have differing mineral requirements, and tendency to accumulate them.

As discussed, levels of some minerals such as iodine, selenium, and zinc in particular geological areas, can be low, because the underlying rock contains limited amounts of them. Iodine is highly soluble, and largely recycled through ocean emission into the atmosphere of organic molecules of marine origin, with attached iodine, which are then transported inland in rain. Marine migration inland of marine species also transports iodine to the interior of land masses. Mountainous areas with limited amounts of ocean derived rainfall tend to have low iodine in soils. As discussed, heat domes by inhibiting 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 3rd volume iodine is crucially important to health, female reproduction and brain development and function.

Further and also as discussed, fertiliser use will inhibit extraction of minerals by the mycorrhiza and bacteria in the soil biome, exacerbating soil mineral insufficiencies. However, given soil fungi are highly efficient at mineral extraction, regenerative agriculture will help minimise deficiencies, but some soils may be truly deficient in a specific mineral (Udo de Haes *et al*., 2012). In such circumstances foliar mineral sprays may be highly beneficial for plant health yields and disease resistance.

Albrecht, growing plants from soil from all over the USA in tea chest containers, showed crop rotation, often suggested as a way of improving the mineral content of soils, simply accelerated the extraction of minerals from soil, presumably by increasing plant vitality and growth. The point being, what Albrecht observed, is that crop rotation improved efficiency of plants, and did not miraculously the denovo create minerals in soil. As above the creation of minerals is a galactic process.

Diversity improves the capacity of plants to abstract minerals, but cannot impact the actual mineral content of the soil. Albeit, in non-containerised soils, there may be improvement in mineral availability thus fertility, as minerals are mined and moved up by deep rooting plants from deeper fragmented rock and subsoil layers. Amounts of mineral stored in soils should be sufficient to supply agriculture for many generations, and are to some extent replaced through dust including from volcanoes and erosion, and breakdown of deeper subsoils.

Albeit, crop rotation has other benefits, for example it may help control diseases caused by phytopathogenic bacteria in cereal crops, by rotating with crops that can act as non-host to the pathogen (Butsenko *et al.*, 2021), but as above does not 'make' minerals.

Most soils should contain sufficient minerals for hundreds if not thousands of years of plant growth, the issue is their availability to plants. Albeit, mineral foliar sprays such as seaweed extract, and sea salt residue, which contain a wide range of 'micro-minerals', and will often contain iodine, have been shown to improve plant health and growth: see '*Seaweed in Agriculture and Horticulture*' (Stephenson & Booth, 1968).

There is clearly much still to learnt in terms of working with nature to improve mineral and mineral-micro-nutrient availability, uptake, enzyme and wider use, and thus optimising plant heath and growth.

IODINE A SPECIAL CASE?

Iodine is very soluble, washed out by rain, and can sublime. At the same time, it is replenished by rain derived from ocean moisture, which does not reach some mountain areas, resulting in deficiency which can manifest as goitre. Whilst there is very limited research into the effect of iodine in crops, there are indications that appropriately used it can positively impact yield and plant health.

As discussed elsewhere the used of seaweed based foliar sprays, as discussed in '*Seaweed in Agriculture and Horticulture*' (Stephenson & Booth, 1968) and the residual salts from the production of sea salt, which if not dried will contain some iodine, reports suggest, may have very favourable effects on crop health, yield and shelf life.

Further iodine deficiency and insufficiency is a real issue in many countries, including in the UK where studies suggest up to 70% of females are insufficient in iodine. It is exacerbated by the use of bromide additives, a biological competitor that may displace iodine with negative health consequences, in foods, and indirectly through uptake from fumigated foods and plants.

Adequate iodine is essential to development in utero including brain development. Iodine and omega 3 DHA are essential 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 to the world. Thus, low-level fortification of crops, including wheat, (Cakmak *et al*., 2017) and other crops. as discussed more widely in '*Use of Iodine to Biofortify and Promote Growth and Stress Tolerance in Crops*' (Medrano-Macias *et al.*, 2016) though use of sea-weed extract of 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 et al., 2017)

Further the use of marine based foliar sprays, though improved mineral content including iodine in crops, would contribute to wider mineral intake, and thus public health. Marine based mineral rich, iodine containing, sprays, based on sea salt production residue, would also likely improve yields plant yields, health disease resistance and shelf life, as reported in '*Seaweed in Agriculture and Horticulture*' (Stephenson & Booth, 1968). More research is required as to the wider introduction and optimisation of what could be a new and additional approach to plant health and growth support.

NPK: YIELDS

There is no doubt that the industrialisation of agriculture has helped massively reduce labour requirements and brought improvements in, technology, knowledge, and plant breeds. Yields per acre for many crops have greatly increased over the last century too, including due to, greater density of planting, better breeds particularly so for wheat and corn, as well as availability of fertilisers. Having said that regenerative farmers report that they are matching average modern fertilizer-based yields. Initial yields when the American Great Plains were first put to the plough, so rich in soil carbon, were surprisingly high.

At the same time, because of fertiliser usage, crop nutrient densities per unit weight have it appears fallen, thus the immediate fertiliser net nutrient gain for global food sufficiency, nutritional value, and health, as against absolute weight and calorific value, are less clear cut than they may first appear (Long, 2009).

There is also debate around the sustainability of NPK increased yields using the current agricultural model. Already, returns are plateauing, and it is clear soil health and hydrology is being badly degraded. Maintaining crop yields is proving increasingly difficult, more demanding, and costly, including in, fertiliser, agrochemicals, and irrigation water.

On the Great Plains of the US, use of synthetic fertiliser soared between its arrival in scale in the late 1950s and early years of the 2,000s. Corn is very demanding of nitrogen, and yields have clearly been helped with artificial fertiliser. Corn yields per hectare roughly trebled over the same period. However, the returns for wheat, hay and cotton have not hugely increased, and again the point is made, regenerative farmers are often matching these yields, whilst improving rather than degrading soils, and increasing water sequestration.

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 *et al*., 2010).

Many soils already contain significant stores of the less soluble, bound forms of minerals including phosphates due to years of application of fertiliser. For plants to gain access to these, it makes more sense to encourage mycorrhiza with compost biology, rather than add more of the same.

In summary, there is sufficient evidence to conclude the current cycle of addiction to NPK is creating a spiral of human, agricultural and ecological poverty. "*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).

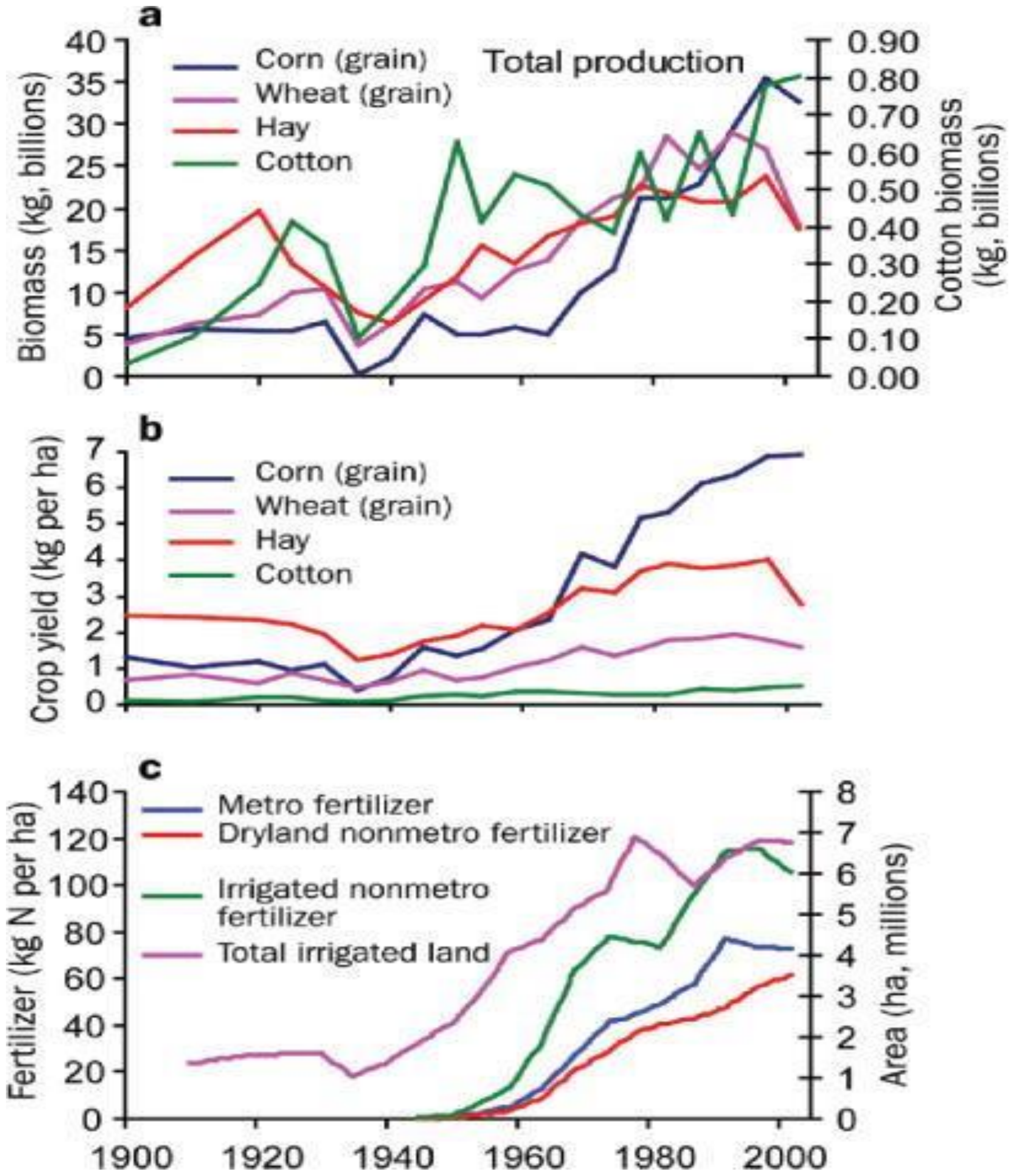

Fig. 98. *From the paper 'Long-term Trends in Population, Farm Income, and Crop Production in the Great Plains',* with many thanks to the authors: *"Total Great Plains plant production for corn, wheat, hay and cotton, and (b) average Great Plains crop yields for the same crops. (c) Total area of Great 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, Gutmann, & Ojima, 2007).

"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. 99. Phosphate mine near Flaming Gorge, Utah, US, 2008 with thanks to Jason Parker-Burlingham.

FARMING 'MIRACLES' - REGENERATIVE AGRICULTURE

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. It was in reaching rock bottom, and the quest for economic survival, that Gabe Brown re-evaluated every facet of his farm and every method that 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 now 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 soon be 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 sixfold 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 those of 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 some do have higher yields but make the point he is more profitable, and his farm is sustainable.

Yield obtained from 2008-2016

	Brown's	***County average***
Corn	*127*	*98*
Spring wheat	*62*	*39*
Oats	*112*	*62*
Barley	*72*	

Summarised soil nutrient values

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

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

Neither are these results unique to Brown's farm. His consultancy now acts for many farmers across North America and globally. He reports, most of his clients are starting to see 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. What's mostly needed by the government, in my opinion, is education. 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).

REGENERATIVE AGRICULTURE v FERTILISER FARMING – PROFIT RATHER THAN LOSS

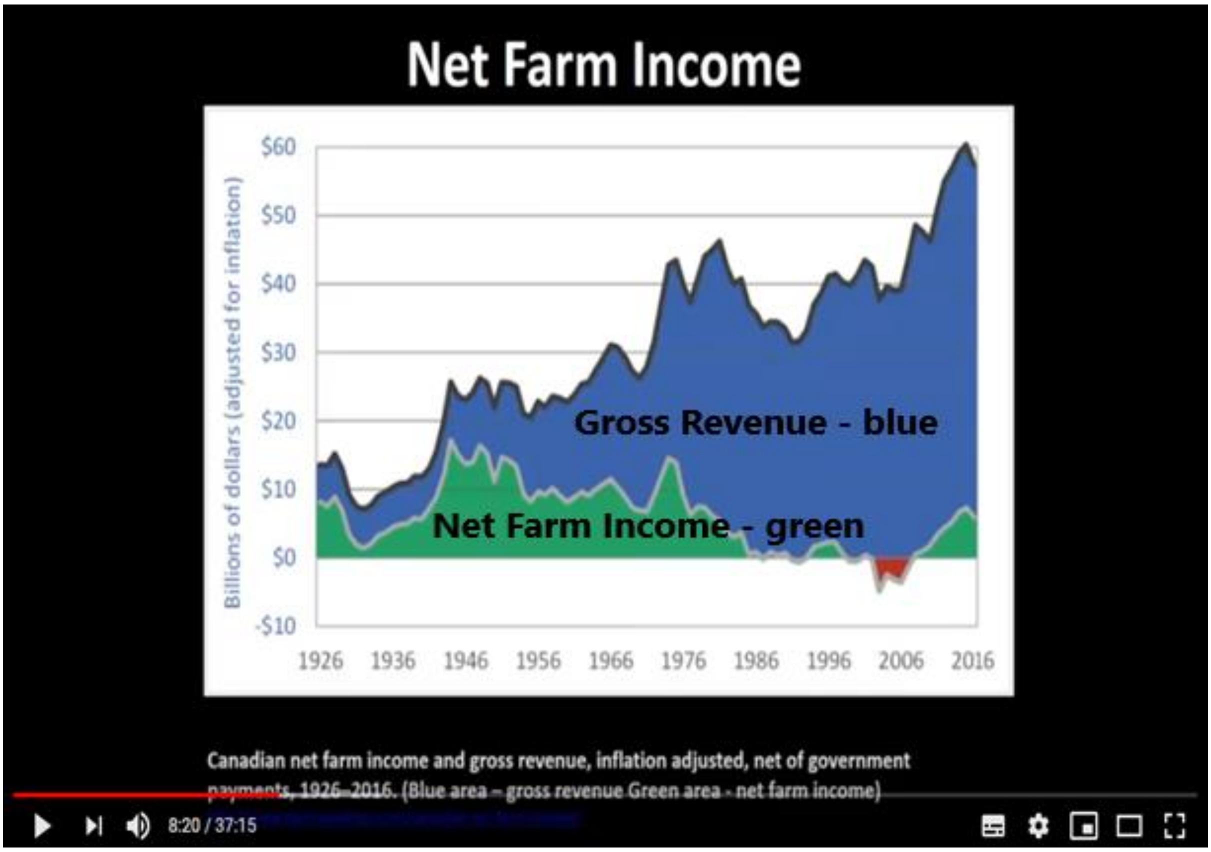

Fig. 100. Annotated slide from lecture by Dr Christine Jones – '*Building New Topsoil Through The Liquid Carbon Pathway*' (@7.20) Conservation Tillage and Technology Conference 2019 with many thanks to the author. (Jones, n.d.-a)

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, yet net profits remain below $10 billion, and the trend has been downward over the past 40 years.

A CHOICE - CREATE LIFE OR DELIVER DEATH

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).

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. If we continue our FATBAS bare ground, NPK based, soil biome killing, farming practices, climate changes, including ocean deoxygenation and sulphidication could lead to a tipping point and consequent extinction event. How many would die we cannot know, but life would be very uncomfortable for any survivors, for very many generations.

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, with no external nitrogen used either. Compared with their neighbours, who persisted with the *status quo*, the Haggertys increased soil carbon by 41.5 per cent; 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 very 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 value of yields by weight, thus human and livestock health, rather than simply maximising content. (Aubert, Schwoob & Poux, 2019; Poux & Aubert, 2018).

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

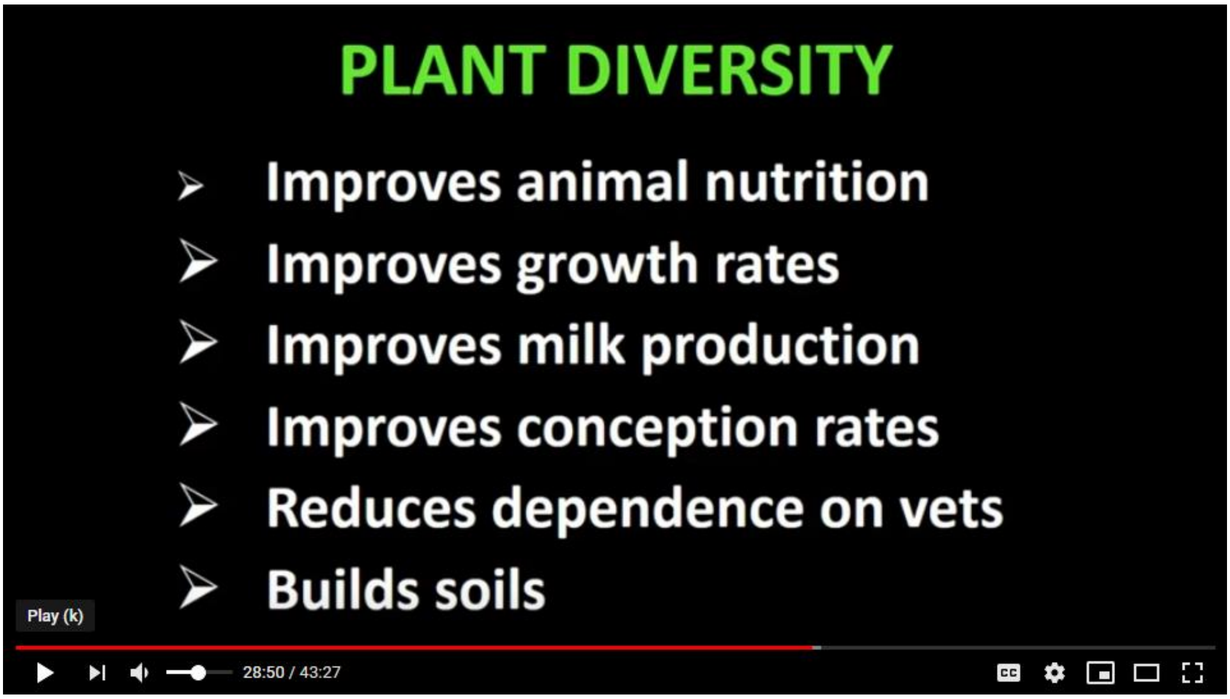

Fig. 101. Slide from '*Quorum Sensing In The Soil Microbiome*' summarising changes seen on Wilith Farm, Atiamuri. With many thanks to the author. (Jones, 2019b)

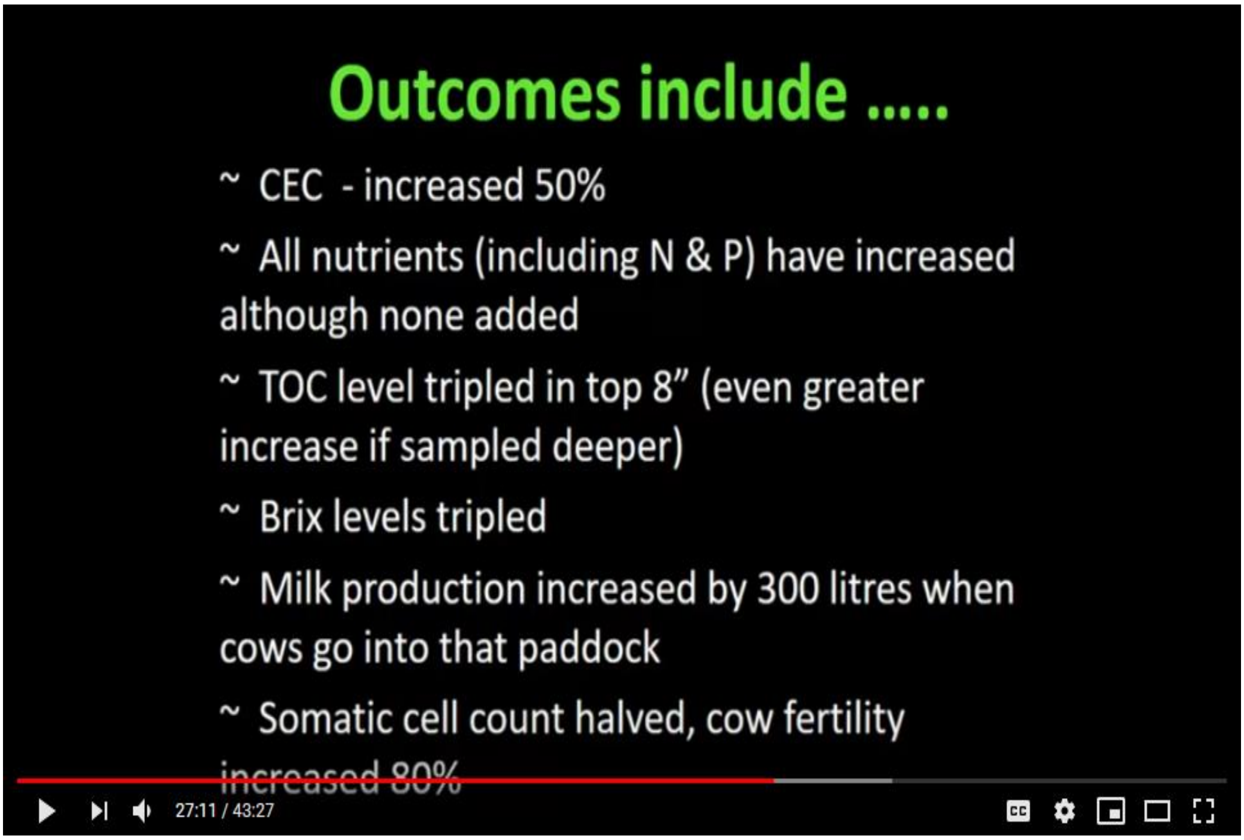

Fig. 102. Slide from '*Quorum Sensing In The Soil Microbiome*' summarising changes seen on Wilith Farm, Atiamuri. With many thanks to the author. (Jones, 2019b)

Many have observed 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.

However, the biggest change of all is perhaps not practical but philosophical. Gabe Brown has gone from losing money to making a living; from failing to succeeding; both of which are major achievements in any person's career of choice. The switch from 'conventional' to regenerative agriculture, represents so much more to Gabe Brown. His description of how his existence has transformed, perhaps cuts to the heart of this review. It is a message that underpins a shift that is needed in societies around the world, if *homo sapiens* is to survive the epoch that bears its name.

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, but in the excitement of new technologies and related agricultural industry profits, it was a message people were not willing to open their minds to.

For 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 single acres for over 4,000 years, by returning all organic matter to the soil, and using; intercropping, mixed species cropping, composting, and generally taking great care of their soils.

In the 1920s – 40s agronomists Howard and Albrecht demonstrated the same principles: return of composted organic matter, combined with careful farming practice, 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 symptoms of the disease. His tomatoes could be transported during the Indian monsoon heat, in old fashioned trains for several days, yet arrive to market in good condition. The foresight, understanding and vision of both Albrecht (Albrecht papers. n.d.) and Howard are fascinating and to be found in their books. Out of copyright versions of many of their publications can be found for free on the web site *'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 the Australian online 'Soil and Health' Library

With thanks to Adobe Stock ©

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.

Predating the work of Gabe Brown and others, he brought together the research and observations of outstanding agronomists from the early 1900s, such as King, Howard, and Albrecht.

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.*

With thanks to Adobe Stock ©

"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.*"

Approaching a century later, New Zealand livestock farmers are starting 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*".

