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Climate-resilient agronomy: Innovations for sustainable agriculture in the Anthropocene

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Abstract
Agriculture is now facing the perfect storm of climate change, increasing costs of fertilizer, water, and energy, and increasing food demands from a larger and wealthier human population. These factors point to a global food deficit unless the efficiency and resilience of crop production is increased. The paradigm of agricultural research and practice in the last half-century has been largely defined by soil-water-plant relationships. The intensification of agriculture, which has focused on improving production under well-defined, optimized conditions, typically with significant agronomic inputs, has brought significant increases in crop yields, allowing the global population to exceed 7 billion by 2013. At the same time, however, this intensive cultivation of a limited number of crop species has drastically narrowed the number of plant species humans rely on, and jeopardizes long-term food security in the face of changing environmental conditions. Since the Pleistocene, 10,000 years ago, it is estimated that about 7,000 plant species have been cultivated; yet today, just three wheat, maize, and rice provide 70% of the world's energy intake.

In a world where optimal conditions for agriculture are becoming less predictable, a new agricultural paradigm is required, one of diversified, resilient agricultural systems that can adapt to the range of environmental conditions expected in a changing climate. Climate-Resilient Agriculture (CRA) should reduce dependence on high-input, ecologically damaging growing practices and increase the diversity and thus the resilience of the agricultural systems. The first five years of the "Anthropocene", a period when human activities dominated the current terrestrial state, have been marked by extreme, unusual global events, ranging from the Japanese Tsunami in 2011 to the reversal of the July 2007 sub-arctic Beaufort High (under the form of cyclones) to repeated droughts in the US and Africa during 2012-2013. There will be economic consequences to the changes in weather patterns; indeed, US market indices showed the trend of having a negative return of investments after January 2012.

Keywords: Agronomy, agriculture, climate, Ai, crispr-cas9

Introduction

Due to globalisation, the changes in temperature may not be uniform across the planet. Within this consortium, the team has been collaborating on several projects focusing on minimising the Greenhouse Gas emissions from horticultural production systems. In the past 19 years, it has been reported that 68% of the observed temperature rise has been due to anthropogenic activities, with this increasing to 111% in the past 10 years. Following projections, the team produced in 2002 its first predictions on how climate change would impact British Agriculture up to 2100. The forecast mentions Southern Britain becoming warmer and dryer, which will influence reduced crop yields from water stress on sandy soils. Further forecasts include increased incidences of pests and plant diseases, with increased storms affecting soil structure due to erosion (Hansen & Coffey, 2012) [28]. Climate-resilient agronomy aims at developing sustainable agriculture systems that can provide lasting, diversified and abundant supplies of food while continuously maintaining or improving the environment and bringing benefits to society. Climatic change, in association with expected sustained growth in population, has raised fears about global food security and agricultural sustainability. A number of pivotal challenges must be addressed in agriculture: (1) to develop monitoring tools and models to better predict forthcoming changes in both biophysical and socio-economical elements and consequences in cropping systems; (2) to design farming strategies able to preserve high inputs efficiency and low environmental impacts, notably concerning water and nutrients; (3) to create innovative cropping systems by developing breeding techniques, genetic resources, and knowledge in crop ecophysiology; and (4) to enhance farm resilience via the development of integrated methods to reduce risks, diversity sources of income biomass, and to increase the sustainability and the overall efficiency of agro-ecosystem management (Clay & S. Zimmerer, 2020) [12]. In the light of the expected impact of climatic change in agriculture, notable recent attempts have been made to circumvent climate alterations. Post-establishing the opportuneness to climate changes and assessing their impacts, however, a key issue consists in the design of appropriate countering actions adapted to the time and the place. For a given cropping system and region, a number of adaptation options may be picked among a quite large set of strategies ranging from the mere delaying of an intervention to radical change in field management. A century of agronomy has revealed a huge diversity of systems and tools able to achieve a given goal while designs of adaptation schemes necessarily rely on a database including both specific scientific knowledge and a long empirical learning obtained through a combination of model studies and field experiments on various spatial and temporal scales.

The Role of CRISPR-Cas9 in Agriculture

Pests and diseases, as well as evoked environmental conditions, contribute significantly to yield losses in crop production. It is estimated that about 20% of potential losses are due to plant diseases, whereas the adverse effect of abiotic stresses makes this rate even more severe. The widely used pesticide vaccinations have destructive effects on beneficial organisms, the food chain, the environment, as well as being a burden on farmers in both additional chemical costs and workload (Erdoğan *et al.*, 2023). For these reasons, it has become mandatory to find alternative advantageous solutions to prevent negative effects on agriculturally advantageous plants. The development of disease and adverse condition-resistant plants today represents one of the pioneering applications in the area of sustainable agriculture.

In every period, it is possible to respond favorably to the environment with high systems such as global warming, the GR gene over-expressed from the soja genome inserted resistance to Sprays so that the patented plants -According to the claim, plants such as soybean are resistant to Sprays herbicides. Dez M. Xavier, a soybean variety producer in Brazil, began to sell soybean varieties containing the alleged genetically modified gene in 2010. Turkish Biotechnology Institute Land Plant Institute Meyve Araþtýrma aggregate botanical expert Canan Makbule Adak had prepared the expert report to prevent the entry of these plants into Turkey and delivered it to the appropriate ministerial units.

ZeLjan RSI with BRDyaY for my ability ZZ alAM attempts to avoid creating a food crisis in Europe by introducing yensi to the European Union rules of my ability relating to directives. However, these plants, on the American continent, soja EuropLos; Over 180 million hectares Soja AmerikLos, including in China, with more than 90% of genetically modified soybeans produced in America-soja by Ren according to biodynamic nces aylaNoTY many things generated and do not create not include change. Because of their inputs. Japan harbors a considerable market potential with Fin increases in the number of unable SaP technicians with patent time consuming plasma emT00. As such, three alternatives to the selection of patented plant technology can be mentioned.

Overview of CRISPR-Cas9 Technology

The programming of cash crops to make them climate-resilient is key to ensuring food security. In turn, the existence of food security is fundamental to the maintenance of civil order and political stability. Food safety is influenced by both the amount and quality of products that can be provided per unit land area. The global area under cultivation is more or less fixed, and thus there is an urgent need to realize sustainable, high-yielding crop production. This is particularly critical given the global population explosion. Not only will the population increase further, but the living standards of growing numbers of persons will also rise, notably in the developing nations. Hence, the quantities of petroleum-based fertilizers and pesticides in use will also increase dramatically. It is already the case that water and soil are being spoiled, and farmland pests are causing damage on a massive scale (Haque *et al.*, 2018) [29]. Since global warming will be aggravated by the petroleum-based agricultural chemicals currently in use, there is a need for environmentally friendly, sustainable agriculture. This must involve a reduction in both amounts used, and frequency of application. The use of most recently developed genome editing technologies to create new materials provides genuine hope for agricultural advances. This approach includes improvements in plant species that have not been successfully manipulated by current biotechnological techniques. Formulation of agrochemical compounds or application of low-toxicity substances that are capable of effectively controlling respective pest species has proven to be tricky militating against comprehensive plant protection under climatically modified pest pressure. That provides the impetus for the exploration of new, durable tools in the agrochemical industry. The rapidly expanding field of genome editing held the promise of a successful contribution to the maturation of these sectors.

Applications in Crop Improvement

As food demand is expected to double in the next 50 years, because of population growth, urbanization trends and dietary changes, it is crucial to guarantee food security in a global context threatened by climate change. Crop cultivation is expected to face the main brunt because of biotic and abiotic stresses that are increasingly affecting yields due to climate change. There is a global consensus among scientists that the temperature is increasing and that those increases are primarily due to greenhouse gas concentrations. Nevertheless, the agriculture sector faces significant challenges: crop yield potential is stagnating, or declining for some crops, while the demand for food, feed and now, increasingly, for biofuels continues to rise. Additionally, the effects of climate change, including on rainfall patterns and intensity, mean that the agriculture sector must adapt while achieving substantial reductions in GHG emissions. Agriculture contributes about 14% of global GHG emissions, with a potential to increase to 18% by 2050. On the other side of the coin, agriculture has the potential to contribute to GHG mitigation. Consequently, efforts are prompted to embrace agriculture transformation and adopt climate-smart practices.

