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The Interconnectedness of Life

Why the phytobiome is the ultimate source of health and the great nutrient collapse

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Researcher, Re-Wilder - Farmer

Nature's Defenders: Alexander von Humboldt – the most important forgotten man of science

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- 200 years ago in his book 'Kosmos' identified that mans behaviour impacted climate.
- Charles Darwin idolised Humboldt, whose encouragement contributed to Darwin's developing theories **regarding the evolution of species**.
- Over the course of his adult life he developed a revolutionary theory that all aspects of the planet, from the outer atmosphere to the bottom of the oceans, were interconnected — a theory he called the **"unity of nature."**

Humboldt portrait

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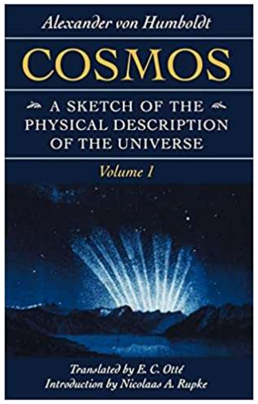
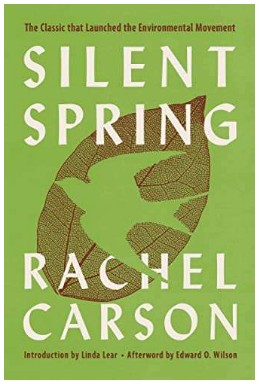
- His works predated James Lovelock's Gaia theory by **172** years and an awareness of climate change by **200**.



- Humboldt encapsulated the future notion of Gaia in a single sentence: **"Every one thing exists for the sake of all things and all for the sake of one."**

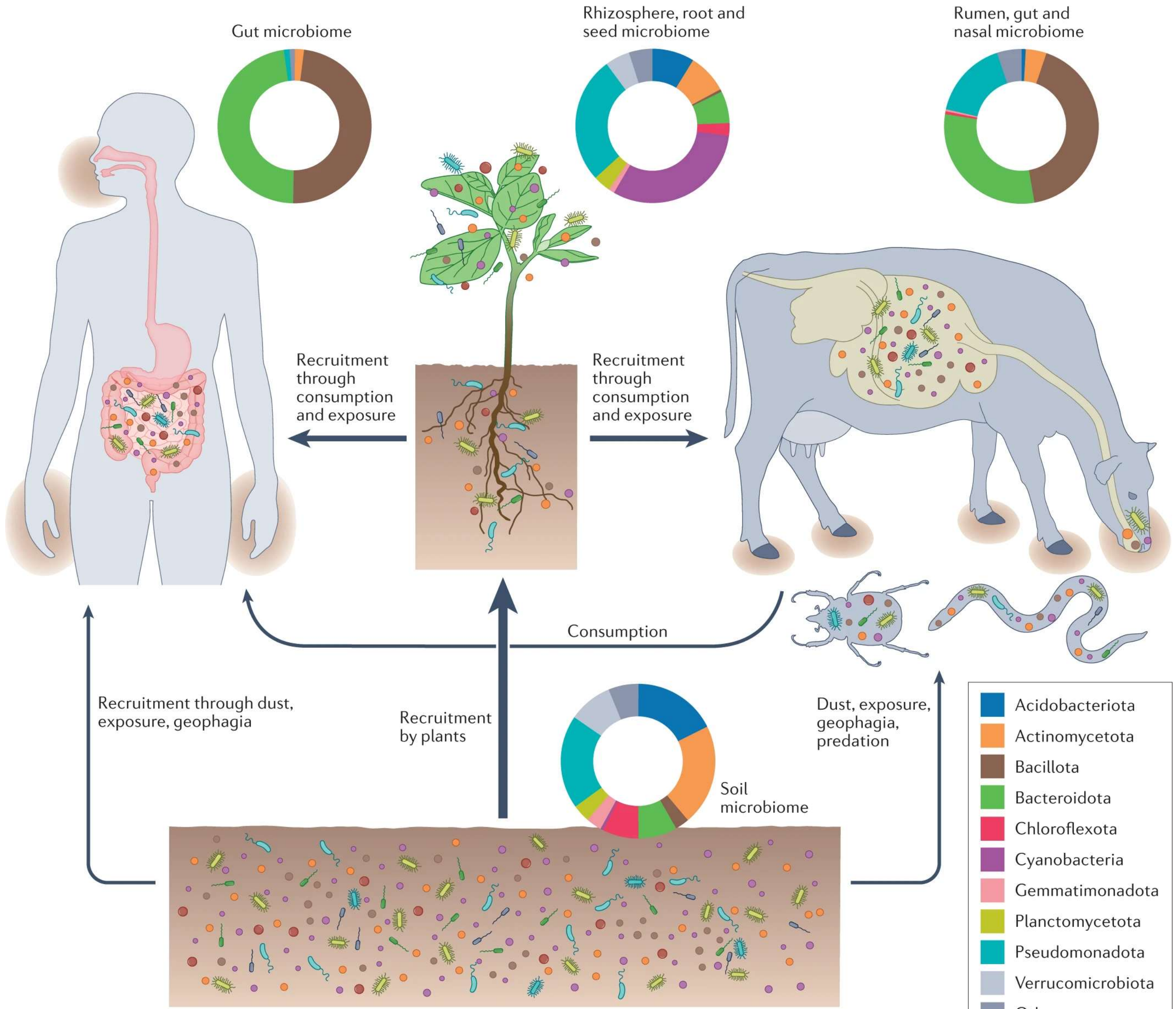


- When Rachel Carson wrote Silent Spring in 1962, her argument for saving the American bald eagle by banning the use of DDT drew on the same logic of interrelated downstream consequences Humboldt had postulated regarding local human-induced climate change at Lake Valencia in Venezuela in **<u>1800</u>**

..it may be useful to adopt a different perspective and to consider the **human intestinal microbiome as well as the soil/root phytobiome as 'superorganisms,'** which, by close contact, replenish each other with inoculants, genes and growth-sustaining molecules.

Key Aims

Higher carbohydrate content combined with lower protein, minerals, and vitamins represent a potential impairment of nutrition-health value for humans that may contribute:
(1) to nutritional deficiencies in protein and micronutrients as well as
(2) to nutritional excess in carbohydrates increasing the risk factors of chronic non-communicable diseases (NCDs) such as metabolic syndrome, obesity, diabetes and cardiovascular disease (CVD).



Microorganisms as the conduit of one health components and soil microbiomes as the microbial reservoir

The link between soil, plant, animal and human microbiomes

Soil is the largest reservoir of microbial diversity on Earth.

Such an incredibly diverse microbial community can have direct and indirect influences on soil, plant, animal and human health and well-being.