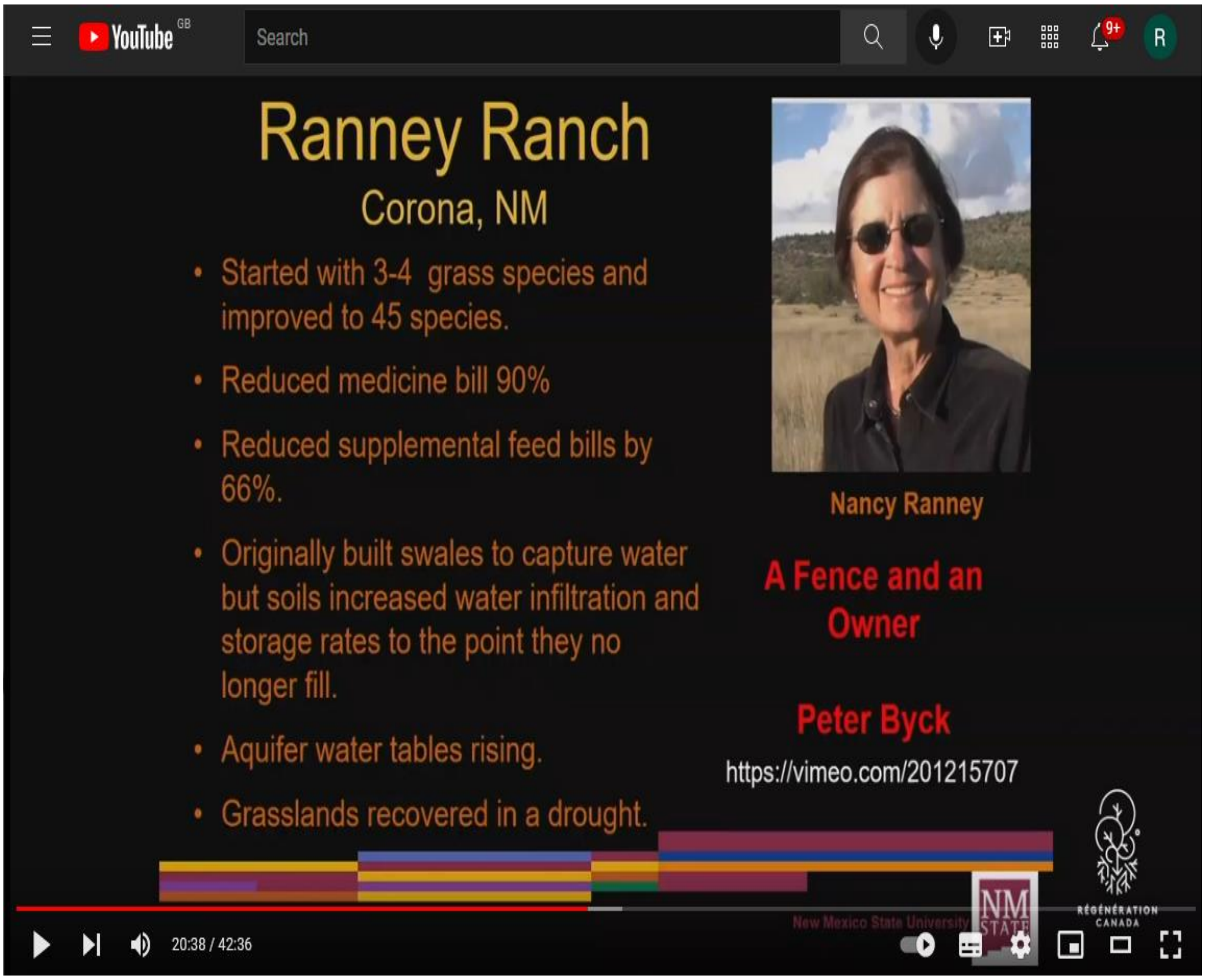

Fig. 103. From video lecture by Dr David Johnson, using the '*The BEAM (Biologically Enhanced Agricultural Management') Approach*" in a ranch context with very many thanks to the authors. (Johnson, 2017)

Nancy Ranney (see slide above) on ranch land, has seen a similar trend (Johnson & Su, 2019). They are also seeing better; fertility, milk yields and reduced disease in their dairy herds, just as Turner did. Farmers have apparently even on occasions 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.

SOIL MYCORRHIZA, BACTERIA, AND WIDER SOIL LIFE, 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 important soluble nutrients in dead bacteria and soil life and their slimes urine and faeces, which will be available for transport to plant roots, providing extra nutrients, reinforcing the importance of the microbiome functioning as an integrated ecosystem. "*Soil microbial composition is mainly related to plant diversity*" (Dwivedi *et al*., 2013).

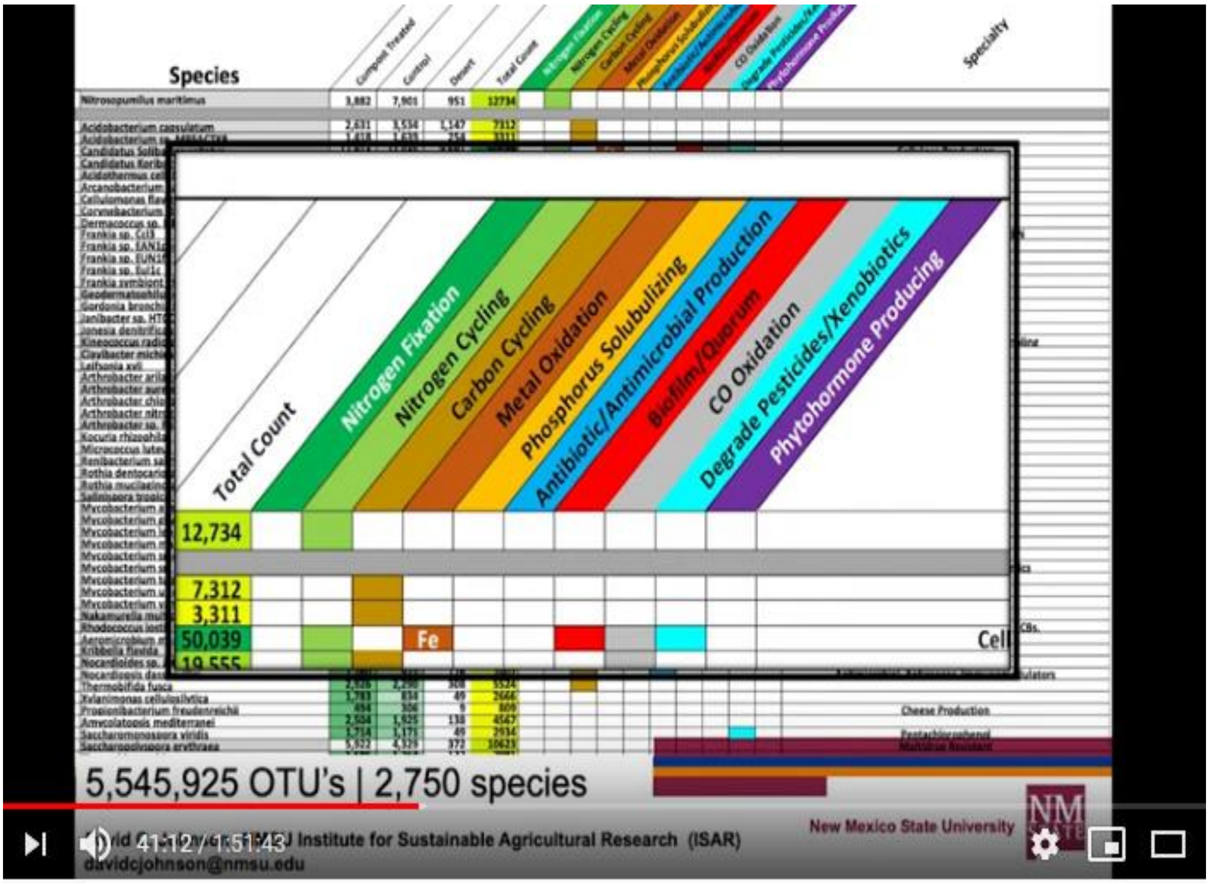

Fig. 104. Mycorrhizal systems have several functions and particular microbes will have their own specialities; from the YouTube lecture '*Dr David and Hui Chun Su Composting*', with very many thanks to the authors. (Johnson & Su, 2019)

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 affinity for particular metals, explaining why a more complex biome may promote better plant growth through more efficient selective nutrient acquisition.

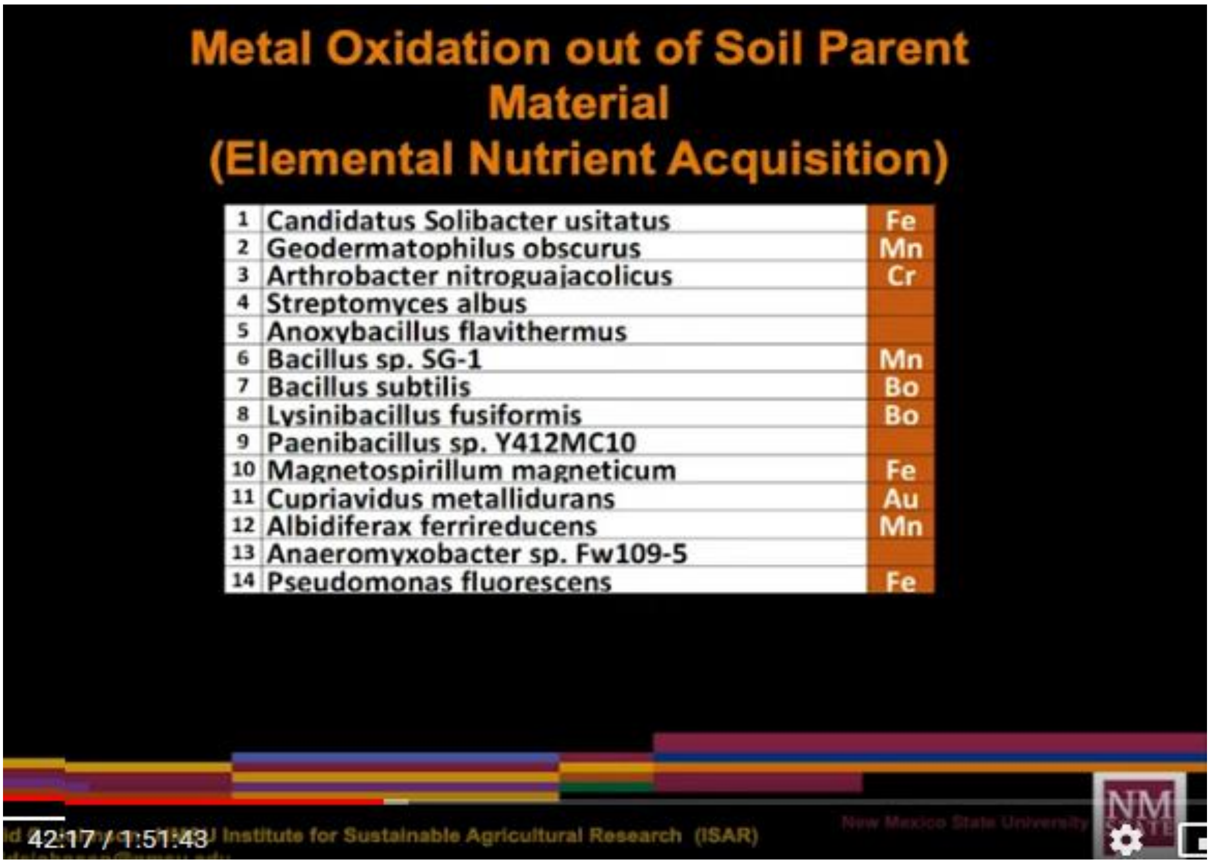

Fig. 105. Microbial '*Metal Oxidation and out of Soil Parent Material*' from the UTube lecture titled '*Dr David and Hui Chun Su Composting',* with very many thanks to the authors. (Johnson & Su, 2019)

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.

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) 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)

Whilst much research remains to be done, carbon in soils clearly has a number of central roles, including in nitrogen fixation and availability, storage, and metabolism, thus return to more 'soil carbon centric' farming, that seeks to optimise the photosynthetic capacity of land, would be economically and environmentally beneficial, including in sequestering nitrogen, and preventing run-off and nitrification of water sources.

WATER PENETRATION OF SOILS

Whilst discussed earlier it is warrants repeating that farmer using regenerative techniques, have seen measured soil infiltration rates rise dramatically, over time from one inch an hour to eleven inches and more, as soil biomes become more diverse and less compacted. Schemes such as the Loess Plateau reclamation, and the Ethiopian example cited later, illustrate the capacity of recovered healthy covered soils to facilitate water infiltration and storage, and restore degraded lands back to healthy ecosystems.

Better water penetration rates, as well as assisting soil water retention, also reduce run-off, erosion, and logically must reduce downstream flooding risks. Water will be released in a more controlled way, in cycles over the whole year, benefiting local hydrology, downstream rivers and water resources. It is self-evident, but a synergistic benefit that such soils need less abstracted irrigation water, helping protect ground water sources, lakes, and rivers, as well as reducing the need for use of sewage treatment water for irrigation, and drinking.

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)

More widely, for the above reasons, a combination of low pH, and high levels of heavy metals, could be a matter for particular concern in some areas. Clearly pH impacts essential mineral uptake in plants, with a wider 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)

Consistent with this, research suggests raising pH 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 *et al*., 2013)

Plants and mycorrhiza can locally alter pH to assist mineral abstraction, so things are complex, but development of healthy soils with balanced pH would clearly 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 *et al*., 2018). Consistent with this, regenerative farmers report higher pH without the use of added lime.

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. Clearly it is important, that once an area is reseeded by cattle movement, the seed is given the opportunity to establish by moving the cattle onto new areas, and the area is not re-grazed for an appropriate time. Those implementing regenerative land management observe, over time, native species, selected by evolutionary pressures, over generations for their suitability, will return, and again start to predominate.

DUNG BEETLES AND OTHER FREE TINY WORKERS

Dung beetles come in a huge variety of species, and perform really important roles in incorporating faeces into soils. A cow produces around 12 tons of dung a year, a herd of a hundred, 1200 tons a year, 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, as well as being 'green', with no time or financial costs. As invertebrates they are killed by deworming chemicals, thus chemical deworming of cattle, negatively impacts on regeneration of degraded ranges.

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. Presumably any parasitic eggs from the cattle, also are a source of food for other insects, again emphasising the need for diversity, and now many issues need understanding better.

The soil biome contains a host of tiny creatures from bacteria and fungi upwards, that help maintain; soil carbon, diversity, support for plant symbiotes, and prey predator balance. However, as discussed, soil life will be killed or inhibited by intensive agricultural practices and by agrochemicals.

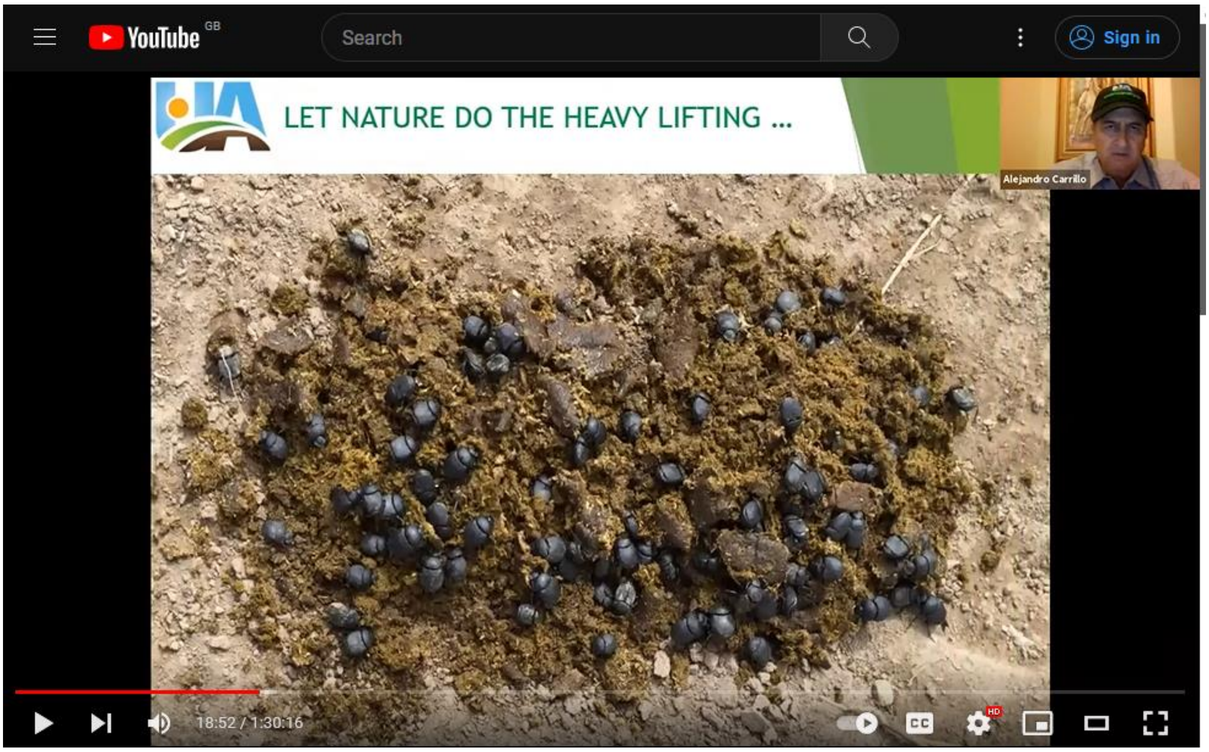

Fig. 106. Las Dama Ranch Mexico, slide from UTube video '*Building Resiliency: Ranch Resiliency with Alejandro Carrillo 10-28-21*' showing dung beetles at work (Carrillo, 2021).

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, at the same time creating vast networks of aeration and rainwater tunnels. Earth worm gut bacteria include nitrogen fixers, thus adding nitrogen to soils. Their mucal coatings are an excellent source of plant nutrients. They chelate minerals making them more bioavailable, as well as providing many other services (''*Earthworms A Gardener's Best Friend*'', n.d.).

As already stressed, soil life provides a huge array of ecoservices for free. 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, that delicately balance between being competitive and symbiotically assistive, because that it what it takes to allow and maintain a diverse evolutionary ecosystem that optimises complexity that supports a stable system within given parameters. Arguably a drive to greater complexity is an essential, built-in, evolutionary parameter.

Fig. 107. UTube video slide '*AgEmerge Breakout Session with Keith Berns*' 2020 with very many thanks to the author and Ag Solutions Network. (Berns, 2020)

INSECTS – PREY PREDATOR BALANCE

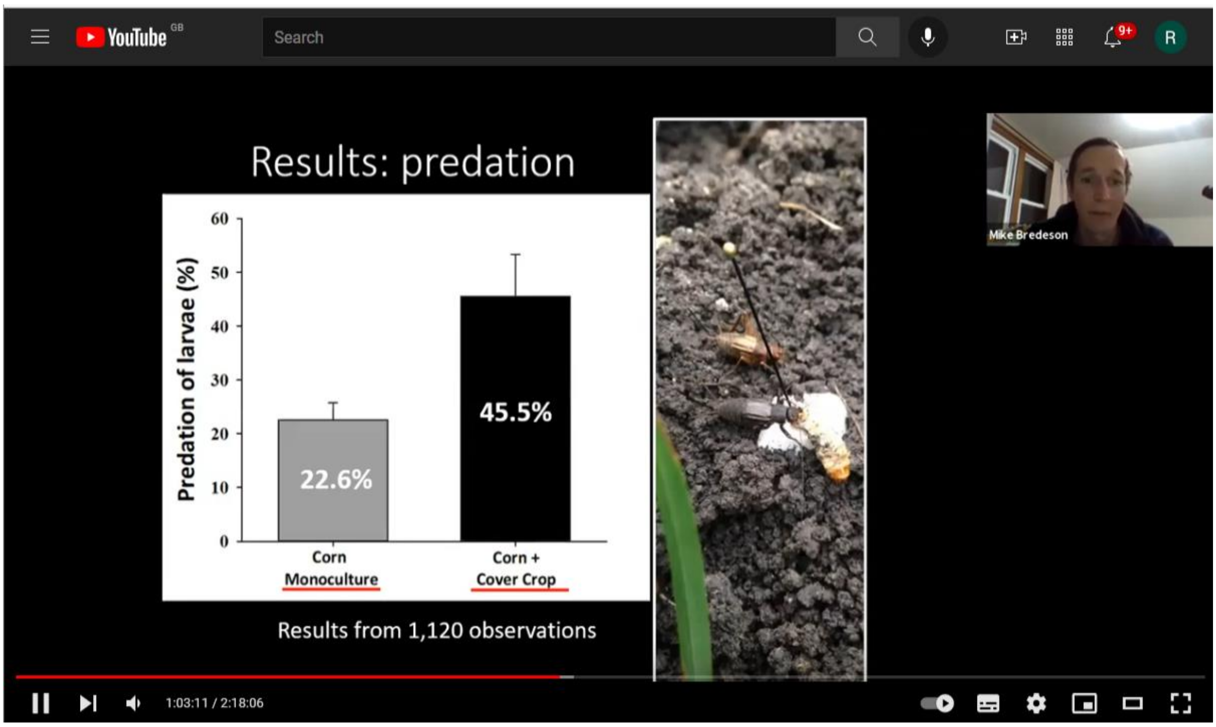

Fig. 108. '*Insects a little known force of nature shaping your farmland*' Mike Bredeson, PhD - regenerative agricultural practices including inter-row cropping increase predator number and balance with very many thanks to the author. (Bredeson, 2021)

Numerous farmers using regenerative principles, report that they rarely or never have to resort to agrochemical, because pest issues that cause crop damage of economic significance, are rare. A combination of heathier more robust plants and natural predation, seems to keep such issues within acceptable limits, and on a cost benefit analysis basis, is a better option than agrochemical deployment. Increased diversity makes also farmers happy.

OVERCOMING SALINITY

There is also considerable evidence that mycorrhizal organisms may help increase plants' tolerance of 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 Haggertys and other farmers in Western Australia, have observed that regenerative agriculture helps reverse the impact of salinisation of soils. The processes are not entirely clear, but as well as helping moderate plants mineral intake, logically soil biomes also engineer the soil they occupy to optimise their own survival, including by likely expelling salts into lower non-colonised layers of the soil?

Fig. 109. 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)

Sir Albert Howard also noted 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)

SELECTIVE UPTAKE OF MINERALS – EXCLUSION OF HEAVY METALS

The soil biome selectively supplies minerals to their plant hosts, increasing supplies of those needed for growth, and excluding damaging heavy metals, thus helping optimise the health of plants and their capacity to supply the soil biome with photosynthetically derived sugar exudates.

It makes sense at an evolutionary level for the soil biome to protect plants, given the symbiotic relationship, and 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*.

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 *et al*., 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.*" (Cabral *et al.*, 2015) "*AMF can mitigate the harmful effects of trace elements to plants, mainly by mechanisms taking place in the roots*." (Cabral *et al.*, 2015)

The review '*Arbuscular mycorrhizal fungi* (AMF) *in phytoremediation of contaminated areas by trace elements: mechanisms and major benefits of their applications*' (Cabral *et al.*, 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.

DETOXIFICATION OF POLLUTANTS AND HEAVY METAL SEQUESTRATION

The soil biome as discussed contains fungi and bacteria. Fungi have potential for remediation of a wide range of organic and other pollutants. They may also be able to selectively supply essential minerals required by plants, whilst at the same time filtering out toxic metals. As remarkable as this is, it would make sense at an evolutionary level, for mycorrhizae to protect their plants 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; through stubble burn-off, and agrochemicals. Many toxins are long lasting and some recycled, "*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 *et al*., 2001). However, more positively, remediation at varying levels does take place in soils. This is a vital service, given otherwise soils will be long-term repositories of organic pollutants, but we are at risk of damaging the soil biome with 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 retention of organic molecules, and may through biome diversity, improve remediation. 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, 'D*iverse Metabolic Capacities of Fungi for Bioremediation*' (Deshmukh, Khardenavis & Purohit, 2016) notes, "*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).