Agricultural strategies have thus far focussed on increasing production through intensification and input increases. These strategies have been partially successful, but have locked in additional vulnerabilities to stresses, and there is now a necessity to simultaneously increase the resilience of agriculture to challenges. A sustainable agricultural system will require agriculture to efficiently manage resources and inputs to limit its impact on biodiversity and water quality and quantity, it will need to adapt to changes already underway (temperature, rainfall, sea level rise) and be made more resilient to extreme and uncertain changes, such as those in the global food supply chain, the trade-offs between pressure on ecosystem services and livelihoods, and the competition for food and feed stocks with other sectors (González Guzmán *et al.*, 2021) [24].

Ethical Considerations and Regulations

In this age of climate change, future generations are increasingly likely to have to cultivate marginal (as yet uncultivated) and/or non-indigenous land to feed themselves and ensure continued biofuel production (Christian Rose & Chilvers, 2018) [51]. Given that our ability to develop soil and land for cultivation has now repeatedly been found to have destroyed healthy land and successful societies, it is yet to be agreed that cultivating marginal land is a good idea, given or accepted. Whatever may be decided, statistics recording agricultural 'frontier expansion' are likely to become essential. It seems obvious that forced agricultural migration in regions abruptly made barren by severe drought affords some chance of documenting this.

Climate-resilient agronomy (and perhaps more importantly, agroecology) will require the generation of entirely novel innovations to keep pace with changing climates, the increasingly accelerated imposition of such change, land-use pressures and legislation (J. S. Hamburger, 2018) [26]. Broadly speaking, such innovations will be of two types. Firstly, they will involve taking an integrated systems approach to agronomy and ecological services that might support agriculture, e.g., to generate and preserve pollinator populations - this would involve multiple 'lines' or innovations, such as development of new technologies, deployments of plant shelters, the implementation of agro-ecological interventions, etc.

Secondly, there are the innovations that, e.g., a commercial agronomist might recommend to a farmer, such as a new cultivar, or would be undertaken at the farm level, like raising hedges to slow wind speeds across fields and accessing new government subsidies. 'Lines' are defined as 'particular examples of intervention type amenable to measurement' that involve an intervention in agriculture.

Microbial Consortia in Soil Health

Soil microbiomes harbor extremely diverse species that play vital functions in sustainable agriculture. They offer a great contribution in the breakdown of organic matter and make all the elements accessible for plant growth and development. Successively, the soil has been studied to understand how the soil-borne microorganisms that interplay with plants and the atmosphere as well. There are a few soil-borne species that are adverse for both plants and their growth, or thriving. The propensity of the plant-nourishing and illnesses causing soil-borne species at the plant-soil interface possess a crucial physiological job in biotic stress behavior and provisions the understanding for toughened agriculture methodologies (Ray *et al.*, 2020) [50]. There have been various assignments over the past century concerning soil-borne microorganisms and numerous microbes have come to be a significant device for harvest pestilence administration. Thereafter, the conventional agribusiness method was applied on an agricultural use and the over utilisation of compound manures elicited to substitute soil adaptation issues and crop productivity, especially in the cultivation of rice.

The chemical method of soil adaptation to succour crop productivity is now at risk. Moreover, the sturdiness of the new plant pests to the existing method of synthesized pesticide has eliminated the need to explore effective, green crop management affairs for safeguarding crops from a diversity of pests. Probiotic is a term that is composed of two Greek root words, that means *viz.*, ‘Pro’ and ‘Biotic’. The term biotic signifies life where ‘pro’ implies pro-life i.e. probiotic signifies life. Probiotics are defined as a passive process, where an organism prudently profits from the host’s microbic compounds and bioactivity, but presents none of his own in return. This review portrays a revolutionary approach to put up probiotic hetero -solitary bacteria, an evaluation of produced by the host feeds, which could enhance the performance of rhizosphere microbes, so as to advocate a potential paradigm from individual biocontrol agents to multifaceted probiotics, for the systematically augments protection to a broader spectrum of pathogens.

Understanding Microbial Diversity

A healthy plant growth-promoting rhizosphere microbial community is the cornerstone of sustainable agriculture and plant health, but we particularly know it poorly. The previously function-oriented and culture-dependent analyses do not capture the worldwide taxonomic and functional diversity in the microbial communities (Ray *et al.*, 2020) [50]. Soil microbial community composition can play a crucial role in the entire soil system, nonetheless protective tillage, labor, and numerous demands are challenged at this time.

Increased interest in the use of rhizosphere microbial community-inducing agricultural applications to improve plant productivity and crop yield emphasizes the necessity of understanding rhizosphere microbial community dynamics. Attempt to determine the relative significance and the interactions of farm-management practices and the environmental factors influencing the rhizosphere microbial community structures of mustard and sunflower seeds. The experiment comprised field sites characterized by differences in soil texture, irrigation, nitrogen application, and water management practices. The population rates of Firmicutes and Bacteroidetes were predominantly affected by environmental parameters. The phyla Proteobacteria, Acidobacteria, Verrucomicrobia, and Actinobacteria exclusively exhibited interaction among management and environmental variables in addition to the sequencing depth. The confinement of the results illustrates how rhizosphere microbial communities of field-grown plants are jointly influenced by farm practice and ecological factors.

Benefits of Microbial Interactions

There is growing interest in optimizing the application of microorganisms in agriculture. Here, a number of microbial interactions are described that could be useful in a variety of applications relevant to agriculture and the environment.

These include events that involve tripartite associations between plants, microbes, and other microbes. Microorganisms are contained in synthesized soil and more than likely live in communities, although many studies examine solely the effects of single microbial species on plants. This synergism serves as a clear indication that one should be careful to recognize that experiments focusing solely on the effects of single microbial species may overlook very important multipartite interactions that are nevertheless more naturalistic than experiments examining all possible permutations of those microbes (Lareen *et al.*, 2016) [40].

Microbes associated with plants may benefit from interacting with other microbes in plants given the shared host. Because of this, studies done in planta may better reflect community interactions as they occur in nature. This review also discusses results of experiments studying multipartite interactions between plants and microbial phyllosphere and rhizosphere communities. Microbes in the phyllosphere and rhizosphere are involved in the processes determining soil productivity when agriculture is considered broadly, notably including: nutrient recycling and availability, preservation of soil structure, degradation of pollutants, and disease protection, to name a few. Given the growing evidence that microbial communities are easily impacted by agricultural practices, this implies that there may be a positive feedback loop in which perturbation of microbial communities through agriculture is exacerbated by the loss of genes with similar functions present in those communities, which would have otherwise provided redundant services (Ray *et al.*, 2020) [50].

Finally, results are provided from experiments examining the effects of the tripartite associations which suggest that microbial interactions are important statistically significant effects of treatment from the community taken from a single plant species and monoderm bacteria as compared with the same communities in the absence of plant roots.

Case Studies of Successful Applications

Climate-resilient agronomy (CRA) takes center stage amidst the pressing need to feed the world in the face of a rapidly changing environment. CRA is set apart by the focus on sustainability; the safe operating space for global food security in the Anthropocene requires sustainable agronomy. Sustainable agronomy (SA) must address both the supply and demand of food. This can be achieved through conventional, organic, and conservation agricultural inputs, based respectively on either external or natural resources (Dinesh *et al.*, 2015) [13]. Conventional inputs consist of mineral fertilizers, synthetic pesticides, and mechanization, and have shown their effectiveness in extensively adopted industrial agriculture. Known as the Green Revolution, it has largely boosted the supply of food to meet the demands of the increased world population since the 1960s.

On the other hand, intensifying agricultural systems to further improve crop yields is increasingly faced with diminishing returns, including environmental degradation from the overuse of certain inputs (K Aggarwal *et al.*, 2018) [2]. In fact, agriculture is one of the largest sources of greenhouse gases and is depleting both non-renewable and renewable resources. As a result, the locally occurring environment may be changing faster than the adaptability of certain agricultural practices and even preclude current modes of production. Agro-ecological methods must thus be employed to ensure the increased global food demand is produced in a sustainable way. This puts CRA in an interesting position; the theories and tools of conventional agronomy generally do not apply uniformly across SA. This is particularly the case for potentially transformative innovations, the advances in technology that might overcome localized constraints and be most critical moving forward. These innovations must generally be developed ad hoc, and currently a coherent framework for such development is lacking. This is especially true in the light of how many contexts will require their introduction, thus more focus on their method of production is required. The goal of this paper is to fill the gap and provide a clear foundation for improving the sustainability of food production globally pre-CRA.

