United Nations Food Systems Summit 2021
Scientific Group
https://sc-fss2021.org/

Food Systems Summit Brief
Prepared by Research Partners of the Scientific Group for the Food Systems Summit, May 2021

CLIMATE CHANGE AND FOOD SYSTEMS

by
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ABSTRACT

Climate change affects the functioning of all the components of food systems, often in ways that exacerbate existing predicaments and inequalities between regions of the world and groups in society. At the same time, food systems are a major cause for climate change, accounting for a third of all greenhouse gas emissions. Therefore, food systems can and should play a much bigger role in climate policies. This policy brief highlights nine actions points for climate change adaptation and mitigation in the food systems. The policy brief shows that numerous practices, technologies, knowledge and social capital already exist for climate action in the food systems, with multiple synergies with other important goals such as the conservation of biodiversity, safeguarding of ecosystem services, sustainable land management and reducing social and gender inequalities. Many of these solutions are presently being applied at local scales around the world, even if not at sufficient levels. Hence, the major effort for unleashing their potential would involve overcoming various technical, political-economic and structural barriers for their much wider application. Some other solutions require research and development investments now but focus on helping us meet the longer-term challenges of climate change on food systems in the second half of this century when most existing food production practices will face unprecedented challenges. In the short term, these pro-poor policy changes and support systems can create a range of positive changes well beyond food systems without delay. In the long-term, investments in research will help ensure food security and ecosystem integrity for coming generations.

INTRODUCTION

Climate change affects the functioning of all the components of food systems[1] which embrace the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption, and recycling of food products that originate from agriculture (including livestock), forestry, fisheries, and food industries, and the broader economic, societal, and natural environments in which they are embedded[2]. At the same time, food systems are a major cause of climate change, contributing about a third (21–37%) of the total Greenhouse Gas (GHG) emissions through agriculture and land use, storage, transport, packaging, processing, retail, and consumption[3] (Figure 1).

Climate change will affect food systems differentially across world regions. While some areas, such as northern temperate regions, may in the short term even experience some beneficial changes, tropical and sub-tropical regions worldwide are expected to face changes that are detrimental to food systems. Such changes will have effects on food and nutrition security through a complex web of mechanisms (Figure 1). Critical climate variabilities that affect food and nutrition security include increasing temperatures, changing precipitation patterns and greater frequency or intensity of extreme weather events such as heatwaves, droughts and floods[3]. They impact the productivity of crops, livestock and fisheries by modulating water availability and quality, causing heat stress, and altering the pests and disease environment, including the faster spread of mycotoxins and pathogens. Increased frequency and intensity of floods and droughts can lead to considerable

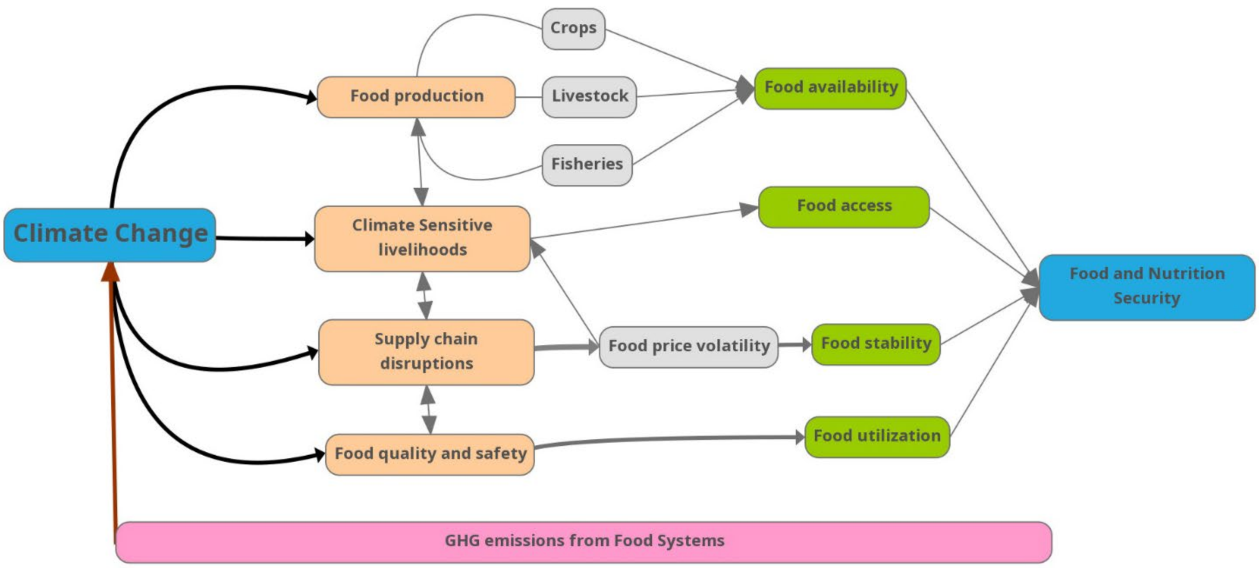

Figure 1: **Linkages between climate change and food systems**

disruptions in food supply chains through harvest failures and infrastructure damage. The exposure of people to heatwaves, droughts and floods can harm their health and lower their productivity affecting their livelihoods and incomes, especially for those engaged in climate-sensitive sectors or working outdoors. This exposure can strongly affect more vulnerable groups in many lower-income countries, e.g., smallholder farmers, low-income households, women and children. Other factors related to climate change that affect food systems are the rise in atmospheric concentrations of CO_2 and, indirectly, land degradation, and reduction in pollination services. Changes in CO_2 levels in the atmosphere affect both crop yields and their nutrient content. Climate change will exacerbate land degradation, through increasing soil erosion especially in sloping and coastal areas, increasing soil salinity in irrigated lands, making climate more arid and prone to desertification in some dryland areas[4,5]. The potential reduction or loss of pollination services also leads to lower crop yields. Conservative estimates, which take into account these climate change impacts only partially, show that the number of people at risk of hunger may increase by 183 million people by 2050 under high emission and low adaptation scenario [i.e., under Shared Socioeconomic Pathway (SSP) 3] compared to low emission and high adaptation scenario (SSP1). An additional 150-600 million people are projected to experience various forms of micronutrient deficiency by 2050 at higher emission scenario[6–8].