The rate of detoxification will be influenced by a number of factors, including; bacterial and mycorrhizal interactions with pollutants, plant uptake; binding to organic or inorganic matter; removal by worms and other creatures; transport to deeper levels and run-off (Magnér *et al*., 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). Filtration and remediation will be increased by a greater density and diversity of microorganisms.

Mycorrhizal species diversity, aka "*soil microbial composition, is mainly related to plant diversity"* (Dwivedi *et al*., 2013). Hence 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.

'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 also be in competition, and be assistive or predatory, according to which plant species' roots they prefer interacting with. They logically would seek to prevent their preferred plant symbiotes being damaged by other competitive organisms - whether fungal, plant or insect - through 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),

including producing antibiotics, phytoalexins, and anti-microbials, which accumulate at the seat of an infection

Indeed, antibiotics used by humans had their origins 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 & Kwakman, 2010). Interestingly, *''Streptomycetes are members of the same taxonomic order as the causative agents of tuberculosis and leprosy (Mycobacterium tuberculosis and M. leprae).''* (Hanekamp & Kwakman, 2010). As well as assisting humans, these products doubtless help maintain healthy, balanced plant biomes.

Thus, streptomycetes – the building blocks of antibiotics – are naturally present in soils, this should surely raise concerns as to the possible impact of anthropogenic resistant bacteria added to soils in sewage sludge and waste water.

FUNGAL BACTERIAL SOIL RATIO IS IMPORTANT

It is not only plants that need nitrogen for function and structure, they are also essential to the soil biome. Carbon and nitrogen are both key obligatory components of organic matter, thus levels of carbon in soils are linked to levels of nitrogen 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 & Elser, 2017).

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 there is sufficient carbon available to create the required additional fungal structures (Farrell *et al*., 2014).

"*The first step in the retention of added N is microbial processing <u>driven by C availability"</u>* ('*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* ***<u>driven by an imbalance of N inputs over C inputs</u>****, 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 fungal bacterial balance, between various stages in soil evolution, from desert sand containing mainly bacteria, to forest soils containing mainly fungi. The change in microbiology of the soil will clearly impact its ability to support life, from small desert succulents to trees in tropical forests. Further the fungal bacterial ratios appear to change between locations. As ever more research is required, but farmers can use regenerative agriculture strategies before the underlying science is fully understood, because the on the ground evidence, is that they work.

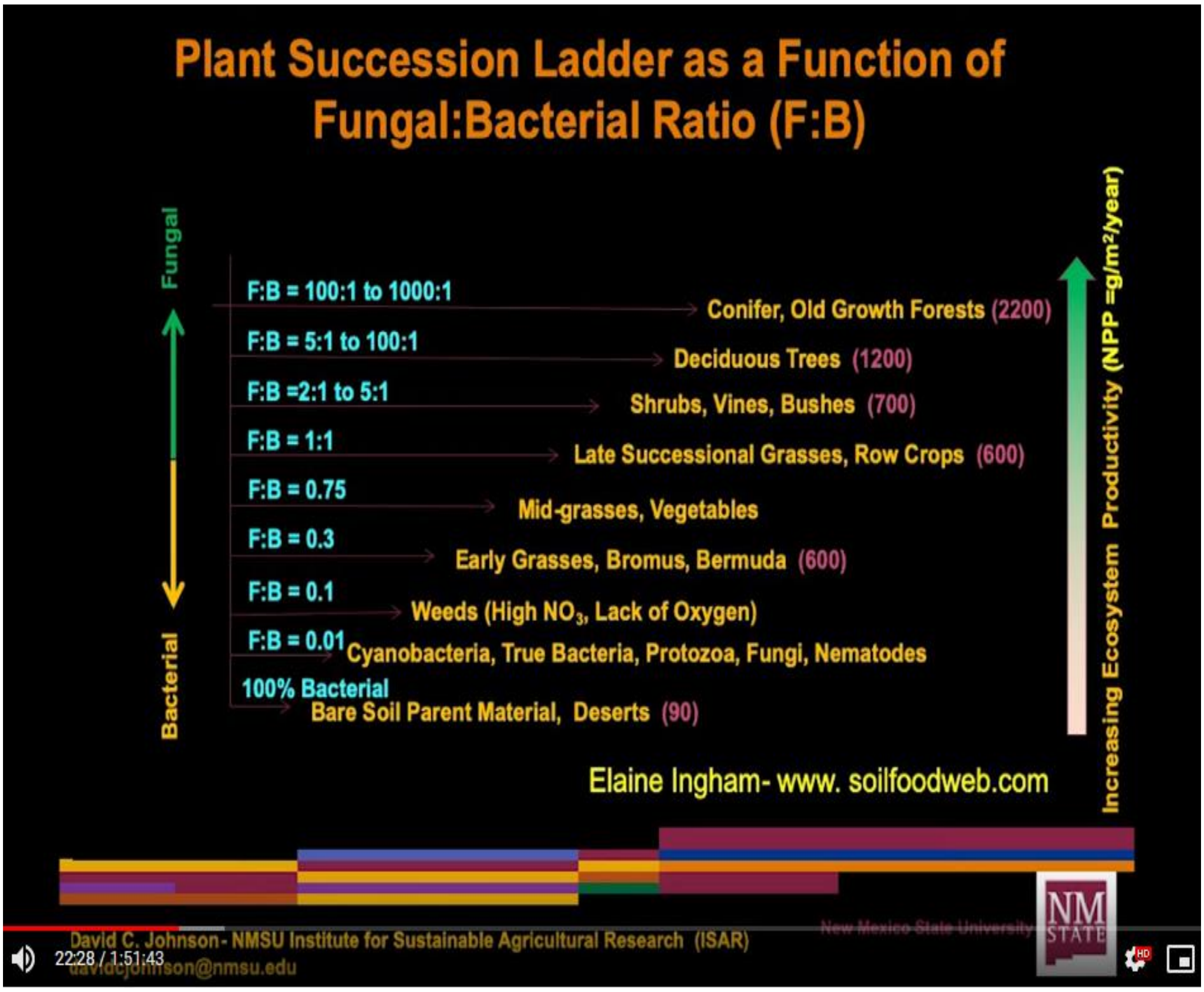

Fig. 110. The balance of bacteria and fungi in soils changes with soil type and vegetation - from the YouTube lecture '*Dr David and Hui Chun Su Composting*', Menoken Farm, with very many thanks to the authors. (Johnson & Su, 2019)

HUMAN CAPACITY TO RENEW AND RECOVER DESERT SOILS

It is of crucial importance, farmers have the capacity to influence and build soils, where the ground up rock dust geology is not eroded, thus present for them to work with. The amount of carbon in, and provided as plant sugar exudates to the soil and mycorrhizal populations present, will determine how that soil evolves, and the capacity of plants to grow in it.

Thus, by coating 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.

Further by planting to provide plant diversity, it is possible to further improve mycorrhizal biome development and function. Healthy diverse mycorrhiza will result in better plant growth, and more effective symbiotic bidirectional nutrient supply. As discussed, addition of 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, Khan & Ellsworth, 2009).

Changing soil microbiology, and carbon content, by natural processes assisted by synergistic human intervention, will improve soil's ability to support differing plant types. Dr Johnson in real world conditions has shown it is possible to bring life back to desertified soils using these techniques.

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 powerfully makes the point, it has limited real-world relevance, in a natural world, dominated by plant soil microbiome interactions.

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 own preferred bacterial and fungal species, but also create wider interactive networks.

Research bears out that the greater the variety of root exudate products, the greater likely variety of organisms, and 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 et al., 2020)

For example, the paper '*Root exudate cocktails: the link between plant diversity and soil microorganisms?*' (Steinauer, Chatzinotas & Eisenhauer, 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 and health, and resultant 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 bio-filter*
- *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)

DIVERSITY OF ROOT STRUCTURES DEPTH AND CHARACTERISTICS

Different species plants have a variety of different root structures, that penetrate different depths, some reaching down many meters. Root variety presence, optimises access to soil minerals and water, as well as potential for mycorrhizal interaction and nutrient exchange.

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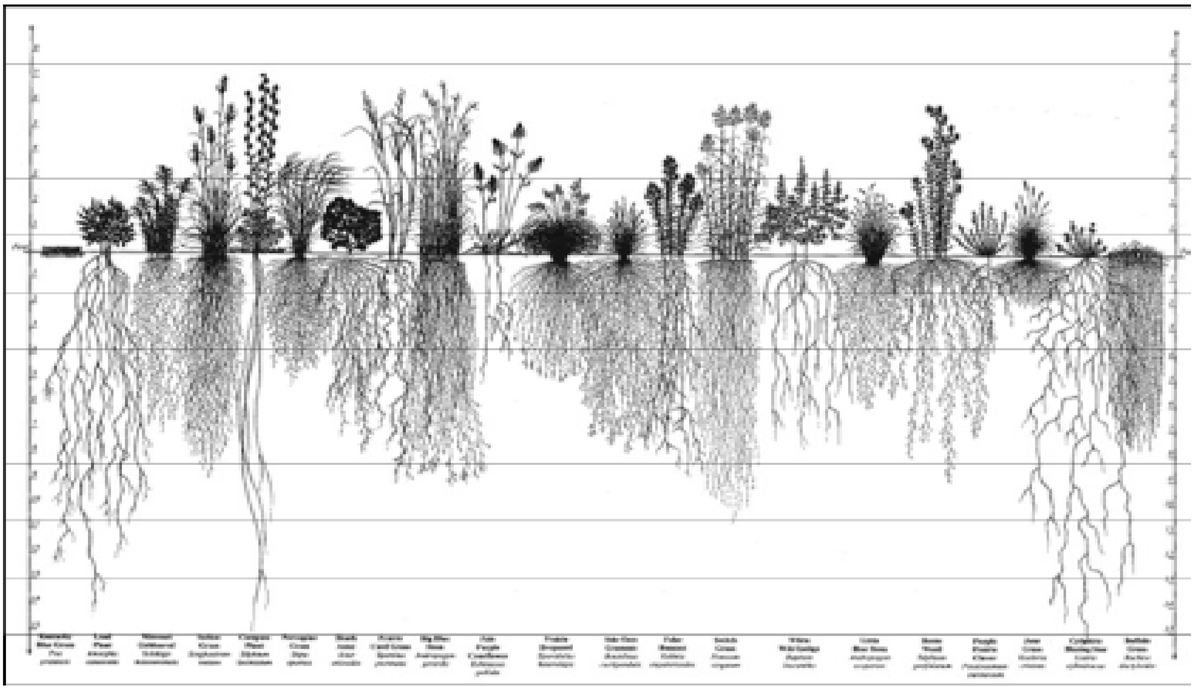


Fig. 111. *"The fundamental basis for encouraging use of native plant species for improved soil erosion control in streams and stormwater facilities lies in the fact that native plants have extensive root systems which improve the ability of the soil to infiltrate water and withstand wet or erosive conditions. 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.)

MULTISPECIES COVER CROPS

As discussed, systems with diverse plants and soil biomes, are healthier, much more productive, improve water retention and hydrology, and sequester carbon. Mixed cropping was practiced by the Chinese for hundreds of generations. In the early 1900s the English botanist Sir Albert Howard, seeing what the Chinese had achieved, and based on his own research, advocated the use of multi-crop growing techniques, and 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)

"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. 112. 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)

The Jena study, reported that much greater increases in nitrogen, were seen with a greater number of cover plant species; one species making little difference; but 16 species when combined, resulted in increased productivity. 16 species with no nitrogen addition, in terms of growth, outperformed 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 and 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 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.113. 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 Burleigh soil cover crop trial in North Dakota, US, was a 2006 experiment involving adjacent field areas. Where 25 mixed species grew together in extremely dry conditions, the plants thrived. Meanwhile, 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.114 a& 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. 115a. 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. 115b.*"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.

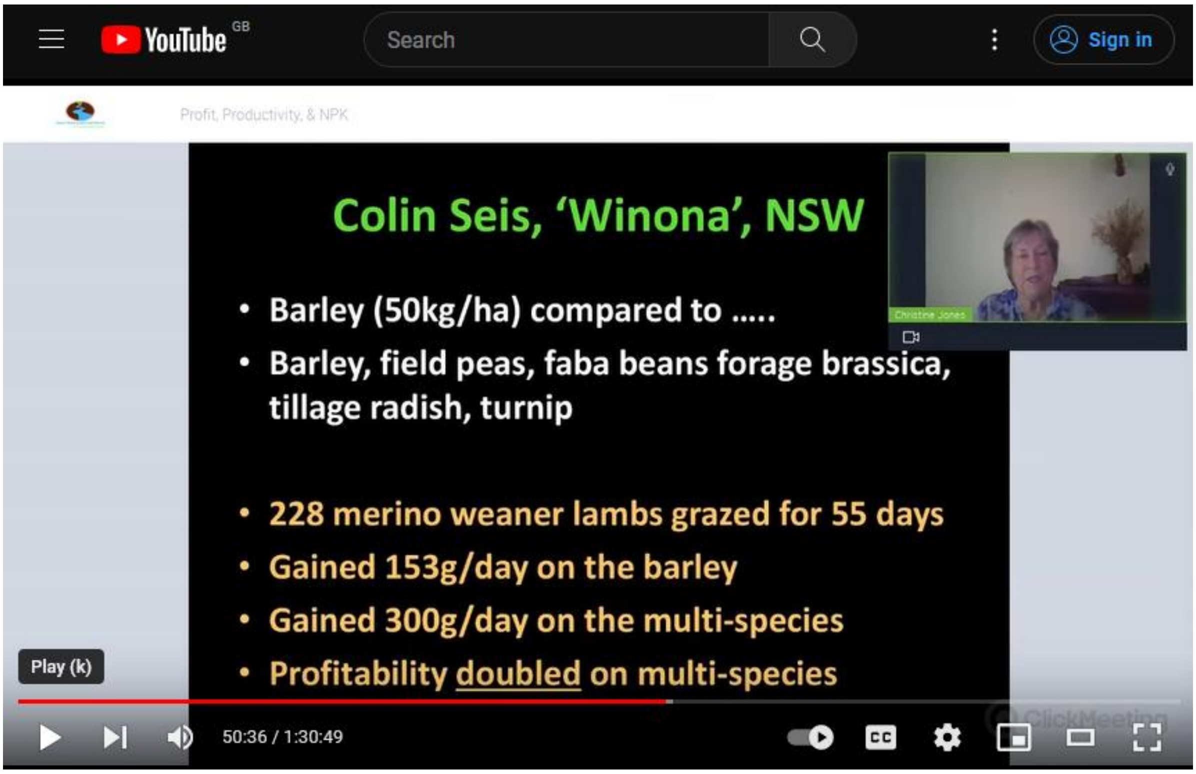


Fig. 116. Sheep grazed for 55 days gained more weight on a multi-species family-crop compared to rye grass. UTube lecture *'Profit, Productivity, and NPK with Dr Christine Jones'* Lower Blackwood LCDC with very many thanks to the authors. (Jones, 2022)

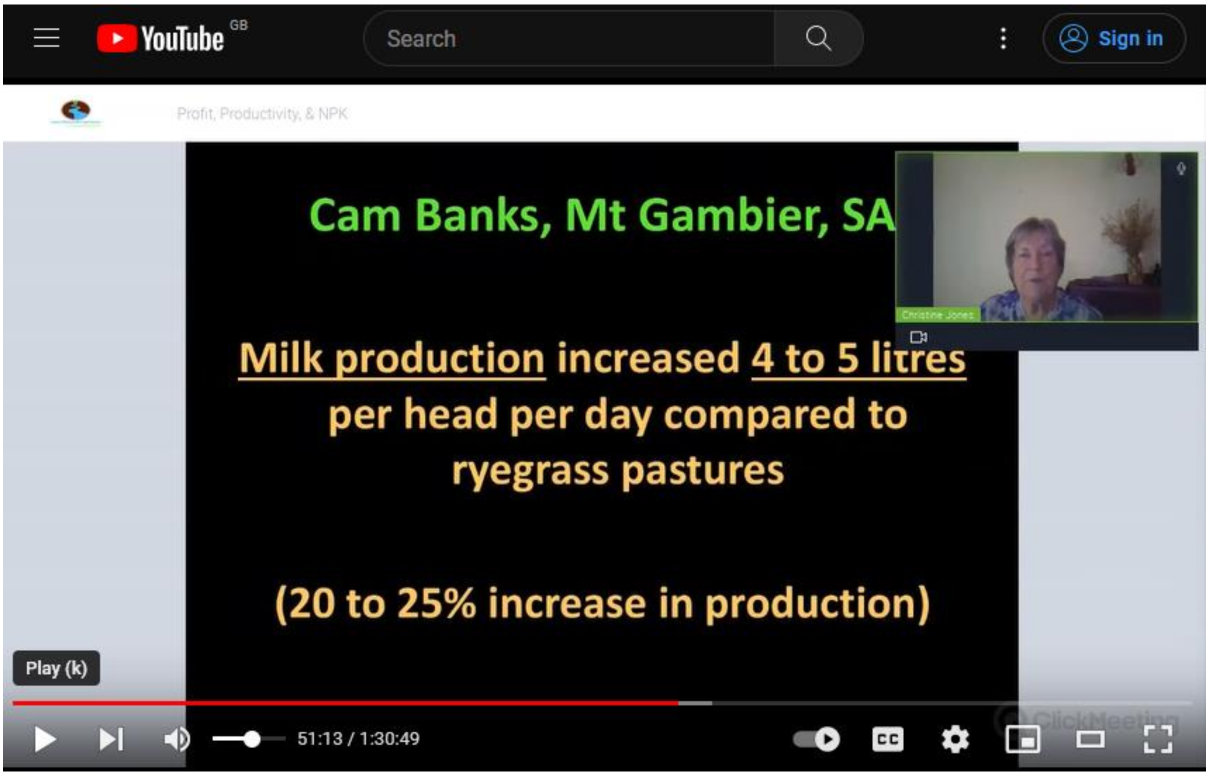


Fig. 117. Milk production increased 4 – 5 litres on multi-species/family crop compared to rye. Slide from the UTube lecture *'Profit, Productivity, and NPK with Dr Christine Jones'* Lower Blackwood LCDC with very many thanks to the authors. (Jones, 2022)

Christine Jones reports in the UTube lecture *'Profit, Productivity, and NPK with Dr Christine Jones',* as recoded and referenced in the slides above, 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 Atiamuri in New Zealand, and by the generality of reports by Gabe Brown.

Once we accept that different plants favour different mycorrhizal organisms and that a thriving microbiome is wholly advantageous, it then becomes clear why the technique of growing multispecies cover crops is so successful in producing healthy soils.

In New Zealand, a farmer using multi species cover crops as cattle grazing pasture; with no artificial fertiliser input; on volcanic pumice, so difficult, but potentially mineral rich soils, remarkably increased his depth of soil approximately 16cm in a year. Cattle grazed on the cover crops grown exhibited improved health, fertility, milk yields and butter fat content; and less need for veterinary visits (Jones, n.d.-a; Jones, n.d.-b, Jones, 2018b; Jones, 2019b).

Similarly, 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)

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) In contrast tillage bare ground and agrochemicals degrades the environmental ecosystem.

With thanks to Adobe Stock

LOW-TILL FARMING V PLOUGHING

For reasons previously discussed avoiding bare soil and using low-till techniques are all central to maintaining soil health. There are a variety of techniques for seed planting that minimise soil disturbance, including; planting into living cover crop and terminating a few days later using crimping; planting into previously crimped crops using disc cuts; light scarification with application of compost after planting; and many other variants.

Ploughing damages soil biome systems by a number of mechanisms. Bare earth wastes opportunities to use sunlight to fix organic carbon from atmospheric carbon dioxide, and leads to moisture loss, reduced rain penetration, soil heating, heat domes, and wind and water-based erosion.

GRAZING LEVELS AND PLANT ROOT MAINTENANCE

Livestock is often used as an integral part of soil-centric farming regimes. Cattle return bacterially-processed organic matter to the earth, and their hooves distribute dung and urine, as well as rooting out dead grasses, and spreading seed.

Restricted high density 'mob' grazing on an area, to about 50 per cent of plant growth, may optimise grazing fodder availability, maximising the overall production capacity of the land by preserving root mass, thus facilitating regrowth. Research suggests 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 per cent. Clearly impact, and capacity to re-graze or not, in any given season will be dependent on the health of the soil, but in any circumstance the avoidance of creation of bare ground is essential.

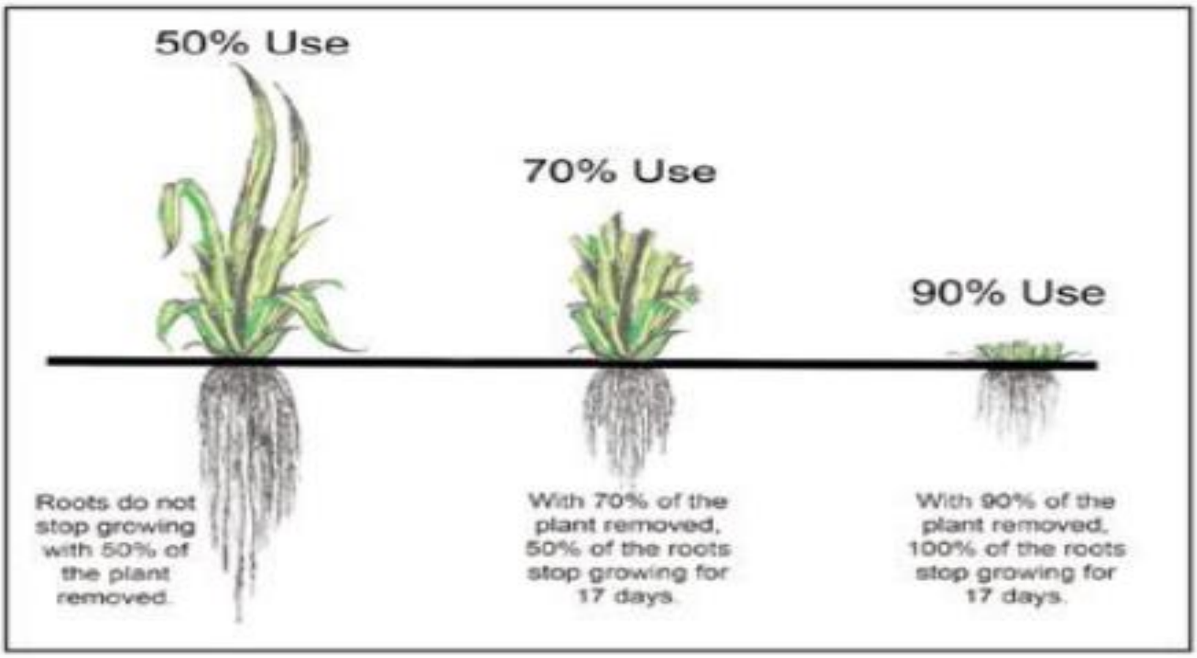


Fig. 118. Relative growth after different levels of grazing is illustrated *'Great "Grass Farmers" Grow Roots'* (Voth, 2015).

"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"*

Fostering root length, and healthy good-sized plants, supports soil biome activity and diversity. Green plant material is needed for photosynthesis of carbon sugars, thus supply of them to the soil biome. The *in-situ* production and deposition of faeces and urine by grazing cattle, will ultimately increase organic matter in soil, as well as adding biology to the soil.

APPROPRIATE MIMICKING OF LIVESTOCK MIGRATION PREVENTS DESERTIFICATION

Crucially, as above, disturbance by grazing animals, of dead grasses carpeting soils, will promote clearance, reseeding, and regrowth, that would not otherwise happen.