Banerjee, S., van der Heijden, M.G.A. Soil microbiomes and one health. Nat Rev Microbiol 21, 6–20 (2023)

Microbiomes for Human Health

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- We frequently overlook the complete food life cycle, focusing on the quality of the last processing phases and ignoring the soil's health, which is essential to sustain the 95% of food derived from the soil. Healthy soil generates a healthy society.
- Soil microbes play a key role in determining the nutrient content of our food through the mineralisation of degradable organic compounds to inorganic forms that are readily available to crops.
- The large diversity of microbiome in soil affects its microbial ecology, including its primary productivity and nutrient cycling.

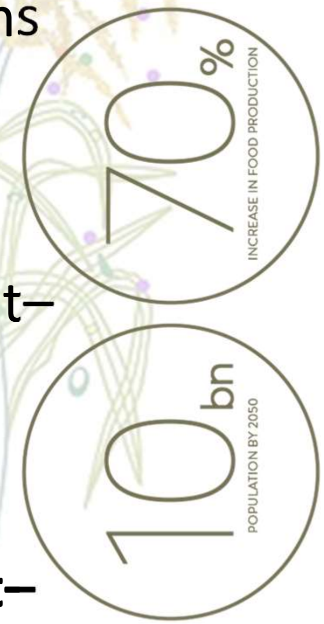
Suman J, Rakshit A, Ogireddy SD, Singh S, Gupta C and Chandrakala J (2022) Microbiome as a Key Player in Sustainable Agriculture and Human Health. Front. Soil Sci. 2:821589.

The Phytobiome

..**is the plant equivalent of the human microbiome**. It includes the plant itself, the plant's environment and all micro and macroorganisms living in, on or around the plant.

Overall, strong evidence is emerging that the reciprocal interplay between the microbiota and the plant immune response shapes plant–microbiome assembly. **Plant based dysbiosis – creates immune and growth challenges**

Plant health and productivity are impacted by tripartite **environment–host–pathogen** interactions that operate on a continuum from resistance to disease.

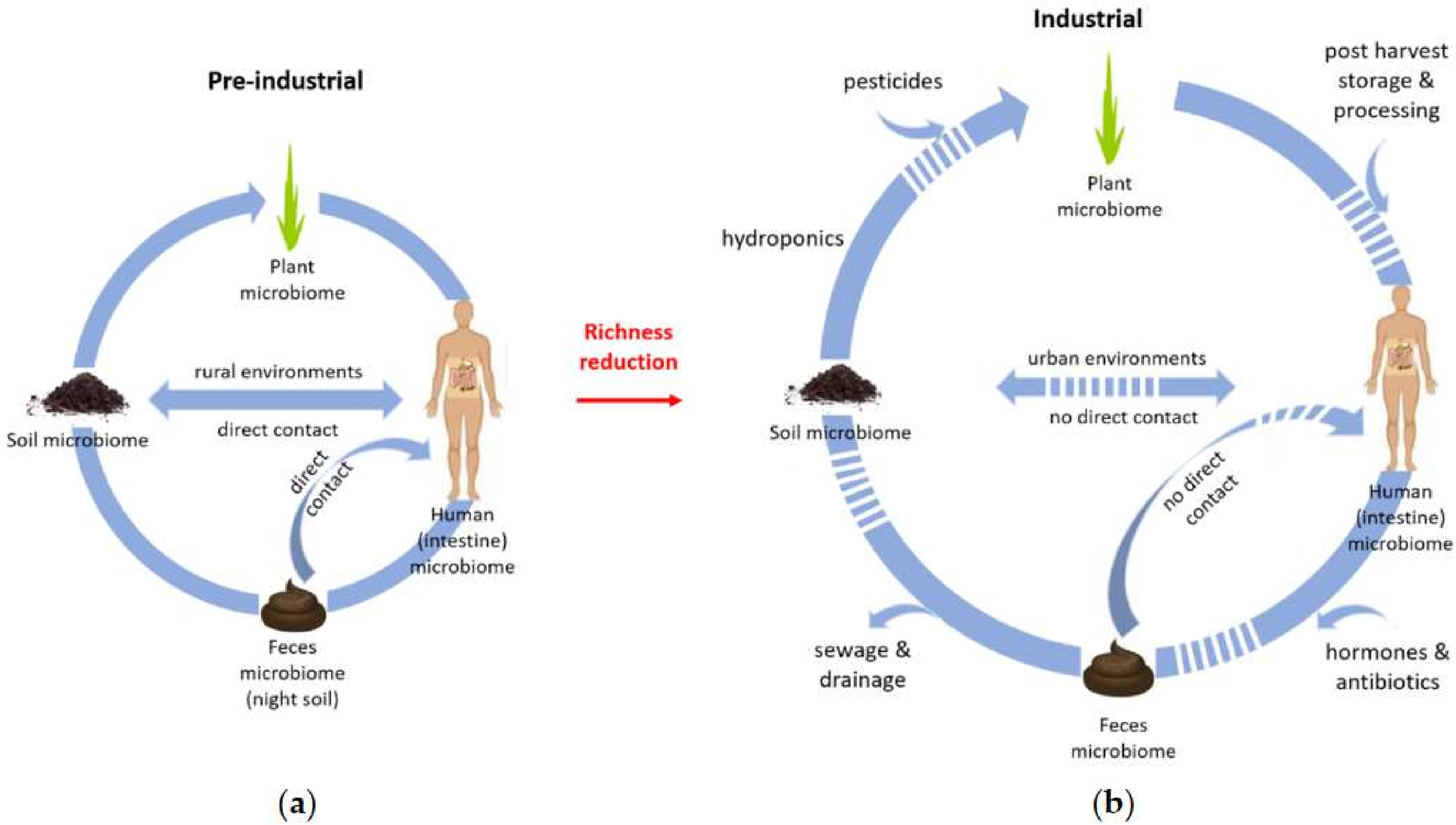


Phytobiomes

- Networks of interactions among plants, their environment, and complex communities of organisms profoundly influence plant and agroecosystem health and productivity

- Global demands for food, feed, and fibre are expected to double in the next 35 years. In the same timeframe, we face a world of diminishing arable land, extreme weather events, unsustainable fertiliser inputs, uncertain water availability, and plateauing crop yields. We need new innovative approaches to sustainably increase global crop productivity and enhance nutrient density.

Soil and the human gut contain approximately the same number of active microorganisms, while human gut microbiome diversity is only 10% that of soil biodiversity and has decreased dramatically with the modern lifestyle.



Blum WEH, Zechmeister-Boltenstern S, Keiblinger KM. **Does Soil Contribute to the Human Gut Microbiome?** Microorganisms. 2019 Aug 23;7(9):287.