The interactions between climate change and food systems have considerable repercussions across all of the dimensions of sustainable development. In fact, in six of the 17 sustainable development goals (SDGs), climate change-food systems interactions increasingly play a major role. These relate to the social goals of zero hunger (SDG 2) and gender equality (SDG5), and the four environmental goals of water resources (SDG 6), climate action (SDG 13), life below water (SDG 14), and life on land (SDG 15). Solutions addressing the challenges posed by climate change - food systems interactions can serve as a critical entry point for promoting the 2030 Agenda for sustainable development well beyond the timeline of the current SDGs[9]. Since these interactions vary according to the country's income, region, and population groups (i.e., gender, age, and location of its population), solutions prioritizing women, younger, and rural people, i.e., "leaving no one behind," can better leverage achievements of SDGs[10].

HOW CLIMATE CHANGE INTERACTS WITH FOOD SYSTEMS AND FOOD SECURITY

Food availability

Considerable evidence has by now emerged indicating that climate change is already negatively affecting crop production in many areas across the world[11,12]. Reductions of 21% in total factor productivity of global agriculture since 1961 have been estimated[13]. It has been found that climate change during the last four-five decades reduced the yields of cereals by about 2%-5% on average globally compared to the situation if there was no climate change[14]. This range of about 5% lower cereal yields due to climate change was also found in regional studies, for example, for wheat and barley in Europe[15], for wheat in India[16], for maize in Africa, Central and Eastern Asia[17], and Central and South America[18]. Higher losses equaling about 5%-20% were found for millet and sorghum yields in West Africa[19], and about 5%-25% lower maize yields in Eastern and Southern Europe[20]. There is growing literature documenting the negative impacts of climate change on the yields of legumes, vegetables, and fruits in drylands, tropical and sub-tropical areas[3,21]. These losses in yields have occurred after taking coping and adaptive actions[3].

In temperate climatic zones, such as northern China, parts of Russia, northern Europe, and parts of Canada, observed climatic changes are increasing the agricultural potentials leading to higher crop production[15,17,22–25]. In many areas, however, this increased production is coming at the expense of lower yield stability due to higher weather variability between seasons. Climate change accounts for about half of food production variability globally. Presently, adaptive strategies to increase crop yields (crop breeding, improved agronomic management, adaptations based on indigenous and local knowledge, etc.) can withstand, at a global average, any impacts of climate change on crop yields. However, the acceleration of climate change can overwhelm this trend in the future; and the impacts are already experienced in many regions. Climate change increased drought-induced food production losses in southern Africa, leading to 26 million people in the region requiring humanitarian assistance in 2015-16[26]. Climate change is also increasing ocean acidification and temperatures, reducing farmed fish and shellfish production as well as wild fish catches, with some regions experiencing losses of 15-35%[3].

The impacts of climate change on food productions are projected to worsen after the 2050s, particularly under higher emission scenarios[3]. In agriculture, the biggest crop yield declines due to climate change are expected to occur in those areas which are already hot and dry, especially in the tropics and sub-tropics, as well as in the global drylands where water scarcity is projected to become more acute[5]. More recent modelling shows that previous projections of climate change impacts on future crop yields underestimated the extent of potential yield declines. For example, many crop modelling studies do not consider the effect of short-term extreme weather events. Although extreme weather events have always posed disruptions in the food systems, climate change is increasing the likelihood of simultaneous crop failures in major crop producing areas in the world[27,28]. Disruptions in storage and distribution infrastructures and on food provisioning due to extreme events systems will also impact food availability, as well as reduction in food exchanges due to lower productivity[29].

New 21st century projections by the Agricultural Model Intercomparison and Improvement Project (AgMIP)[30] using ensembles of latest-generation crop and climate models suggest markedly more pessimistic yield responses for maize, soybean, and rice compared to the original ensemble. End-of-century maize productivity is shifted from +5 to -5% (SSP126) and +1 to -23% (SSP585) — explained by warmer climate projections and a revised crop model ensemble[31]. In contrast, wheat shows stronger high-latitude gains, related to higher CO_2 responses. The 'emergence' of the climate impact signal — when mean changes leave the historical variability — consistently occurs earlier in the new projections, in several main producing regions by 2030. While future yield estimates remain uncertain, these results suggest that major breadbasket regions may contend with a changing profile of climatic risks within the next few decades[31]. While many fruit, vegetable and perennial crops are understudied, higher temperatures are projected to negatively impact their production, with one study estimating a 4% reduction in fruit and vegetable production from climate change[32].

The impacts of climate change on livestock systems and fisheries are studied much less than the major crops. Still, considerable evidence indicates that increased frequency of heatwaves and droughts under climate change can lower livestock productivity and reproduction through heat stress, reduced availability of forage, increased water scarcity and the spread of livestock diseases[3,33]. Increased levels of CO_2 can favor the growth of pasture grasses, especially during rainier seasons and more humid locations [5,34]. In contrast, in many arid and semi-arid locations, the projected effects are mostly negative[33,35,36]. Climate change was found to reduce the maximum sustainable yield of several marine fish populations by about 4%[37]. Every 1°C increase in global warming was projected to decrease mean global animal biomass in the oceans by 5%[38], also redistributing fish populations away from sub-tropical and tropical seas towards poleward areas[39]. It is clear that the association between climate change and human nutrition goes beyond issues of caloric availability, and a growing challenge by 2050 will be providing nutritious and affordable diets.[32]

Food access

The impacts of climate change on agricultural production, supply chains and labor productivity in climate sensitive sectors will influence both food prices and incomes, strongly affecting people's ability to purchase food through these price and income changes[40]. Climate change is projected to increase global cereal prices between 1% to 29 %, depending on the Shared Socioeconomic Pathway considered[3]. The reductions in the yields of legumes, fruits and vegetables will also lead to their higher prices. The impacts of these price increases on food access are not straightforward. Net food selling agricultural producers can benefit from higher food prices[41]. Higher food prices will hurt primarily the urban poor and net food buying agricultural producers[3]. Increased temperatures and more frequent heatwaves will reduce labor productivity for outdoor work and work in closed areas without air conditioning. Lower labor productivity will result in lower incomes and lower purchasing power.

Food stability

Climate change will increase the frequency of extreme water events, such as droughts, floods, hurricanes, and sea storms. Resulting inter-annual variability in food production, destruction of transportation infrastructures, and higher food price volatility can ultimately lead to more volatile global and regional food trade, undermining people's ability to access food in a stable way[3]. These disruptions could have a particularly negative impact on land-locked countries with fewer infrastructural access to global food trade and vulnerable social groups, especially in those locations without functioning and sufficient social protection schemes[12].