Fig. 119. 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 a number of publications on planned holistic grazing and management; in arid areas, impairment of reseeding by clumping of dead grass contributes to desertification. In a natural grassland system, Savory suggest 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: the process cannot happen. (Savory, 2013)

Before human intervention, all available grazing resources would have been utilised to greater or lesser extent, through the presence of a variety of 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. Large herds would have been harassed by predators. 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. 120. Planned grazing outcome in East Africa '*How to green the world's deserts and reverse climate change*' A slide from a UTube talk by Allan Savory with very many thanks to the author. (Savory, 2013)

The website of Holistic Management International – catch-lined '*Healthy Land, Healthy Food, Healthy Lives*' - links to a useful and extensive range of information on range-land management.

BENEFIT OF LIVESTOCK TO FARMING

Cattle and other livestock used as a mechanism to maintain and help restore soil diversity and fertility, and to bring value to areas that are otherwise not suitable for arable farming, arguably outweigh any negative effects as to climate warming (Schwartz, 2013). In contrast, industrial feedlot farming poses a number of environmental issues which are outside the scope of this publication (Thornton *et al.*, 2001).

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 use of livestock is not essential, but rotational grazing will speed soil improvement, including the rate of carbon build up. It has also greatly increased land livestock carrying capacity by multiples of two and more. Herbivores also allow extraction of food and value from sloped and other land that is unsuitable for tillage.

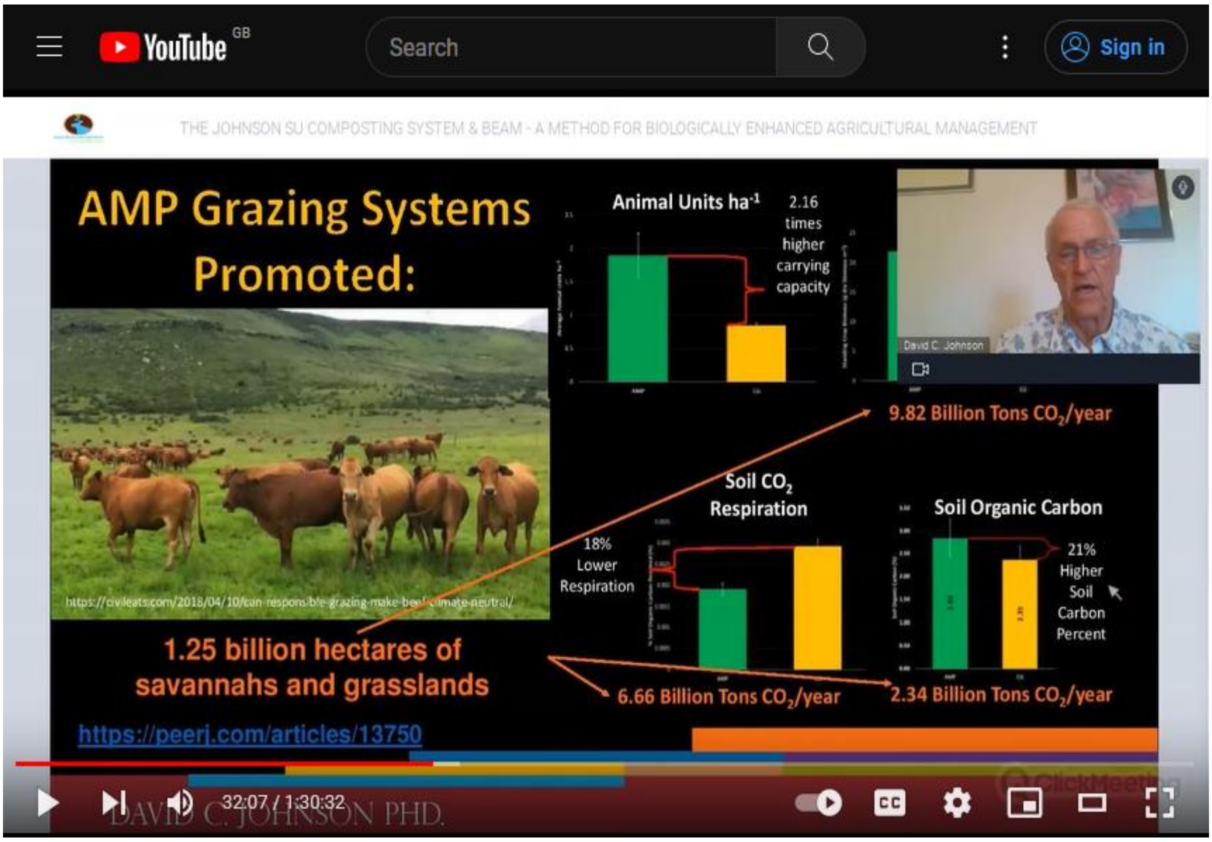


Fig. 121. Doubled carrying capacity, and soil carbon sequestration with Adaptive Multi-paddock Grazing 'AMP' aka 'rotational grazing'. Slide from the UTube lecture The Johnson Su Composting System & BEAM (Biologically Advanced Agricultural Management) with very many thanks to the authors. (Johnson & Su, 2022)

Pre human population expansion, huge 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 consumptions by soil bacteria is complex, and we should be cautious about lumping grass grazed cattle with feed yard cattle, before we better understand the biological interactions and complexities, and more so given appropriate cattle use, speeds soil carbon sequestration, thus atmospheric carbon dioxide capture. As above ruminants, in sustainable number, regeneratively farmed, play important roles in maintaining ecosystems.

Grass land carbon sequestration could form part of a strategy to draw down atmospheric carbon dioxide. As discussed, successful implementation of a strategy to sequester a ton per hectare of global agricultural soils could buy time to develop sustainable energy sources.

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 risk of nutrient imbalances. More of the nutrient value of feedstocks ends up in an animal's manure than in the animal itself. "B*etween 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 *et al.*, 2014). Thus, migrant herbivores, and now cattle, move, circulate nutrients between locations, helping to even out immediate regional differences in soil mineral availability.

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.*"

Approaching a century later, New Zealand livestock farmers are starting to use multi 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 are seeing better; fertility, milk yields and reduced 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. Dr Jones quips farmers reportedly have even on occasions forgotten the vet's number!

REDUCED NEED FOR AGROCHEMICALS

Farmers using regenerative agriculture including, Gabe Brown, the Haggertys, Dave Brandt, and Rick Clarke are all reporting that they no longer or very rarely need to use chemical pest or disease control. Plant health and disease resistance has 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 provides the perfect scenario for crop specific pests to prosper.

RICE

Rice has been given a separate section given it is a global food staple, and because it is grown, thus commented on less, than other western staples in regenerative circles. One billion people derive their livelihood from rice. It represents 20% of the world's caloric intake feeding 3 billion people (MacArthur, 2022). Rice production also has significant specific potential environmental impact at a number of levels, particularly water requirements and methane production.

Agriculture globally is a significant user of the world's water. Traditional rice production, with permeant root immersion, alone "*uses an estimated 34-43% of global irrigated water, or 24-30% of the total freshwater withdrawals (Bouman et al. 2007)*". Further, permanent submersion of the roots in water results in anaerobic soils, which produce large amounts of methane a climate change gas. Rice accounts for 2% of global greenhouse gas emissions. 11 to 15% of global methane emissions are from flooded rice fields (MacArthur, 2022).

Rice farmers using various forms of regenerative agriculture, including '*System of Rice Intensification*' SRI protocols, and 'mixed farming' techniques, greatly reduce water requirements, yet achieve equivalent or often better yields, without artificial inputs.

"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).

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,
- 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 fertilizers,
- no permanent immersion - intermittent wetting and draining of paddies during growth.

Fig. 123. 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)

The SRI system also significantly reduces water requirements, and results in a net benefit of greenhouse gases, with reduced methane, but increased nitrous oxide production, which may be further reduced where artificial fertilisers are not used. It also results in a net reduction of fossil fuel usage due to reduce pumping requirements.

Fig. 125. 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)

Fig. 126. 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)

In a project working with Wageningen University & Research, a farmer using mixed farming with constant immersion, increased rice yield to 10 tons a hectare, with 2 to 3 crops a year, and reduced weeding, with no artificial input. The farmers used fish in the paddy's, which aerated the water and created nutrients in the faeces; ducks that cleared weeds and further aerated the water; plants such as water fern; and planting of the banks separating the paddies with nitrogen supplying plants. "*Not only was the system the most resilient in extreme weather, but it turned out to be the most productive compared to the conventional and organic agriculture. This robust form of agriculture with higher yields and without the use of pesticides or artificial fertilizers could be an example for all the rice-producing countries.*" (Bezemer, 2019; Khumairoh, 2018)

There is also emerging large scale interest in the West. Kellogg's have announced a 2-million-dollar program to support climate smart practice in the Lower Mississippi Basin rice growing region (''*Kellogg announces regenerative ag program for Lower Mississippi Basin rice farmers''*, 2022). The USDA has funded climate smart projects, including regenerative agriculture rice. CGIAR have an SRI program in Vietnam (CGIAR, 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 those nutrients which end up in smoke including carbon, heat damages soil surface biology, and the smoke including pesticide residues in contains, causes considerable pollution, exacerbating poor air quality in stressed cities.

There are a number of videos on the topic, including training material (''*SRI Introduction: The spread of SRI in East Africa*'', 2012). A number of papers are listed by Cornell University. (''*Scientific Research Documenting and Explaining SRI*'', n.d.), who have a global SRI network and resource web page, listing projects, presentation, 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 evidences, the success of SRI. It has been quoted from in depth because of its importance, and impossibility of improving on the original. References removed from the text to save confusion, can be found in the original, which is freely available on ResearchGate (Upoff *et al.*, 2009). The extent to which the practice has spread is evidenced on the Cornell global SRI network and resource web page referred to above ("*SRI International Network and Resources Center*", n.d.).

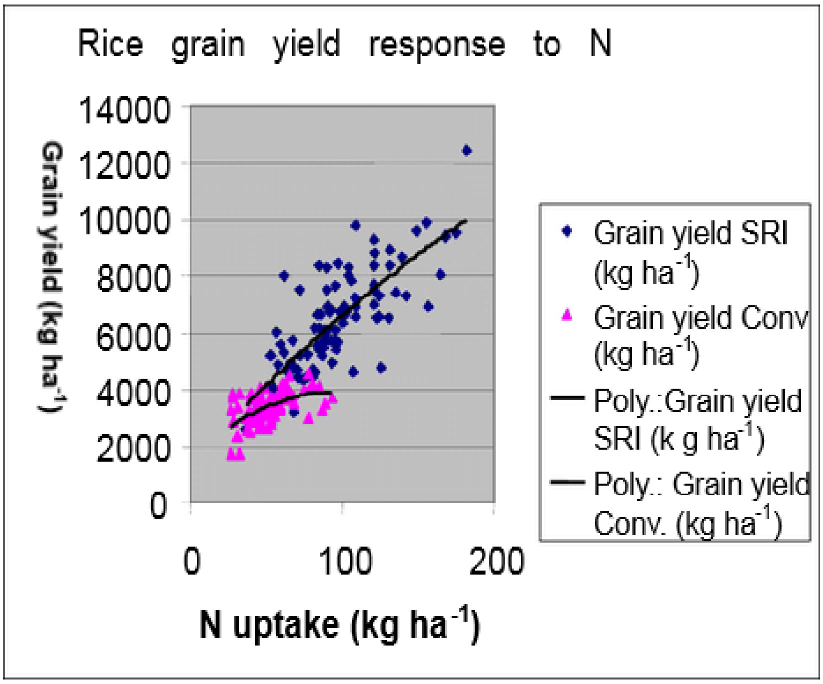


Fig. 3. Grain yield response as a function of nitrogen uptake for two sets of rice plants grown with SRI or conventional methods (N=109), four locations in Madagascar. Source: Barison (2003).

Fig. 127. 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)

"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 *et al.*, 2009)

Fig. 1. These two rice plants grown on the farm of Sr Luis Romero in San Antonio de los Baños, Cuba, are both the same age (52 days after germination) and same genotype (VN 2084 variety). Both started in the same nursery, but when 9 days old, the plant on the right now with 42 tillers was transplanted into a field managed according to SRI methods: wide spacing, aerobic soil conditions, more organic fertilization. The plant on the left with five tillers was kept in the nursery, relatively crowded, for transplanting at the usual stage in Cuban practice (50–55 days). The following season, a video was made to document sequentially the differentiating growth of rice plants on Romero's farm (http:ciifad.cornell.edu/sri/countries/cuba/SICAenglish.wmv). Photo by Dr Rena Perez.

Fig. 128. 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 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 *et al*., 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 *et al.*, 2009).

The authors continue by explaining why they believe SRI techniques are so productive. SRI focuses on plant symbiosis with soil organisms, the generality of which has much in common with wider regenerative agricultural principals. The history of SRI illustrates the reluctance of established systems to be open to taking on new ideas, particularly ones that are nature based, even when there is a wealth of observable evidence, they do indeed work.

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

Table. 5. 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)

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

Many regenerative farmers are reporting they have at least maintained yields, and are 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 UTube slides, reproduced on the pages below.

In the UK a major firm of agricultural estate and land agents Strutt & Parker, owned by the bank Paribas, has produced an advisory document on regenerative agriculture, a clear indication the subject is gaining wider traction and respectability (Strutt & Parker, 2021).

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

Further, and of great importance, a study of 100 good sized regenerative farms, of at least 5 years standing, average size 1400 acres (see slide page 20 above) in the USA, funded by Cargill the privately held Food Corporation, found that most farmer in their group reported greater profits for corn and soy, often with improved yields, as reported in the slides 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 Haggerty's, and 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).

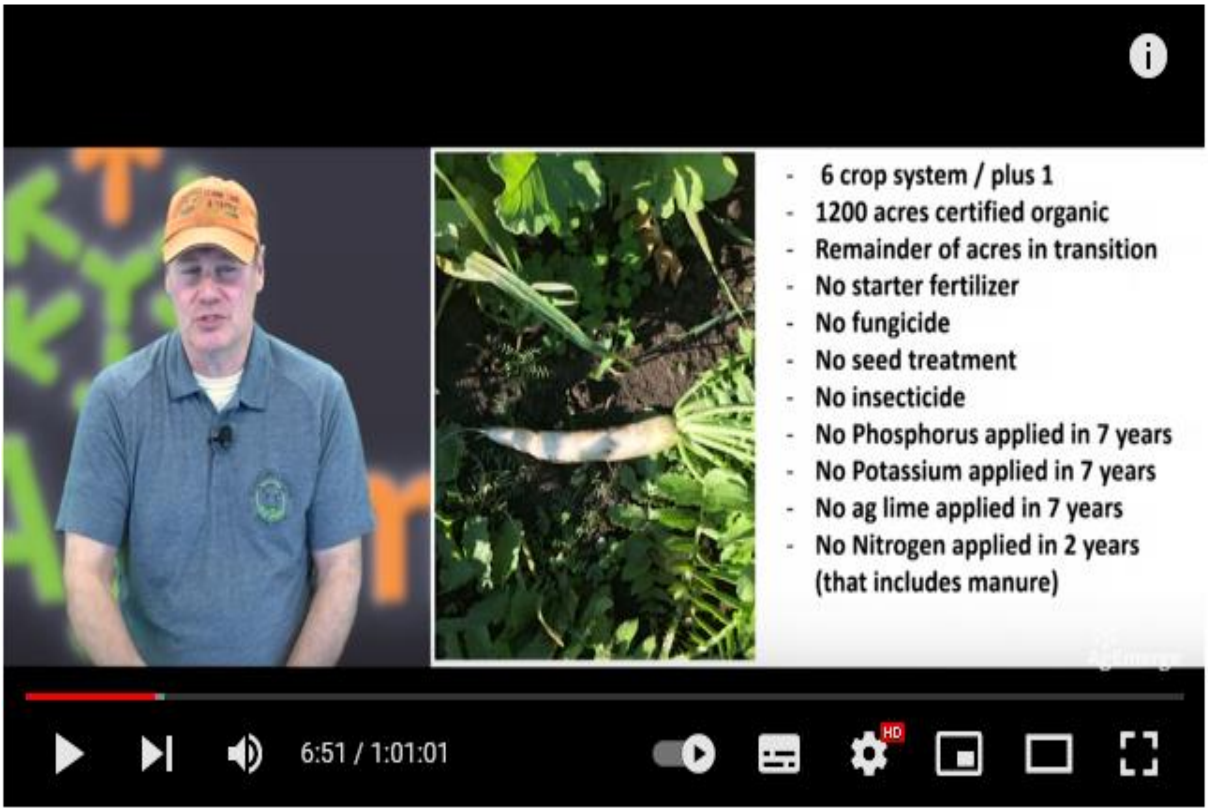


Fig. 129. From AgEmerge Breakout Session with Rick Clarke - Farmers making money in real life with Reg Gen Ag: practicalities, and benefits of green fertiliser, agrochemical free 'regenerative' agriculture, many very thanks to the author. (Clarke, 2021)

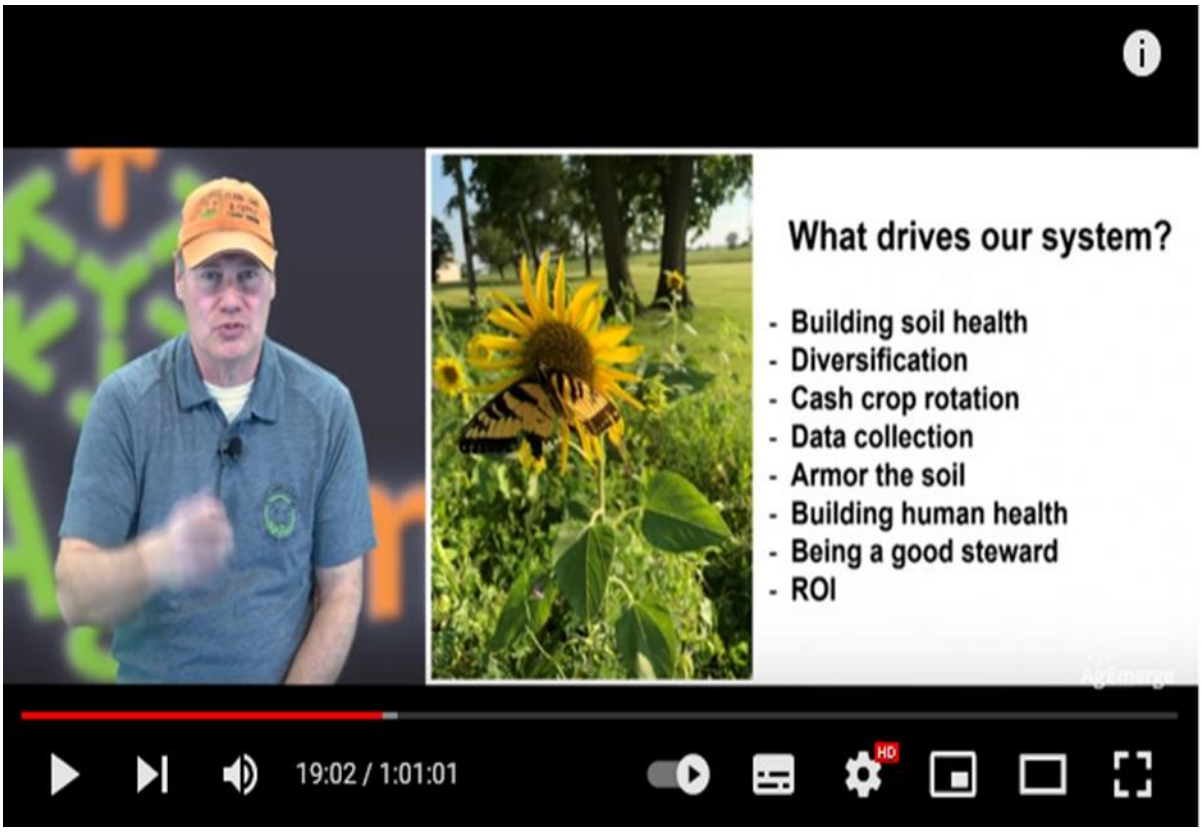


Fig. 130 a & b. AgEmerge Breakout Session with Rick Clarke - Farmers making money in real life with Reg Gen Ag: practicalities, and benefits of green fertiliser, agrochemical free 'regenerative' agriculture, with very many thanks to the author. (Clarke, 2021)