Healthy Soils

….are the foundation of sustainable and productive agroecosystems, and they can be maintained by following basic soil health principles, such as minimal soil disturbance, protecting surface soils by growing cover crops, increasing plant diversity through crop rotation, and organic manure enhancing soil microbiome, etc.

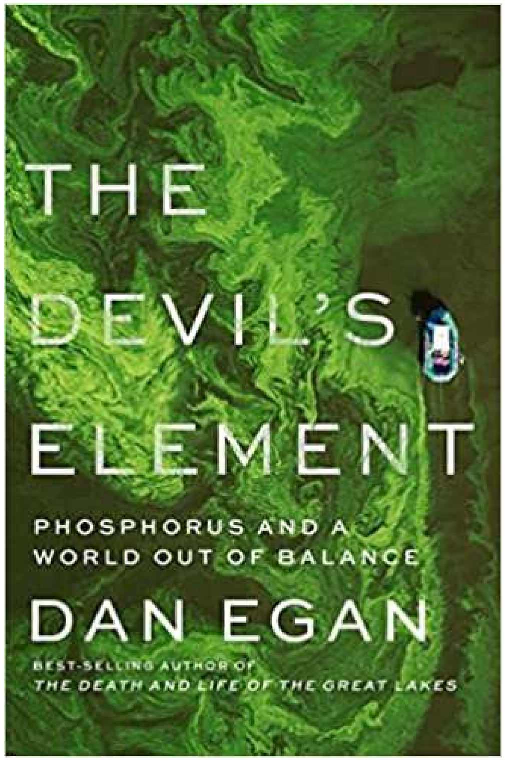
- German scientists Fritz Haber (1868-1935) and Carl Bosch (1874-1940), who developed a synthetic fertiliser that saved some 2.7 billion lives by helping the world grow nutritious food.
- Without their discovery, the expansion of the world's population from 1.6 billion in 1900 to over 7 billion today would not have been possible

"nitrogen is supplying life's quality, while carbon provides the quantity" (Pollan, *The Omnivore's Dilemma*, 2006).

Our Phosphorus Future

Recycling phosphorus-rich organic wastes and manures is critical for phosphorus sustainability and a transition to a more circular economy for phosphorus.

Beyond agronomic benefits, the win-wins are numerous, with benefits to society, human health, environment, economy, and business growth.



https://www.opfglobal.com/

Manipulating the plant–soil microbiome

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- to increase plant productivity in the face of climate change has been recognised as a priority by many national and international policy agencies (Singh *et al*., 2020b; Trivedi *et al*., 2021).
- These interventions can range from direct manipulation of the plant microbiome, functional manipulation via land management practices and/or the use of probiotics.
- Environmental pressures are Changing the **'ionome'** – the mineral and trace element composition of plants **and by circumstance in humans as well.**

The Great Nutrient Collapse

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- The atmosphere is literally changing the food we eat, for the worse. And almost nobody is paying attention.
- Hidden shift of the ionome of plants exposed to elevated CO_2 depletes minerals at the base of human nutrition
- This means that your health, and that of the soil, plants and animals is inextricably linked to climate change.
- Increased carbon dioxide (CO2) can affect the growth and nutrient content of plants in various ways. One of the main effects is that it tends to **increase the starch content of plants while reducing their mineral content.**

Loladze I. Hidden shift of the ionome of plants exposed to elevated CO_2depletes minerals at the base of human nutrition. Elife. 2014 May 7;3:e02245.

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"Every leaf and every grass blade on earth makes more and more sugars as CO2 levels keep rising. We are witnessing the greatest injection of carbohydrates into the biosphere in human history—[an] injection that dilutes other nutrients in our food supply."

"There is extensive evidence from multiple studies and meta-analyses that increasing [CO_2] will reduce protein and mineral concentrations from a wide-variety of plant-based food sources, with substantial global consequences for human and animal nutrition and health."

Ziska LH. Rising Carbon Dioxide and Global Nutrition: Evidence and Action Needed. Plants (Basel). 2022 Apr 6;11(7)

The Need For Essential Elements & The Problem Of Micronutrient Malnutrition

- The human body needs **at least 24 chemical elements**. Although some of the elements, such as chromium (Cr), Fe, I, selenium (Se), or zinc (Zn), comprise <0.01% of human body weight, their absence renders our life impossible. Because the human organism cannot generate any element that is lost through excretion, we must replenish it from our food. **Plants are the basis of human nutrition, providing a staggering 84% of calorie intake worldwide.**
- Climate change has an impact on the accumulation of minerals and protein in crop plants, **with eCO_2 being the underlying factor of most of the reported changes**. The effects are clearly dependent on the type, intensity and duration of the imposed stress, plant genotype and developmental stage.

Assessment: Human Nutrition

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- With respect to staple crops, a meta-analysis of 228 observations on barley, potato, rice and wheat reported **reductions in protein concentrations** that ranged from ca −10 to −15%.

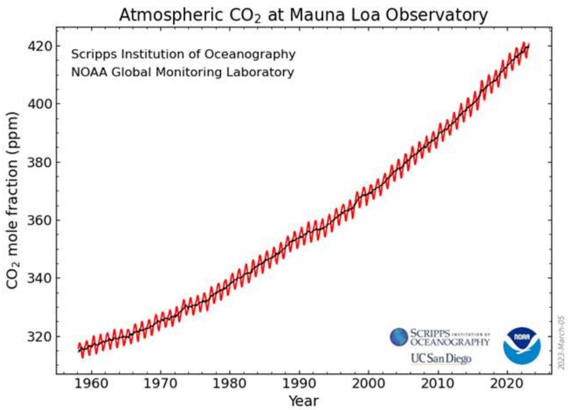
Taub D.R., Miller B., Allen H. Effects of elevated CO2 on the protein concentration of food crops: A meta-analysis. Glob. Chang. Biol. 2008;14:565–575

- A more extensive meta-analysis of 7761 pairs of observations over 130 species and cultivars reported an **average 8% decline in mineral concentrations, excepting Manganese**.

Loladze I. Hidden shift of the ionome of plants exposed to elevated CO_2depletes minerals at the base of human nutrition. Elife. 2014 May 7;3:e02245.

- A meta-analysis of vegetable responses (57 articles and 1015 observations) reported declines in the concentrations of **protein, nitrate, magnesium, iron and zinc by 9.5%, 18%, 9.2%, 16.0% and 9.4%, respectively**.