Food utilization and safety

Climate change is projected to adversely impact childhood undernutrition and stunting, undernutrition-related childhood mortality and increase of disability-adjusted life years lost, with the largest risks in Africa and Asia[42]. Moreover, climate-related changes in food availability and diet quality are estimated to result in 529,000 excess climate-related deaths with about 2ºC warming by 2050[32]. Most of them are projected to occur in South and East Asia. Extreme climate events will increase risks of undernutrition even on a regional scale via spikes in food prices and reduced income. Exposure to one pathway of food insecurity risks (e.g., lower yields) does not exclude exposure to other pathways (e.g., income reduction). Higher concentrations of atmospheric CO_2 reduces the protein and mineral content of cereals, reducing the quality of food and, subsequently, food utilization[3]. Rising temperatures are improving the conditions for the spread of pathogens and mycotoxins, posing risks to human health and increasing food waste and loss[43]. Climate change is projected to increase the area of spread of mycotoxins from tropical and sub-tropical areas to temperate zones[3]. Reduction in water quality due to climate change will also negatively affect food utilization.

Impacts of food systems on climate systems

GHG emissions from food systems are a major contributor to climate change. Food systems are responsible for about one quarter of global GHG emissions, and even one third if indirect effects on deforestation are included (21%-37%)[3]. Specifically, new estimates by the Food Climate Partnership[44] show that total GHG emissions from the food system were about 16 CO_2 eq yr^{-1} in 2018, or one-third of the total global anthropogenic GHG emissions. Three quarters of these emissions, 13 Gt CO_2 eq yr^{-1}, were generated either during on-farm production or in pre- and post-production activities, such as manufacturing, transport, processing, and waste disposal. The remainder was generated through land use change of natural ecosystems to agricultural land. Results further indicate that pre- and post-production emissions were proportionally more important in high income than in low income countries, and that during 1990-2018, land use change emissions decreased while pre- and post-production emissions increased[45].

Even if fossil fuel-related emissions were stopped immediately, continuation of the current food system emissions could make the below 2°C climate target unachievable[46]. There are significant opportunities for reducing these emissions[47], at the same time, it is important to bear in mind the food security implications when implementing climate mitigation efforts[48,49]. Without compensating policies in place, stringent, abrupt and large-scale application of mitigation options, particularly those which are land-based, can have a negative impact on global hunger and food consumption, with the detrimental impacts being especially acute for vulnerable, low-income regions that already face food security challenges[42]. However, many climate solutions can have mitigation and adaptation synergies together with other co-benefits, including for health, livelihood, and biodiversity[47,50].

SOLUTIONS FOR CLIMATE CHANGE ADAPTATION AND MITIGATION IN FOOD SYSTEMS

Based on the above assessment as well as on the recent IPCC special report on Climate Change and Land[1], the following actions are proposed for uptake by governments, the private sector and civil society. These actions are of two types. Firstly, there are a wide range of both well-tested ready to go solutions, and potential solutions for climate change adaptation and mitigation in the food systems[51] (Actions 1 to 7). Many of these already available solutions are well-known and are being applied at local scales around the world, even if not at sufficient levels. Hence, the major effort for unleashing their potential would involve overcoming various technical and structural barriers for their much wider application. The second type of actions (8 and 9) focus on key promising solutions which can help us meet the longer-term challenges of climate change on the food systems in the second half of this century when most food production practices will face unprecedented challenges.

1. *Amplify efforts for sustainable land management*

Sustainable management of land (SLM), which includes water, supports and maintains ecosystem health, increases agricultural productivity, and contributes to climate change adaptation and mitigation[4,5]. SLM is defined as the use of land resources, including soils, water, animals and plants, to produce goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions (UN 1992 Rio Earth Summit).

There are many practical examples of SLM. Application of water-efficient irrigation methods such as sprinkler and drip irrigation can help increase resilience to increasing aridity under climate change[5]. Adoption of drought resistant crop cultivars under diversified cropping systems is an essential adaptive strategy in many dryland areas[5]. Where suitable, agroforestry is a powerful practice for reducing soil erosion and increasing carbon sequestration, while diversifying livelihoods[47]. Rangeland management systems based on sustainable grazing and re-vegetation can increase rangeland resilience and long-term productivity, while supporting a wide range of ecosystem services. Agroforestry practices, shelterbelts and silvio-pasture systems help reduce soil erosion and sequester carbon, while increasing biodiversity that supports pollination and other ecosystem services[52]. SLM also includes agroecological practices, such as use of organic soil amendments, crop diversification, cover crops, intercropping, etc., which can have positive impacts on ecosystem services, food security and nutrition[53–57]. Indigenous knowledge and local knowledge hold a great array of practices for SLM[58]. Protection and restoration of peatlands and climate-friendly management of peatlands are a key element for ambitious emission reduction strategies[59].

Although SLM has proven positive social and economic returns, the adoption is currently insufficient. Important barriers for adoption are access to the resources for changing practices and the time required for the new practices to become productive. Introduction of payments for ecosystem services and subsidies for SLM can help. Enabling policy frameworks that include both incentives and disincentives, are needed for promoting the adoption of SLM. Land tenure considerations are a major factor contributing to the adoption of SLM[4], particularly for women. Various forms of collective action are crucial for implementing SLM in both privately and communally managed lands[60], however, such efforts need to be strengthened and supported by policy[61]. A greater emphasis on understanding gender-specific differences over land use and land management practices can promote SLM practices more effectively. Improved access to markets, including physical (e.g. transportation), economic (e.g. fair prices), and political (e.g. fair competition) support, raises agricultural profitability and motivates investment into climate change adaptation and SLM. Developing, enabling and promoting access to clean energy sources and technologies can contribute to reducing land degradation and mitigating climate change through decreasing the use of fuelwood and crop residues for energy, while significantly improving health for women and children[62]. Finally, looking at co-benefits between addressing climate change (adaptation and mitigation) and other urgent problems, like land degradation and biodiversity conservation, much can be gained by promoting SLM in agriculture.

2. Promote open and equitable food trade

The very heterogeneous effects of climate change on food production worldwide and the increase in extreme weather events that disrupt local food production activities highlight the importance of international food trade as a key adaptation option to this volatile environment[63,64]. At the same time, strengthening regional and local food systems, through policies and programs which support sustainable local production, can help build a resilient food system. Such policies can include support for urban and peri-urban production, public procurement, and subsidies that encourage the application of sustainable production approaches.

