CLIMATE CHANGE AND AGRICULTURE

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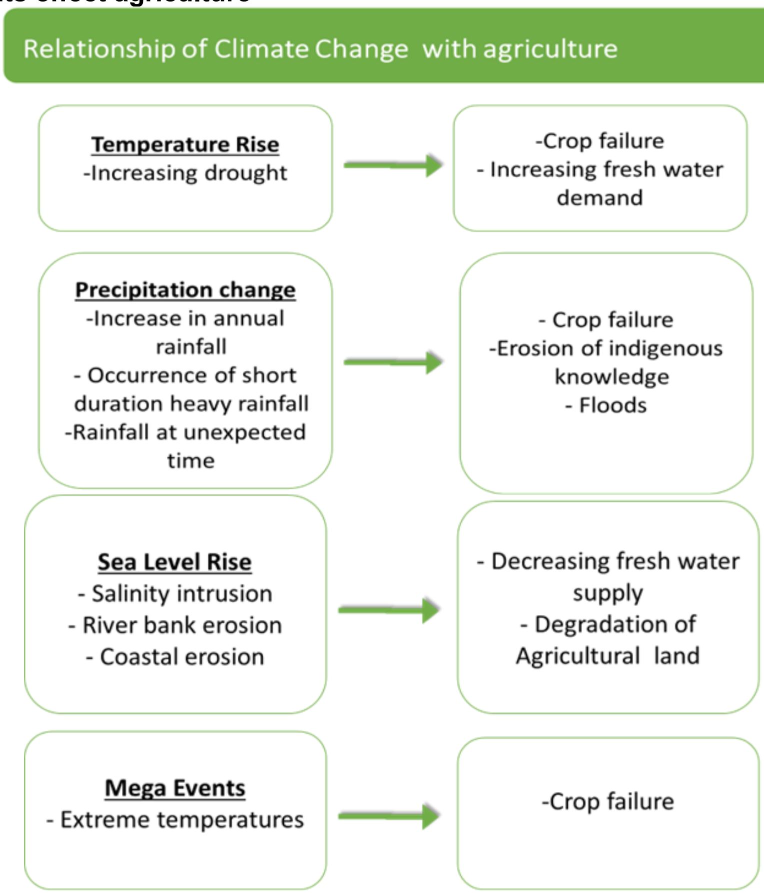
Agriculture sector is the most heterogeneous of the standardized IPCC sectors, though there is an underlying similarity among the subsectors—namely, they involve land use and/or ocean use. Beyond this feature of the sector, it is unique because of its importance as a *sink* for carbon emissions. In fact, many of the most important issues about the sector concern the capacity of the forests and oceans to continue to absorb enormous quantities of carbon each year. In any case, agriculture, forestry and other land use sector was responsible for 13–21% of total global anthropogenic greenhouse gasses (GHG) emissions during the decade 2010–2019 (IPCC, 2021). All of the sub-sectors are exposed to multiple effects of climate change, and these are discussed in the individual subsectors.

Climate change its effect agriculture



The major impacts of climate change on agriculture are -

- General decrease in cereal crop yields in mid-latitudes
- Decreased crop yields in areas of increased drought
- Food prices increase relative to projections that exclude climate change
- Decreased cereal crop yields in most tropical and subtropical regions
- Increased heat stress in livestock and crop damage from heat waves
- Decreased frost damage for some crops

Climate change and variability are major causes of declined agricultural productivity across the globe. Agriculture in future will face multiple challenges that include the production of more food and fiber for billions of populations and higher production of feedstocks for bioenergy production. Generally, we think that the major threats to the environment are GHGs coming from different anthropogenic activities, not food needed for our breakfast, lunch, and dinner. But the truth is food will be the biggest dangers to the planet Earth. Agriculture is contributing a lot to GHG emissions as compared to buses, cars, trucks, trains, and airplanes (Fig. 1). Methane (CH_4) mainly comes from cattle and rice farms, while oxides of nitrogen are coming from fertilized fields. Higher emissions of carbon dioxide (CO_2) are due to cutting of rain forest to clear land that can be further used to raise animal and grow crops (Crippa et al. 2021; Poore and Nemecek 2018; Lynch et al. 2021).