Dong J, Gruda N, Lam SK, Li X, Duan Z. Effects of Elevated CO_2 on Nutritional Quality of Vegetables: A Review. Front Plant Sci. 2018 Aug 15;9:924



Global Impact of eCO2 Rising

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- the meta-analysis of vegetables, elevated [CO_2] **increased the concentrations of fructose, glucose and total soluble sugar by 14.2%, 13.2% and 17.5%, respectively.**

Dong J, Gruda N, Lam SK, Li X, Duan Z. Effects of Elevated CO_2 on Nutritional Quality of Vegetables: A Review. Front Plant Sci. 2018 Aug 15;9:924

- **Plants provide the bulk of global nutrients: 63% of dietary protein, 81% of the iron and 68% of the zinc**.

Elevated eCO2 Decreases Plants Carotenoid Concentrations

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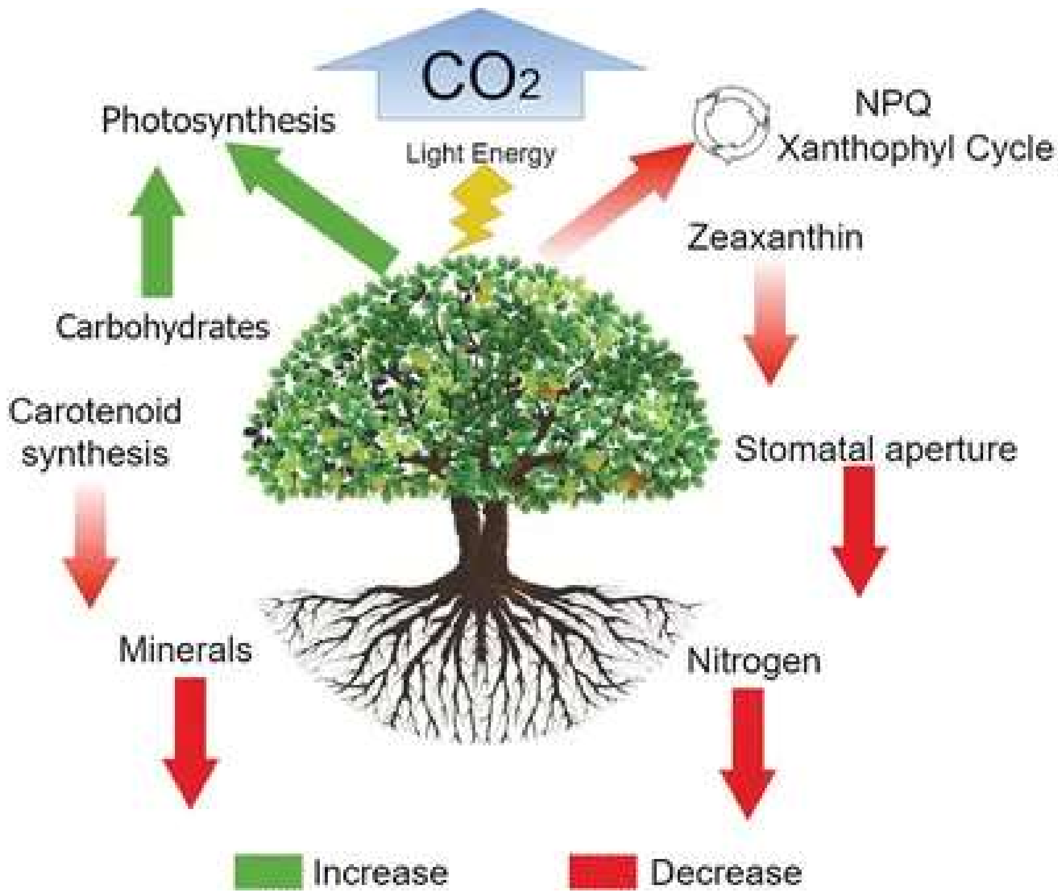


Similar to the downshift in plant minerals observed previously, a downshift in carotenoid concentration also exists.
The mechanism by which this 15% decline occurs can be either **passive (via dilution by carbohydrates**, for example) or **active (due to lower carotenoid synthesis as a result of lower carotenoid demands by plants).**

Nolan, J., Loladze, I., Nolan, J. M., Ziska, L. H., Knobbe, A. R., **Rising Atmospheric CO2 Lowers Concentrations of Plant Carotenoids Essential to Human Health: A Meta-Analysis**. Mol. Nutr. Food Res. 2019, 63, 1801047

Bitter Compounds – Plant Defences – they do not want to be eaten!

Bitter foods might contain healthful compounds that blur the line between nutrient and drug.

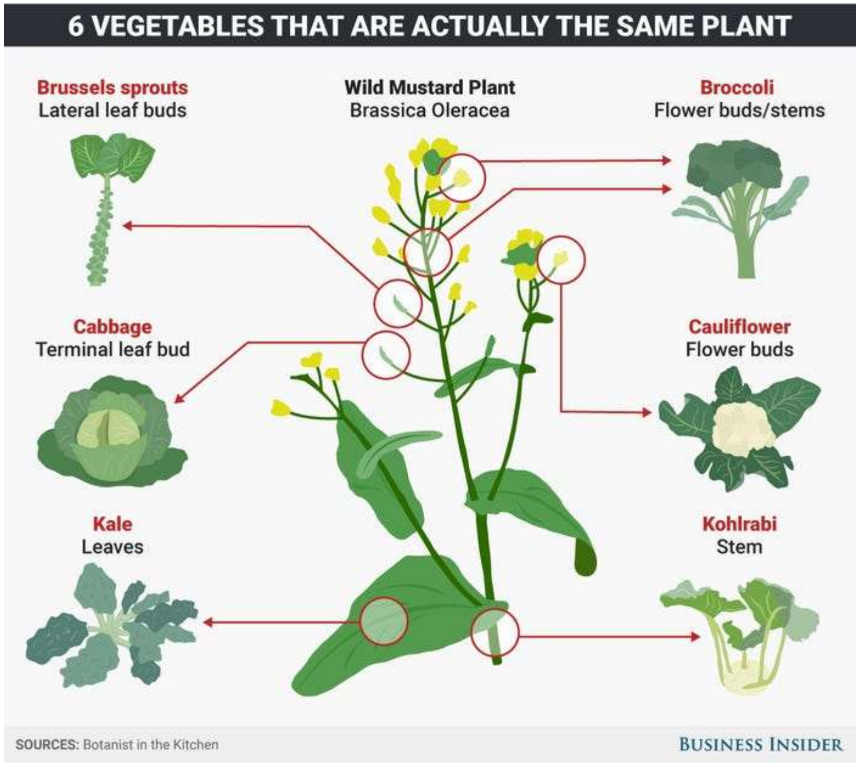
If bitter-tasting chemicals in plant foods have health benefits, then removing these compounds (through manufacturing of processed foods or selectively breeding plants for low bitterness or by eCO2 effects) may have negative consequences.