Adapting to changing climate will require a combination of enhanced regional and local food trade as well as international food trade that can act as safety nets in the context of climate crises. To this aim, reducing transaction costs of food trade and maintaining transparent, equitable and well-enforced international food trade governance can strengthen food systems resilience. This will particularly include avoiding imposing export bans. Food trade and food sovereignty are complementary elements of food security, and should not be regarding as mutually exclusive, rather, transparent and fair norms need to be agreed.

Fiscal instruments (e.g. carbon taxes) need to be given high priority in order to reduce fossil fuel use in agriculture. Agricultural subsidies need to be adjusted to encourage the application of sustainable production approaches and to reduce any negative effects from them through trade, and that take power differences into account, e.g. the impacts of subsidized food exports by high-income countries making it harder for farmers in low-income countries to use sustainable methods or sell their products. Trade agreement mechanisms that allow low-income countries to have an equal say in trade governance are needed.

3. *Include food systems in climate financing at scale*

Food systems represent a range of actors and their interlinked value-adding activities that are most impacted by climate change. Food systems are also a major source of GHG emissions. This makes food systems a high priority target for adaptation and mitigation investments. Investments into climate change adaptation and mitigation in the food systems, however, have so far been a tiny fraction of the total amounts of climate finance. Investments into climate change mitigation in the food systems need to be commensurate with the share of GHG emissions coming from the food systems, i.e. about a third of all mitigation funding, which is presently dominated by the energy sector and infrastructure. To illustrate, there are considerable opportunities for climate change adaptation and mitigation through investments into land restoration (e.g. reforestation, sustainable land management, re-seeding degraded rangelands) which allow for sequestering carbon in soils, increase crop and livestock productivity and provide a wide range of other ecosystem services. Estimates show that every dollar invested in land restoration yields from 3 to 6 dollars of return depending on the location across the world[65]. Investments into food value chains for reducing food waste and loss is another area with substantial mitigation and adaptation benefits. A wide range of public and private sources could be harnessed for these investments, such as increasing substantially the annual development aid dedicated to agricultural and rural development, food and nutrition security; increasing investments by the international and regional development banks into food systems, more active involvement of the private sector (e.g. green bonds) and philanthropies.

4. *Strengthen social protection and empowering of the vulnerable*

It is now practically impossible to fully adapt to climate change impacts. Even without climate change, extreme weather events periodically inflict significant disruptions in food systems at the local, regional and even global levels. Climate change will make these disruptions more frequent and more extensive. Therefore, it is essential to strengthen the social protection for vulnerable populations in terms of accessing food during the times of such disruptions. Social protection can involve many forms such as access to subsidized food banks, cash transfers, insurance products, pension schemes and employment guarantee schemes, weather index insurance, and universal income.

Impacts of climate change on food systems are not suffered equally by all social groups. Age, class, gender, race, ethnicity, disability, among others, are social factors that make some peoples more vulnerable than others. Actions to address such inequity and differential impacts imply, on the one hand, strengthening social protection and, on the other hand, empowering marginalized social groups through collective action. Empowering women in societies increases their capacity to improve food security under climate change, making substantial contributions to their own well-being, to that of their families and of their communities. Women's empowerment is crucial to creating effective synergies among adaptation, mitigation, and food security, including targeted agriculture programs to change socially constructed gender biases[66]. Empowerment through collective action and groups-based approaches in the near-term has the potential to equalize relationships on the local, national and global scale[67].

5. *Encourage healthy and sustainable diets*

Transitioning to more healthy and sustainable diets and minimizing food waste could reduce global mortality from 6% to 19% and food-related GHG emissions by 29–70% by 2050[32,68]. According to the WHO, healthy diets are essential to end all forms of malnutrition and protect from non-communicable diseases, including diabetes, heart disease, stroke and cancer. Currently, food consumption deviates from healthy diets with either too much (e.g., red meat and calories) or too little (e.g., fruits and vegetables) food and nutrition supply[69]. Healthy diets have an appropriate calorie intake, according to gender, age, and physical activity level. They are mainly composed of a diversity of plant-based foods, including coarse grains, pulses, fruits and vegetables, nuts, and seeds with low amounts of animal source foods[68]. The current diets of many high-income countries consist of a large share of animal-source foods that are emission-intensive, with red meat consumption higher than the recommended value. Simultaneously, consumption of fresh fruits and vegetables is below recommended value in most countries[70]. Changes toward healthier diets have a mitigation potential of 0.7–8.0 $GtCO_2$-eq $year^{-1}$ by 2050, but social, cultural, environmental, and traditional factors need to be considered to achieve this potential at broad scales[3,50]. One critical problem is that currently, healthy diets are unaffordable to broad sections of societies, even in high-income countries. Sustainable and healthy diets based on diversified intake are often linked to diversified production systems, highlighting the linkages between production and consumption[71].

To encourage dietary transitions towards healthy and sustainable diets, a full range of policy instruments from hard to soft measures are needed[68]. For example, unhealthy consumption of emission-intensive animal-source foods can be disincentivized by applying taxes and charges, whereas adequate consumption of healthy foods such as fruits and vegetables can be incentivized by providing subsidies and raising consumer awareness. Importantly, policies promoting healthy diets need to pay due consideration to the differential roles of animal-source foods in different parts of the world and the important role livestock can play in sustainable agriculture. For example, a recent study from Nepal, Bangladesh, and Uganda showed a reduction in stunting in young children due to adequate intake of animal source foods[72].

6. *Reduce GHG emissions from the food systems*

Before promoting particular changes to the food systems it is important to have an overview of where the most important potentials for reducing GHG emissions are. Agriculture is responsible for about 60% (or even 80% if the indirect land-use change is included) of the total GHG emissions from the global food system[3]. One important message from a systematic meta-analysis of 38,700 farms and 1,600 food processors is the wide range of emissions – about 50-fold difference between the best and worst practices[73]. This means that political and economic measures can achieve major reductions in GHG emissions from existing food systems by applying more broadly current best practices and without waiting for new technologies or behavior changes.