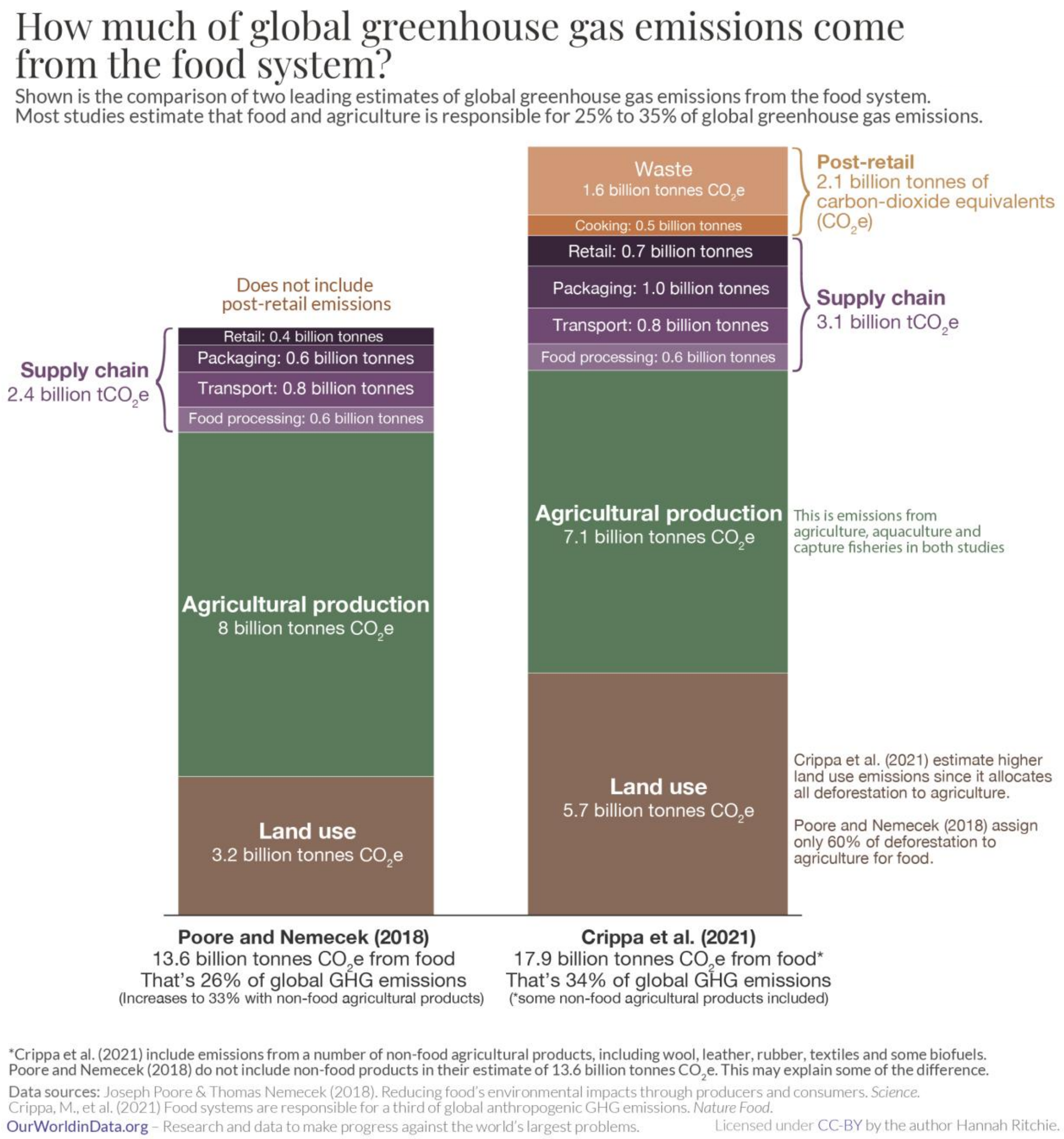


Fig. 1 Food system and greenhouse gas emission

Similarly, farming is using a lot of water, and it pollutes nearby water bodies and underground water via runoff from manure and fertilizers. Water footprint of agriculture is increasing day by day, and it is using 70% of existing freshwater as shown in Fig. 2. Water footprint is further divided into blue (consumption of ground and surface water), green (use of rainwater), and gray (water use in the dilution of pollutants). In future, climate change will result to the further increase in water footprint from north to south as irrigation demands will rise from 6% to 16%. Decrease in green water footprint was estimated due to change in precipitation. Among crops, rice is the crop, which have a higher water footprint, and simulated outcome of study reported that blue water footprint in rice will increase as compared to green water footprint. Gray and green water footprint in Amazon for soybean have been increased by 268% and 304%, respectively, in 2050, if current soybean expansion and intensification will remained as such. Thus, in future, efficient water resource management (e.g., reduction of evapotranspiration and crop water use, and optimal fertilizer application) is necessary to ensure food security under changing climate.

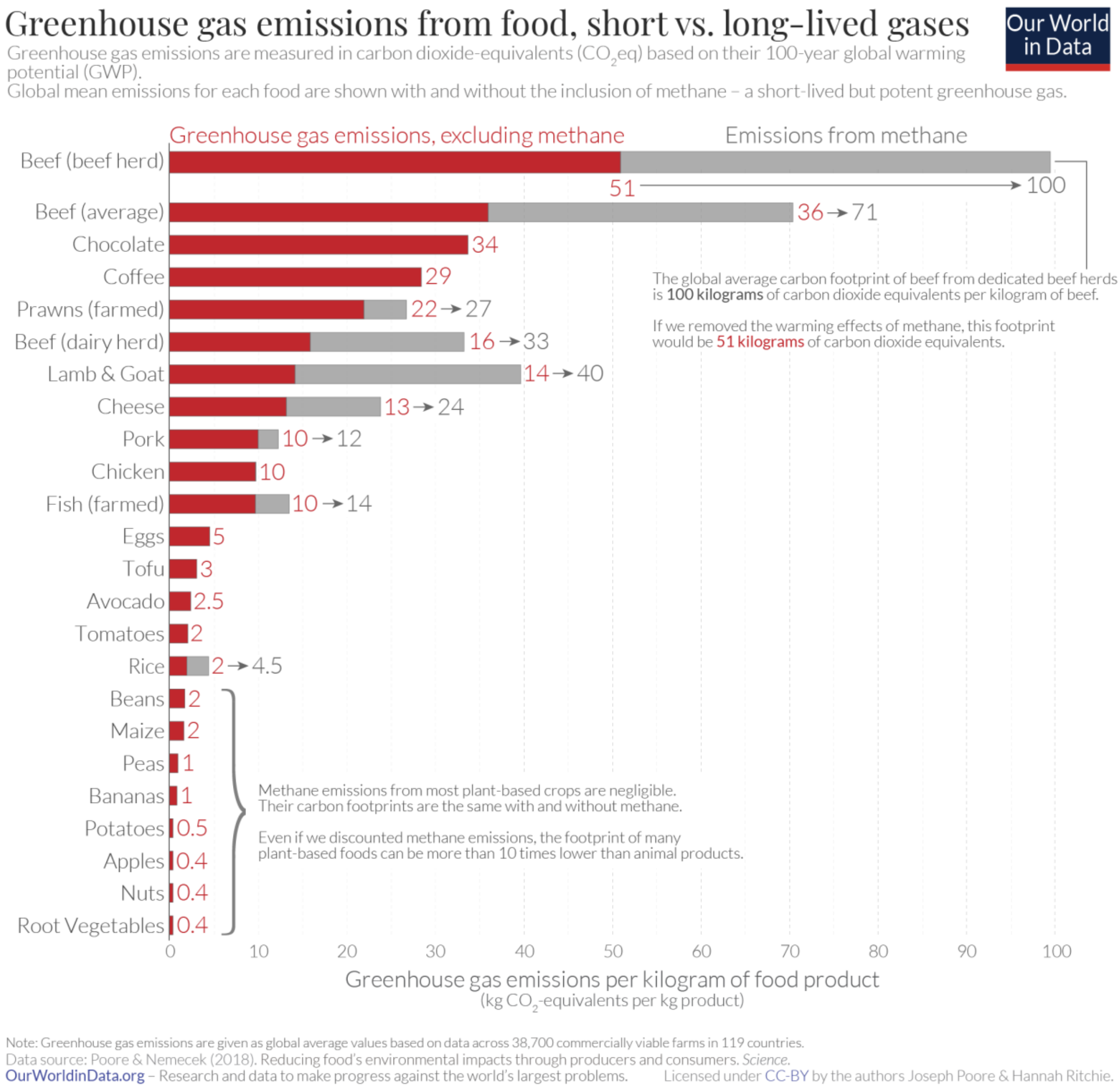


Fig. 2 Global greenhouse gas emissions from food system

Agriculture is also the main cause of accelerated loss of biodiversity. In future, agriculture will pose more threat to the environment, as we must feed two billion more mouth (>9 billion) to feed by mid-century. The countries with the highest population will need more meat, eggs, and dairy, which will boost pressure to grow more crops like corn and soybean to feed animals. Hence, with this population growth and diet habits, we must double the amounts of crops production by mid-century. Furthermore, debates among conventional agriculture/global commerce and local food systems/organic farms to address the global food challenge have been polarized. Both are right in their point of views, as conventional agriculture talks more about higher food production through the applications of modern tools while organic farming produces quality food with higher benefits to the small-scale farmers and ecosystems. Jonathan Foley asked a question from team of experts, and it has been published in

National Geographic magazine. The question was how world can double food availability by minimizing the environmental harm.

Jonathan Foley and team of scientist proposed a five-step mechanism to solve the world's food dilemma, which they got after analyzing a huge amount of data on agriculture and environment. It includes the following:

- Freeze agriculture footprint (stop deforestation for crop production).
- Grow more on farms we have got.
- Use resources more efficiently.
- Shift diets.
- Reduce waste.

Agriculture footprint has caused the loss of whole ecosystems across the globe, e.g., prairies of North America and the Atlantic Forest of Brazil and tropical forests. Converting tropical forest to agriculture was one of the most damaging acts to the environment by human beings, although it does not contribute a lot to global food security. Reducing yield gaps and increasing yield on less productive areas could bring global food security and that needs to be opted by all researchers across the globe. Yield gap could be minimized by identifying yield-limiting factors, designing crop ideotypes, opting high-tech precision farming systems, as well as approaches from organic farming. Similarly, using resources more efficiently through commercial and organic farming can improve soil health, conserve water, and build up nutrients. Shift in diets from livestock to crops could help to feed 9 billion population by 2050 as well as it can minimize agriculture footprint. Waste minimization is another very good option suggested by Jonathan Foley to ensure food security, as 50% of total food weights and 25% of global food calories have been lost before it should be consumed. These proposed five steps could help to double the world's food supply, cut the environmental impact of global agriculture, and ensure food security.

Agricultural Vulnerabilities to Climate Change

Agriculture is exposed to many of the direct effects of climate change, including droughts, floods, and variable precipitation rates. Developing countries are particularly vulnerable because of the importance of agriculture in their societies, their relatively low-income levels, and their exposure to droughts (Fig. 3). Population growth also entails increasing demand for agricultural production and thus increasing vulnerabilities to climate change.