Connolly EL, Sim M, Travica N, Marx W, Beasy G, Lynch GS, Bondonno CP, Lewis JR, Hodgson JM and Blekkenhorst LC (2021) Glucosinolates From Cruciferous Vegetables and Their Potential Role in Chronic Disease: Investigating the Preclinical and Clinical Evidence. Front. Pharmacol. 12:767975

Brassica vegetables are a good source of vitamin C, calcium, magnesium, phenolics, tocopherols and carotenoids, as well as dietary fibre.

However, a unique group of compounds present in brassica vegetables that is considered to be particularly beneficial to health is the glucosinolates (GSLs), or, more precisely, one group of metabolites of GSLs, the isothiocyanates (ITCs).

These can be adversely affected when exposed to increased atmospheric CO2.



Impact of Hidden Hunger

New global research reveals that the number of people around the world estimated to suffer from micronutrient deficiency has been massively underestimated, and the actual number is probably about **four billion, or half the world's population**.

In high-income countries, huge proportions of women — **one in three women in the United States and one in two women in the United Kingdom** — suffer from one or more micronutrient deficiencies

Stevens GA, Beal T, Mbuya MNN, Luo H, Neufeld LM; **Global Micronutrient Deficiencies Research Group. Micronutrient deficiencies among preschool-aged children and women of reproductive age worldwide: a pooled analysis of individual-level data from population-representative surveys**. Lancet Glob Health. 2022 Nov;10(11):e1590-e1599

Consequences of micronutrient and phytonutrient deficiency through the life cycle

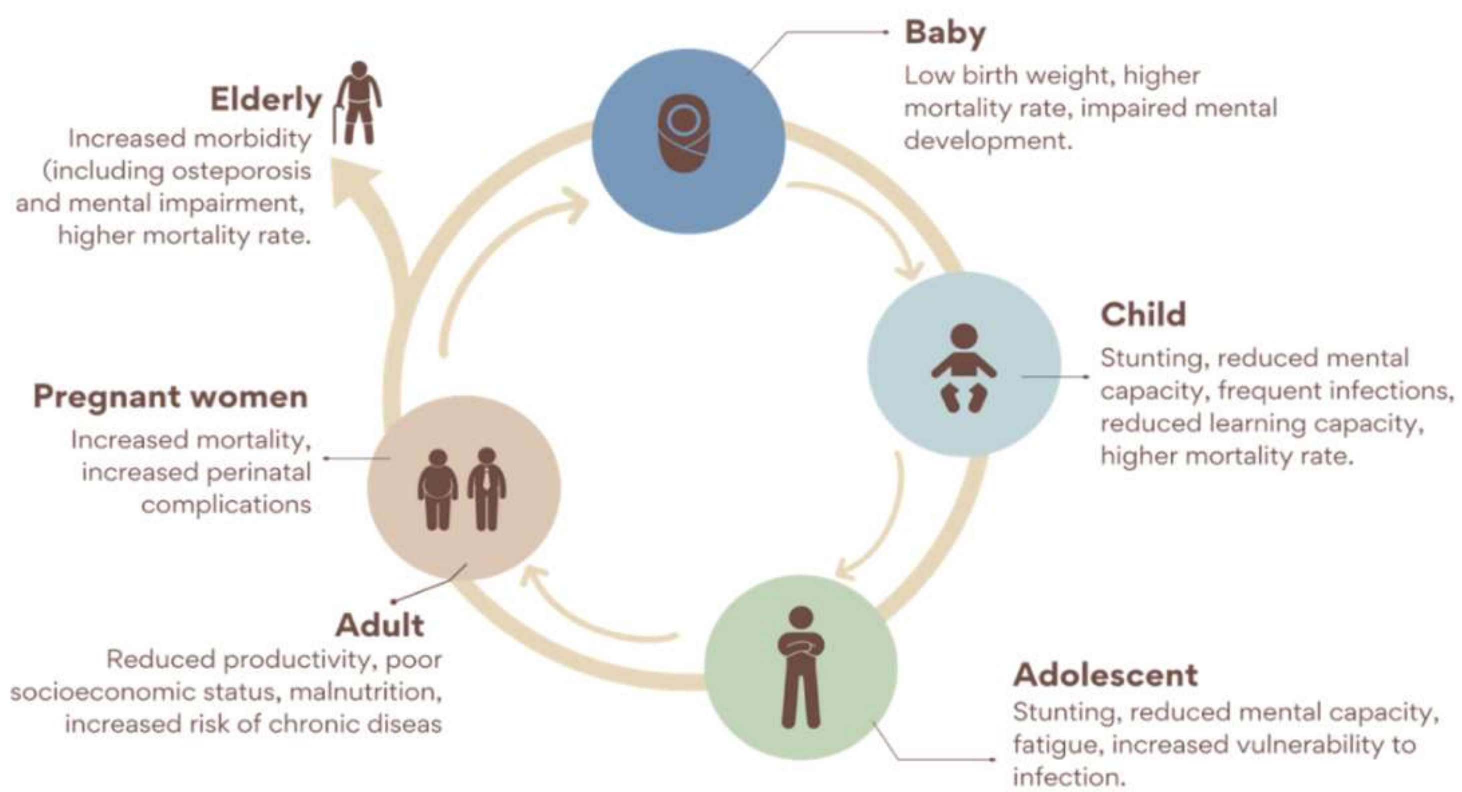


FIGURE 2
Consequences of micronutrient deficiency through the life cycle [Modified from (56)].

Ofori KF, Antoniello S, English MM, Aryee ANA. Improving nutrition through biofortification-A systematic review. Front Nutr. 2022 Dec 9;9:1043655.

Solutions

Different fortification strategies are being used to address hidden hunger. The two main approaches being studied are direct intervention and indirect intervention.

- **Direct intervention is nutrition-specific and concentrates on food consumption behaviour such as food fortification and supplementation and creating a diverse diet.**
- **Indirect intervention is nutrition-sensitive, and it includes biofortification of crops**

From a Systematic Perspective,

- human diets are dependent on a small fraction of available food sources, i.e., about 75% of human food is derived from 12 plant and 5 animal species.
- PRESCOTT-ALLEN, R. and PRESCOTT-ALLEN, C. (1990), How Many Plants Feed the World?. Conservation Biology, 4: 365-374
- Potential benefit from genetic and agronomic management. Increased consumer awareness and selection of nutritional vegetables and fruit from producers who employ practices or genetics that reduce greenhouse gas (GHG) emissions is one incentive for diet diversity.
- Such an incentive would serve as "double-duty" in reducing agricultural contributions to anthropogenic warming.
- Policy incentives could also encourage producers to grow more diverse foods, or food companies to create more nutritionally- enhanced products while limiting GHGs

Ziska LH. Rising Carbon Dioxide and Global Nutrition: Evidence and Action Needed. Plants (Basel). 2022 Apr 6;11(7):1000.