Reducing GHG emissions requires integrated interventions both at the production and consumption sides. On the production side, all those practices increasing soil organic matter contribute to both adaptation and mitigation, while decreasing soil degradation and erosion. Globally cropland soils have lost an estimated 37 GtC (136 Gt CO_2) since the Neolithic revolution[74], recapturing that lost carbon through SLM would not only contribute to climate change mitigation, it would also increase the ecological resilience of agro-ecosystems and provide opportunities for income and employment in rural societies. A wide range of practices exist, e.g. conservation agriculture practices, lower GHG emissions from fertilizers, agroecology-based approaches, agroforestry or integrating agriculture and livestock systems, which have an estimated potential to sequester 3-6.5 $GtCO_2$-eq/year[75]. In rangelands as well, extensive and mixed farming systems, through improved management practices, have the capacity to reduce emissions. Presently, there are between 200 and 500 million pastoralists in the world who act as stewards for 25% of the world's land[76].

Meat and dairy consumption is often considered a major culprit of high GHG emissions from food systems, but the discussion often lacks nuance. It is clear that the overall emissions from consumption of animal protein (mainly meat and dairy products) must be reduced to achieve mitigation targets compatible with the Paris Agreement. However, in some regions of the world, an increased consumption of animal protein would be desirable from a health perspective. It is also clear that livestock plays an important role in sustainable food systems – particularly extensive livestock can help to reduce the need for mineral fertilizers, and they can produce food from areas unsuitable for growing crops (notably drylands, cold regions, and mountainous regions). Finally, expansion of post-harvest processing, refrigeration, subsidy shifts and behavioral changes are needed to reduce food loss and waste and lower the consumption of animal products in those places where intake is too high. Incentives for emission reductions should be given to agricultural producers by applying GHG emission taxes also in agriculture, or including agriculture in existing emission trading schemes.

7. Support urban and peri-urban agriculture

Promoting urban and peri-urban agriculture (PUA) can help increase the resilience of local and regional food systems, create jobs, and under certain conditions, help reduce GHG emissions from food transportation[77] and decrease uncertainties that may be associated with disruptions in food systems. PUA includes crop production, livestock rearing, aquaculture, agroforestry, beekeeping, and horticulture within and around urban areas[78]. Around 1 billion urban inhabitants (i.e., 30% of global urban population) can be nourished by producing food in PUA[79]. Simultaneously, PUA can support the regionalization of food systems, reducing emissions from food transportation[77]. Moreover, PUA is multi-functional and is practiced to follow various purposes: it helps to improve food security, generate income, provide employment[80,81], especially for women and youth and reconnect urban habitants with nature cycles. Subsequently, PUA has not only a great potential to reduce poverty, and improve nutrition, but also provides a series of ecosystem services such as reduced urban heat island effects[82], or fixation of atmospheric nitrogen and carbon when using the appropriate vegetation[83], thus contributing to climate change mitigation and adaptation. PUA also comprises elements of circular economy, where household organic waste can be used as livestock and poultry feed rather than treated as waste[84], subsequently reducing environmental pollution and greenhouse gas emissions. PUA contributes to increasing the resilience of urban poor households to food price shocks. Previous research on PUA showed that it was the main and only economic activity of poor urban households in many low income countries. And even when PUA is not the main economic activity of poor urban households, it made a significant contribution to smoothening seasonal food consumption shocks among the urban poor[80].

8. Invest in research

There have been tremendous advances in better understanding of the interactions between climate change and food systems in recent decades[1,85]. These investments in research and science need to be expanded into the future, not least to ensure viable agricultural systems in the long term when climate change will expose current staple food crops to unprecedented stress. Areas for investments include agroecological approaches to food production, which have received much lower investment,[97] breeding of drought-resistant crop cultivars and cultivars with improved nitrogen use to avoid emission of N_2O[86], improved understanding of climate change impacts on both staple and non-staple foods (including impacts on nutritious values of crops[87], particularly vegetables and fruits, and the subsequent implications for the healthy diets and the full costs of healthy diets. Along with these environmental dimensions, increased investments into research on social and economic impacts of climate change are needed, for example, on such areas as understanding the impacts of climate change and mitigation and adaptation options on vulnerable groups, research on participatory and transdisciplinary approaches to facilitate dialogue between indigenous and scientific knowledge, research on collective action, social innovation and mechanisms to increase food security.

9. Support perennial crop development and cultivation

About 87% of the world's harvested area is cultivated with annual crops, mainly grains (cereals, oilseeds, and pulses) that are terminated and resown every year/season[88]. A shift to perennial grain crops would drastically cut GHG emissions from agriculture, and even turn cropping into a carbon sink, while significantly reducing erosion and nutrient leakage. Continued climate change is rendering our existing cultivars increasingly vulnerable to stress and ultimately unfit for many regions of the world[89]. New perennial cultivars have the potential to create cropping systems that are genuinely adapted for the climatic conditions towards the second half of this century. Perennial crops have the potential to drastically reduce the costs of farming by cutting the need for external inputs (seeds, fertilizers, pesticides, machinery, energy, and labour) and hence generate social and economic advantages particularly to farmers and rural societies[90].

Development of new perennial grain crops through *de novo* domestication and wide hybridization have advanced tremendously in the last decade thanks to scientific and technological advancements such as genomic selection technology[91]. The key benefits of perennial crops are that their widespread root systems can help sequester carbon in the soils for extended periods of time, water and minerals are used by perennial plants more efficiently, weeds are effectively managed[90,92]. Many of them are also exceptionally drought resistant and can bring soil erosion and nutrient leaching to practical minimum[93]. There are already commercial cultivars of perennial rice[94] and successful semi-commercial experiments with perennial Intermediate Wheatgrass, a wheat relative[95]. The yields of Intermediate Wheatgrass are still low compared to conventional wheat, but continued breeding can result in a competitive perennial alternative to wheat in 20-25 years[96]. A range of other crops is in the pipeline for domestication and breeding as perennial crops such as barley, oilseeds, and pulses. Equally important is the development of perennial polycultures, such as intercropping of perennial grains and legumes, making the system more or less self-sufficient in nitrogen[98]. These results are proofs of concept that high yielding perennial cultivars can be developed in the timeframe of a few decades, but research on all aspects of such a "perennial revolution" are urgently needed.