Agroecological Diversification Strategies

Like other ecosystems, agroecosystems can adapt to a new climate within a certain range of variability. This allows similar but different ecosystems to flourish in different environmental conditions, such as warm versus colder regions. As such, climate change will not only pose challenges to agriculture, but also open up new options. The challenge will be to anticipate those changes and develop adaptive strategies that are not only sustainable but also build on renewed global and local agroecological knowledge. Thus, despite holding only 10% of the global surface freshwater, Africa is expanding its irrigated farmland. In this context, greater investment will be needed in sustainable agronomy at local scales. Since the years of the Green Revolution, Africa has invested heavily in agronomy distributed by seed and pesticide salesmen. These agronomists often see fields across a windshield, prescribing overly simplified linear recipes to manage what is in reality a complex agroecosystem.

Table 1: Principles of Agroecology

Aspect	Key Points	Details	References
Definition	Agroecology as science, practice, and social movement.	Combines ecological principles with social equity, focusing on sustainable resource management, biodiversity preservation, and opposition to industrial agriculture. Originated in the 1920s.	Altieri (2002) [3]; Wezel *et al.* (2009) [61]
Core Principles	Sustainability, biodiversity, farmer empowerment, decentralized knowledge.	Prioritizes ecological health over profit, rejects privatization of natural resources, and emphasizes participatory knowledge creation among farmers, researchers, and communities.	Gliessman (2014) [23]; FAO (2018) [18]
Social Dimension	Collective action and resistance to industrial agriculture.	A network of farmers, pastoralists, and activists advocating for alternatives to commercialization of agriculture. Promotes local governance and equity in food systems.	Méndez *et al.* (2013) [44]; Anderson *et al.* (2019) [5]

Aspect	Key Points	Details	References
Policy & Practice	Institutional support and research renewal.	Governments and institutions (e.g., France's PACA region) design support mechanisms aligned with agroecology. Case studies highlight farmer-technician collaborations for sustainable practices.	Gascuel-Odoux *et al.* (2022) [19-20]; Duru *et al.* (2015) [14]
Case Study	Agroecological dynamics in France's PACA fruit/vegetable sector.	Qualitative research (2013-present) involving interviews with farmers, technicians, and researchers. Explores challenges in transitioning from productivist to agroecological models.	Gascuel-Odoux *et al.* (2022) [19-20]

Crop genetic diversity is the raw material and foundation of agroecology, the most appropriate science for adapting agriculture to climate change, in all its biological, ecological, political and sociological multiform splendour. Agroecology is rooted not only in the reductionist principles of Darwin but in the holistic ethno-botanical knowledge and practice by which people have crafted genetic diversity for over ten thousand generations. It has a history of success. While the amount of arable land per capita has halved, largely due to the rise in population, continuous agricultural innovation has provided the resources for societal development thus far. Climate change is happening in perfect concordance with an urban-planning driven global demographic shift which is swiftly stripping gifts to the tillers. 99.7% of humanity across political submerged landscapes. Climate science has shown just how tenuously stable the conditions for agricultural development have thus far been, and that the climate resilience of contemporary agriculture, focused as it is on safeguarding only high-energy throughput yields, is a chimera. And so agro ecological diversification strategies, drawing on agroecology's foundation in the ecology of biological/experiential diversity and its long-time managerial role in agro-biodiversity will have a central role in developing equitable forms of sustainable agriculture. This can only be good for the farmer and for agronomy in general (Meldrum *et al.*, 2017) [43].

Principles of Agroecology

Agroecology is a scientific discipline, a range of practices, and a housing network. As a scientific discipline, agroecology has been building a new vision of agriculture since the 1920s, the central theme of which is the sustainable management of natural resources and empowerment. But agroecology is also a housing network far from the industrial model. It is a collective of farmers, researchers, consumers, pastoralists, agronomists who oppose the privatization of living and the relentless commercialization of life. The cornerstone of agro ecological logic is preserving living things in all their diversity. As a housing network, agroecology is to provide a base for a new extension policy. By agroecology, one designates an approach that calls into question modern agriculture and places ecology at the center of an agrarian project. Agroecology is an inspiration in the design of support measures for farmers. With agroecology, the renewal of research and support tools is designed. Specifically, the idea is to involve the various institutional actors in the production of knowledge on sustainable agriculture. Principles of agroecology can be a lever to achieve the organic target. Leaders who have not succeeded in breaking with the productivist logic are heading towards the reference and the security of control. Executives, technicians, and agricultural professionals massively convert to agroecology. Moreover, most support mechanisms are designed according to principles of agroecology. This article deals with research conducted in France on the agroecological dynamic of PACA's fruit and vegetable sector. These elements derive partly from qualitative research carried out since 2013 from in-depth interviews conducted with farmers, consultants, representatives of agricultural Chambers, researchers, and/or technicians from the French Institute of Technology for Horticulture (Gascuel-Odoux *et al.*, 2022) [19-20].

Crop Rotation and Companion Planting

Identifying good matches among field-grown crops for companion planting is one important aspect of a diverse cropping strategy that can be used to implement a diversified crop rotation. These innovative agronomic practices, based on intercropping science but using, when possible, alternative approaches owing to the complexity of field-scale systems, play a predisposing role in addressing stress resistance. There is a history of failed crop rotation studies dating back into American agricultural extension efforts in the early 20th century. Most have sought to compare simple rotations with continuous monoculture cropping (C. M. Gaudin *et al.*, 2015) [21]. The current re-evaluation of crop rotation as a potential intervention for modern, future-demanding agriculture takes a comprehensive, system-wide approach to 3 main considerations relevant to flawed historical studies.

Integrating Livestock and Crop Production

Integration of livestock with crop production is widespread in smallholder farming systems, with livestock fulfilling numerous roles, such as producing draught power, manure, meat and milk and constituting a form of savings (Homann *et al.*, 2013) [33-34]. Contrary to conventional wisdom, model analyses showed substantial proportions of livestock in both maize production sites to be climate-smart. The largest of these effects were associated with the employment of draft oxen, the cessation of continuous ploughing, off-farm livestock net sales and manure applications, all of which are moderated by grain market dynamics.

Table 2: Integrating Livestock and Crop Production

Aspect	Key Points	Details	References
Role of Livestock	Multi-functional contributions to smallholder systems.	Livestock provide draught power, manure, meat/milk, and act as financial assets. Integration enhances resilience and economic stability in mixed farming systems.	Homann *et al.* (2013) [33-34]; Herrero *et al.* (2013) [31]
Climate-Smart Practices	Synergies between livestock and crop systems for GHG mitigation.	Use of draft oxen, reduced tillage, manure application, and off-farm sales reduce emissions and improve yields. Market dynamics influence adoption.	Thornton & Herrero (2015) [56]; Rosenstock *et al.* (2016) [52]
Conservation Agriculture	Off-farm livestock integration boosts sustainability.	Manure recycling and livestock sales enhance soil fertility and liquidity, enabling investments in climate adaptation (e.g., food reserves, diversified planting).	Giller *et al.* (2009) [22]; FAO (2013) [16]
Agroforestry Systems	Mixed tree-crop-livestock systems as carbon sinks.	Agroforestry in tropical regions (Africa, Asia, Latin America) enhances biodiversity, sequesters carbon, and improves livelihoods. Incentives for tree planting increase land cover and climate mitigation.	Nair *et al.* (2010) [47]; Jose (2009) [39]
Policy Incentives	Aligning incentives for agroecological transitions.	Financial/technical support (e.g., payments for ecosystem services) encourages farmers to adopt integrated systems, fostering global warming mitigation.	Miller *et al.* (2020) [45]; FAO (2020) [17]

Climate-smartness is indicated by the positive relationships found between these practices and the mitigation of greenhouse gas emissions or adaptation to climate change through yield-expressive mechanisms. The innovative application of conservation agriculture practices which integrate livestock proceedings to off-farm uses in the form of sales and sacrificed manure would deliver multiple benefits, increasing crop yields and providing liquidity for the transformational adaptation of planting and food reserves. Cultivation of mixed tree and crop systems is essential for the conversion of agriculture in tropical countries to a carbon sink. Mixed agroforestry systems are extremely important in traditional and smallholder agriculture in tropical countries of Africa, Asia and Latin America. Providing farmers with the right incentives often results in a net increase in the number of trees outside forests, so that the enrichment of the land cover with trees outside forests becomes an integral part of political actions to foster the mitigation of global warming.