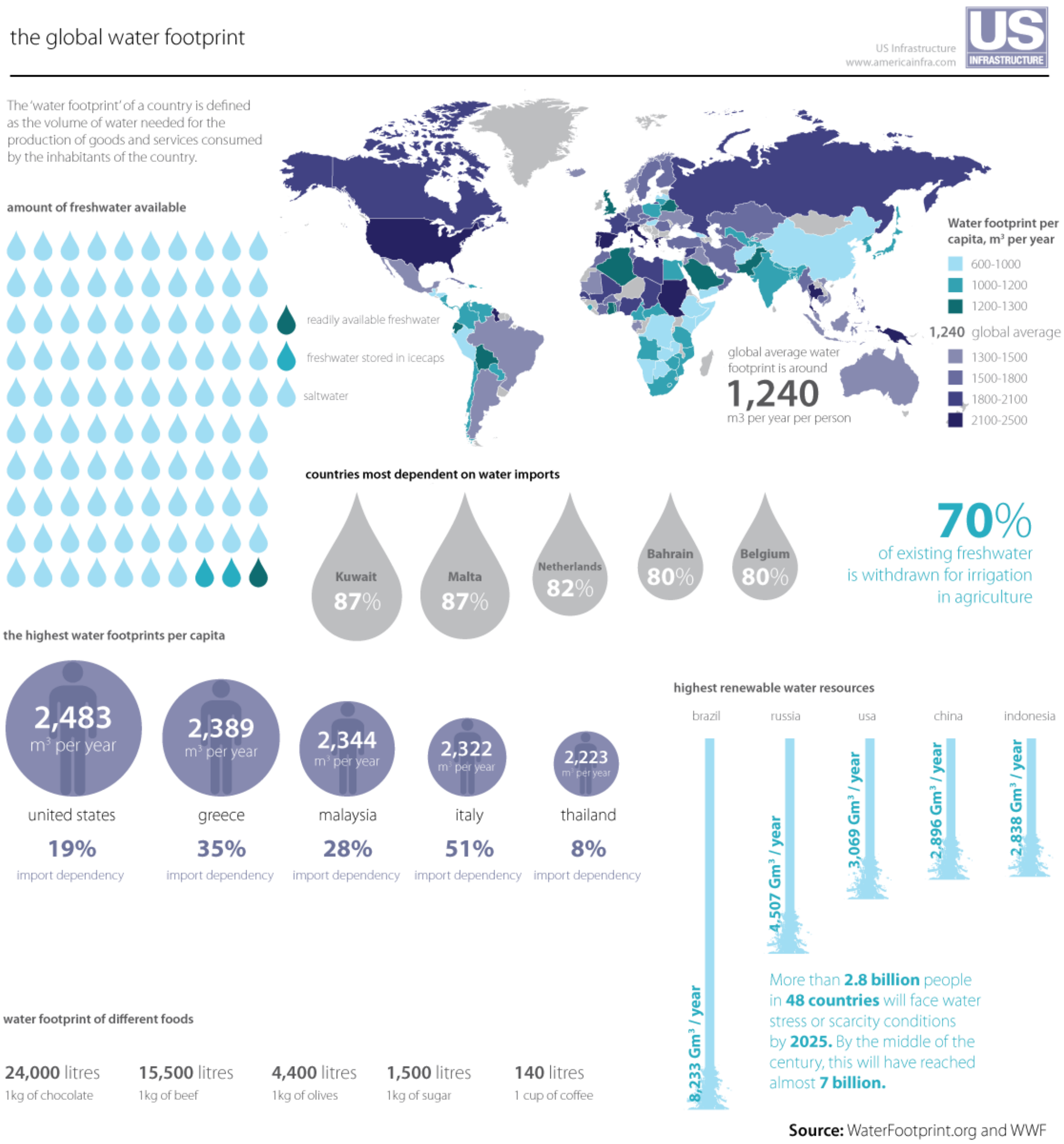


Fig. 3 The global water footprint

Agricultural Emissions

The global food system contributes about one-third of annual global CO_2 equivalent GHG emissions—for instance, 30% in 2020. About one-fifth of the food system share, however, is attributed to transportation and other processes not included in this chapter's sector. Within the total food system, agriculture contributes about 40%. An important feature of agriculture's emissions is that they are dominated by methane and nitrous oxide, which are both highly potent. The proportions of agriculture's total are that methane contributes 54%, nitrous oxide 28% and carbon dioxide 18%.

Atmospheric lifetimes and GWPs of agricultural emissions

Emissions	Average atmospheric lifetime (years)	GWP 20 years/100years
Methane (CH_4)	11.8	81/27
Nitrous oxide (N_2O)	109	273/273
Carbon dioxide (CO_2)	100	1/1

Source IPCC (2021a)

Sources of agriculture emissions

Sources of emissions	Global total: Gt CO_2-eq (2020)	Emission details
Enteric fermentation	2.85	Methane from digestive system of cattle
Manure management	0.28	Methane from decomposition
On-farm energy use	1.03	Carbon dioxide from electricity and machinery fuel
Synthetic fertilizers	1.01	Nitrous oxide and carbon dioxide
Rice cultivation	0.69	Methane from flooded rice fields
Crop residues	0.23	Methane from decomposition and burning

Source Excerpted from Rosa and Gabrielli (2023)

As for the future, a report of the IPCC (2022) concluded that:

Taken together, recent research shows that achieving global food security in the coming decades, while limiting warming to 1.5°C, cannot be done without significant changes to food production and consumption. Shifting demand, increasing productivity, and changing on-farm practices and technologies, combined, are necessary to reduce global emissions.

Food security

Food security exists when "all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life". According to the United Nations, food security can be defined as physical, social, and economic access to food by all people at all times to sufficient, safe, and nutritious food to meet their dietary needs according to their food preferences for an active and healthy life.

Under current international scenario, food security is becoming a formidable challenge. In a developed world, most attention is given to biofuel production, and it is using huge quantities of grain, e.g., 50 million tons of maize is used to produce biofuel products. Similarly, increased used of corn grain to produce ethanol is altering the landscape and ecosystem services. Food security is also on stake due to climate change, increased prices of food grain, and livestock product which has been further aggravated by continuous rise in fuel prices. The cascading effects of climate change on food security have been shown in Fig. 4. The earlier world was striving hard to meet the Millennium Development Goals (MDGs) to reduce hunger and poverty to half by 2015 but unable to achieve the UN target. There were eight MDGs with less attention to environmental sustainability.