CONCLUSION

This policy brief has two central messages. The bad news is that climate change is projected to affect food systems around the world significantly, often in ways that exacerbate existing frailties/weaknesses and inequalities between regions of the world and groups in society. The good news is that many practices, technologies, knowledge and social capital already exist to address climate change constructively, both in terms of mitigation and adaptation, as well as synergies between them and co-benefits with other important goals such as the conservation of biodiversity and other ecosystem services. Therefore, food systems, can and should play a much bigger role in climate policies. In the short term, pro-poor policy changes and support systems can unleash a range of positive changes well beyond food systems without delay. In the long-term, there is an urgent need to invest in research for ensuring food security and ecosystem integrity for coming generations.

Acknowledgments
The authors thank Dr. Timothy Crews (The Land Institute, Salina, USA), and Prof. Dr. Joachim von Braun (Chair, UNFSS Scientific Group) for comments on the earlier versions of the brief.

REFERENCES

1. IPCC. *Climate Change and Land: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. (2019).

2. von Braun, J., Afsana, K., Fresco, L. O., Hassan, M. & Torero, M. *Food Systems – Definition, Concept and Application for the UN Food Systems Summit. A paper from the Scientific Group of the UN Food Systems Summit.* (2021).

3. Mbow, C. *et al.* Food Security. in *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (eds. [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Z., R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. P. P. & P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. M.) (2019).

4. Olsson, L. *et al.* Land Degradation. in *Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (2019).

5. Mirzabaev, A. *et al.* Desertification. in *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (eds. P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. P., D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. P. & J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. M.) (2019).

6. Myers, S. S. *et al.* Climate Change and Global Food Systems: Potential Impacts on Food Security and Undernutrition. *Annual Review of Public Health* **38**, 259–277 (2017).

7. Zhu, C. *et al.* Carbon dioxide (CO2) levels this century will alter the protein, micronutrients, and vitamin content of rice grains with potential health consequences for the poorest rice-dependent countries. *Sci. Adv.* **4**, (2018).

8. Medek, D. E., Schwartz, J. & Myers, S. S. Estimated effects of future atmospheric co2 concentrations on protein intake and the risk of protein deficiency by country and region. *Environ. Health Perspect.* **125**, (2017).

9. Pradhan, P., Costa, L., Rybski, D., Lucht, W. & Kropp, J. P. A Systematic Study of Sustainable Development Goal (SDG) Interactions. *Earth's Futur.* **5**, 1169–1179 (2017).

10. Warchold, A., Pradhan, P. & Kropp, J. P. Variations in sustainable development goal interactions: Population, regional, and income disaggregation. *Sustain. Dev.* **29**, 285–299 (2021).

11. Kim, W., Iizumi, T. & Nishimori, M. Global patterns of crop production losses associated with droughts from 1983 to 2009. *J. Appl. Meteorol. Climatol.* **58**, 1233–1244 (2019).

12. FAO. *The future of food and agriculture – Alternative pathways to 2050*. (2018).

13. Ortiz-Bobea, A., Ault, T. R., Carrillo, C. M., Chambers, R. G. & Lobell, D. B. Anthropogenic climate change has slowed global agricultural productivity growth. *Nat. Clim. Chang.* **11**, 306–312 (2021).

14. Iizumi, T., Shin, Y., Kim, W., Kim, M. & Choi, J. Global crop yield forecasting using seasonal climate information from a multi-model ensemble. *Clim. Serv.* **11**, 13–23 (2018).

15. Moore, F. C. & Lobell, D. B. The fingerprint of climate trends on european crop yields. *Proc. Natl. Acad. Sci. U. S. A.* **112**, 2970–2975 (2015).

16. Gupta, R., Somanathan, E. & Dey, S. Global warming and local air pollution have reduced wheat yields in India. *Clim. Change* **140**, 593–604 (2017).

17. Ray, D. K. *et al.* Climate change has likely already affected global food production. *PLoS One* **14**, e0217148 (2019).

18. Verón, S. R., de Abelleyra, D. & Lobell, D. B. Impacts of precipitation and temperature on crop yields in the Pampas. *Clim. Change* **130**, 235–245 (2015).

19. Sultan, B., Defrance, D. & Iizumi, T. Evidence of crop production losses in West Africa due to historical global warming in two crop models. *Sci. Rep.* **9**, 1–15 (2019).

20. Agnolucci, P. & De Lipsis, V. Long-run trend in agricultural yield and climatic factors in Europe. *Clim. Change* **159**, 385–405 (2020).

21. Scheelbeek, P. F. D. *et al.* Effect of environmental changes on vegetable and legume yields and nutritional quality. *Proc. Natl. Acad. Sci. U. S. A.* **115**, 6804–6809 (2018).

22. Potopová, V. *et al.* The impacts of key adverse weather events on the field-grown vegetable yield variability in the Czech Republic from 1961 to 2014. *Int. J. Climatol.* **37**, 1648–1664 (2017).

23. Meng, Q. *et al.* The benefits of recent warming for maize production in high latitude China. *Climatic Change* **122**, 341–349 (2014).

24. Wang, H. & Hijmans, R. J. Climate change and geographic shifts in rice production in China. *Environ. Res. Commun.* **1**, 011008 (2019).

25. Bisbis, M. B., Gruda, N. & Blanke, M. Potential impacts of climate change on vegetable production and product quality – A review. *Journal of Cleaner Production* **170**, 1602–1620 (2018).

26. Funk, C. *et al.* 18. Anthropogenic enhancement of moderate-to-strong El Niño events likely contributed to drought and poor harvests in southern Africa during 2016. *Bull. Am. Meteorol. Soc.* **99**, S91–S96 (2018).

27. Anderson, W. B., Seager, R., Baethgen, W., Cane, M. & You, L. Synchronous crop failures and climate-forced production variability. *Sci. Adv.* **5**, eaaw1976 (2019).

28. Heino, M., Guillaume, J. H. A., Müller, C., Iizumi, T. & Kummu, M. A multi-model analysis of teleconnected crop yield variability in a range of cropping systems. *Earth Syst. Dyn.* **11**, 113–128 (2020).

29. Rivera Ferre, M. G. Impacts of Climate Change on Food Availability: Distribution and Exchange of Food BT - Global Environmental Change. in (ed. Freedman, B.) 701–707 (Springer Netherlands, 2014). doi:10.1007/978-94-007-5784-4_119

30. Rosenzweig, C., Mutter, C. Z. & Contreras, E. M. *Handbook of Climate Change and Agroecosystems -- Climate Change and Farming System Planning in Africa and South Asia: AgMIP Stakeholder-driven Research (In 2 Parts). Series on Climate Change Impacts, Adaptation, and Mitigation (Vol. 5).* (World Scientific Publishing, 2021).