Impact of Climate Change on Agriculture

Agriculture is the primary livelihood for more than a billion poor people globally, the majority of whom live in the dry areas, rainfed regions and/or the harsh environments of the developing world. Smallholder farmers in developing countries produce a significant proportion of the world's food, with 40-60% of food in the region classified as edible lost post-harvest before consumption. Despite increased investments in agricultural research, education, and infrastructure over the past several decades in many parts of the world, significant challenges remain.

Table 3: Impact of Climate Change on Agriculture

Aspect	Key Points	Details	References
Vulnerability	Smallholder farmers in developing countries are disproportionately affected.	Over 1 billion people in dry/rainfed regions rely on agriculture. Post-harvest losses reach 40-60% in developing countries. Extreme weather and lack of insurance exacerbate risks.	Morton (2007) [46]; FAO (2011) [15]
Climate Projections	Irreversible long-term changes in temperature, precipitation, and sea levels.	Global temperatures and sea levels will rise even with reduced emissions. By 2025, cereal production in Africa/South Asia may decline due to temperature stress on crops.	IPCC (2014) [36]; Challinor *et al.* (2014) [11]
Adaptation Strategies	Management practices, policy reforms, and technology investments.	Agrobiodiversity (e.g., neglected crops, resilient varieties) enhances resilience. Social innovations and breeding programs are critical for climate adaptation.	Altieri & Koohafkan (2008) [4]; Jarvis *et al.* (2008) [38]
Agrobiodiversity	Untapped genetic diversity aids climate resilience.	Traditional crops and genetic resources improve sustainability. Technologies expand the use of underutilized species, reducing dependency on climate-vulnerable staples.	Pretty *et al.* (2018) [48]; Thrupp (2000) [57]
Climate Services	Seasonal forecasting informs agricultural decisions.	Predictive tools (e.g., rainfall models) help farmers optimize planting/harvesting. Institutional support is needed to scale these services.	Hansen *et al.* (2019) [27]; Vaughan *et al.* (2019) [59]

The world is already committed to long-term changes in the climate. As a result of increased levels of greenhouse gases in the atmosphere, it is near certain that global average temperature and sea level will increase and that changes in precipitation and other local climate variables will occur over multi-decadal timescales. Even if anthropogenic emissions of greenhouse gases could be stopped or dramatically reduced, it would be a long time before atmospheric levels, or the radiative forcing and climate changes fell back to their pre-industrial levels. Impacts and adaptations to changes in the climate have been increasingly studied at the global and regional scale. Many of the poorest countries are the most exposed to climate change. For example, by 2025 the models predict a significant reduction in aggregated cereal production in tropical regions such as Africa and SouthWest Asia, due to the higher proportion of crops that are near to their long-term temperature tolerance. Since agriculture is the sector most directly affected by climate uncertainty and extreme events and is rarely formally insured or protected, the need for effective response measures is extreme.

Options to adapt agriculture to climate change include altering management practices, amending policies, or investing in new technologies. Agribiodiversity can help to manage risks and increase resilience to shocks, as well as contribute to improvements in agricultural sustainability and production. Agriculture is impacted by climate change through effects on crop suitability and pest status. Unutilized agrobiodiversity has a major role to play for the adaptation of agriculture to climate change, mostly in terms of breeding new varieties. Social innovations are necessary in research and development to understand and improve the application of agricultural biodiversity to address the issues emerging from climate change. With improvements in technologies, the whole scope of adaptation using agrobiodiversity will be widened, leading to the increase of sustainability in agricultural systems, and also to an increase in the knowledge and production of those traditional or neglected crops only known to a limited number of people. Climate services such as seasonal climate forecasting have demonstrated the ability to significantly change outcomes in decision-making in relation to agricultural practices.

Understanding Climate Variability

Farming practices especially in developing countries are generally highly dependent on climatic conditions. While most farmers are observant to uphold basic agronomic knowledge, there exists a significant challenge in coping with the consequences of climate variability due to the rapidly changing climate, limited resources or poor access to climatic data, and sometimes erroneous long-held indigenous knowledge. Thus there is a need to develop more accurate and readily understandable approaches to provide weather and climate advisories.

In the semi-arid tropics, where climatic conditions are marginal and highly variable, farming is a risky enterprise. The main source of this risk is the variability in rainfall at multiple timescales. Farming in these regions can therefore provide valuable insights into peoples' perceptions and experiences about climate variability and variability in rainfall, which in turn can be used to help develop a better understanding of the risks and opportunities for agriculture that changes in climate may bring (PC Rao *et al.*, 2012) [49]. Because of the extreme variability of climate at a particular location, it is important for farmers to have a good understanding of the risks and opportunities that this brings in order to make best use of the available resources (Hansen & Coffey, 2012) [28]. There is very good evidence that with a good understanding of current climatic conditions including climate forecasts, it is possible to tailor the management of agricultural systems in a way that can provide substantial benefits. For example, farmers could be encouraged to plant shorter duration crops if the climate is forecast to be drier than normal because shorter duration crops are affected to a lesser degree by extreme events which could be beneficial to food security.

Effects on Crop Yields and Food Security

This effect on crop yields under a future climate change scenario is not addressed. It would be useful to integrate this study in spatial models of land use change to assess more realistically the effects of the two major future dynamics of agriculture expansion: yield increase and tropicalization, on forest cover.

Global change challenges agriculture to double its yield by 2050. Modeling studies have been showing that reaching this yield increase by the sole extensification of agriculture may lead to high tropical forest conversion (J. Vermeulen *et al.*, 2011) [60]. Moreover, on-going economic globalization of trade and market are two major factors influencing cropland expansion. It is thus crucial to assess what could be the current trend of cropland extensification vis-à-vis the environmental limits and to investigate the role of markets and trade in this process.

There are different strategies to increase crop yields, i.e. intensification, a combination of better soil quality and management, closure of yield gap, and genetic improvement of crops (Islam *et al.*, 2016) [37]. All these strategies will increase the carbon intensity of food and feed products and thus exert a pressure on land use change, especially in the tropics. By reducing the need for additional cropland, this "land sparing" effect of yield increase may reduce the pressure on deforestation.

Adaptation Strategies for Farmers

A variety of strategies represent economic, institutional, infrastructural, and business innovations by which farmers and farming communities are adapting to climate change and achieving climate resilience objectives. Of the 52 strategy descriptions collected, three quarters specify technological or practice innovations. Adaptive changes concern various agronomic activities such as maintaining soil fertility, water harvesting and irrigation, tuber preservation, and hillside conservation measures, amongst others. These also involve new crop practices, for example planting new crops, planting before the main rainy season, and cultivating vegetables during the dry season, as well as new varieties (E. Ikehi *et al.*, 2022) [35]. Livestock strategies mostly pertain to animals, with ration improvements or total abandonment of those with poor margins, while those involving land mostly refer to mixed farming. On the strategies farmers might be expected to take up, most common were improved water management such as collecting rainwater infrastructure, irrigation, or water usage monitoring, and shifts in cropping timings such as earlier planting or cold period crop shifting (M. Tabbo & Amadou, 2017) [55]. This is likely because the proposed schemes for these strategies are generally the simplest and easiest to implement, are technologically undemanding, and would be likely to have a quick return. In terms of the proposed sectoral implementation of these strategies, the majority of the programs funded came from initiatives to support adaptation in agriculture. These programs typically aim to increase adaptive capacity through the promotion of sustainable farming techniques, such as rainwater collecting infrastructure, improved crop management, and the like. Most of the adaptation methods introduced to farmers were temporary solutions. Typically, the techniques hinge on farmers practising soil and water conservation, trying different crops and sowing times, and attempting water management. However, these do not modify the fundamental problem of declining or unreliable rainfall and were generally considered only to be delaying the issue for some years. Some of the more sustainable strategies, such as planting perennial crops and installing irrigation infrastructure, were not perceived as practical for farmers, even despite extensive training programs designed to facilitate their implementation.