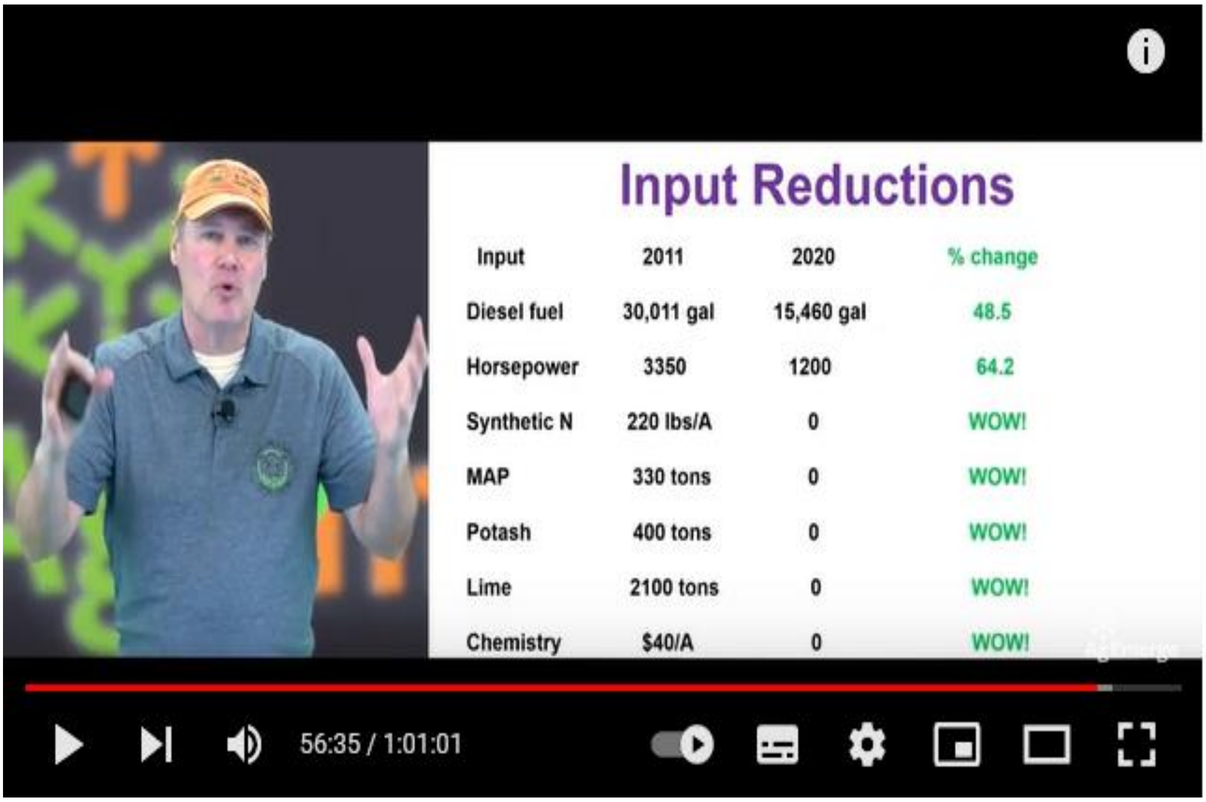
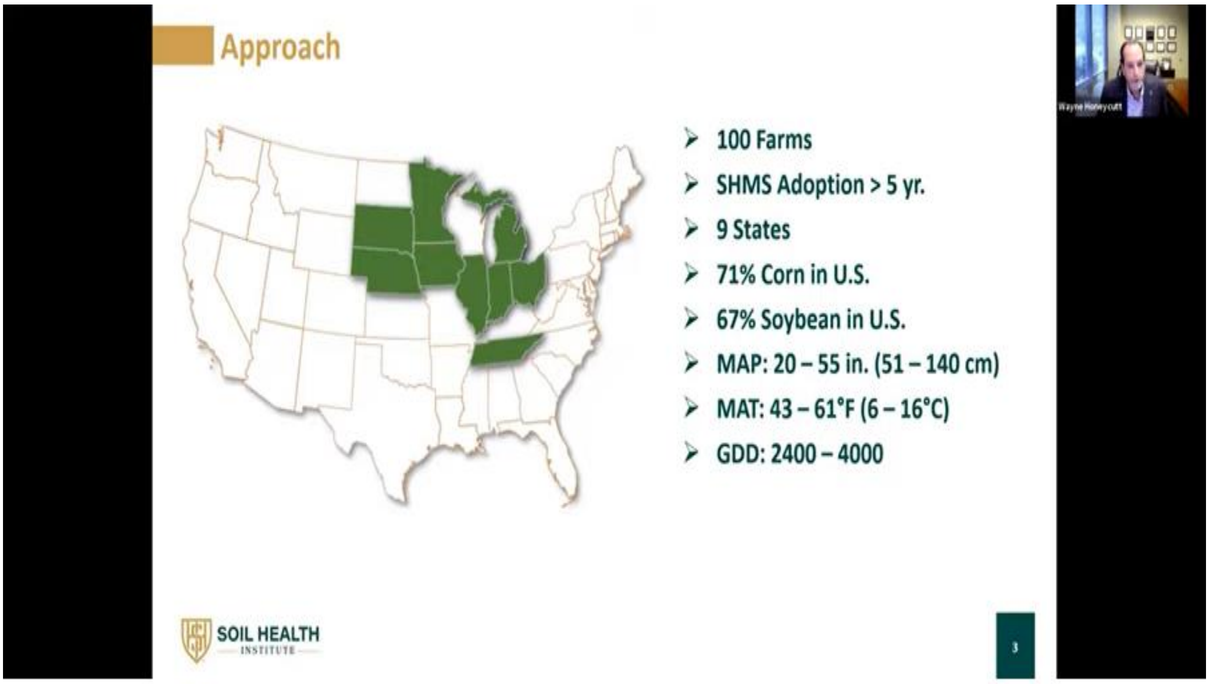
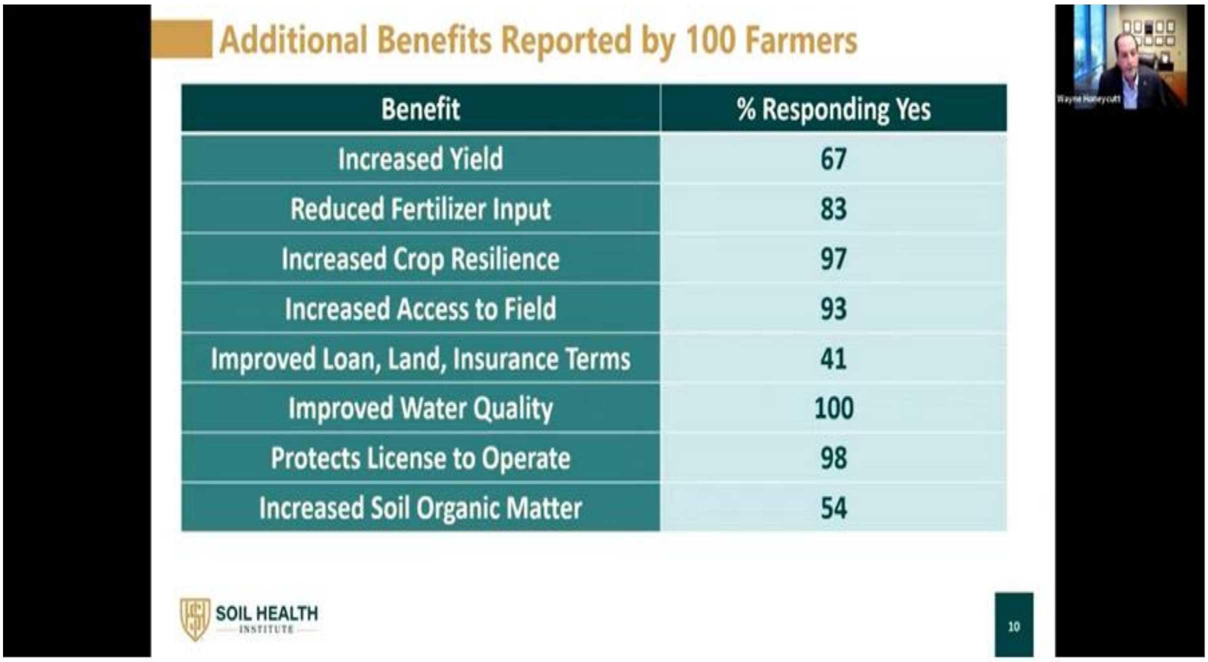


Fig. 131. AgEmerge Breakout Session with Rick Clarke - Farmers making money in real life with Reg Gen Ag: practicalities, and benefits of green fertiliser, agrochemical free 'regenerative' agriculture, with very many thanks to the author. (Clarke, 2021)



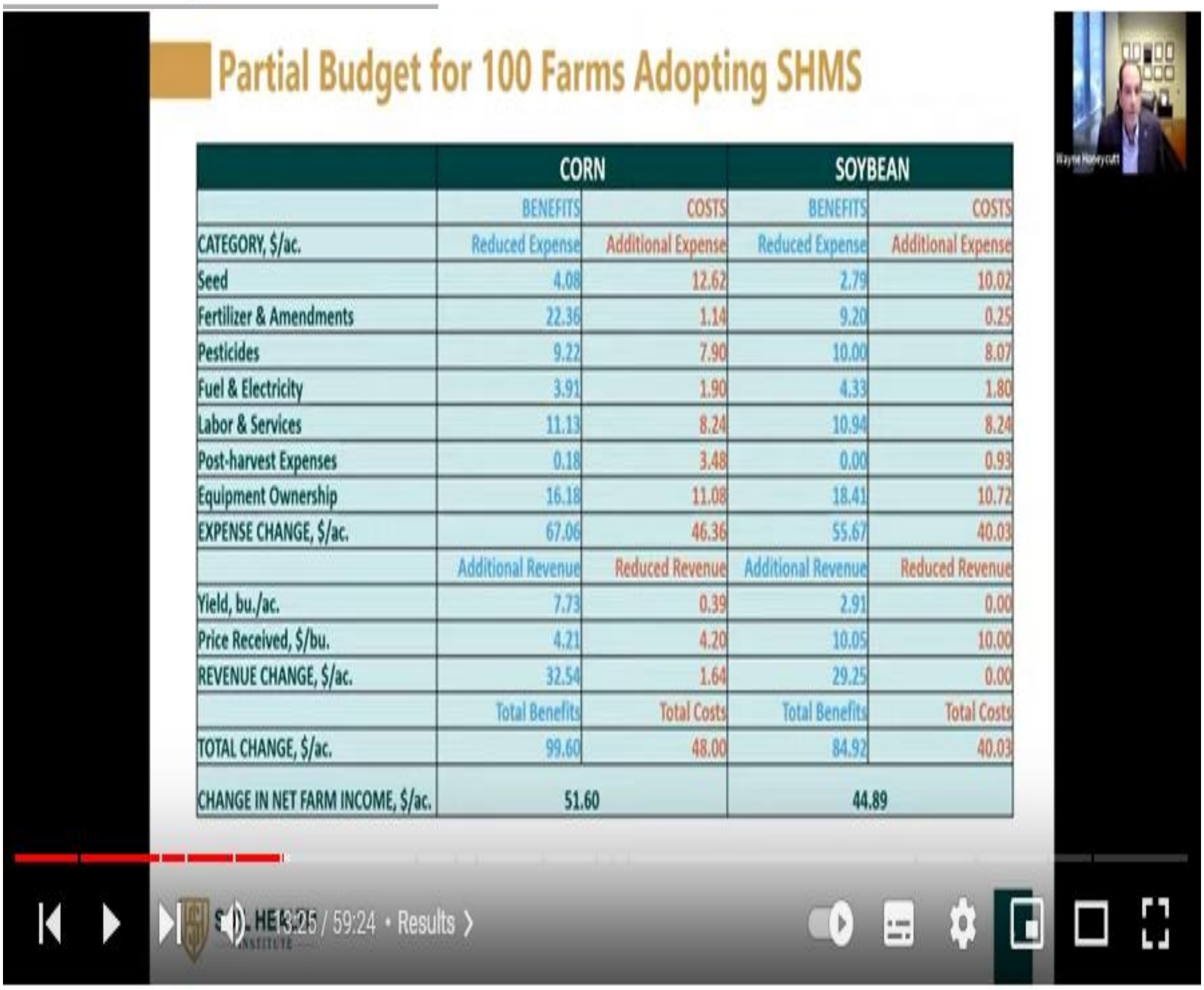
Economics of Soil Health Systems

Fig. 132. 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)



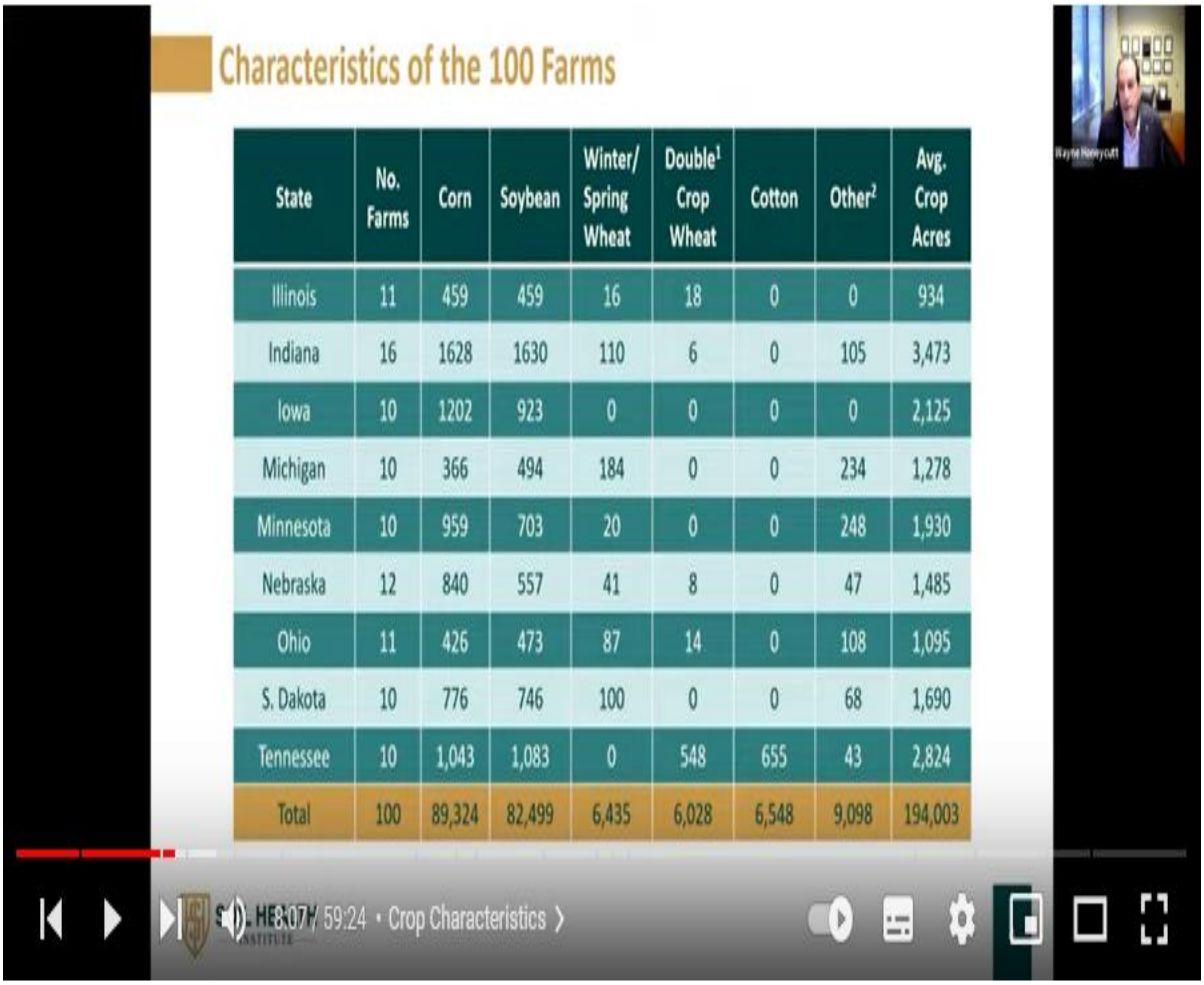
Benefit	% Responding Yes
Increased Yield	67
Reduced Fertilizer Input	83
Increased Crop Resilience	97
Increased Access to Field	93
Improved Loan, Land, Insurance Terms	41
Improved Water Quality	100
Protects License to Operate	98
Increased Soil Organic Matter	54

Economics of Soil Health Systems



	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	10.05	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	

Fig. 133. 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)



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. 133. 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)

SIR ALBERT HOWARD – COMPOST PROVIDES BIOLOGY

For nearly two decades at the beginning of the 20th century, Sir Albert Howard was invested with the rather grand title '*Imperial Economic Botanist to the Government of India*'. 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 took inspiration from Chinese composting.

Among his numerous highly thought-provoking publications is '*An Agricultural Testament*' (1943), which looked at how application of compost, and good land management can generate improvements in yield, disease resistance, crop quality, and shelf life.

Table 3
The increase general fertility at Indore

Year	*Area in acres of improved land under cotton*	*Average yield in lb. per acre*	*Yield of the best plot of the year in lb. per acre*	*Rainfall in inches*
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)

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)

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].

Strikingly, Howard's results show compost application significantly improves the resistance of plants 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 important, 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 experience in a trial with rice, including on salinised land; and his colleagues following testimony referred to earlier …

"*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.*

"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 remaining 15 acres are as before with the rice scraggy and thin. 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).

Compost not only delivers diverse 'fertilising' biology, but its very physical properties 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, Young, & Raneiri 2016);

In addition, as discussed, and of critical importance, compost provides accessible biology to facilitate germinating seeds. In a machinery world, compost seed soaks, injected compost extract, and foliar spray likely are more effective, certain and economic to apply, than application of a thin layer of compost on the surface of the soil. 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. Clearly if not incorporated, or if seeding is delayed, the biology in the compost could over time be damaged by sun exposure due to surface heat and UV – more research is required.

AGRICULTURAL FACILITATORS

There are a number of products and processes, including those outlined in the sections below, that are in principle compatible with regenerative agriculture. They are not widely used, and some are limited by available resource levels, but have all shown benefits to varying degrees, and warrant further research.

MICROBIOME INOCULANTS

Howard showed the yields and health of many crops could be improved with compost. 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 application of compost extract, containing a rich microbiome of fungal spores and bacteria. Mark Tupman gives advice on priming seeds with inoculants (Tupman, 2022).

Dr Johnson's Biologically Enhanced Agricultural Management (BEAM) system, focuses on supporting soil organisms as a means to increasing 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).

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 *et al*., 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 control under varying levels of irrigation, found the former produced significantly bigger yields: 290.4 g/m^2 compared with 133.05 g/m^2. In addition, pea quality improved and the crops were markedly more drought-resistant (Kristek *et al*., 2017).

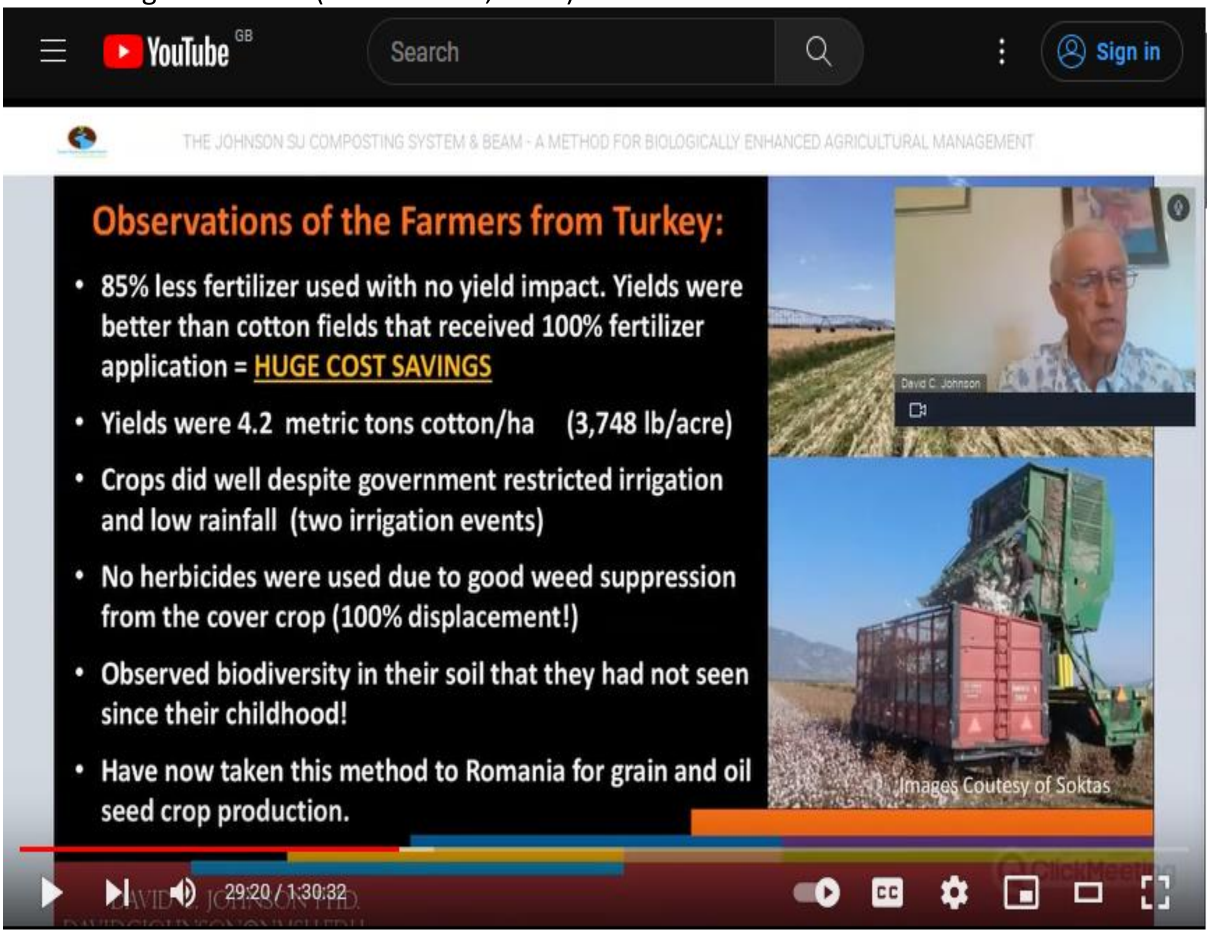


Fig. 134. Improvements in cotton yields using BEAM (Biological Enhanced Agricultural Management), involving microbiome spore-rich compost extracts. Slides from the YouTube lecture, The Johnson Su Composting System & BEAM (Biologically Advanced Agricultural Management) with many thanks to the authors. (Johnson & Su, 2022)

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.

MICRONUTRIENTS

The need for, and potential sources of, micronutrients, including microminerals and iodine and the consequent the 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 *et al*., 2012)

Minerals are difficult to extract, mix, and mine, as well as being expensive and often rare. As discussed, rock phosphates contain, a limited palette of minerals, as well as heavy metals, and radioactive nuclides, in sufficient quantities to pollute soils. NPK fertilisers as discussed, also block supply of minerals to plants by the soil biome. In contrast sea salt residue is a non-toxic natural by-product of the sea salt industry, produced in an energy efficient way using sunshine.

It is possible that high yield crop producing countries achieve good yields because they have mineral rich and carbon rich soils, and conversely those that fail to achieve good yields would likely benefit from a combination of carbon rich soils and provision of microminerals using foliar including iodine, as was seen with the historic use of sea-weed extracts – yes more research required.

SEAWEED

Seaweed provides minerals and iodine, and historic commercial usage and related then research suggests, seaweed, as a soil additive or foliar spay improves, plant health, keeping qualities, disease and pest resistance, growth, and livestock feed quality, but self-evidently supplies are limited, albeit renewable.

The book '*Seaweed in Agriculture and Horticulture*' (Stephenson & Booth, 1968) is a trove of information on the subject and sets out many observed benefits, including increased; shelf life, resistance to pests, diseases, and frost; as well as better crop quality and yield. Seaweed extract may be a useful addition to soluble compost extracts when used as organic fertiliser, seed treatments, drips or sprays.

SEA SALT RESIDUE

As mentioned earlier, marine-extracted minerals, such as 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. They further provide a full range of minerals, including micronutrients, some phosphate, and importantly iodine. Interestingly the Haggerty's I believe, use some sort of marine based additive 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?

Salt is used by some, as part of an SRI protocol in a rice seed soak. Christine Jones, and Mark Tupman, (Tupman, 2022) suggests that mineral additives need careful use as excess application at planting may inhibit plant growth, but Tupman does add seaweed extract, and some mineral sources, to his seed inoculant mix.

Stephenson and Booth in "*Seaweed in Agriculture and Horticulture*" (Stephenson & Booth, 1968, p.107) reported dramatic increase in 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 minerals elements including phosphates (Atkins, 1926) and, where not completely 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 a number of 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. Bittern deployed in hydroponic systems, boosted the antioxidant rating of green peppers. Sea salt residue is high in magnesium, which is often lacking in plants, but is "*required for chlorophyll formation and plays a key role in photosynthetic activity"* (Farhat *et al.*, 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 on the subject of bitterns (Murray, 2003; Walters, 2005; Zeigler, 2014), by early regeneratively inclined farmers, but it has not been the subject of mainstream research and development, either as a foliar spray, or additive to compost solute fertilisers.

Interestingly, use of bitterns causing soil salination, has not been reported by users thus far, and interestingly there does not appear to be a salinity problem following inundation of agricultural land by seawater flood events; in fact, some suggest improved fertility. As discussed, healthy soil biome systems seem to counteract 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 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 could be recovered from desalination systems discharge, which is itself environmentally damaging. It might also be possible to use it as an additive to compost solute fertilisers.

As above, soil salinity, is not reported as a problem by those that use sea salt residue, effects are generally described as positive, and a number of books have been written on the subject of sea salt residue use in agriculture (Murray, 2003; Walters, 2005; Zeigler, 2014). Clearly whilst more research is required, as this is an omission worth addressing, and a potential industry waiting to happen.

ROCK DUST

Rock dust has been successfully used as a soil conditioner and fertiliser since the late 1880s, when a flour mill owner Hensel, noticed grindstone residue application to land improved crop yields and quality.

Hensel published '*Stone Meal as a Fertilzer*' (Hensel, 1894), contained 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 denigration of those who whistle blow in such circumstances.

As noted, earlier, in the artificial fertilisers section, by way of a quote, Hensel observed artificial fertilisers had negative effects of plant growth.

In contrast he claimed of 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."*

It now appears his concerns as to the sue of artificial fertilisers were well founded. In addition, several companies currently sell tested rock dust as a soil conditioner; anecdotal and market indications are, that the product assists soil fertility, yields and health. Rock dust needs testing to ensure that it does not contain excess heavy metals. Overall, the use of rock dust, a waste product of the aggregate industry, has significant potential as an additive strategy for mineral availability enhancement.

With thanks to Adobe Stock

However, massive long-term usage of rock dust, to support global agriculture, except as a quarry biproduct, is unsustainable. Ultimately there are only so many mountains to grind up, transport is expensive; and reapplication is required every few years. Further some rocks are likely to contain high levels of undesirable minerals. Rock dust is only likely 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.