100 YEARS OF AGRICULTURAL CHANGE: SOME TRENDS AND FIGURES RELATED TO AGROBIODIVERSITY

- Since the 1900s, some 75 percent of plant genetic diversity has been lost as farmers worldwide have left their multiple local varieties and landraces for genetically uniform, high-yielding varieties.
- 30 percent of livestock breeds are at risk of extinction; six breeds are lost each month.
- Today, 75 percent of the world's food is generated from only 12 plants and five animal species.
- Of the 4 percent of the 250 000 to 300 000 known edible plant species, only 150 to 200 are used by humans. Only three - rice, maize and wheat - contribute nearly 60 percent of calories and proteins obtained by humans from plants.
- Animals provide some 30 percent of human requirements for food and agriculture and 12 percent of the world's population live almost entirely on products from ruminants

Source: The Food and Agriculture Organization of the United Nations. 1999b

Global plant diversity as a reservoir of micronutrients for humanity

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- **With more than two billion people suffering from malnutrition and the same from obesity and diets homogenising globally**, it is vital to identify and conserve nutrient-rich species that may contribute to improving food security and diversifying diets.
- Of the approximately 390,000 vascular plant species known to science, thousands have been reported to be edible, yet their nutritional content remains poorly characterised.
- Edible-plant diversity has the potential to complement existing strategies to improve nutrition, provided we make it accessible to those who need it most, use it sustainably and guarantee its long-term conservation.

Cantwell-Jones, A., Ball, J., Collar, D. et al. Global plant diversity as a reservoir of micronutrients for humanity. Nat. Plants 8, 225–232 (2022).

Indigenous Knowledge is Key to Sustainable Food Systems

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By tripling cereal production within four decades post WW2, the spread of agricultural technologies helped to alleviate hunger and poverty in some places. However, in others it created food insecurity and exacerbated pollution, deforestation and the displacement of Indigenous and small-scale production systems

ROYAL BOTANIC GARDENS · KEW ·

For humanity to progress towards a sustainable world with a secure food supply, the data now clearly show that we must change diets, reduce waste, diversify food systems — in existing or reduced agricultural land — and develop more-circular ways to produce food

At Kew, 210 collaborators from more than 40 countries, have compiled information about more than 7,000 plant species with documented uses as human food in an effort spanning more than 20 years. Some 7 million plant and 1.2 million fungal species, are digitised so that users anywhere in the world can have free access to high-resolution images and their associated data.

Ulian, T, Diazgranados, M, Pironon, S, et al. Unlocking plant resources to support food security and promote sustainable agriculture. *Plants, People, Planet*. 2020; 2: 421– 445.

Biofortification-A Frontier Novel Approach to Enrich Micronutrients in Field Crops to Encounter the Nutritional Security

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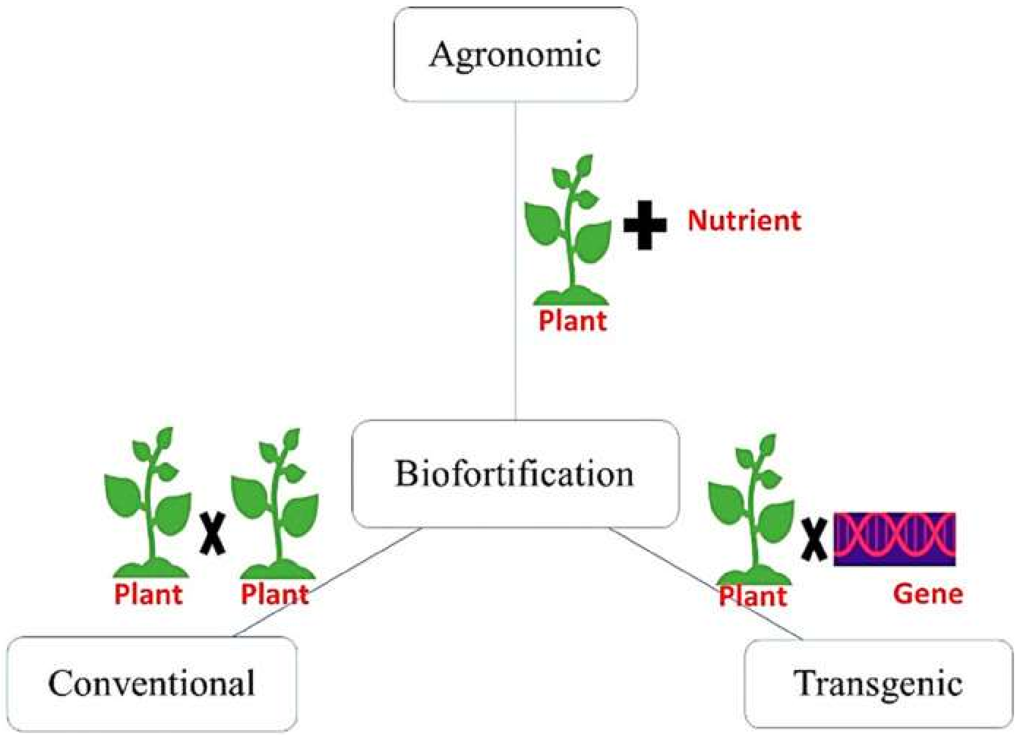
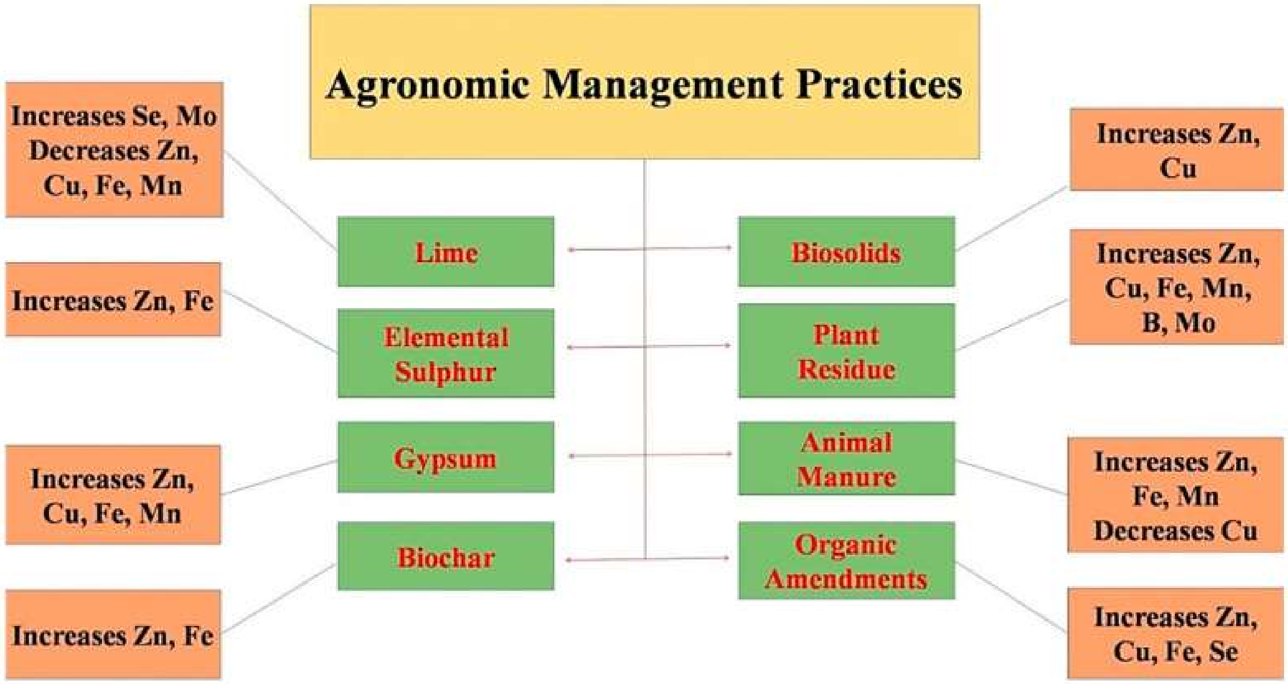