Sustainable Practices in Agronomy

Introduction in the Anthropocene era, a profound awareness of the urgency with which ground-breaking sustainable innovations are needed in agronomy is beginning to take root. Agrarian societies now look to agronomists for environmentally- and ethically-sound production systems that will support communities through the vagaries of climate change. This focuses on practices adopted in agronomy or farming, rather than on biotechnologies. The mitigation or adaptation practices discussed are sustainable in respect of human well-being. Discussion begins with the traditional agronomic cornerstones of sustainable intensification: the integration of livestock, minimally invasive soil management, edge-of-field management, agroforestry, and fertilizer management. It then turns to how a changing climate exacerbates the complexity of making agronomy sustainable, and on the 15 practices shown by research to be robust between different environmental conditions (Datta *et al.*, 2023).

Livestock Integration Mixed crop-livestock systems can effectively recycle farm nutrients and produce food from land unsuitable or undesirable for growing grains or vegetables. There is a potential role for livestock in ecosystem-based adaptation for agriculture in agroforestry practices and as an economic and fertilizer resource. However, the sustainability of current systems is questioned, and the future redesign of livestock systems as vital components of truly resilient, rather than merely buffered, agriculture is needed (González Guzmán *et al.*, 2021) [24].

Soil Management The ability of soil to fulfill its natural biological and biochemical functions, its ’soil health’, needs to be managed sustainably. Excessive tillage leads to the loss of topsoil and organic matter. Direct seeding or minimum tillage have, therefore, been developed and related agricultural practices are being widely adopted. However, climate change is making it increasingly difficult to predict the outcomes of such soil management options, particularly in regard to the release of greenhouse gases. The potential for cover cropping, another soil management practice, to conserve excessive soil moisture and reduce soil erosion is also under close scrutiny.

Organic Farming Techniques

Farmer communities in Kerala, who maintain diverse and complex farming practices, expressed deep concern over the present situation and the changes they anticipate in farming. Central among these is a rise in the uncertainty and unpredictability of weather and of its impact on farming. The bulk of the smallholder agriculture in the region is rain-fed. There is a perceived increase in the frequency and the intensity of extreme weather events, such as heavy downpours and dry spells, and in uncertainty about the pattern and timing of the monsoon. Only recently, farmers’ unions have gained ground in the region, and the farmers participating in the study take an active interest in the work of one such institution. Billions of poor people worldwide who depend on agriculture and especially on rain-fed agriculture face an uncertain future because of climate change. In the South Indian state of Kerala, farmers expressing strong commitment to traditional practices in agriculture are engaged to look into the distinctive capacities of their way of farming to adapt to and to mitigate effects brought by climate change. Diverse farming practices and strategies reflect social concerns as well as environmental conditions, and many of the practices followed seem to offer a deliberate response to the changing agro-climatic situation.

Conservation Tillage Methods

This method mimics the natural dense turf that once covered the Ohio prairies. Similarly offset sweeps are used to form a groove with a firm seedbed in the bottom. The groove has continuous berm ridges 12 to 16 inches high on each side. The continuous ridge mulch receives and directs rainfall, minimizing tillage damage from erosion events. This severely limits further erosion of the ridge mulch, retains it in place, and decomposes more slowly, so the ridge benefits from erosion control for two cropping seasons. Machines were designed to cultivate row crops. They now provide added capability to plant small grains using a drill-propelled transplanter to plant into standing stale seedbeds. The machine also incorporates accessories to improve seedling disability and to incorporate cover crops.

Selecting the tillage system best suited to a particular farming situation is an important management decision. A well-planned system can be economical, improve soil quality, and work with, rather than against, natural conditions. Today, conservation tillage systems are used to reduce preplant tillage operations, thus reducing soil erosion and moisture loss while saving labor and fuel. The label "conservation tillage" represents a broad spectrum of farming methods, and is most often defined by the amount of residue cover remaining on the soil surface. The minimum amount recommended is 20 to 30 percent after planting. Research has shown that leaving at least this much residue will reduce erosion by more than 50 percent of that occurring from a cleanly tilled field. These ridges will reduce the soil loosening from continuous vibration and reduce the rate of seedbed degradation. To achieve effective erosion control, this minimum residue cover should be maintained during the critical soil erosion period between spring seedbed preparation and crop canopy establishment.

It has been observed across the conservation fields that corn responded particularly well under no-till planting systems with substantial yield increases in many fields. Using mixed farming in a crop rotation procedure, suburban smallholdings can be more profitable, encouraging the survival of traditional farming. Areas with high percentages of small farmers and cattle ranches can improve their fringe land conservation with some land reform.

Water Management Strategies

A number of technologies have been adopted in farming systems world over aiming at conserving soil and water together. Compartmental bunding and broad bed and furrow are popularly known soil moisture conservation practices that are very effective in conserving run-off and curtailing soil erosion. Cultivators are an age-old equipment used for interculturing in vegetable crops. Animal drawn cultivators are suitable for operation in fields of 3-5 years while in the double dug type raised beds, machine drawn cultivators are found appropriate. Raised bed system ensures better aeration which is essential for the growth of plants. Raised bed and flat bed geometries significantly influence rain water productivity. Flatbed system and single furrow bed and furrow materials are better than other bed configuration and furrow systems for improving rainwater productivity in arecanut palm bio-system. Acceptance and adoption of new technology depends on many factors. Percentage of adoption is higher in respect of raised bed planting and TDP casting in paddy fields while it is low in respect of cotton based intercropping. Adoption of raised bed planting and other interactions with other studies is significant. Use of bullocks for seed cum fertilizer drill has significant association with operational land holding. Almost more than 90% area was sown by Bullock drawn seed drill used in good condition during rabi season and a small number of areas were under cultivators drawn seed drill. In the rice production view, paddy transplanting has a higher probability to produce 4182 q/ha of rice production than the puddling rotary bed and Jyoti type TDP system only 3415 q/ha.

The Future of Agricultural Biotechnology: The current trajectory regarding climate change suggests that the global population will surpass 9 billion people by 2050, leading to widespread food insecurity and conflict across the globe. This assertion is supported by the slow pace with which policy makers have reacted to these scientific projections. However, in the past 5 years, progress has been made toward rectifying these oversights. The most significant occurrence was the ratification of the Paris Agreement on April 22, 2016, when 175 countries signed the United Nations Framework Convention on Climate Change with the purpose of keeping the increase in global temperature below 2°C above pre industrial levels (N. Archibald *et al.*, 2023) [6]. Another major commitment to countering climate change was the White House's Clean Power Plan, which was enacted on August 3, 2015. These regulatory actions were enacted just as agricultural biotechnology had become advanced enough to help accelerate the development of more climate-resilient agronomy. The combination of this new regulation and petroleum-reducing technologies has the potential to ignite an agronomic revolution to ensure global access to nutritious food for the duration of the current century.

The nitrogen in chemical fertilizers responsible for crop-area expansion since the Green Revolution in the 1960s may no longer be affordable without crude oil subsidies, and produce may become nutritionally drained as aridification continues to restrict water allocation for irrigation. Thus, modern agriculture and future societal infrastructure will need to adapt in order to be sustainable during the Anthropocene. Moreover, Africa and Australia are expected to be hardest hit by global warming, which may cause their entire croplands to turn into barren wasteland as early as 2030. According to the latest figures from the United Nations, sub-Saharan Africa suffers 12% annual crop loss. Climate change is projected to only make annual temperatures hotter and droughts more frequent, so African farmers will need to achieve new agronomic paradigms to continue to grow their staple crops. In January 2003 it was estimated that by 2023 worldwide, taps will run dry for more than 3.5 billion of Earth's population. Africa's current water-storage infrastructure alone is projected to be incapable of providing enough moisture for all its crops by 2040 (E. Hoffman, 2022) [32].