With thanks to Adobe Stock

There is a lack of mainstream research into the area, and arguably should be more, as waste rock dust from quarries has significant potential as an add-on strategy for optimising the mineral content of soils. However, as above, as with phosphates, ultimately there is only a limited supply of the most suitable rocks from which to make rock dust fertilisers. Except for use where a biproduct, sea salt residue would seem to be a better alternative.

DOMESTIC AND OTHER ASH

In historic research, domestic ash, plant residue minerals, was shown in some instances, to be more effective than manure and phosphate at promoting growth; making the point that a range of minerals are required for plant, livestock, and human function, thus health.

For example, research on compost in the 1940-50s, recorded in a book called '*Fertility From Town Wastes*' (Wylie, 1955), suggested 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 been 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, is likely to be more polluted, than when it was originally 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, provider of char, and a compost improver.

The role of ash in improving crop growth, illustrates how subtle the mineral needs of plants are, how much we do not understand in terms of their metabolic pathways, and the importance of recycling mineral nutrients to agricultural lands (Stephenson & Booth, 1968). Further some caution as to wood ash causing acidification of soils, but possibly 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 *et al.*, 2015), the use of ash needs to be considered with care, and particularly in respect of heavy metal contamination. For example, classes of ash such as fly ash (Mupambwa, Dube & Mnkeni, 2015), and chicken manure ash, pose particular potential risks. Nonetheless, careful consideration should be given as to the need to maximise potential benefits where environmentally sustainable.

USE OF BIOCHAR, URINE EARTH CLAYS, ETC.

Biochar produced by a variety of methods, and from a variety of substrates, including agricultural products (Jindo *et al.*, 2014), is suggested to be a useful soil additive, and as providing a number of 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 *et al.*, 2010) Whilst *w*ater retention was improved, the effect was not massive, and needs comparison 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 in grasslands have a significant 'biochar' pyrolysed carbon content. The stored carbon in both processes was derived from combustion of carbon stored in forest, or grass and related vegetation flooding and run-off. Some run off will eventually be sequestered as ocean floor deposits. 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 annual burn of 'crop-stubble', contributes to as much as 50% of serious downstream urban air pollution including smog, and where agrochemicals have been used, 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 winte*r' 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 terms of promoting short term crop enhancement. Some may have negative effects on plant growth (lettuce) (Mikajlo *et al.*, 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 *et al*., 2010). Interaction of biochar with phosphorous, is complex, and can be positive, but is not always so (Glaser & Lehr, 2015).

Where 'biochar' ash is an existing bi-product, of combustion, under controlled conditions, for example from combustion of timber pellets in energy production plants, there may be significant net benefits to its utilisation as a soil additive, but carful 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 *et al.*, 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 that it first appears. Different effects may be seen where NPK is and is not used. More research is required into use of biochar biproduct, 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.

DE-DESERTIFICATION - RESTORING FERTILITY

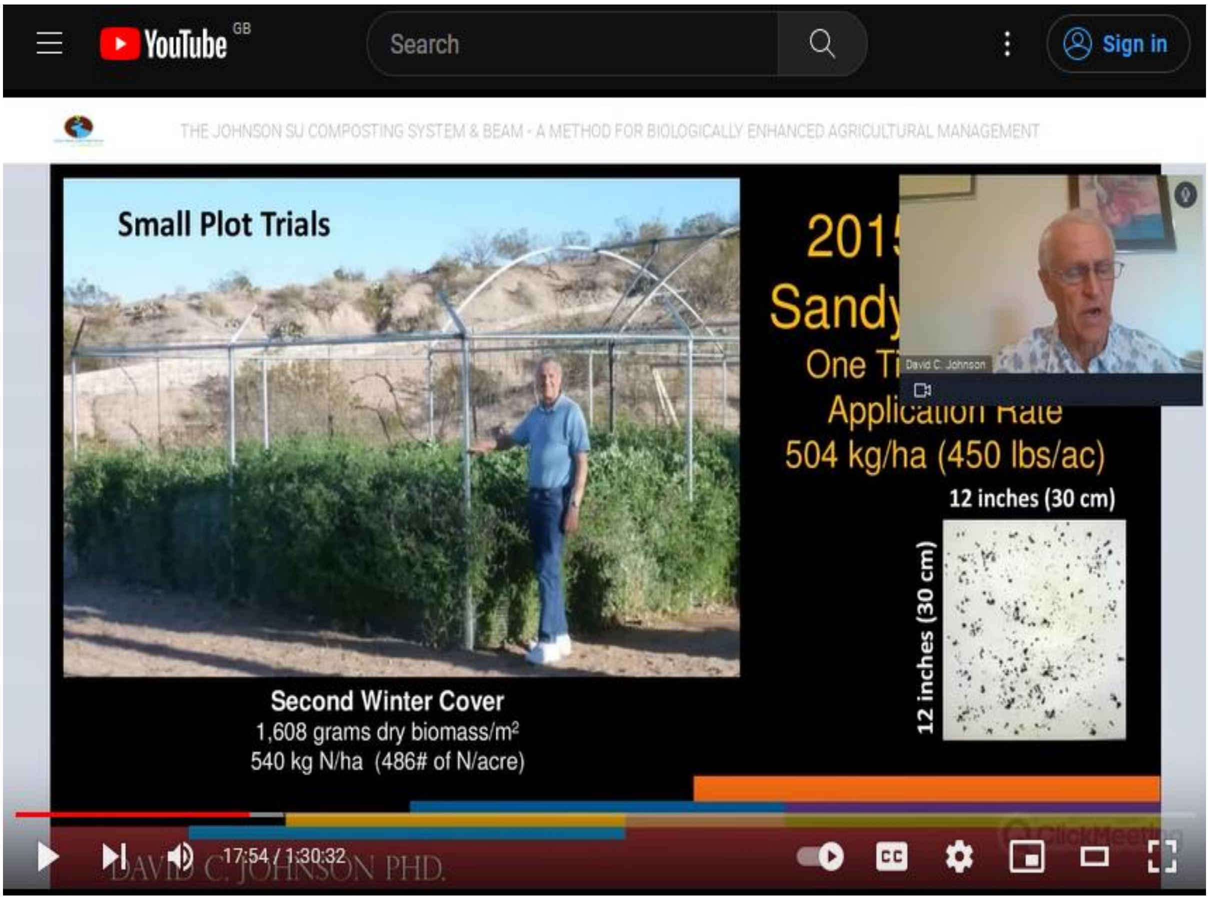


Fig. 136. The use of compost teas, as seed soaks, drips and foliar sprays, biologically rich mediums containing a wide range of bacteria, and fungal spores, particularly on degraded land, greatly improve seed germination, plant health and growth, and thus soil carbon sequestration rates. David Johnson calls this '*Biologically Enhanced Agricultural Management*' (BEAM). 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)

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 land, by restoring its biology including though the use of biologically rich compost extracts, is evidenced by the work of Dr Johnson in growing crops in light sandy desert soils. Different variants of techniques to restore soil biology have been used, including composts and compost tea extracts. Surely as knowledge increases over time our capacity to restore soil biology will improve.

Vast swathes of China's Loess Plateau, that had become minimally-productive, parched and severely eroded, have now been recovered with simple techniques, including 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 replenished including in, Australia, Ethiopia, India, Zimbabwe, Israel, Mexico, and China. The recovery of the Loess Plateau project was recorded by John D Liu. Other land recovery projects including 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 a control, and reminder, as to 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 to the way it operated, and in 2018 moved further towards optimal adaptive management principles involving regular moving of livestock and long rest periods between grazing. Consequent on the impact of these changes over time, they report tripled cattle carrying capacity and profitability (Dean, n.d.).

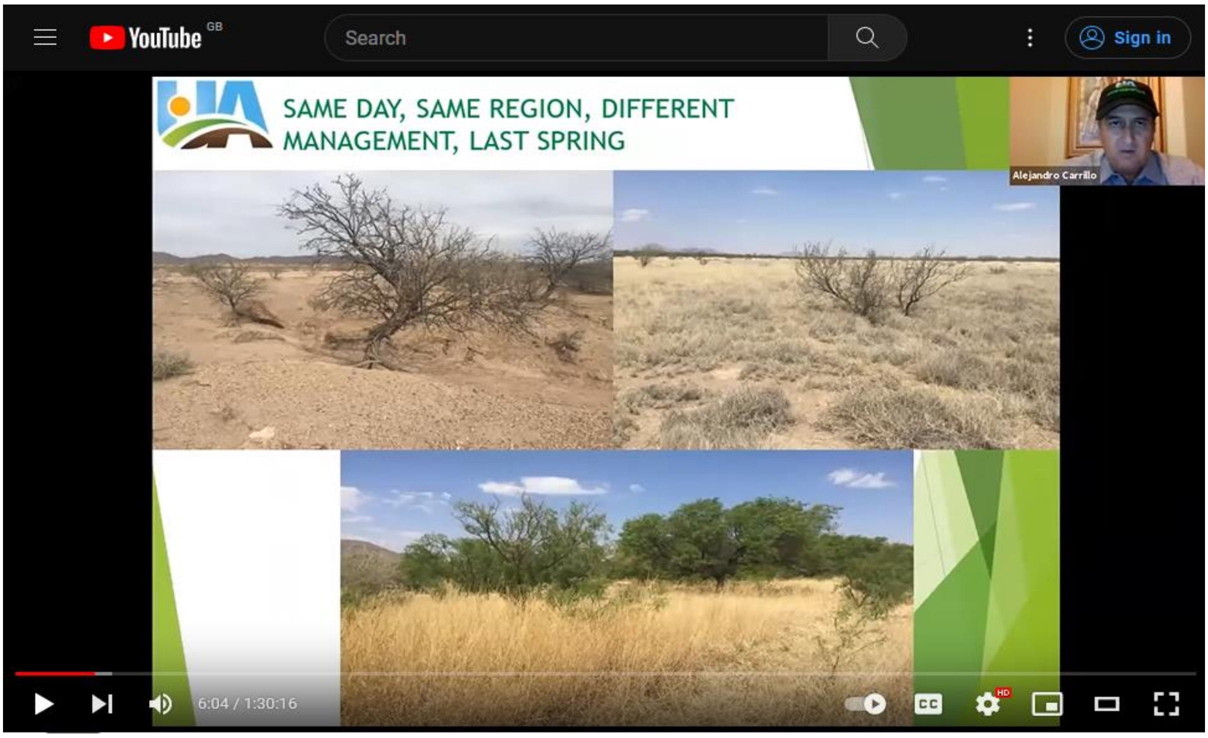


Fig. 137. Las Dama Ranch Mexico, UTube video '*Building Resiliency: Ranch Resiliency with Alejandro Carrillo 10-28-21*' comparing regenerative outcomes with adjacent traditionally managed properties, many thanks to the authors (Carrillo, 2021).

Fig. 138 a & 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).

Fig. 139 a & 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).

The changes at Las Damas are recorded in a number of UTube videos illustrated above, 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, thus microclimatic moisture, and airborne bacteria are slowly seeding greater rainfall over Las Damas, which is feasible, and hopefully more than wishful thinking.

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. 140. 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 UTube 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)

Fig. 141. 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 have risen and streams ran all year. Formerly marginally-productive areas with uncertain cropping, was once again supporting families, and bringing life, hope, and 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 to actually implement those relatively simple and affordable recovery strategies, as they have done in the massive and successful Loess Plateau project in China.

Fig. 142. a & 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. 143. '*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).

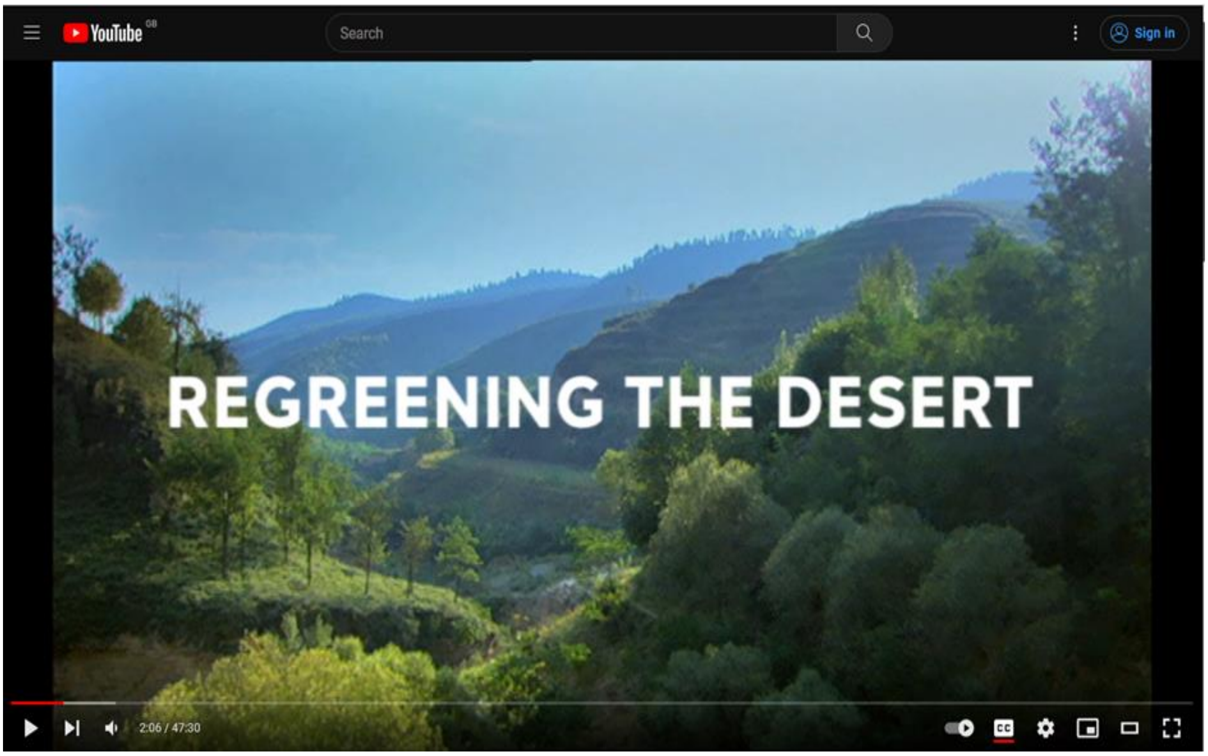


Fig. 144. '*Regreening the desert*', images of landscaping of the Loess Plateau after terracing, building of simple stone and earth dams, and removal of livestock, particularly goats from the erosion vulnerable upper slopes allowing natural vegetation and water retention to return. With many thanks to the author. (Liu, 2012)

Recovering and better utilising degraded lands - including major watersheds of economically significant rivers such as the Nile – helps provide, water, food, as well as capacity to make a living in hope, military, political and economic stability, to both urban conurbations, and rooted rural communities. The vast improvements in these landscapes are a stunning exhibition of what co-operative human behaviour, and simple common sense, can achieve at minimal cost. As history teaches us, those who can feed and educate their families, feel hopfull of the future are less likely to resort to violence.

Thus, landscaping to retain water, feeding of livestock in enclosures, improvement of water retention in soils, efficiency of water uses by crops, and improved regional hydrology and weather, through improved farming techniques, are areas of research that should warrant huge effort and focus, because they are cheap, apparently highly effective, available to all, and bring hope for a brighter future.

CLOSING THE CYCLE – FAECES URINE COMPOST

The modern issue of the unclosed cycle of soil, food, urine and faeces, and use of partly processed or unprocessed sewage water and sewage sludge, disposed of largely into rivers, and onto land, remains to be resolved.

Sir Albert Howard, a leading light in the 'West' on the topic of composts, including composting of animal and human urine, clearly demonstrated the value of properly prepared biologically rich compost. His Indore composting techniques were gaining traction before World War II, improving yields, and crop health, but the emergence of artificial fertiliser in the 1950s diverted attention, and albeit with misplaced confidence, and pushed aside '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 waste water plant, or simply dumped untreated into watercourses. Source separated urine and faeces, collected from vacuum WC systems, could be anaerobically digested at source, and the residue would need to be tankered or otherwise transported to specialist treatment centres.

Currently, 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 composting. Research is needed to further improve such composting techniques. The subject is discussed in more detail in volume 1.

The benefits of quality compost, including by 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 *et al.*, 2017), has negative effects similar to those seen with industrial fertiliser.

Sewage sludge applied to land, as discussed, contains a wider range of contaminants, which will to varying extent be taken up by plants (Kipper *et al.*, 2010; Madikizela, Ncube & Chimuka, 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 the current methods of disposal 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 the composting of it.

RESOURCE VALUE OF HUMAN AND ANIMAL WASTE

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 needs to be resolved.

A small study in Zimbabwe found the use of urine and humanure (faecal matter) on exhausted soils, achieved more than twice the maize yields of fields compared with no treatment – 3,500 kg compared with 1,500 kg. Water requirements were also lower: 1,300 m^3/ton versus 2,300 m^3/ton. Also, the yields delivered were greater than 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 polices 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, which gives rise to a number of 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 *et al*., 2017)

The development of simple collection at source systems, 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 volume one and three.

Carbon in organic matter is a significant component of faeces. Carbon increases water retention. 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 help both meet nutritional needs, as well as mitigate climate change impacts, such as drought and famine.

FARMERS OF FORTY CENTURIES

Eminent US agronomist Dr Franklin King has been referred to many times already in this review. King was an experienced respected soil and farming specialist. He is so inspired by what he saw, and struck by the importance of it, he implores readers heed the issues raised.

The final observations on agriculture, from the early 1900s, based on at 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.

More than a century has passed since King made his travels in East Asia, and documented his findings in both word and image. During that time, 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.

King's book records then 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, whilst keeping the same land in productive good health over many centuries.

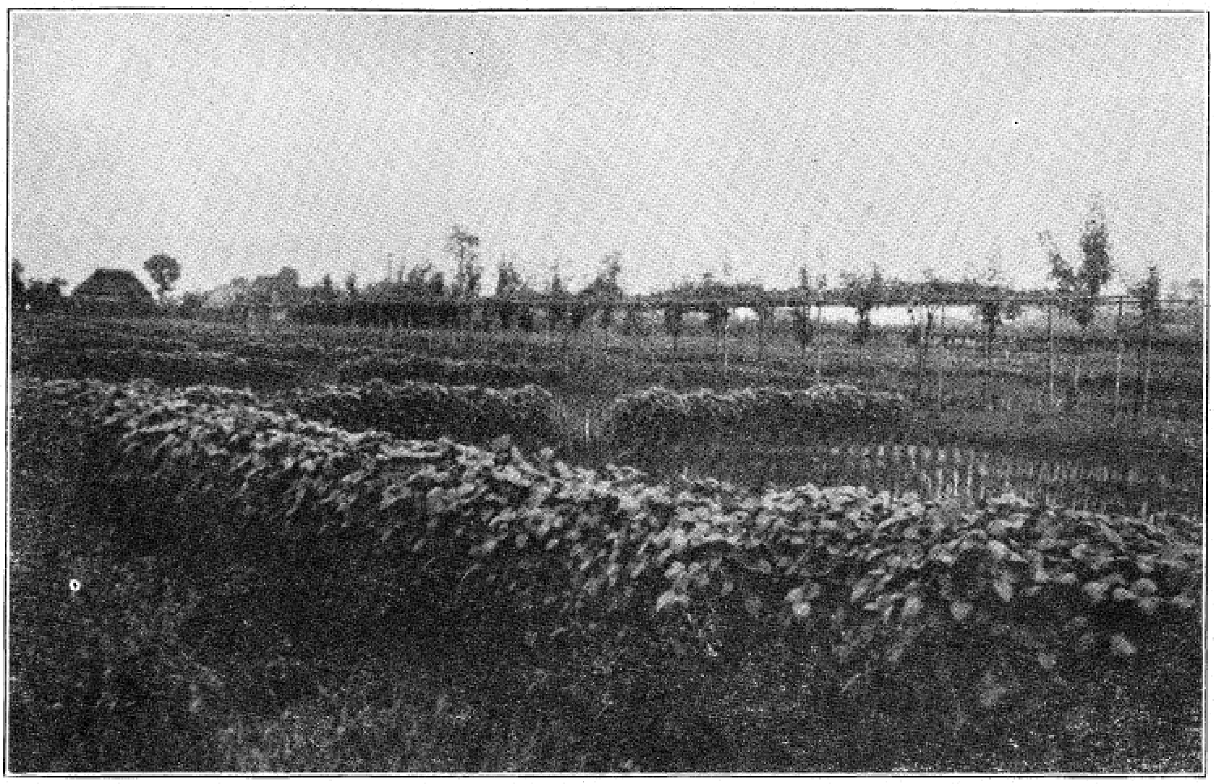


Fig. 15.—The entire field completely occupied by crops, rendering effective service. Soy beans on the dividing lines, rice in the paddies, pear orchard on the narrow raised ridge.

Fig. 145. 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 clearly struck by the productivity, longevity and high standards of agricultural practices in the region. 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 witness arguments.

He repeatedly makes the point nothing was wasted; everything organic, human and animal waste, all organic matter, including indirectly their ancestors buried on their own 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 is 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.

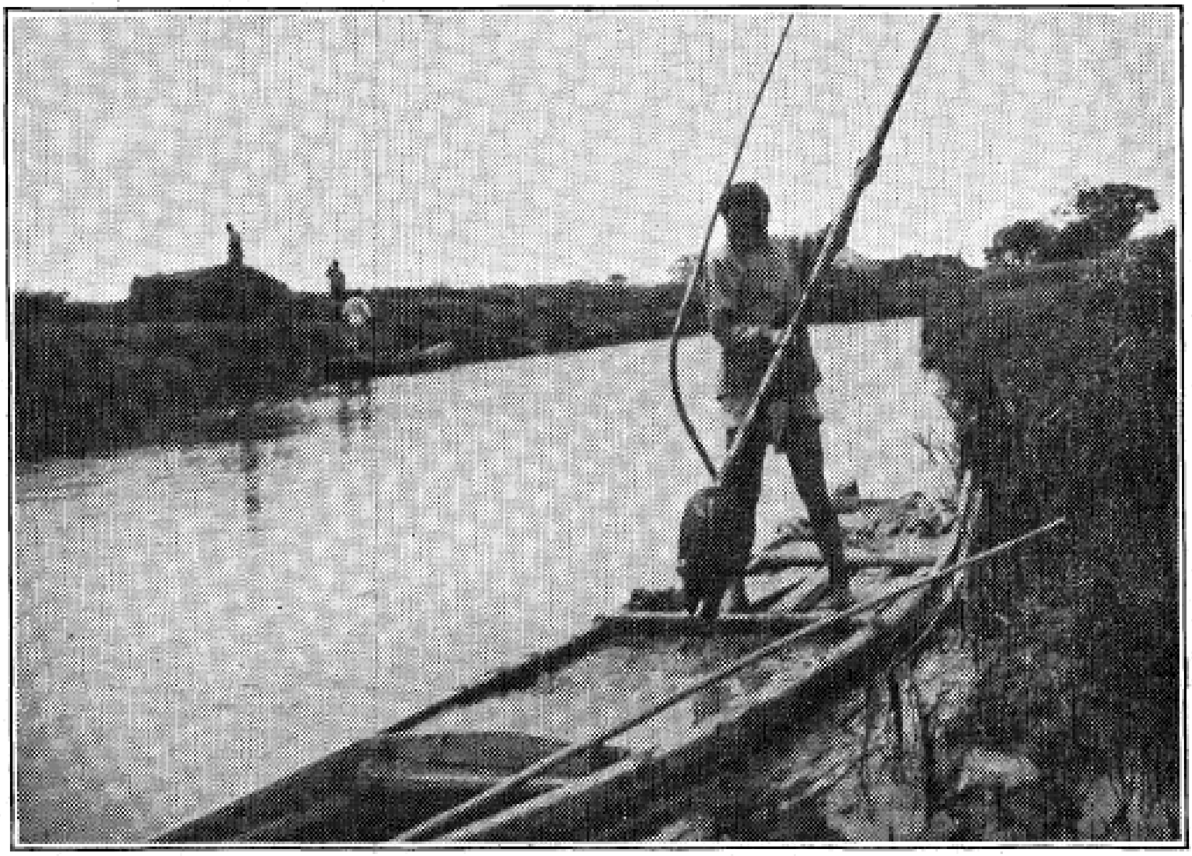


Fig. —The young man is loading his boat with canal mud, using the long-handled clam-shell dredge which he can open and close at will.