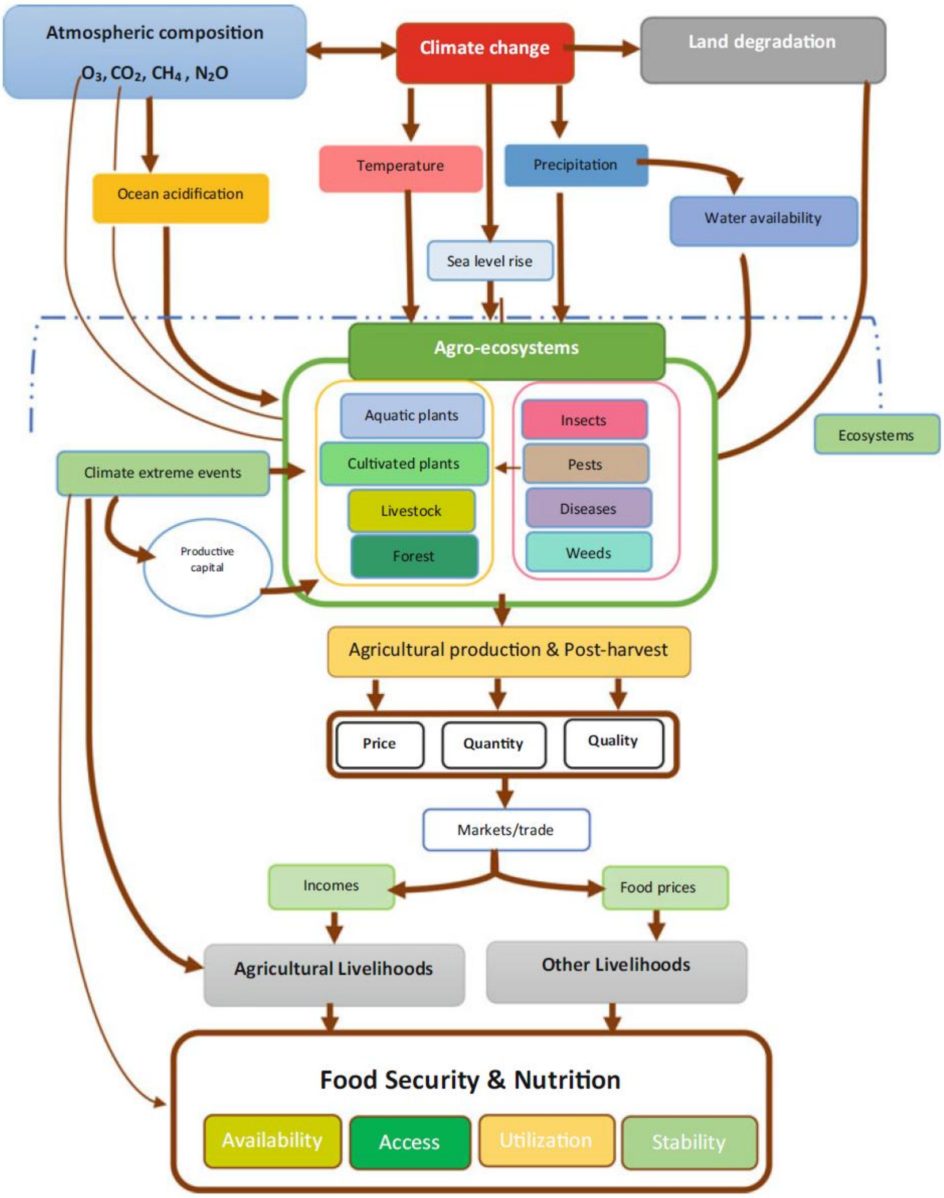


Fig. 4 Cascading effects of climate change on food security and nutrition. (Source: FAO)

Predicted effects of climate change on agriculture by 2050

Climatic element	Expected changes by 2050's	Confidence in prediction	Effects on agriculture
CO_2	Increase from 360 ppm to 450 - 600 ppm (2005 levels now at 379 ppm)	Very high	Good for crops: increased photosynthesis; reduced water use
Sea level rise	Rise by 10 -15 cm Increased in south and offset in north by natural subsistence/rebound	Very high	Loss of land, coastal erosion, flooding, salinisation of groundwater

Climatic element	Expected changes by 2050's	Confidence in prediction	Effects on agriculture
Temperature	Rise by 1-2°C. Winters warming more than summers. Increased frequency of heat waves	High	Faster, shorter, earlier growing seasons, range moving north and to higher altitudes, heat stress risk, increased evapotranspiration
Precipitation	Seasonal changes by ± 10%	Low	Impacts on drought risk' soil workability, water logging irrigation supply, transpiration
Storminess	Increased wind speeds, especially in north. More intense rainfall events.	Very low	Lodging, soil erosion, reduced infiltration of rainfall
Variability	Increases across most climatic variables. Predictions uncertain	Very low	Changing risk of damaging events (heat waves, frost, droughts floods) which effect crops and timing of farm operations

Current projections, from the 4th Assessment report by the Intergovernmental Panel on Climate Change (IPCC) published in 2007, suggest that global temperatures will rise between 1.8°C and 4.0°C (best estimate) by 2100 depending on emissions of greenhouse gases and that global sea levels are likely to rise from anywhere between 180 mm and 590 mm.

Soils and Climate Change

Soil is the loose surface material that covers the land, and it is the basic resource needed for the survival of living organisms. It contains organic and inorganic material. It is a living treasurer under our feet. Soil is a mixture of mineral matter, water, air, and organic matter as shown in Fig. 5. It is the natural medium which nourishes and supports plants. Soil is the end product of decomposition of the parent material. This weathering of the parent material is dependent upon climate, topography, and organisms like flora, fauna, and human. Hence, soil differs in texture, structure, color, physical, chemical, and biological properties. Soil is an important component of land and ecosystems, and it also determines the social and economic conditions of the region. Soil is the second largest store or sink of carbon after ocean, and to mitigate climate change, it is essential to improve soil organic matter (SOM) through different land management's techniques. The relationship between soil and climate change has been well described by the European Environmental Agency (Fig. 6).