Emerging Technologies in Crop Science

The next big leap in agriculture is expected to come from multidisciplinary research programs. Several countries are developing policies to mitigate climate change and promote sustainable development. There is a need for appropriate research findings to adopt recommended sustainable agriculture practices for diverse agroecosystems and farming systems. In this context, developing an integrated 'climate-resilient agronomy', combining a wide range of sustainable practices and expert knowledge, might provide a good opportunity for the scientific stakeholders to contribute to the transformation of current agriculture practices into climate-smart ones, as well as to enable rapid adoption across multiple scales (González Guzmán *et al.*, 2021) [24]. It is believed that such an approach could be a game-changer in the way agronomic research is currently being conducted, prove transformative for the poor suffering from the impacts of climate change, and support the transformation of this living world and current society to the next, inevitable 'Anthropocene' (K Varshney *et al.*, 2018) [58].

A 'climate-resilient agronomy' should provide farming communities with sustainable resources, practices, and policies which can enhance and preserve yields and meet the food and nutritional needs of a growing population, amidst unfavourable climate change conditions. Nevertheless, the challenge is to increase the amount and quality of food while globally establishing a healthier environment. To provide balanced solutions, an evaluation of holistic approaches that reconcile food supply chains with renewable energy production, environmental goals, ecosystems, biodiversity, and use of resources such as water and soil as well as the role of local biogeochemical cycles is necessary. In the last centuries, technological progress has changed and shaped agriculture, but it often required external high inputs such as the use of synthetic fertilizers, chemical phytosanitary products, seeds, or energy. Agricultural technology has become knowledge-intensive and it is essential to educate for innovation and to integrate agricultural and environmental policies in an age of rural exodus and global climate changes. To make agriculture more sustainable, the goal is to integrate the best techniques of biodynamic farming, agroforestry, conservation agriculture, to adapt crop breeding selections to natural ecosystems and the environmental and social constraints of territories, a sound organisation of markets, and measures to level the playing field among producers involved in a fair trade logic.

Potential Risks and Benefits

Climate change is one of the main challenges in the Anthropocene. Although global food production has increased since the intensification of agronomy, constituents of human societies still suffer from insufficiencies in food. Currently, 795 million people face insufficient food and 98% of them are living in underdeveloped countries (K Aggarwal *et al.*, 2018) [2]. Particularly, some regions, such as South and Southeast Asia, the Caribbean and Sub-Saharan Africa, have fewer food supplies. Some projections show that the insufficiency in food security will be exacerbated if more effective strategies to diminish the consequences of climate change are not adopted in these regions. Generally, food security can be defined as a balance between food availability, food access and food usage. Food supplies must be obtained under various conditions, such as calories, proteins and nutrients. Considering that all necessary constituents come together in biological productions, food security is closely linked with agronomy; therefore, every phenomenon affecting agronomy should be considered in solving the problems of food security.

As a consequence of global warming due to escalating greenhouse gases, the average Earth surface temperature has increased significantly over the past century and is expected to continue increasing in the near future, which is called climate change. Changing temperatures show up in air, land and oceans. All records present clear scientific evidence of warming. Primarily, the increase in temperature means that the lower limit of the zone is displaced in the direction of poles and shadows, which has been observed over the past century. Questioning these phenomena is not convenient from a sustainability point of view, but the way these accounts will affect agronomy is not that clear. In specific, it is probable that the extent, intensity and length of disasters such as floods, landslides, avalanches and droughts will worsen in fragile geographies in terms of social and environmental impacts. On the other hand, the increase in temperature over the past century is said to be anthropogenically caused by the excessive use of fossil fuels. Energy needs of communities have escalated dramatically; therefore, the use of fossil fuels such as coal, natural gas and oil has escalated in the same way. These compounds encompass greenhouse gases such as carbon dioxide, methane and nitrous oxide, leading to the so-called greenhouse effect, which trammels the heat the Earth emits to the universe.

Public Perception and Acceptance

Human population growth and climate change exert compounding pressures affecting global agriculture (Julián Cárdenas Pardo *et al.*, 2023) [10]. As the global population booms, there is increased urgency to provide more nutritious, more food energy, and more food diversity, and to do so sustainably in the face of even greater climate change than has already been triggered. Meeting these food security, nutritional security, and climate adaptation targets will require transformative changes across the global food system, as well as new partnerships between researchers, farmers, and farmer groups. One priority for innovation is sustainable agronomic methods because these can have significant impact at large scale on greenhouse gas emissions and the environmental goods and services that are needed by all agriculture (Christian Rose & Chilvers, 2018) [51]. Hence, research is presented that supports the idea that low-tech agricultural methods can be improved for greater climate resilience and much wider take-up by farmers.

Indeed, some of the many appealing features of long-established low-tech farming innovations are that they can improve climate resilience and that they are low- or no-cost. However, part of the global food security and climate adaptation challenge is that more farmers need to adopt them, and that adoption is partly hindered by low awareness of the innovations and by uncertainty and lack of information about local effectiveness. An innovative approach to increasing and systematising the trials-adoption method is described and evaluated in terms of improving trial efficiency and farmer learning outcomes. Off-the-shelf smartphone technology is utilised that is readily available to most people in low- and middle-income countries in the global South. At its simplest, the method is about using better-designed evidence gathering to encourage iterative innovation and refinement by farmers themselves. The argument is developed with reference to data from a unique mass experiment of this approach in Kerala, South India, involving 1000 farmer participants and 12 organic farming innovations emerging largely divorced from the technologies studied in the biophysical and farm practice literature.

Policy and Governance in Agriculture

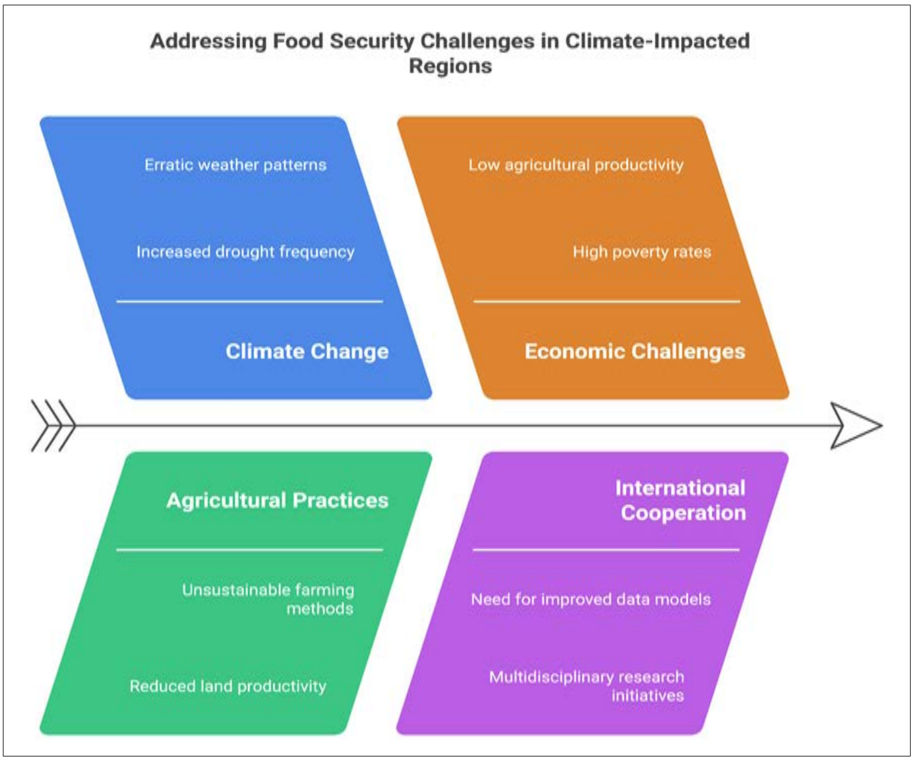
Agriculture is often the main source of local livelihoods. But agricultural development is environmentally constrained because food systems and climate change are inextricably interlinked. Climate change threatens food systems, especially if current livestock and soil management practices continue. A challenge therefore, is to feed the future global population without compromising environmental integrity. This needs to take place alongside more stringent implementation of polluter-pays principles and carbon taxes within the food system. There is a growing literature on how to deliver national food security goals while achieving consumption patterns that would be consistent with the Paris Agreement and high probability of the global average temperature rise not exceeding 1.5°C (Stringer *et al.*, 2020) [54]. A simple solution is herd reduction. This, along with an intensification of the industry, may stop national food consumption exceeding the Paris Agreement limits, but is unlikely to be socially feasible and would impose large costs on the public purse. Not to mention the impact this would have on a population-dependent livelihood. There is therefore a need for innovative land use strategies to reconcile trade-offs between conflicting climate and land-related goals. One theoretical solution is land rental markets and as a consequence consolidation, which would remove the need for large herds and free up land for forestry and other environmental uses. However, in many areas, this would not be a seamless transition, or desirable of itself. There are concerns that consolidating over common land may export degradation elsewhere, while also creating dispossessed and poverty-stricken 'public grazers'. Longer-term actions include policies that support populations not just to develop secondary and tertiary industries in rural areas, but also so they have the necessary support to exit rural agriculture and engage with urbanization. This should happen in line with dietary shifts and the implementation of sustainable food security strategies. There are also efforts to develop new technology to monitor environmental impacts and exert polluter pays principles.