Three major strategies to accomplish nutritional security through agri biofortification are

1. conventional biofortification,
2. transgenic biofortification and
3. agronomic biofortification soil or foliar fertilisation

Owing to multiple benefits, micronutrients application through soil is the most versatile and effective method, particularly to correct the deficiencies

Dhaliwal SS, Sharma V, Shukla AK, Verma V, Kaur M, Shivay YS, Nisar S, Gaber A, Brestic M, Barek V, Skalicky M, Ondrisik P, Hossain A. Biofortification-A Frontier Novel Approach to Enrich Micronutrients in Field Crops to Encounter the Nutritional Security. Molecules. 2022 Feb 16;27(4):1340.



Dhaliwal SS, Sharma V, Shukla AK, Verma V, Kaur M, Shivay YS, Nisar S, Gaber A, Brestic M, Barek V, Skalicky M, Ondrisik P, Hossain A. Biofortification-A Frontier Novel Approach to Enrich Micronutrients in Field Crops to Encounter the Nutritional Security. Molecules. 2022 Feb 16;27(4):1340.

Human Biofortification

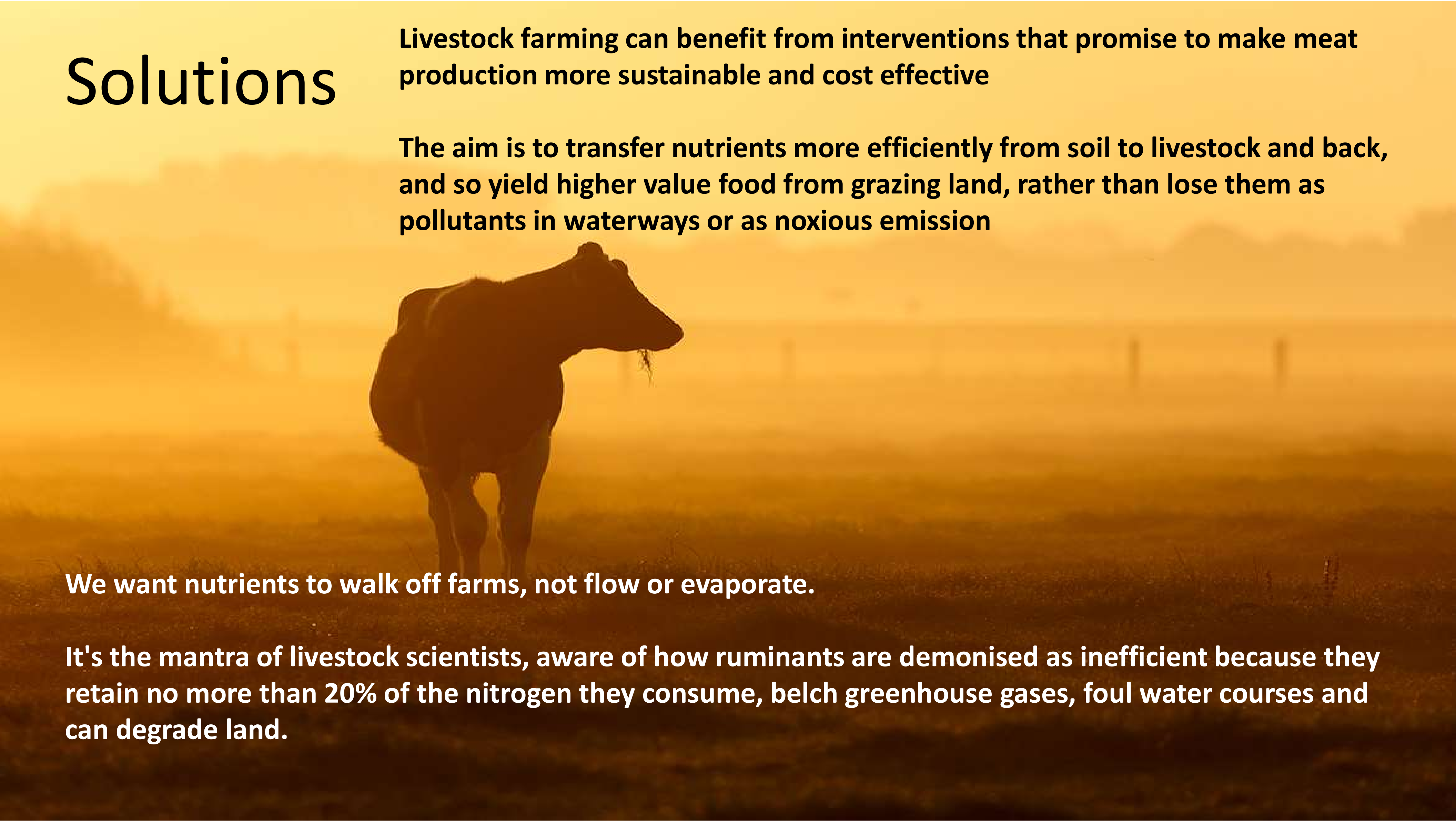
- Food supplements
- Food fortification
- Careful food selection (inc meats)
- Reduction of competing anti nutrients
- Reduction or removal of UPF
- Reduction or exogenous toxins

The authors of a paper published in the journal Nature Climate Change agree that **supplementation, fortification, and biofortification are solid strategies to help ameliorate the possibility of dangerous levels of micronutrient deficiency around the world** [1]

The scientific evidence now strongly suggests that increasing CO_2 levels can negatively impact the nutrient quality of many foods and when nutritional value declines, micronutrient deficiencies increase.[2]

2. Branca F, Lartey A, Oenema S, Aguayo V, Stordalen G A, Richardson R et al. Transforming the food system to fight non-communicable diseases BMJ 2019; 364 :l296

1, Smith, M.R., Myers, S.S. Impact of anthropogenic CO2 emissions on global human nutrition. Nature Clim Change 8, 834–839 (2018).