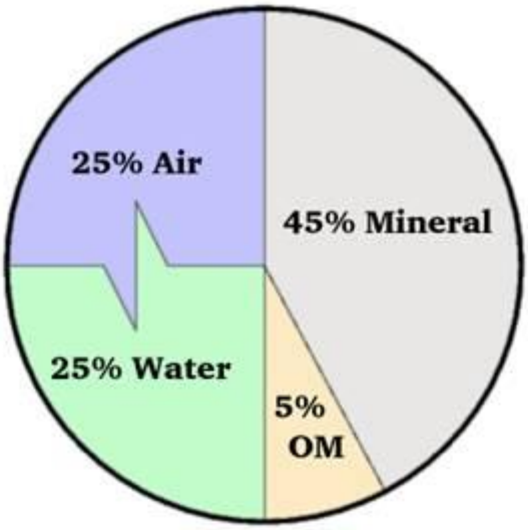


Fig. 5 Composition by volume of soil

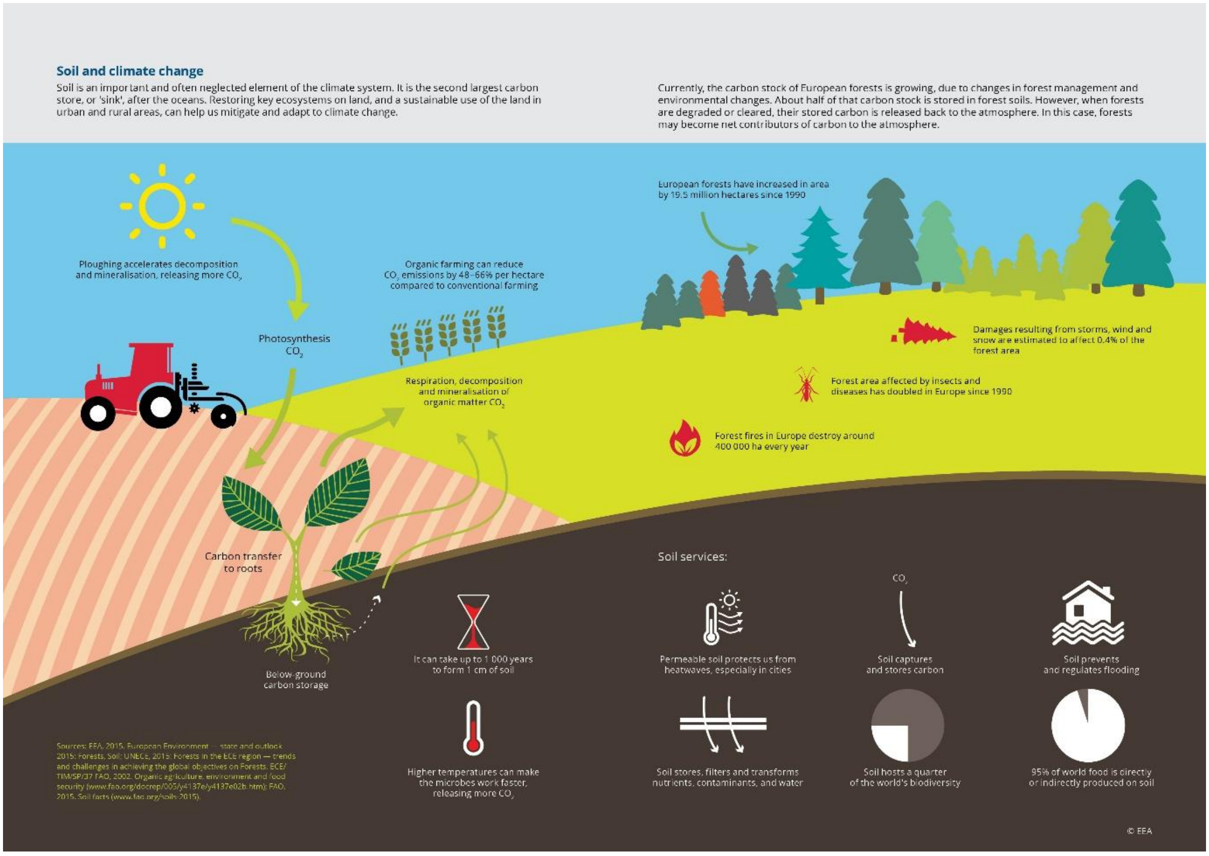


Fig. 6 Soil and climate change (Source: European Environmental Agency (EEA))

Soil management can play an important role in climate change adaptation and mitigation (Fig. 7). Improving carbon (C) in soil will help to protect soil from degradation, increases water holding capacity (WHC) of the soil, promotes microbial growth, and ensures food security. C-sequestration is the transfer of atmospheric CO_2 into different global pools (e.g., oceanic/pedologic/biotic and geological strata) to reduce the increase of CO_2 in the atmosphere. It is a very important technique which can help to maintain the concentration of CO_2 in the atmosphere, as concentration of CO_2 is increasing at a rapid pace. It has been increased from 280 ppm (1850) to 417 ppm (2022). This higher CO_2 concentration resulted to the increased surface temperature (1.5–5.8 °C) (IPCC 2001, 2014).

C-sequestration have two basic methods, i.e., (i) direct (immediate binding at the source) and (ii) indirect (fixation of CO_2 by photosynthesis or its binding in a soil environment). Agriculture can play a significant role in C-sequestration. It is possible through agroforestry, soil mulching, residue incorporation, application of biochar, proper fertilization, intercropping, crop rotation, and growing of cover crops, which can further improve soil health by preventing soil degradation. C-sequestration is an important climate change mitigation approach. Therefore, C-farming was promoted to reduce climate change impact. Reduction in atmospheric CO_2 loading is possible through biological, chemical, and technological options.

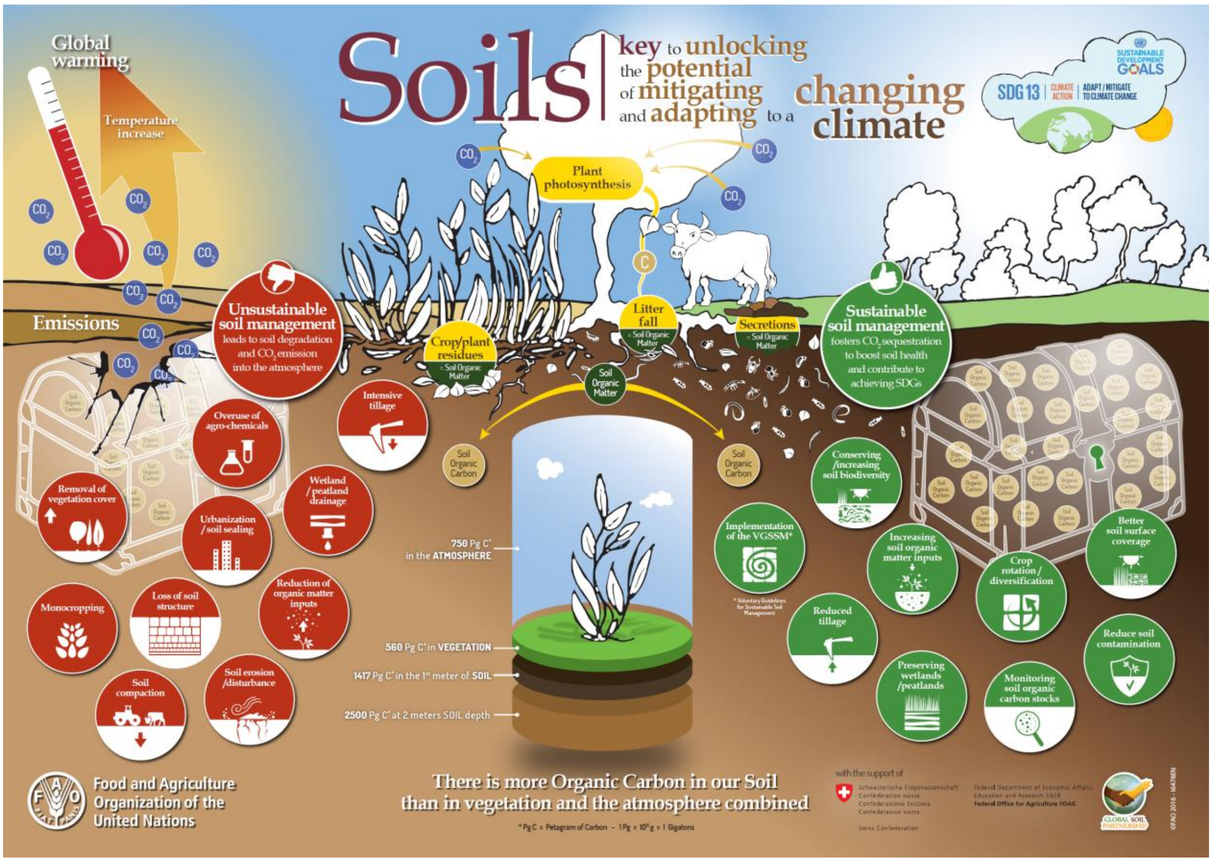


Fig. 7 Unlocking potentials of soil to mitigate and adapt to climate change. (Source: FAO)

C-sequestration technique in which CO_2 is injected below the ground surface to form carbonates, has so many benefits, which can enhance ecosystem services (e.g., improving soil quality and health, enhancing biodiversity, improving ground water quality, and increasing use efficiency of agronomic inputs), and ensures food security. Furthermore, C-sequestration reduces greenhouse effect. Annual increase in atmospheric CO_2 can be halted if soil carbon could be increased by 0.4% on a yearly basis. Hence, soil C- sequestration is an important mitigation tool.

Different management practices as elaborated below could be opted to minimize the impact of climate change from soil.