Role of Government in Supporting Innovation

Innovation is the process by which new ideas are generated and converted into usable applications, including products, processes and services. These are introduced to the market, facilitating value creation and increasing well-being. In agriculture, innovation leads to increases in agricultural productivity, safety and sustainability, helping to harness highly diverse ecosystems for human and other activities. Innovation also assists in adapting to new challenges, such as public health issues or climate change (Campos, 2020) [9]. The COVID-19 pandemic highlights the pressing need for effective innovation where infections and fatalities are minimized while restrictions on economic and social activities are gradually relaxed. If, however, the rate of innovation success is too slow, there remains great potential for disasters and widespread suffering. In turn, the need for success in innovation increases, particularly in tackling grand challenges like sustainability and climate change. There are many stakeholders within a sector, such as animal or aquaculture production, that need to interact effectively in the innovation process. A public organization or representative council could therefore benefit from information, analysis and insights into a range of issues related to the agricultural research and innovation system (Hall *et al.*, 2005) [25]. The intention here is not to suggest that a national agricultural research organization or council should be established. However, in the business, communication, and health sectors, the effectiveness of efforts to innovate should be improved, the detection and exchange of innovative ideas and good practices should be encouraged, and the alignment of public research and innovation priorities should be assessed and enhanced.

International Cooperation for Food Security

Global food security is intricately connected with climate change, as projected changes in temperature and rainfall will impact agriculture, the main livelihood of the world's poor. In particular, the farmers of Africa, Asia and South America are under climatic stress such as increase in frequency of drought and erratic weather patterns and also suffering from reduced productivity of arable land due to unsustainable agriculture. A number of likely effects of global climate changes on agriculture within various regions are discussed. Climate change, agricultural development and food security affects all the countries of the South Asian region and a full consensus on this issue with the developed countries is made. Given the high poverty headcount index and a substantial portion of low-income countries in health and education, many are food insecure and have low agricultural productivity. There is a clear awareness that climate changes may exacerbate these situations and at the same time, a strong concern of the effects of climate changes can be directed at the primary sector that still provides the main source of livelihood for the poor in such countries.



Therefore there is a major link between climate change, agriculture and food security in poorly developed countries. It is suggested that priority should be given to improve data and climate models, understanding of the interaction between climate change, agriculture and food security and multidisciplinary research on these issues. To improve the economic modeling with appropriate data and data handling capabilities, an invitational forum for international agencies, academic institutions and national regulatory agencies is created. The assessment formulates a strategy and a research plan to address the gap, and the process is developed jointly with key international agencies and experts and the plan is used to initiate efforts to address the critical research topic. A knowledge base, establishing the empirical link between climate change, agriculture and food security, is built and shared with national researchers and other entities, including various database tools. Efforts are also made to provide national researchers with the tools for conducting climate impact.

Regulatory Frameworks for Biotechnology

With the adoption of Directive 2001/18/EC revising its GMO legislation, the European Commission entrusted the European Food Safety Authority (EFSA) with the scientific safety assessment of GE plants, coordinated by its GMO Panel, which resulted in the issue of an overall opinion. The safeguard clauses on this opinion are then carried out by the Economic European Community (J. Smyth, 2020) [53]. This simplified the regulatory procedure, which was expected to rule on applications within the 6-month deadline, but over time, it was considered insufficiently rigorous or favouring commercially powerful interests over health and environmental protection. Addressing societal concerns and changing socio ecological conditions requires moving beyond dichotomous stop-go decisions towards more nuanced considerations of how, when, under what conditions, and in what directions, the development of or dealing with biotechnology (and other controversial technologies) may wish to move forward (Hartley *et al.*, 2016) [30]. In 2017, there was the first CRISPR test for the coronavirus approved in the United States for early diagnostics. The saga of biotech food in Europe continued with the safety standards for the authorization of GE plants for food and feed being reinforced by the introduction of the environmental risk assessment and labeling of GE food and feed. Requirements for traceability and post-market monitoring are tightened and penalties for non-compliance. Although the mandate of EFSA does extend to the biodiversity and long-term effects of GE organisms, unintentional effects and long time scales, which nevertheless are subject to rapid advances in technology, are particularly difficult to study and predict. In 2019 the first human challenge study to catch self-induced flu was conducted. (mostly healthy) volunteers would be exposed to the flu virus to lessen the heavy burden of the aged on healthcare every mountain must inadvertently stumble; a clause hidden in an extensive body of EU legislation banned GE patenting but was left unapplied for a long time, until an Indian-based small company had their GE brinjal patent revoked.

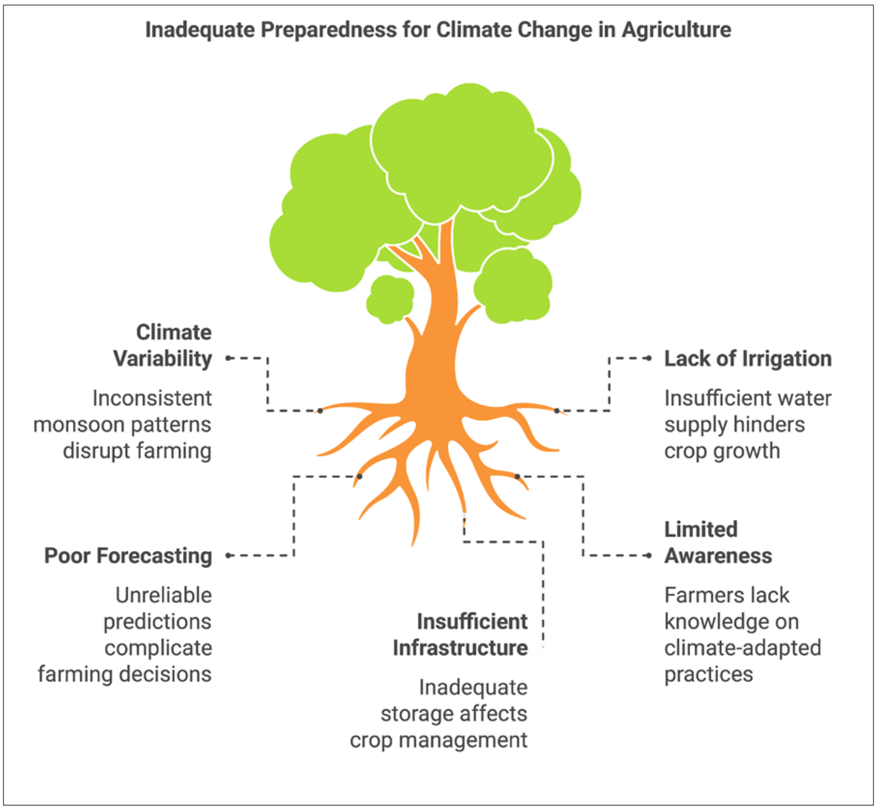
Community Engagement and Education

Agriculture is highly dependent on local weather conditions and is the most vulnerable sector to climate change. Climate, on the other hand, is larger than weather, with oscillations and a huge spectrum from decadal to millennial timescales. Extreme dry or wet periods, just like temperature extremes, are very harmful to agriculture. The core problem though, is that climate is changing not only on its own but also in part due to human activities, which is often referred to as the Anthropocene (M Mandapati, 2018) [42]. Agriculture is a major sector that's been affected by human activities, since the green revolution. However, research and development on agronomy has been neglected after the second green revolution, unlike other sciences and fields. Thus, agricultural crop ecology remains largely similar or even worse than what it was four decades ago.