31. Jägermeyr, J. *et al.* Climate change signal in global agriculture emerges earlier in new generation of climate and crop models. *Nat. Food(under Rev.*

32. Springmann, M. *et al.* Global and regional health effects of future food production under climate change: A modelling study. *Lancet* **387**, 1937–1946 (2016).

33. Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T. & Woznicki, S. A. Climate change and livestock: Impacts, adaptation, and mitigation. *Clim. Risk Manag.* **16**, 145–163 (2017).

34. Herrero, M. *et al.* Climate change and pastoralism: Impacts, consequences and adaptation. *OIE Rev. Sci. Tech.* **35**, 417–433 (2016).

35. Fao. *Climate change and food systems: Global assessments and implications for food security and trade*. (2015).

36. Boone, R. B., Conant, R. T., Sircely, J., Thornton, P. K. & Herrero, M. Climate change impacts on selected global rangeland ecosystem services. *Glob. Chang. Biol.* **24**, 1382–1393 (2018).

37. Free, C. M. *et al.* Impacts of historical warming on marine fisheries production. *Science (80-.).* **363**, 979 LP – 983 (2019).

38. Lotze, H. K. *et al.* Global ensemble projections reveal trophic amplification of ocean biomass declines with climate change. *Proc. Natl. Acad. Sci. U. S. A.* **116**, 12907–12912 (2019).

39. Oremus, K. L. *et al.* Governance challenges for tropical nations losing fish species due to climate change. *Nat. Sustain.* **3**, 277–280 (2020).

40. Baarsch, F. *et al.* The impact of climate change on incomes and convergence in Africa. *World Dev.* **126**, 104699 (2020).

41. Hertel, T. W., Burke, M. B. & Lobell, D. B. The poverty implications of climate-induced crop yield changes by 2030. *Glob. Environ. Chang.* **20**, 577–585 (2010).

42. Hasegawa, T. *et al.* Risk of increased food insecurity under stringent global climate change mitigation policy. *Nat. Clim. Chang.* **8**, 699–703 (2018).

43. Battilani, P. Recent advances in modeling the risk of mycotoxin contamination in crops. *Current Opinion in Food Science* **11**, 10–15 (2016).

44. Rosenzweig, C., F., Tubiello, D., Sandalow, Benoit, P. & Hayek, M. Finding and Fixing Food System Emissions: The Double Helix of Science and Policy. *Environ. Res. Lett.* (2021).

45. Tubiello F. N. et al. Greenhouse Gas Emissions from Food Systems: Building the Evidence Base. *Environ. Res. Lett.* (2021).

46. Clark, M. A. *et al.* Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. *Science (80-.).* **370**, 705 LP – 708 (2020).

47. Smith, P., J. *et al.* nterlinkages Between Desertification, Land Degradation Food Security and Greenhouse Gas Fluxes: Synergies, Trade-offs and Integrated Response Options. in *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (eds. [P.R. Shukla, J. Skea, E. C. B., V. Masson-Delmotte, H.- O. Portner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. H., S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. & Press, I.) (2019).

48. Frank, S. *et al.* Agricultural non-CO2 emission reduction potential in the context of the 1.5 °C target. *Nat. Clim. Chang.* **9**, 66–72 (2019).

49. Hasegawa, T. *et al.* Risk of increased food insecurity under stringent global climate change mitigation policy. *Nature Climate Change* **8**, 699–703 (2018).

50. Rosenzweig, C. *et al.* Climate change responses benefit from a global food system approach. *Nat. Food* **1**, 94–97 (2020).

51. Herrero, M. *et al.* Innovation can accelerate the transition towards a sustainable food system. *Nat. Food* **1**, 266–272 (2020).

52. Kuyah, S. *et al.* Agroforestry delivers a win-win solution for ecosystem services in sub-Saharan Africa. A meta-analysis. *Agron. Sustain. Dev.* **39**, 1–18 (2019).

53. Bezner Kerr, R. *et al.* Can agroecology improve food security and nutrition? A review. *Glob. Food Sec.* **29**, 100540 (2021).

54. Beillouin, D., Ben-Ari, T. & Makowski, D. Evidence map of crop diversification strategies at the global scale. *Environmental Research Letters* **14**, 123001 (2019).

55. Muller, A. *et al.* Strategies for feeding the world more sustainably with organic agriculture. *Nat. Commun.* **8**, 1–13 (2017).

56. Tamburini, G. *et al.* Agricultural diversification promotes multiple ecosystem services without compromising yield. *Sci. Adv.* **6**, eaba1715 (2020).

57. Kremen, C. & Merenlender, A. M. Landscapes that work for biodiversity and people. *Science* **362**, (2018).

58. Rivera-ferre, M. G. *et al.* Traditional agricultural knowledge in land management: the potential contributions of ethnographic research to climate change adaptation in India, Bangladesh, Nepal, and Pakistan. *Climate and Development* (2021). doi:10.1080/17565529.2020.1848780

59. Humpenöder, F. *et al.* Peatland protection and restoration are key for climate change mitigation. *Environ. Res. Lett.* **15**, 104093 (2020).

60. Pretty, J. Social Capital and the Collective Management of Resources. *Science* **302**, 1912–1914 (2003).

61. Isgren, E. 'If the change is going to happen it's not by us'': Exploring the role of NGOs in the politicization of Ugandan agriculture'. *J. Rural Stud.* **63**, 180–189 (2018).

62. Sana, A., Meda, N., Badoum, G., Kafando, B. & Bouland, C. Primary cooking fuel choice and respiratory health outcomes among women in charge of household cooking in ouagadougou, Burkina faso: Cross-sectional study. *Int. J. Environ. Res. Public Health* **16**, (2019).

63. Van Meijl, H. *et al.* Comparing impacts of climate change and mitigation on global agriculture by 2050. *Environ. Res. Lett.* **13**, 064021 (2018).

64. Stevanović, M. *et al.* The impact of high-end climate change on agricultural welfare. *Sci. Adv.* **2**, e1501452 (2016).

65. Nkonya, E. *et al. Global cost of land degradation*. *Economics of Land Degradation and Improvement - A Global Assessment for Sustainable Development* (2015). doi:10.1007/978-3-319-19168-3_6

66. Kerr, R. B., Chilanga, E., Nyantakyi-Frimpong, H., Luginaah, I. & Lupafya, E. Integrated agriculture programs to address malnutrition in northern Malawi. *BMC Public Health* **16**, 1–14 (2016).