Management practices to increase soil C-sequestration and CO_2 removals

S. No	Management practices	Benefits	References
1.	Crop rotations and cover cropping	Higher C-sequester and economic returns Mitigating climate change Improvement in the soil quality Decrease CO_2 emission Improvement in soil temperature, moisture, and total aboveground biomass Reduces erosion and nitrogen leaching, fix atmospheric nitrogen and improves soil health Mitigation of CO_2 emissions	Chahal et al. (2020), Smith et al. (2008), Abdollahi and Munkholm (2014), Nguyen and Kravchenko (2021), Kaye and Quemada (2017) and Rigon and Calonego (2020)
2.	Composting	Reduces emissions of greenhouse gases (GHGs)	Favoino and Hogg (2008)
3.	Manuring	Reduction in GHGs emissions	Dalgaard et al. (2011)
4.	No tillage, zero tillage	Mitigate GHG emissions Viable greenhouse gas mitigation strategy Lower GHGs fluxes Application of DAYCENT model in the estimation of GHGs Minimizing emissions of GHGs Preservation of soil organic carbon	Ogle et al. (2019), Krauss et al. (2017), Forte et al. (2017), Rafique et al. (2014), Mangalassery et al. (2014) and Haddaway et al. (2017)
5.	Cultivation of perennial grasses and legumes	Higher soil C storage Reduced N_2O emissions Suppress weed invasion Reduced use of inorganic fertilizer Lowering of C-footprint	Yang et al. (2019), Liu et al. (2016) and Gan et al. (2014)
6.	Plantation of deep-rooted crops	Improved soil carbon budget Reduced emissions of CO_2 Improves soil structure Improves water and nutrient retention	Jansson et al. (2021) and Kell (2011)
7.	Rewetting organic soils	Lowering CO_2 and N_2O emissions	Wilson et al. (2016) and Paustian et al. (2016)
8.	Grazing land management	Lowers atmospheric CO_2 emissions and surface temperature Improvement of soil carbon stocks	Mayer et al. (2018) and Conant et al. (2017)
9.	Biochar application	Reduced N_2O emissions Improved soil water holding capacity Suppression of soil CO_2 emissions Variable response in CO_2 production Soil greenhouse gas (GHG) fluxes remained variable in response to different biochar application	Martin et al. (2015), Conant et al. (2017), Spokas and Reicosky (2009) and He et al. (2017)
10.	Plant-soil interactions	Restoration of degraded soil	Maiti and Ghosh (2020)

Climate change will negatively affect SOM dynamics, soil organisms, and soil properties, but warmer conditions could lead to the higher availability of soil N due to higher mineralization rate. Hence, soil management particularly N application will be governed by future climate change (Jat et al. 2018). SOC dynamics is the core of interlinked environmental problems. However, its management is a mystery due to its complex relationship with N availability, moisture, and temperature. Soil may act as a potential C sink if managed properly (e.g., management of soil inorganic N pools and its proper linkage with microbial processes). Climate change mitigation is the implementation of efforts to halt or reverse climate change through behavior, technological, and management strategies (Fig. 8). With practical on ground mitigation practices, soil can play a role to reduce CO_2 emissions. It can be a carbon sink instead of the source.

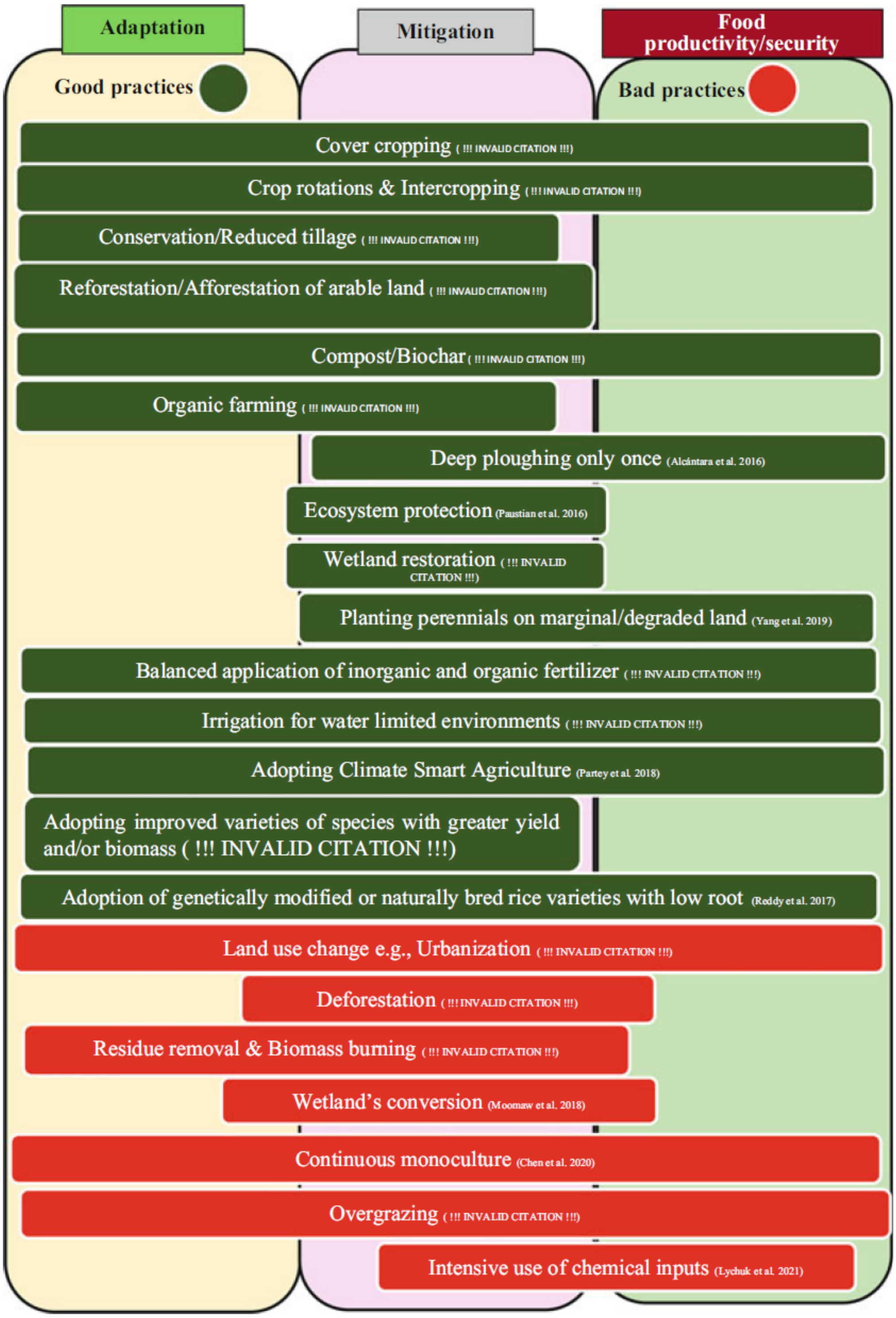


Fig. 8 Management strategies for the improvement of soil health and their impacts on climate change adaptation, mitigation, and food productivity/security

Climate change and soil processes

The potential for soils to support agriculture and distribution of land use will be influenced by changes in soil water balance:

- Increase in soil water deficits i.e. dry soils become drier, therefore increased need for irrigation but:
- Could improve soil workability in wetter regions and diminish poaching and erosion risk
- Higher temperatures and, higher rainfall levels, will accelerate soil organic matter break down
- Low organic matter soils hold few nutrients and are more susceptible to drought
- Soil erosion will be higher

Degraded soils: Typical monoculture cropping systems leave soil bare for much of the year, rely on synthetic fertilizer, and plow fields regularly. These practices leave soils low in organic matter and prevent formation of deep, complex root systems. Among the results: reduced water-holding capacity (which worsens drought impacts), and increased vulnerability to erosion and water pollution (which worsens flood impacts).