Agriculture thrives in a specific range of temperature, precipitation, and other weather variables. A rise in mean temperature would increase the maximum and minimum temperature and increase the incidence of heat waves; above certain conditions it could reduce the crop yield dramatically. It would alter the precipitation in a region and make dry places drier; where in turn agriculture ceases to be possible. There's a stronger impact even with small changes in temperature and precipitation. Agriculture on the other hand, is directly responsible for one third of GHG accumulation and practices like deforestation for cultivation only make it worse, turning plain parts of India and South America literally into deserts. Agriculture and allied activities have lost the salient character of being unsustainable. On one side, the agricultural practices are stressful to the environment; on the other hand it makes agriculture, by definition itself, highly vulnerable to environmental stress, which is quite antithetic.

Building Awareness on Sustainable Practices

Climate change is the greatest challenge facing humanity. The agriculture sector will be hardest hit economically as it heavily relies on weather (M Mandapati, 2018) [42]. In semi-arid tropics of Africa, where 95% of its agriculture is rainfed, climate change issues have to be addressed. Beginning with the high variability in the onset and cessation of monsoons, the children and people in developing countries are the most vulnerable. Lack of irrigation, dependence on insufficient water, failure of the monsoon, and insufficient warehouses make agriculture dependent. Several studies have shown that climate change, due to increased levels of CO_2, will lead to warming and a significant decrease in crop yields.



Now, the first time in South East Asia since 1983 is expected to occur in intense activities of the El Nino effect. Therefore, farmers must be prepared for disaster. Significant recent advances have been made in understanding the monsoon and forecasting it, yet scientists take into account the unique method of Lee Layered is still weak, and the monsoon remains the least understood on the Earth's large - scale natural flux. While the prediction of Indian monsoon is difficult, even more difficult are the predictions of the arrival of monsoons, the number of rainy days, the lack of precipitation during the rainy season. By installing rain gauges and showing posters on the role of the monsoon in irrigation and agriculture, farmers can be taught which cultivators best suit the climate in different years.

Empowering Local Farmers

The effects of climate change to agriculture are largely location specific. Consequently, it is critical that adaptation measures recognize the value of targeted, context-specific, community-based strategies and processes. The aim of the research is to apply participatory action research methods in facilitating community-based adaptation with smallholders in the climate-smart villages of Myanmar. A portfolio of context-specific adaptation options was applied, in a participatory process, in four targeted climate-smart villages. These adaptation options were also promoted alongside institutional reforms that might scale-out such adaptation interventions.

Smallholder farms were targeted in four unique agro-ecologies: the Ayeyarwady Delta, plain zone of the central dry zone, plantation zone of the central dry zone, and the Shan hill and mountain regions. Results and insights from the participatory action research effort chronicle how the climate-smart village approach was implemented in the four targeted climate-smart villages, herein referred to as A yua gyi, Lay Daung Kone, Pan Le and Htan Ta Pu. The 'appropriate' and 'feasible' local and external support systems needed for the effective community engagement in implementing the climate-smart villages are also discussed. The reality is that what is 'appropriate' and 'feasible' will evolve over time and the active process of research for development needs to respond to address these. Social learning in the climate-smart villages helped nurture the capacities of farmers, as a community-of-practice, to find solutions, to test and improve adaptation options, and to critically engage in the broader processes of research for development and policy (John Barbon *et al.*, 2021) [7].

Each of the four targeted climate-smart village approaches required a tailored combination of socio-technical processes. In an iterative and longitudinal process, smallholder farmers, the research-for-development facilitators, and other relevant community members collectively improved their understanding of climate change (both generic and location specific), the drivers of vulnerability, and the existing coping activities. Within this researched and shared understanding, the farmers in the climate-smart villages then collectively identified a menu of adaptation options that they would test and adopt. This "portfolio approach" to deriving adaptation options ensured that there was a diversity and complementarity, as opposed to a 'silver-bullet' technology. The portfolio of identified adaptation options ranged from the biophysical to the societal, from the low-cost/low-tech to the more transformative. It was intrinsic to the community-level adaptation process that there were opportunities for men, women, and landless households to participate, and to benefit, from the collective adaptation-innovation process. This gender and social sensitive approach to local adaptation options meant that the farmers themselves could determine what was their preferred entry point. Invariably, such bottom-up approaches nurtured incremental adaptation, with the associated incremental learning. The targeted locations of climate-smart villages also dictated that land tenure regimes would influence the nature of the adaptation options, and their eventual uptake.

Collaborative Research Initiatives

Climate-resilient agronomy is an emerging area of research and practice around the world. It involves using a suite of agronomic practices - both ancient and modern - to build soil health and provide the necessary nutrients to crops. This in turn helps them enhance their ability to tolerate heat, flood, and drought in the face of the climatic oscillations of the Anthropocene or Sixth Age of the extinction of biodiversity and destabilization of the world's ecosystems. As yet, there has not been a large fund of research from which to draw good communication for the development of subsequent extension programs modeling the emerging commercial-scale use of climate resilient regenerative agriculture in different climatic and soil conditions. This experiment tested compost as a new type of organic resource incorporation to influence the abundance and composition of soil microbial communities and biological functions in the context of long-term inorganic fertilization comparison with two other organic resources, rice straw, and farmyard manure, under greenhouse conditions (D. Basche *et al.*, 2014) [8]. Collaboration between experts from different fields is increasingly considered essential in order to sustainably solve key problems in a changing climate and world. New scientists need to be trained in transdisciplinary skills and encouraged to embrace the approach. Climate change poses formidable challenges to agriculture globally, and modern breeding strategies targeting heat tolerance could greatly benefit from the novel efforts of innovative basic research breeding approaches. Heat tolerance is among the most challenging stress tolerance traits to improve in crop plants, and the impact of global climate change will aggravate this challenge.

Tropical and subtropical maize grows under well-developed heat stress during the flowering period, hence with potential for further increase under global warming. While heat has a coordinated effect on all cells, and tissues abiotic stress-induced signaling is initiated at the cellular level in very localized sites, typically in membranes and metabolites, which implies that monitoring the responsive components, rather than the stress, provides relevant information. Agricultural research and development projects are increasingly initiated by collaborative models and adhere to the principles of co-learning and co-production of pertinent knowledge within partnerships that include multidisciplinary teams. Moreover, these projects often work on complex themes that require new thinking on the part of the collaboration partners and perhaps development of new methodologies. However, for various reasons the projects become estranged. In presenting the results of an analysis of a four-year experience of distance learning that was used as a base for this study, the collaborative process documented during the life of a support mechanism for a portfolio of agriculture and natural resources projects in

Southern Africa, is examined from the perspective of collaboration of team members after the life of the project.

Conclusion

Over the course of the next 80 years, the population of Earth is anticipated to more than double, with the majority of this growth occurring in regions like Africa and South Asia. The realities of climate change are projected to impose additional strain on global agriculture and our natural resources, making the need for effective solutions all the more urgent. This text delves into a decade-long effort undertaken by the agricultural community to clearly define a practical and actionable plan aimed at addressing the interconnected challenges posed by global food security and climate change. It is widely believed that the agricultural community should strategically adopt five key pathways to reinforce global climate resilience while simultaneously improving food security. Since 2009, substantial work has been in progress to gather solid evidence and consult extensively with various stakeholders to develop a comprehensive roadmap for transformational change. Five initial focus regions were meticulously selected for this purpose, chosen for their diversity yet representativeness in terms of various agro-climatic zones and the differing challenges they face. This extensive effort culminated in a broad consultation process that reached across the globe, engaging a wide array of stakeholders including policymakers, researchers, farmers, bilateral donors, and representatives from international financial institutions. The resulting roadmap is a thorough compilation that summarizes the evidence base collected, outlines the identified pathways, and suggests priority actions that should be taken on an international scale in response to these pressing issues. Since 2009, work has been underway to provide the hard evidence, and consult widely to develop a roadmap for transformation. Five initial focus regions - diverse yet representative in terms of agro-climatic zones and challenges - were selected in which to carry out detailed studies. The effort culminated in broad consultation across the world with policymakers, researchers, farmers, bilateral donors, and international financial institutions. This roadmap comprises a summary of the evidence base, the pathways, and suggests priority action in the international.

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