Fig. 146. Plate from 'Farmers of Forty Centuries'. Canal mud was used as a soil improver (King, 1911).

In the late 1800s, the most productive and populous areas in China 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).

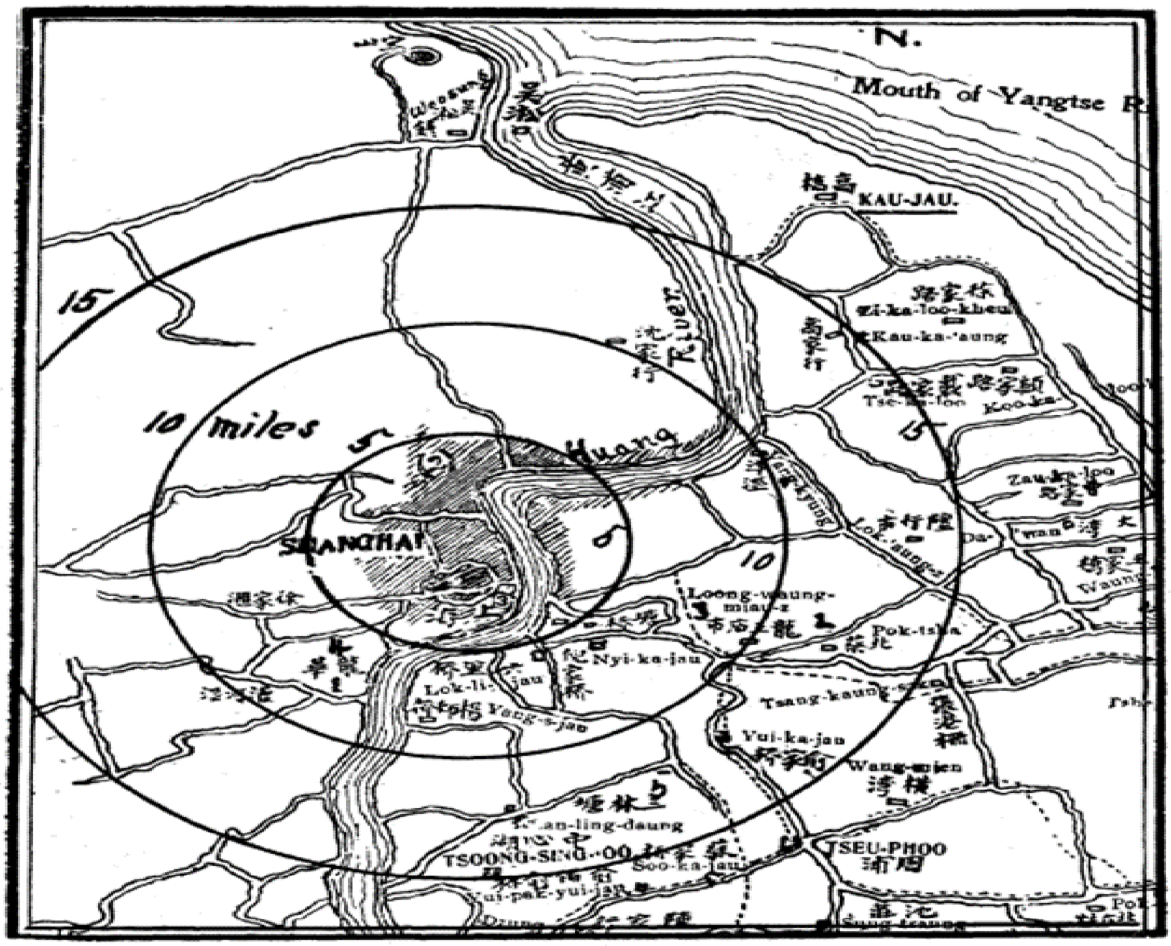
Fig. —Father and children returning from *genya* lands with herbage for use as green manure or for making compost. The daughter carries the tea kettle to supply their safe, sanitary drink.

Fig. 147. 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 and 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 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 *et al*., 2011), with the latter figure still as high as 84 per cent in 2007 (Liu, Huang & Zikhali, 2014). Illustrations from '*Farmers of Forty Centuries'*, showing the lengths and effort farmers would go to in order to create composts to improve their land, to 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 .148. 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 - lands and their productive capacity became degraded. As set out in Lowdermilk's book, degradation of soil has been seen in a large number of civilisations globally.

China is, in some ways, Westernising, which brings its own issues. Concerns about hygiene are driving the country to more centralised WC facilities and implementation of a '*Toilet Revolution'* (Cheng et al, 2017). As a result, China will potentially face those same issues around 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 century led to the need for better maintenance of soils. Strategies adopted included the import of bones, use of guano, and deployment of night soil from urban environments, however use of composted night soil was abandoned with the advent of water based Flush and Forget technology, and the consequent 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). In China, as previously noted, King observed, 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 then 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 through use of 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 'artificials' 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. A hundred years, and much damage to our soils and climate, later, 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, Dr Walter Jehne, and Dr Kristine Nicole, and provides and initial list to provide a starting point.

FARMING PROFITABLY

Dr Christine Jones explains in her video lecture, '*Building New Topsoil Through The Liquid Carbon Pathway'*; bare soil fertiliser chemical based farmers are spending more and making less.

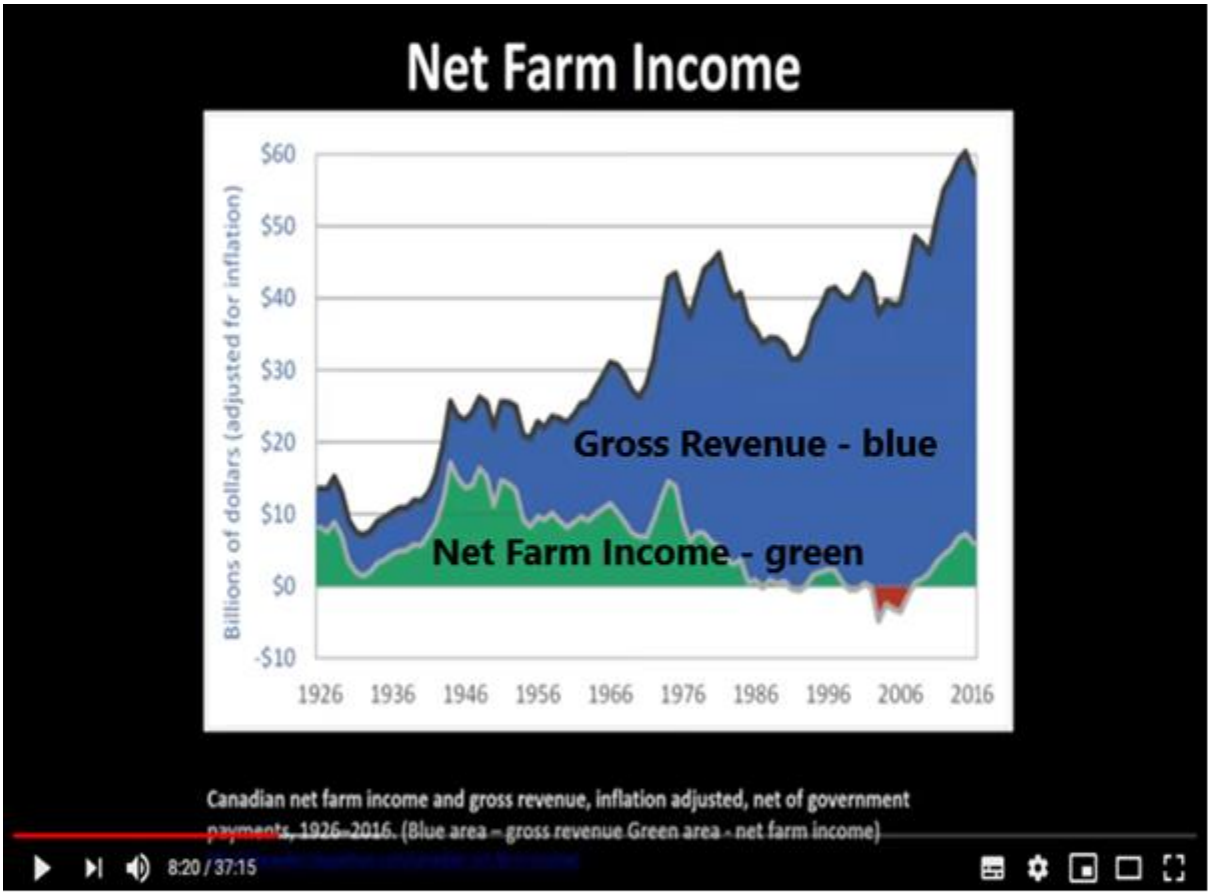


Fig. 149. Annotated slide from lecture by Dr Christine Jones – '*Building New Topsoil Through The Liquid Carbon Pathway*' (@7.20) Conservation Tillage and Technology Conference 2019 with many thanks to the author. (Jones, n.d.-a)

Some suggest that farming profits and productivity in significant areas of the great Plains in America, would fail without application of artificial fertilisers, due to low potassium and or phosphorus, yet these soils were, when first put to the plough, extremely fertile (Fixen *et al.*, 2007), and it is likely adequate minerals are still present 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.

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.

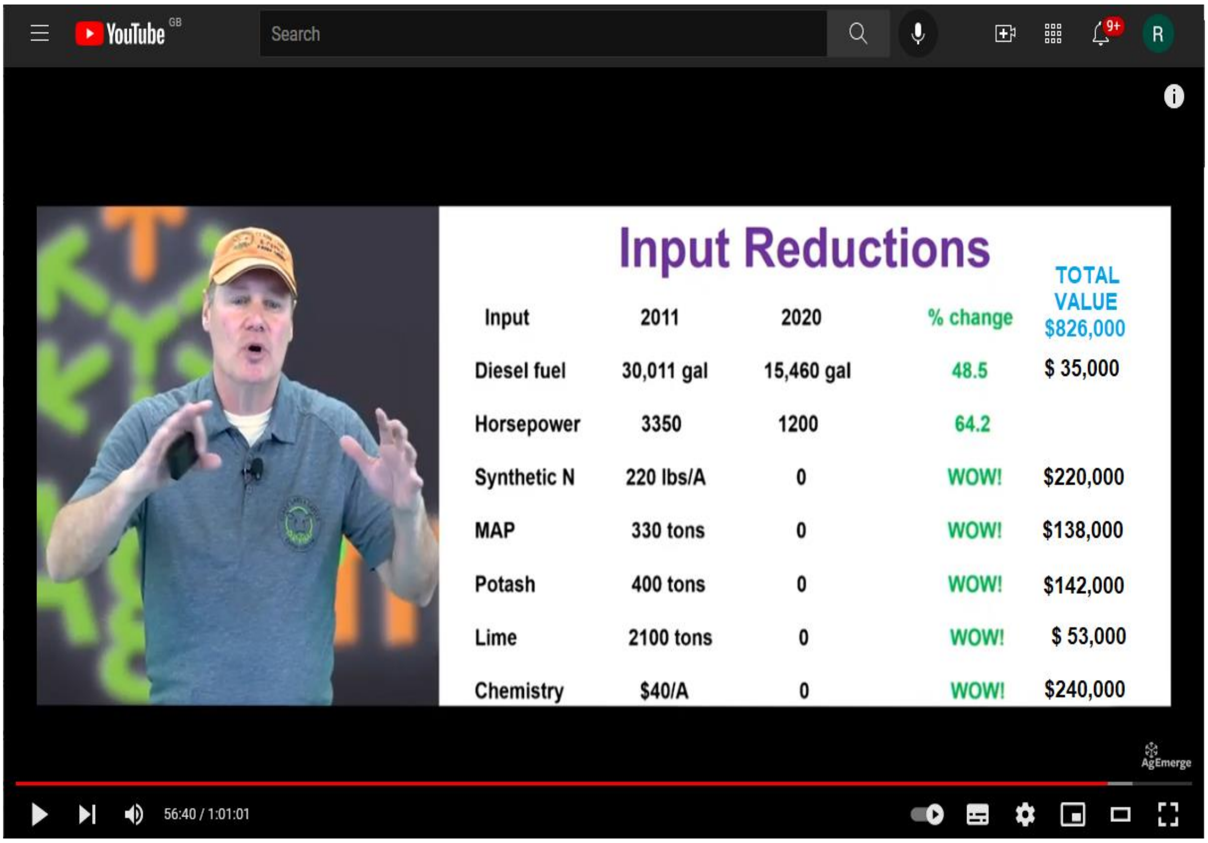


Fig. 150. Farmers making money in real life with Reg Gen Ag – practicalities – input reductions with green 'regenerative' type agriculture - 2021 AgEmerge Breakout Session with Rick Clarke (Clarke, 2021).

Evidence is re-emerging, as originally reported by Howard, Albrecht, and Turner and others, that 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).

Clearly, there would-be short-term costs in moving to more sustainable farming methods, but early indications suggest subsequently farming profits rise, due the considerable savings in terms of agricultural product costs. Further there are multiple important environmental benefits, including importantly a potentially positive rather than negative carbon footprint, sequestering rather than producing carbon dioxide, as well as in water retention and diversity.

Movement to multispecies cover crop, low till, no fertiliser use, combined with where practical, at the same time 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.

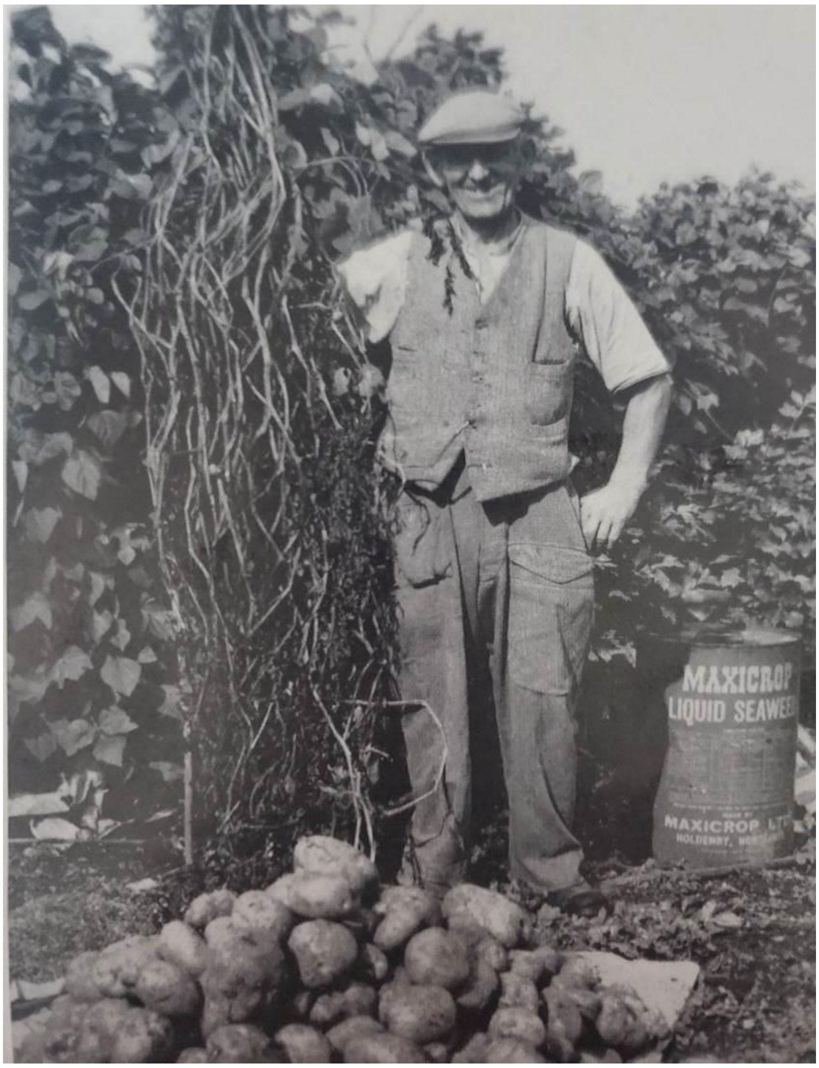


Fig. 151. A very large and productive potatoes plant! Image from 'Seaweed in Agriculture and Horticulture' by W A Stephenson with very many thanks to the author. (Stephenson & Booth, 1968).

Give plants the nutrients they need and they will achieve remarkable growth, as is evidenced by; the SRI rice experience, successful regenerative farmers, and at the extremes, those that specialise in growing giant vegetables.

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; also adding seaweed meal, and used a foliar spray. From 6 potato sets in 1965 he grew 563 lbs of potatoes. The image speaks for itself as to the growth capacity and productivity of plants, given adequate nutrients and appropriate productive soil conditions.

Yes, surely all the care that went into growing these exceptional potatoes would not be commercially viable, but the size and yield of the potato plant above, makes the point 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.

CONCLUSION

Through human intervention, agriculture now occupies a significant portion of the plant productive, terrestrial land surface, climatically suitable for intensive sunlight driven plant growth. Humans have taken over management of approximately 4 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.

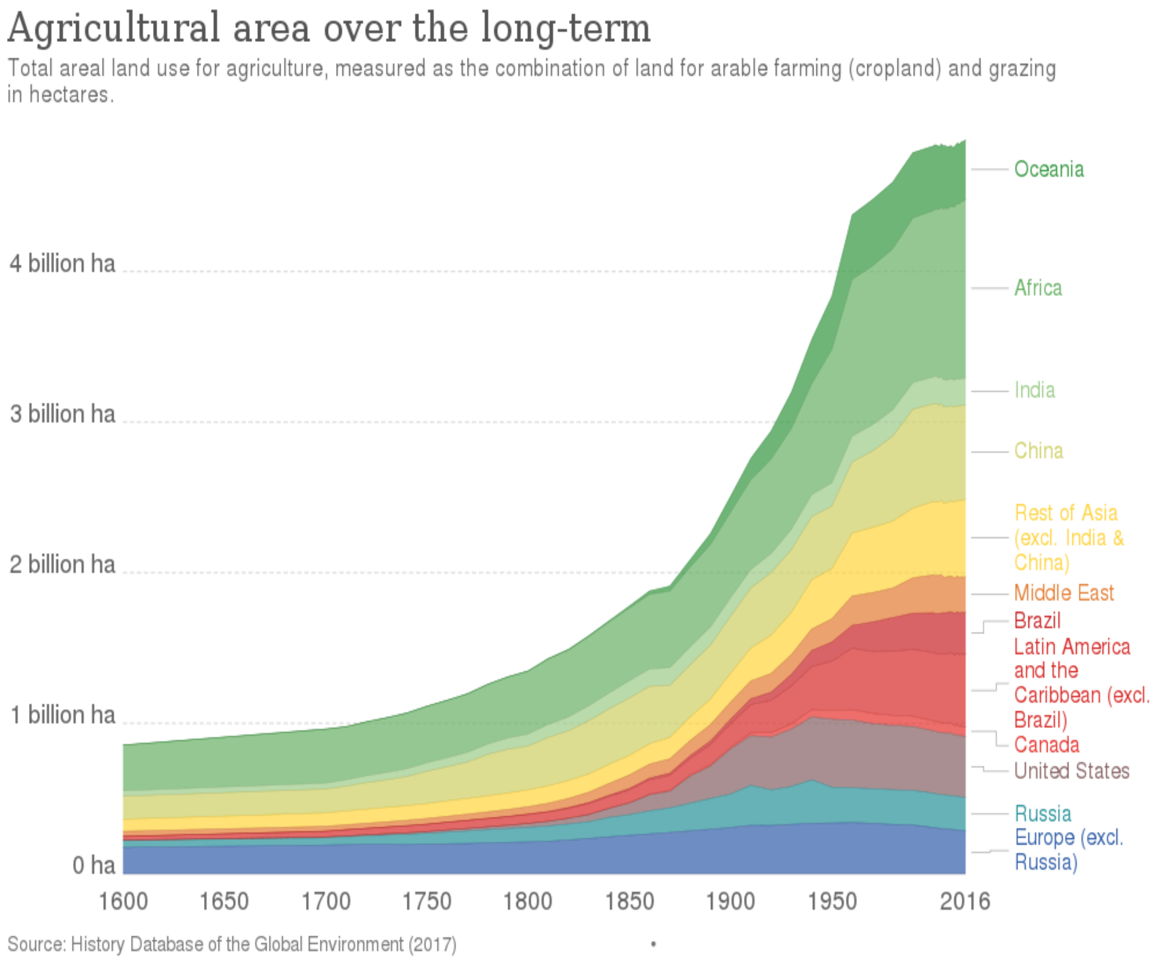


Fig. 152. With thanks to Wikipedia and Our World in Data for the figure (Wikipedia, 2021)

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 wider 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 in the event human behaviour leads to an Anthropocene extinction event, there is no guarantee human civilisation, or indeed the human species will survive.

We understand that we are causing climate change; through combustion of fossil fuels, and wider system damage through pollution of various sorts, but 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.

We, through our need to feed 'humanity', 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, lead to the adoption of the FATBAS NPK bare ground agrochemical agricultural model, which initially showed great promise, but over time lead to the land degradation we now witness.

Though 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 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 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 historic sages, who went unheard, the wider agricultural community and 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 wider 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 wider 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 huge 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 provide them with regenerative agriculture crops. Just this week "*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 very good news, and hopefully indicative of future trends, and corporate wider aspirations, for a healthier world and society.

Similarly, it has very recently been announced, "*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 **<u>re</u>**occurrence, of historic ocean deoxygenation-based, hydrogen-sulphide-emission-related extinctions 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 23-03-23.

BIBLIOGRAPHY

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

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

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 Weekl*y. Retrieved February 1, 2023, from https://www.fwi.co.uk/arable/land-preparation/soils/three-canadian-farmers-reveal-their-secrets-to-soil-health

ARTE. (2022). India: Sikkim - A Green New World. *ARTE.tv Documentary* Retrieved February 1, 2023, from https://www.youtube.com/watch?v=dBcmlXb_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=rLHZNNd0pAc

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 CO_2 levels climb, millions 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

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/Catalogue Iddri/Décryptage/201904-ST0219-TYFA GHG.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.

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

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/

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=ZWYiArlKoxc

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

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=uUmIdq0D6-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

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

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-agr-colas-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

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

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

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

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/

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/

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

Clarke, R. (2021). AgEmerge Breakout Session with Rick Clarke. *Ag Solutions Network*. Retrieved February 1, 2023, from https://www.youtube.com/watch?v=c9sm7I86hfA

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., Nellemann, 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 Pro-gramme, 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., Mrozik, 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., Hocher, 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

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

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

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. (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. (2020). Global Soil Partnership. Retrieved February 1, 2023, from https://www.fao.org/global-soil-partnership/areas-of-work/soil-organic-carbon/en/

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. (2018b) Global Soil Organic Carbon Map Technical report. Retrieved February 1, 2023, from https://www.fao.org/3/I8891EN/i8891en.pdf

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, (2017). Soil Organic Carbon, the hidden potential. Retrieved February 1, 2023, from https://www.fao.org/3/i6937e/i6937e.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. (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 Earthscan, London.* London: . Food and Agriculture Organization of the United Nations, Rome and Earthscan. Retrieved from fao.org/3/a-i1688e.pdf

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

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

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

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

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

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

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

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

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

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 NewZealand Grassland Association*, *56*, 27–31. https://doi.org/10.33584/jnzg.1994.56.2129

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.