Crops

The effect of increased temperature and CO_2 levels on arable crops will be broadly neutral:

- The range of current crops will move northward
- New crop varieties may need to be selected
- Horticultural crops are more susceptible to changing conditions than arable crops
- Field vegetables will be particularly affected by temperature changes
- Bean, onion and sweet corn are most likely to benefit commercially from higher temperatures
- Water deficits will directly affect fruit and vegetable production

Changes in Crop Quality

Climate change has a significant effect on nutrition quality. Enhancing greenhouse gases, particularly CO_2 concentration, has caused the reduction of contents of zinc and iron in cereal crops and legume crops. Malnutrition is a serious problem due to climate change across the world. Climate change has significantly influenced on the antioxidant activity of all type of crops. For instance, air temperature is considered to be the utmost significant factor, which can influence on antioxidant activity in crops, vegetables, and fruits. Higher temperature stress has been linked to a reduction of vitamin levels in all type of fruits, vegetable crops, and agronomic crops under changing climatic conditions. Raised levels of carbon dioxide reduced the inclusive minerals contents of the crop plants by approximately 8%. At the same time, raised levels of carbon dioxide have caused more enhancements in the ratio of the solvable carbohydrates, such as starch and sugars, to proteins. Climate change caused thermal stress which resulted in a reduction of minerals such as zinc and iron in wheat, maize, rice, and soybean grains. These studied crops were fully-grown in an open atmosphere (free air carbon dioxide enrichment; FACE) experiments comprising the level of carbon dioxide, which might be increased by the middle of this century. Climate change reduced the period, as well as the contents, of protein accumulations (Fig. 9). The composition of accumulated proteins was also changed under the thermal stress as a result of variations in the quantity of whole nitrogen assimilated in the period of grain-filling phase of wheat crops. Protein fractions in grains, particularly albumins as well as globulins, were negatively affected due to higher temperature stress condition in lentil crops. In soybean crop, higher temperature stress, such as 35 °C in the period of seed filling, reduced oil content to 2.6%, in comparison to those grains from the plants, which were exposed to 29 °C air temperature.

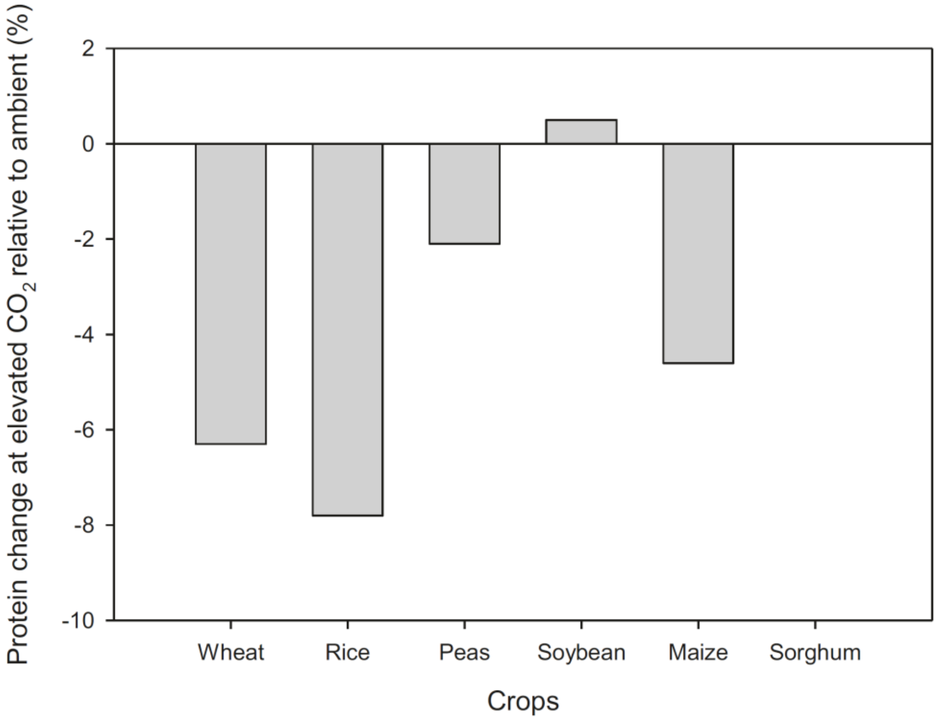


Fig. 9 Changes in protein concentration for different C_3 grasses and legumes as well as C_4 grasses at elevated CO_2 relative to ambient CO_2 (Myers et al. 2014)

Most existing studies of the effects of climate change on crop quality focus on the effect of factors such as radiation, temperature, and precipitation. Studies show that corn genotypes and environmental factors are the main determinants of crop grain quality, and in particular, climatic factors such as light, temperature, and water have a significant effect on corn quality. For example, the phytotron was used to simulate the effects of a high CO_2 concentration (700 ppm) accompanied by a high temperature, and the synergy of CO_2 concentration (350 ppm and 700 ppm) and moisture (relative soil moisture is, respectively, equal to 70 to 80% and 30 to 40% of the field water holding capacity), on the content of amino acids, crude protein, and crude starch in winter wheat and corn, as well as the content of amino acids, crude protein, and crude fat in soybeans. Their study results showed that soil water stress serves to improve crop grain quality and that a high CO_2 concentration accompanied by a high temperature is not only detrimental to the improvement of crop grain quality but also inhibits the improvement of crop grain quality under drought conditions. Normally, high atmospheric CO_2 levels have a fertilizing effect on crop production (i.e., crops are able to absorb more CO_2 during photosynthesis), but the other resulting climate change factors (e.g., temperature rise and precipitation reduction) reduce crop quality.

Today, climatic factors affecting crop quality are non-uniform, including temperature differences, accumulated temperature, and precipitation. Diurnal- or monthly-scale climatic factors affect the protein content of winter wheat grains. High temperature and radiation during the grain-filling period improve the protein content of wheat. However, the effect of precipitation is uncertain, or more specifically, increased precipitation has either a promotive effect or a negative effect on the protein content of wheat. Climate warming has significantly changed the quality indices (e.g., content of protein, nutrients, and non-nutrient elements) of wheat grains, a 1 °C increase in the average temperature during the reproductive period brings about a 1.6% decrease in the starch content of spring wheat but a 0.8% increase in its protein content.

The relationship between wheat quality and related factors (e.g., meteorology, soil, and pest and disease types) indicated that moderate drought during the reproductive period can improve wheat grain quality, soil nutrient changes have no significant effect on grain quality, pest and disease control can improve wheat quality significantly, and precipitation has a significant effect on wheat quality. Regarding the spatial heterogeneity of climatic elements, the effects of temperature, precipitation, and radiation on the protein content of winter wheat showed that the prediction of the protein content of winter wheat on a county-wide scale should consider spatial heterogeneity; specifically, a 1° increase in latitude brings about a 0.29% increase in protein content. Studies of the predicted effect of future climate change on crop quality show that temperature rise and precipitation reduction in the coming century will improve harvest conditions for two types of corn (early and late sown corn).

- In general, the higher levels of carbon (CO_2) will lead to crops (seeds or, in the case of forages, leaves and stems) that are higher in carbon and lower in protein.
- On the other hand, material with higher sugar contents will make better silage.

Pests' resurgence

Climate change is one factor driving the spread of pests and diseases, along with increasing global trade. Climate change can affect the population size, survival rate and geographical distribution of pests; and the intensity, development and geographical distribution of diseases.

Temperature and rainfall are the big drivers of shifts in how and where pests and diseases spread, according to experts. In general, an increase in temperature and precipitation levels favors the growth and distribution of most pest species by providing a warm and humid environment and providing necessary moisture for their growth. However, when temperatures and precipitation levels get too high, this can slow the growth and reproduction of some pest species and destroy them by washing their eggs and larvae off the host plant, he explains.

This would explain why many pests are moving away from the tropics towards more temperate areas. Pests like warmer temperatures – but up to a point. If it is too hot or too cold, populations grow more slowly. Since temperate regions are not currently at the optimal temperature for pests, populations are expected to grow more quickly in these areas as they warm up. Crop diseases are following a similar pattern, particularly when it comes to pathogens like fungi.