Solutions

Livestock farming can benefit from interventions that promise to make meat production more sustainable and cost effective

The aim is to transfer nutrients more efficiently from soil to livestock and back, and so yield higher value food from grazing land, rather than lose them as pollutants in waterways or as noxious emission

We want nutrients to walk off farms, not flow or evaporate.

It's the mantra of livestock scientists, aware of how ruminants are demonised as inefficient because they retain no more than 20% of the nitrogen they consume, belch greenhouse gases, foul water courses and can degrade land.


Turning food wastes
into high-value and sustainable products
Elemental
www.elemental.uk

The Process: Resource Recovery & Lower Emissions

- **20% CO_2 saving** from Elemental Technology (protein and fat extraction)
- Equivalent carbon footprint saving of **reducing herd size by 25,000** to maintain current protein output based on 150,000 cattle processed. **Reduction of 17%**
- **48% less energy** required to convert the organic matter waste to fertiliser via Elemental technology compared to rendering
- A **34% reduction** in CO_2 eq/kg of fertiliser produced by Elemental's technology compared with conventional mined fertiliser
- **Better resource recovery** compared to the rendering with less waste going to incineration/landfill and Elemental's solution sits higher on the **UK waste hierarchy**
- **Thallo®** fertiliser trial published in **Plos One** journal (2019) demonstrated crop yields comparable to conventional fertilisers and in low nutrient substrates showed a yield improvement. Across all trials there was an increased uptake of minerals into the crops
- **Rothamsted Research** paper (2021) provides evidence that Thallo® is able to boost plant defence against insect pests and could be used on farms as a new pest management tool

"Elemental Technology Delivers Sustainable Environmental Impacts with Lower CO_2 Emissions Creating a Smaller Carbon Footprint"

Regenerative agricultural..

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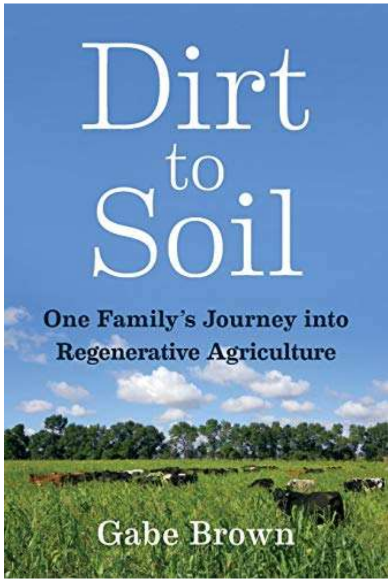
- ..methodologies seek to add to the soil through a self-nourishing ecological system that benefits the environment in the process. A closed-loop system that doesn't halt humans' impact on the environment, but ***reverses*** it.
- not only is regenerative agriculture worth investing in, but the largest food companies in the world are already doing it.
- Each one-percent increase in soil organic matter helps soil hold up to 20,000 gallons more water per acre. This means crops are more resilient through times of drought or heavy rain. By maintaining surface residues, roots, and soil structure with better aggregation and pores, soil organic matter reduces nutrient runoff and erosion.

Regenerative agriculture aims to restore the fertility of the soil and the overall health of the land it's conducted on.

..consistent with sustainable agriculture practices such as limiting the use of synthetic inputs like pesticides and fertilisers, limiting tillage of the soil, which can negatively impact soil health. **But often regenerative agriculture involves livestock integration**.

The healthier the soil, the healthier the crop. When plants have the nutrients and roots systems they need to thrive, they build compounds to help protect against insects and disease.

Growing evidence qualifies that a healthy soil phytobiome full of necessary bacteria, fungi, and nematodes is more likely to produce nutrient-dense food, promoting better human health



It's also always worth noting that regenerative agriculture is by no means new. Indigenous cultures have used many of its farming practices and principles for millennia.

Thinking of a healthy body as an extension of a healthy farm, and vice versa, is a paradigm shift for many of us. But when we consider that all of our cells get their building blocks from plants and soil then, suddenly, it all makes sense. In fact, it is not too much of a stretch to say:

‘We are soil’

Way back in the 1940s in the book ‘An Agricultural Testament’ the author Sir Albert Howard stated that;

“the failure to maintain a healthy agriculture has largely cancelled out all of the advantages we have gained from our improvements in hygiene, in housing and our medical discoveries”.

"Every one thing exists for the sake of all things and all for the sake of one."

Alexander von Humboldt

Suppose that starting tomorrow and without our knowledge,
the baseline mineral content of all plants on Earth drops by 5%

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Taking supplements or intentionally shifting one's diet toward mineral-rich foods, for example animal products, can eliminate the deficit. Such dietary changes, however, presuppose behavioural adjustments on the part of the individuals who are aware of their mineral deficiency and have both the means and motivation to address it. A simpler way to compensate for the mineral deficit is to increase food intake, whether consciously or not. (The notion of compensatory feeding is not entirely alien—herbivores do increase consumption by 14–16%, when consuming plants grown in eCO2; Stiling and Cornelissen, 2007; Robinson et al., 2012).

For a calorie deficient person, eating 5% more (to be exact 5.26%, because 1.0526*.95 ≈ 1) is likely to be beneficial. However, for a calorie sufficient but mineral deficient person, eating 5% more could be detrimental. The dynamic mathematical model of human metabolism, which links weight changes to dietary and behavioral changes (Hall et al., 2011), can help to quantify the effect of a prolonged 5% increase in food intake. When parameterized with anthropometric data for an average moderately active American female (age 38, height 163 cm, weight 76 kg, BMI 28.6, energy intake 2431 kcal/day [10171 kJ]) (Fryar et al., 2012; CIA, 2013), the model outputs a weight gain of 4.8 kg over a 3-year period, provided all other aspects of behavior and diet remain unchanged. For a male, the respective weight gain is 5.8 kg. The results are congruent with Hill et al. (2003), who argued that a 4–5% difference in total daily energy intake, a mere 100 kcal/day, could be responsible for most weight gain in the population.

Loladze I. Hidden shift of the ionome of plants exposed to elevated CO_2 depletes minerals at the base of human nutrition. Elife. 2014 May 7;3:e02245.