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/

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=PLdFVkeklZuqwrgwDzTGlQSnTtCsOI8W3o&index=14

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

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/

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.

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=K4ygsdHJjdI

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

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

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

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

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

Kpomblekou-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/

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

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 PO_4. *Proc Natl Acad Sci U S A.*, *113*(21), 5862-5867. https://www.pnas.org/doi/10.1073/pnas.1521038113

Liu, J. D. (2012). Regreening the Desert with John D. Liu. *Vpro documentary*. Retrieved February 1, 2023, from https://www.youtube.com/watch?v=IDgDWbQtlKI

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

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

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=FuB9u1l0pS4

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. & Triebskorn, 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/

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/

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

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.aaq0932

McCain. (n. d.) McCAIN'S Regenerative Agriculture Framework. Retrieved February 1, 2023, from https://www.mccain.com/media/4036/mccain-foods-regenag-framework.pdf

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

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

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

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

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

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

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

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

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

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

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., Sladecek, 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

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

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

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

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

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

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.

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=vpTHi7O66pI

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

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/

Sewage Sludge Incineration. (n.d.). Retrieved February 1, 2023, from https://gaftp.epa.gov/ap42/ch02/s02/final/c02s02_jan1995.pdf

Sikkim. (n. d.). Cereals. *Government of Sikkim, Horticultural Depertment*. 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

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

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/

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

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

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 CO_2 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/

Under Cover Farmers - Feature Length. (2012). USDA NRCS East National Technology Support Center. Retrieved December 19, 2019, from https://www.youtube.com/watch?v=nWXCLVCJWTU

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. & Thiyagaranjan, 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

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

Use of Reclaimed Water and Sludge in Food Crop Production. (1996). National Academies Press. https://doi.org/10.17226/5175

van Dijkhorst, H., Kuepper, B. & Piotrowksi, 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

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 form 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/

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

Wetzel, R. G. & Tuchman, N. C. (2005). Effects of atmospheric CO_2 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.

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/

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) Agricultrual land. Retreived 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. Retrieved February 1, 2023, from https://en.wikipedia.org/w/index.php?title=Solar_irradiance&oldid=1129249470

Wikipedia. (2023a) Retreived March 12th 2023. https://commons.wikimedia.org/w/index.php?title=File:Mutualistic_Relationship_Between_Plants_and_Mycorrhiza.svg&oldid=643090326

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

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

Wylie, J. C. (1955). Fertility from Town Waste. Faber and Faber Ltd., London.

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.

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.

Zhang, J. & Elser, J. (2017). Carbon:Nitrogen:Phosphorus Stoichiometry in Fungi: A Meta-Analysis. *Frontiers in microbiology*, *8*(1281), 1-9. https://doi.org/10.3389/fmicb.2017.01281

Zheng, Y., Li, F., Hao, L., Shedayi, A. A., Guo, L., Ma, C., Huang, B & Xu, M. (2018). The optimal CO_2 concentrations for the growth of three perennial grass species. *BMC Plant Biology*, *18*(1). https://doi.org/10.1186/s12870-018-1243-3

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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Fig. 74. 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).
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Fig. 79. 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).
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Fig. 81. 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)
Fig. 82. 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).

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Fig. 85. 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)
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Fig. 88. "*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).
Fig. 89. '*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)
Fig. 90. NPK is a market now worth upwards of $100 billion [£710 million] a year (Jones, 2017).
Fig. 91. Eutrophication of the Potomac River, US, with thanks to Alexandr Trubetskoy.
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Fig. 97. Stubble burning in Essex, England, in 1986, with many thanks to John Roston.
Fig. 98. *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, Gutmann, & Ojima, 2007).

Fig. 99. Phosphate mine near Flaming Gorge, Utah, US, 2008 with thanks to Jason Parker-Burlingham.

Fig. 100. 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)

Fig. 101. Slide from '*Quorum Sensing In The Soil Microbiome*' summarising changes seen on Wilith Farm, Atiamuri. With many thanks to the author. (Jones, 2019b)

Fig. 102. Slide from '*Quorum Sensing In The Soil Microbiome*' summarising changes seen on Wilith Farm, Atiamuri. With many thanks to the author. (Jones, 2019b)

Fig. 103. 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)

Fig. 104. 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)

Fig. 105. 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)

Fig. 106. Las Dama Ranch Mexico, slide from UTube video '*Building Resiliency: Ranch Resiliency with Alejandro Carrillo 10-28-21*' showing dung beetles at work (Carrillo, 2021).

Fig. 107. UTube video slide '*AgEmerge Breakout Session with Keith Berns*' 2020 with very many thanks to the author and Ag Solutions Network. (Berns, 2020)

Fig. 108. '*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)

Fig. 109. 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)

Fig. 110. 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)

Fig. 111. "*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.)

Fig. 112. 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)

Fig.113. 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)

Fig.114 a& 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. 115. 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. 115b. *"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. 116. Sheep grazed for 55 days gained more weight on a multi-species family-crop compared to rye grass. UTube lecture '*Profit, Productivity, and NPK with Dr Christine Jones'* Lower Blackwood LCDC with very many thanks to the authors. (Jones, 2022)

Fig. 117. 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)

Fig. 118. Relative growth after different levels of grazing is illustrated *'Great "Grass Farmers" Grow Roots'* (Voth, 2015).

Fig. 119. 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)

Fig. 120. Planned grazing outcome in East Africa '*How to green the world's deserts and reverse climate change*' A slide from a UTube talk by Allan Savory with very many thanks to the author. (Savory, 2013)

Fig. 121. 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)

Fig. 122. Removed

Fig. 123. 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)

Fig. 124. Removed

Fig. 125. 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)

Fig. 126. 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)
Fig. 127. 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)
Fig. 128. 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)
Fig. 129. 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)
Fig. 130 a & 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. 131. 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. 132. Slides from Wayne Honeycutt Ph.D UTube lecture titled '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.
Fig. 133. 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)
Fig. 134. 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)
Fig. 136. 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. David Johnson calls this '*Biologically Enhanced Agricultural Management'* (BEAM). 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)
Fig. 137. 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).
Fig. 138 a & 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).
Fig. 139 a & 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).

Fig. 140. 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)
Fig. 141. Legesse Negash, emeritus professor of plant physiology at Addis Ababa University '*Regreening the desert*', with many thanks to the author. (Liu, 2012)
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Fig. 143. '*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).
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Fig. 145. Plate from 'Farmers of Forty Centuries'. Mixed farming maximising agricultural land capacity and creating diversity (King, 1911).
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Fig. 150. Farmers making money in real life with Reg Gen Ag – practicalities – input reductions with green 'regenerative' type agriculture - 2021 AgEmerge Breakout Session with Rick Clarke (Clarke, 2021).
Fig. 151. 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).
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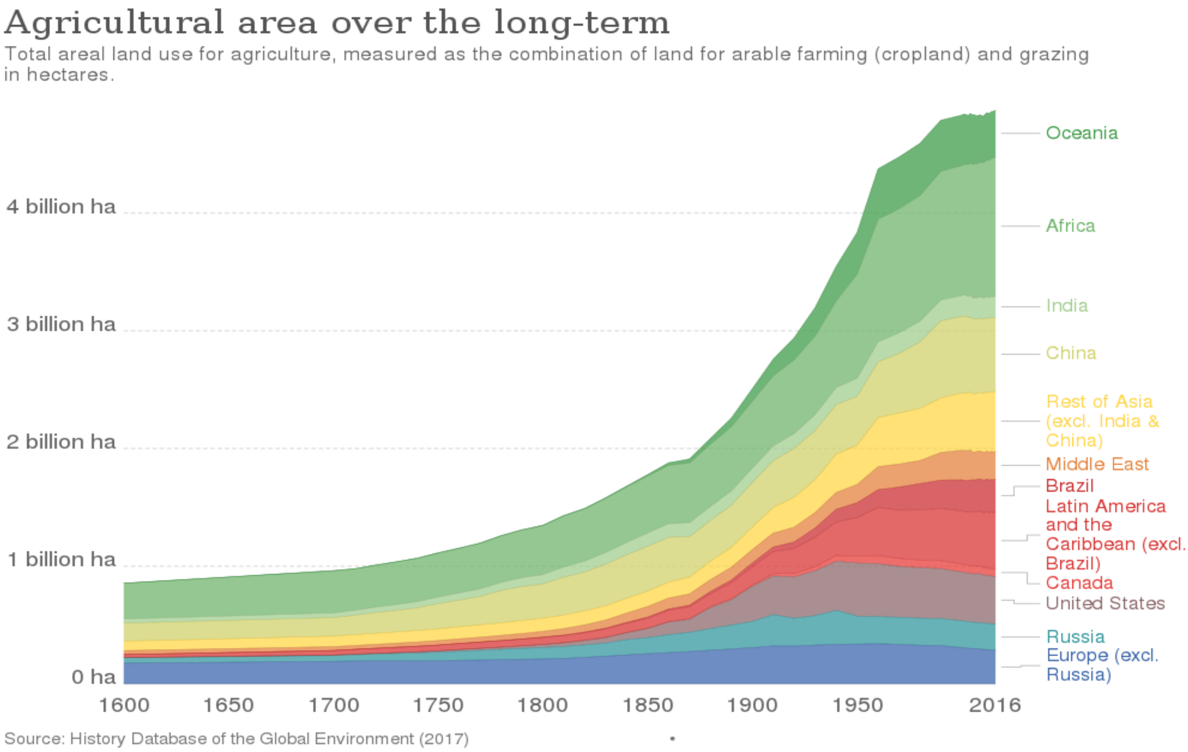
TABLES

ADDITIONAL MATERIAL

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.



- **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

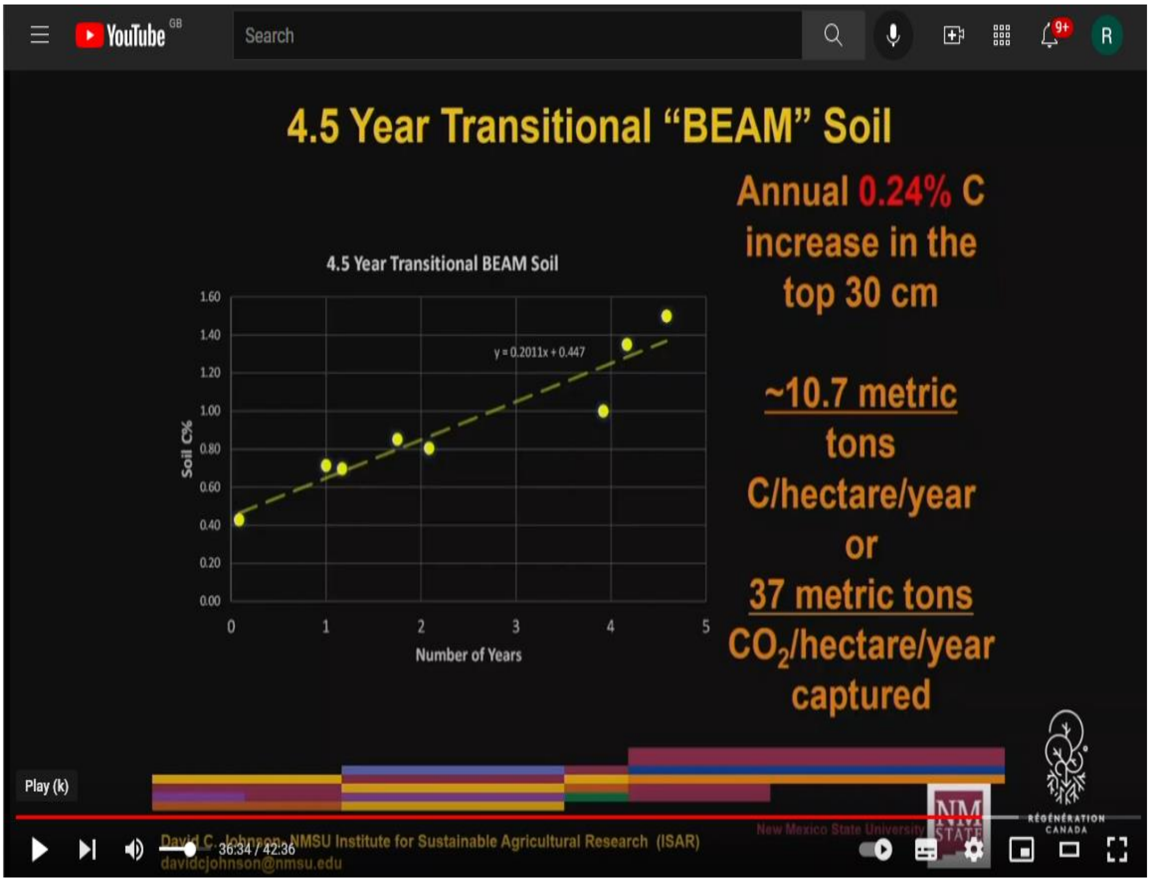
biology. Soils reach temperatures sufficient to kill soil biome biology in the surface layers. Visible and ultraviolet sunlight heat energy is absorbed by terrestrial surfaces, re-radiated in the infra-red spectrum: that which is not reflected into space, has to go somewhere, namely the atmosphere, land 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 sequestrartion of it as carbon in soils will cool the planet, (the reverse of buring 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. Surly this should be given the same priority as human technology based chemical and mechanical carbon capture.



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 availably.
- 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 natures 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 derivates 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 <u>NOT</u> 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 -
  - Fertiliser and agrochemical use per and post transiton;
  - Initial total soil mineral levels (soluble and bound), to ensure not insufficient in phosphates, selenium, sulphur, boron, iodine etc;
  - Initial soil carbon at various depths;
  - Water retention;
  - Historic and new yields and crop mineral and protein content;
  - 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 -
  - cattle health and related costs;
  - 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 heath, 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

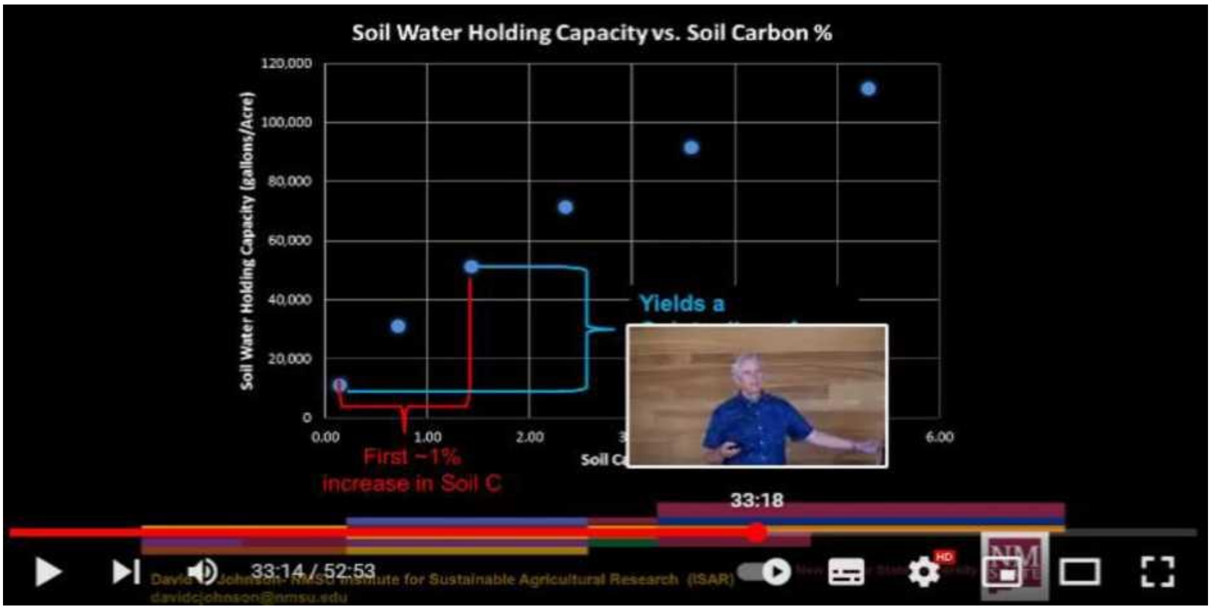
UNFAO Soil Organic Carbon – the treasure beneath our feet
https://www.youtube.com/watch?v=Ymy0IO7nizw

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=XlB4QSEMzdg&t=1s (see below)

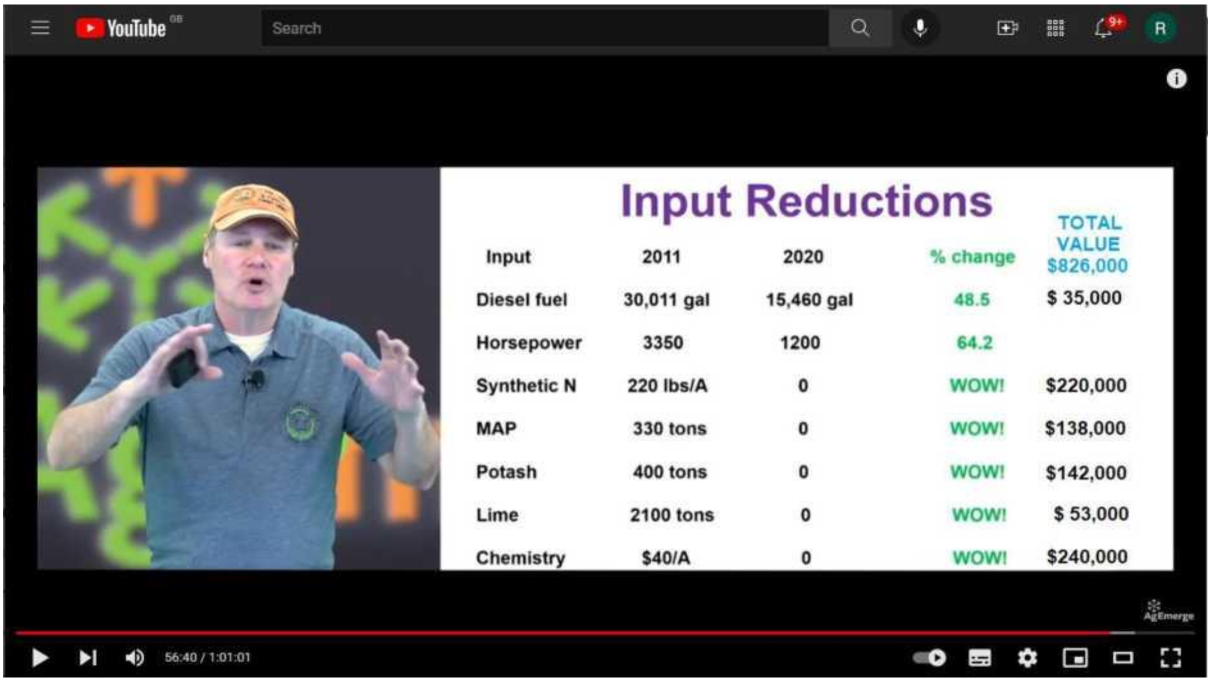
Regenerative rice farming using cover crops, crimp rolling and low till planting – yields health and resilience increasing substantially, with improvements even in the first year

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=aGiJt6e gqQ

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=IoyvVaqoK0

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=pEmnPtmtoSo

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=PLdFVkeklZuqwrgwDzTGlQSnTtCsOI8W3

Agriculture - Gabe Brown - No till on the plains - Iowa - Regenerative farmer with a focus on profitability

https://www.youtube.com/watch?v=uUmIdq0D6-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=EX6eoxxoWKI
Fireside Chat with Dr. Christine Jones and Ray Archuleta

https://www.youtube.com/watch?v=EX6eoxxoWKI
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=lSjbVxTyF3w

Dr Christine Jones - "The Phosphorus Paradox"

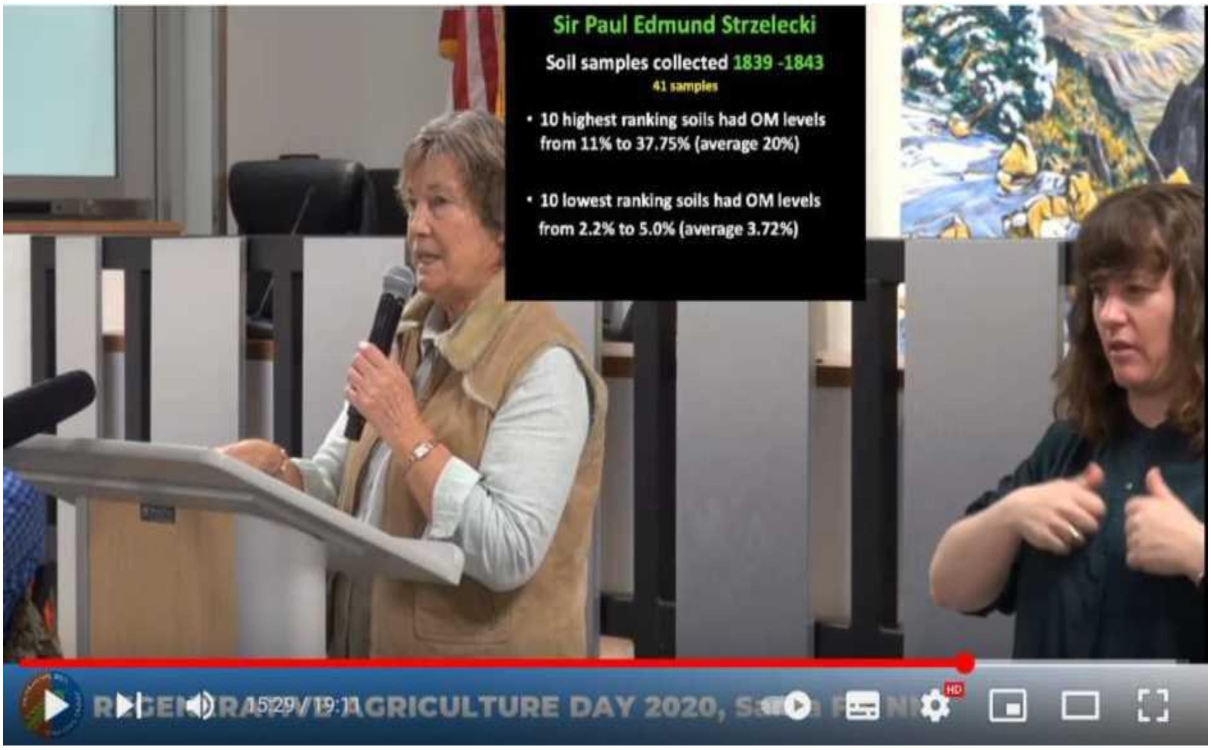
https://www.youtube.com/watch?v=rIXqmksTUQQ

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=C3 w Gp1mLM

Dr. Christine Jones - Building New Topsoil Through The Liquid Carbon Pathway

https://www.youtube.com/watch?v=K8 i1EzR5U8&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 inched 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=Gs-ffXC 29w

Dianne Haggerty & Stuart McAlpine - Leading innovators in the WA farming landscape

https://www.youtube.com/watch?v=m8fTJdSr61o

NutriSoil A New Agriculture, Di Haggerty Presentation

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 Elain 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=XlB4QSEMzdg&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 transitionalpricing

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=c9sm7I86hfA

Rick Clarke Part 1 Introduction To Farming Green With Diverse Covers

https://www.youtube.com/watch?v=Kdoq8woEyKg

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/0B6tV3TorfmstbXllUU5yMXB2MWM/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=tXVLa4zSXbM

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=K4ygsdHJjdI

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=K4ygsdHJjdI&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=vpTHi7O66pI

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-XlPnqxI

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=WxXy9lsiUPM - 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=wX IwUfuu9A

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=rllu71I- 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=aGiJt6e_gqQ

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=IoyvV_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=pEmnPtmtoSo

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-XlPnqxI
('Probe: Pharmaceuticals In Drinking Water', CBS News, n.d.),