67. Ringler, C., Quisumbing, A. R., Bryan, E. & Meinzen-Dick, R. *Enhancing Women's Assets to Manage Risk Under Climate Change: Potential for Group-based Approaches*. (International Food Policy Research Institute, Washington, DC, USA, 65 pp., 2014).

68. Willett, W. *et al.* Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *The Lancet* **393**, 447–492 (2019).

69. Pradhan, P. & Kropp, J. P. Interplay between diets, health, and climate change. *Sustain.* **12**, 3878 (2020).

70. Bodirsky, B. L., Dietrich, J. P., Martinelli, E., Stenstad, A., Pradhan, P. & Gabrysch, S., Mishra, A., Weindl, I., Le Mouël, C., Rolinski, S., Baumstark, L., Wang, X., Waid, J. L., Lotze-Campen, H., Popp, A. The ongoing nutrition transition thwarts long-term targets for food security, public health and environmental protection. *Sci. Rep.* (2020).

71. Chepkoech, W., Mungai, N. W., Stöber, S. & Lotze-Campen, H. Understanding adaptive capacity of smallholder African indigenous vegetable farmers to climate change in Kenya. *Clim. Risk Manag.* **27**, 100204 (2020).

72. Zaharia, S. *et al.* Sustained intake of animal-sourced foods is associated with less stunting in young children. *Nat. Food* **2**, 246–254 (2021).

73. Poore, J. & Nemecek, T. Reducing food's environmental impacts through producers and consumers. *Science (80-.).* **360**, 987–992 (2018).

74. Sanderman, J., Hengl, T. & Fiske, G. J. Soil carbon debt of 12,000 years of human land use. *Proc. Natl. Acad. Sci.* **114**, 9575 LP – 9580 (2017).

75. Arneth, A. *et al.* Restoring degraded lands. *Annu. Rev. Environ. Resour.* **46**, (2021).

76. Niamir-Fuller, M. Towards sustainability in the extensive and intensive livestock sectors. *OIE Rev. Sci. Tech.* **35**, 371–387 (2016).

77. Pradhan, P. *et al.* Urban Food Systems: How Regionalization Can Contribute to Climate Change Mitigation. *Environ. Sci. Technol.* **54**, 10551–10560 (2020).

78. Clinton, N. *et al.* A Global Geospatial Ecosystem Services Estimate of Urban Agriculture. *Earth's Futur.* **6**, 40–60 (2018).

79. Kriewald, S., Pradhan, P., Costa, L., Ros, A. G. C. & Kropp, J. P. Hungry cities: How local food self-sufficiency relates to climate change, diets, and urbanisation. *Environ. Res. Lett.* **14**, 094007 (2019).

80. Poulsen, M. N., McNab, P. R., Clayton, M. L. & Neff, R. A. A systematic review of urban agriculture and food security impacts in low-income countries. *Food Policy* **55**, 131–146 (2015).

81. Warren, E., Hawkesworth, S. & Knai, C. Investigating the association between urban agriculture and food security, dietary diversity, and nutritional status: A systematic literature review. *Food Policy* **53**, 54–66 (2015).

82. Li, D., Bou-Zeid, E. & Oppenheimer, M. The effectiveness of cool and green roofs as urban heat island mitigation strategies. *Environ. Res. Lett.* **9**, 055002 (2014).

83. Beniston, J. & Lal, R. Improving soil quality for urban agriculture in the north central U.S. in *Carbon Sequestration in Urban Ecosystems* 279–313 (Springer Netherlands, 2012). doi:10.1007/978-94-007-2366-5_15

84. Ibrahim, A. A. M. & Elariane, S. A. Feasibility tools for urban animal husbandry in cities: case of greater Cairo. *Urban Res. Pract.* **11**, 111–138 (2018).

85. Wheeler, T. & Von Braun, J. Climate change impacts on global food security. *Science* **341**, 508–513 (2013).

86. Coskun, D., Britto, D. T., Shi, W. & Kronzucker, H. J. Nitrogen transformations in modern agriculture and the role of biological nitrification inhibition. *Nature Plants* **3**, 1–10 (2017).

87. Soares, J. C., Santos, C. S., Carvalho, S. M. P., Pintado, M. M. & Vasconcelos, M. W. Preserving the nutritional quality of crop plants under a changing climate: importance and strategies. *Plant and Soil* **443**, 1–26 (2019).

88. Monfreda, C., Ramankutty, N. & Foley, J. A. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochem. Cycles* **22**, (2008).

89. Altieri, M. A., Nicholls, C. I., Henao, A. & Lana, M. A. Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development* **35**, 869–890 (2015).

90. Crews, T. E., Carton, W. & Olsson, L. Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. *Glob. Sustain.* **1**, (2018).

91. Crain, J., DeHaan, L. & Poland, J. Genomic prediction enables rapid selection of high-performing genets in an intermediate wheatgrass breeding program. *Plant Genome* e20080 (2021). doi:10.1002/tpg2.20080

92. DeHaan, L. *et al.* Roadmap for Accelerated Domestication of an Emerging Perennial Grain Crop. *Trends in Plant Science* **25**, 525–537 (2020).

93. Sprunger, C. D., Culman, S. W., Peralta, A. L., DuPont, S. T., Lennon, J. T., & Snapp, S. S. (2019). Perennial grain crop roots and nitrogen management shape soil food webs and soil carbon dynamics. Soil Biology and Biochemistry, 137, 107573..

94. Zhang, Y. *et al.* An innovated crop management scheme for perennial rice cropping system and its impacts on sustainable rice production. *Eur. J. Agron.* **122**, 126186 (2021).

95. Lanker, M., Bell, M. & Picasso, V. D. Farmer perspectives and experiences introducing the novel perennial grain Kernza intermediate wheatgrass in the US Midwest. *Renew. Agric. Food Syst.* **35**, 653–662 (2020).

96. Bajgain, P. *et al.* 'MN-Clearwater', the first food-grade intermediate wheatgrass (Kernza perennial grain) cultivar. *J. Plant Regist.* **14**, 288–297 (2020).

97. HLPE, 2019. Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. FAO, Rome, pp. 1–162.

98. Crews, T. E. *et al.* Going where no grains have gone before: From early to mid-succession. *Agriculture, Ecosystems and Environment* **223**, 223–238 (2016)

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