- Weeds, diseases, insects will spread from warmer areas into formerly cooler ones.
- Warmer winters allow overwintering of larvae in areas where this was not possible.
- Increased number of generations possible.
- Longer time for development and feeding and a wider range of pests.

Changes of Grassland Species

- Where dry hot areas become more so there will be a shift from C_3 to C_4 species
- In temperate-moist areas increasing CO_2 will favor C_3 over C_4 species.

Intensive inputs

The commercial farm's heavy reliance on fertilizers and pesticides may become even more costly to struggling farmers as climate impacts accelerate soil erosion and increase pest problems. Heavy use of such chemicals will also increase the pollution burden faced by downstream communities as flooding increases. Farmers may also increase irrigation in response to rising temperature extremes and drought, further depleting precious water supplies.

Changes in farming practices and declines in biodiversity

- Concentration on winter crops with a consequent loss of spring crops,
- Increased farm specialization with a decline in livestock and grass enterprises in arable areas
- Changes in cultivation dates
- Loss of semi-natural habitat in farmland, including field margins.

Intensified upland grazing management

- Changes in land management are the main cause of environmental degradation
- Increased stocking densities on upland grazing resulting in sward damage and reduction or loss of species

- Intrusion of farming activities disturbing plant and wildlife, domestication of landscape (i.e. feed troughs, hardcore tracks etc.)
- Increased competition for grazing between domestic and wild species.

Pesticide & fertilizer drift

Accidental spray drift into hedge bottoms is very common, particularly in arable fields that are cultivated right up to the field boundary. The removal of hedge base flora has been shown to reduce insect numbers, having an indirect effect on predatory invertebrates, bird, mammal and where relevant, reptile and amphibian populations. The same factors apply to the use of insecticides, many of which are 'broad spectrum' and consequently lethal to a diverse range of invertebrates.

Changes in species

- Global warming has the potential to cause extinctions in a majority of the world's especially valuable ecosystems.
- Depending on a species responses to the warming, especially their ability to migrate to new sites, habitat change in many ecoregions has the potential to result in catastrophic species loss.
- Global warming is likely to have a winnowing effect on ecosystems, filtering out species that are not highly mobile and favoring a less diverse, more "weedy" vegetation and ecosystems that are dominated by pioneer species, invasive species.

Changes in arable farming practices have been identified as important factors in the decline of wildlife.

Water Resources Impacts

- Decreased water quantity and quality in some areas of increased drought
- Increased flood damage due to more intense precipitation events
- Decreased water supply in many water stressed countries (half-billion people in central Asia, southern Africa, and countries surrounding the Mediterranean affected)
- Increased water supply in some other water stressed countries (e.g. parts of Asia)

Consequences for Poultry and Fish

- Changes in temperature and precipitation could cut breeding populations of ducks and other poultries.
- Cold water fish habitat may be reduced and lost
- Migration/breeding cycles may be disrupted for species that depend on temperature signals

Consequences for Livestock production

- Changes in temperature decrease the forage production.
- Heat stress for livestock
- Habitat for livestock will be declined

Human Health impacts

- Expansion of the areas of potential transmission of malaria and dengue fever (medium-to-high confidence); roughly 300 million more people at risk of malaria
- Increased heat-related deaths and illness, affecting particularly the elderly, sick, and those without access to air conditioning
- Increased risks to human life, risk of infectious disease epidemics and many other health risks where floods, droughts or storms increase in frequency and/or intensity
- Decreased winter deaths in some temperate regions

Ecosystem Impacts

- Coral death from exposure to 3-4ºC higher seasonal maximum sea-surface temperatures for 6 months or more
- Substantial reduction in glacier and ice-cap volume; tropical glaciers particularly vulnerable to elimination
- Loss of unique vegetation systems and their endemic species (e.g. vegetation of Cape region of South Africa and some cloud forests)

- Extensive reduction in Arctic summer sea-ice extent with benefits for shipping but adverse effects on sea-ice dependent animals (e.g. polar bears, seals, walrus)
- Coastal wetland loss from sea level rise (up to 10% globally for 20 cm rise, higher percentages in some areas)
- Increased disturbances of ecosystems by fire and insect pests
- Increase net primary productivity of many mid- and high-latitude forests
- Extinction of some critically-endangered and endangered species

Agricultural Carbon Sinks

The potential of agricultural carbon sinks is currently being *reduced* by many common farming operations: "Agricultural practices that disturb the soil—such as tilling, planting mono-crops, removing crop residue, excessive use of fertilizers and pesticides and overgrazing—expose the carbon in the soil to oxygen, allowing it to burn off into the atmosphere."

Yet, there are numerous ways that carbon sequestration measures *could* enhance the use of agricultural land as carbon sinks (OECD, 2022):

- Mineral carbonation of soil
- Erosion control
- Fire management
- Grazing land management
- Improved rotations
- Perennial crops
- Management of organic soils
- Nutrient management
- Organic resource management
- pH management
- Tillage management
- Water management.

The OECD (2022) estimates that such measures have the potential to offset 2–4% of total global GHG emissions by the end of the century.

Potential positive effects of climate change

- Higher temperatures and higher CO_2 concentrations is improving ecosystems productivity
- Increase photosynthesis for some crop plants
- Melting of Arctic ice is opening the Northwest Passage in summer
- Increase in temperature due to global warming, is favorable condition for algae
- Rise in the dense forestation
- Formation of oil reserves

Further Readings:

1. **Climate Change: Observed Impacts on Planet Earth (3rd Edition)**
   Author: Trevor Letcher
   Publisher: Elsevier
   Paperback ISBN: 9780128215753, eBook ISBN: 9780128215760
2. **Global Climate Change**
   Author: K.K. Srivastava, Pardeep Singh, S. Rangabhashiyam, Suruchi Singh
   Publisher: Elsevier
   ISBN: 9780128230978, 0128230975
3. **Climate Change Biology**
   Author: Lee Hannah, Lee Jay Hannah
   Publisher: Academic Press
   ISBN: 9780080921105, 0080921108
4. **Climate Change, Vulnerability and Migration**
   Author: R. B. Bhagat, Sebastian Irudaya Rajan
   Publisher: Routledge, India
   ISBN: 9780367345419, 0367345412
5. **Climate Change Biological and Human Aspects**
   Author: Jonathan Cowie
   Publisher: Cambridge University Press
   ISBN: 9781139852135, 1139852132
6. **The Adaptive Challenge of Climate Change**
   Author: Elin Selboe, Karen L. O'Brien
   Publisher: Cambridge University Press
   ISBN: 9781107022980, 1107022983
7. **Climate Change and Climate Modeling**
   Author: J. David Neelin
   Publisher: Cambridge University Press
   ISBN: 9781139491372, 1139491377
8. **Climate Change Science**
   Causes, Effects and Solutions for Global Warming
   Author: David S-K. Ting, Jacqueline A Stagner
   Publisher: Elsevier
   ISBN: 9780128237670, 0128237678
9. **Introduction to Modern Climate Change**
   Author: Andrew Dessler
   Publisher: Cambridge University Press
   ISBN: 9781107096820, 1107096820
10. **Global Warming: Understanding the Forecast**
   Author: David Archer
   Publisher: Wiley, John Wiley & Sons, Inc.
   ISBN: 9780470943410, 0470943416
11. **Climate Vulnerability**
   Understanding and Addressing Threats to Essential Resources
   Author: Jimmy Adegoke, Roger A. Pielke (Jr.)
   Publisher: Academic Press
   ISBN: 9780123918956, 0123918952
12. **Extreme Weather and Climate**
   Author: C. Donald Ahrens, Perry J. Samson
   Publisher: Cengage Learning
   ISBN: 9781111780241, 1111780242

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