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Climate Smart Crops for Food Security

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Abstract

After ensuring the food security for over 50 years, the green revolution is eventually reaching its biological limits which are very much reflected by the ongoing stagnancy in yield increased over the past few decades. Meeting the increasing food demands due to increasing population is the greatest challenge for today's plant scientists. Changing climatic conditions are posing additional threats to crop growth, productivity and yield. After successfully deploying gene editing to modify simple traits, scientists are now embarked on more ambitious adventures in genomics to combat challenges of food security in the wake of increasing population and climate change adversaries. The chapter outlines use of new technologies in tailoring crops beyond simple traits aiming to harvest the desired diversity lost during domestication and manipulating complex traits, which evolved over evolutionary timescale with special emphasis on the development of climate smart crops.

Keywords: climate change, food security, climate smart crops, breeding, biotechnology

1. Introduction

Climate change including extreme weather and other associated events are representing challenges to agriculture of developing countries and global food security [1]. Crop production is very sensitive towards climate change. This is influenced by long-term trends in precipitation and average temperature, inter-annual climate variability, shocks in certain developmental stages and extreme weather events. Some plants are more tolerant towards certain types of stresses than others, and at each developmental stage, different types of stresses affect different plant species in different ways [2].

By 2050, it is expected that another 2.4 billion people be added to the population of developing countries of the world. Agriculture in developing countries is a key source of employment, but at present more than 20% of the population falls on an average, in the category of food-insecurity [3]. About 75% of the world's poor population is residing in the rural areas, and again agriculture is their ultimate source of earning [4]. Enhancing agricultural productivity and incomes in the small-scale production sector is very important to mitigate poverty and achieve food security, as a key component and driver of economic transformation and development, and within the wider perspective of urbanization and advances in the non-farm sector. It is estimated that globally by 2050, agriculture sector must have to expand by 60% to

meet the increasing demand due to continuously increasing human population, and it can only be possible by increasing crop productivity under climate change [5].

2. Temperature shifts under climate change

Change in temperature can occur in different forms like fluctuation in overall average temperature, changes in the day and night temperatures, or changes in time, duration and intensity of extreme cold or hot weather. Generally, plants have been more vulnerable to the elevated temperature during the reproduction as well as grain filling or ripening stages. Response of plants to increasing temperature is species specific and facilitated by photosynthetic activity for the accumulation of plant biomass which control the plant growth, as well as managed by all changes in plant morphology and physiology that occur during all day. All kind of temperature stresses have their different impacts on harvesting time as well as on productivity of the crops. The impact of stress depends upon the sensitivity of every particular species to its developmental stage to the fluctuation in temperature. A different kind of response mechanism is needed to adapt for these effects. Increase in temperature during the growing season of plants caused a high respiration rate which means a low amount of energy left for support and growth of plant. Even an increase of 1 °C in average temperature can cause the reduction of 5-10% in major food crops [6].

3. Climate smart agriculture (CSA)

Climate Smart Agriculture (CSA) is an approach in which technological, strategic and investment conditions are developed to reach sustainable agricultural development for food security under climate change. The extent to which climate change is affecting agricultural systems necessitates ensuring comprehensive consolidation of these effects into national agricultural planning, investments and programs (**Figure 1**). CSA is transforming and reorienting sustainable agricultural systems to support food security under the new realities of climate change [8].

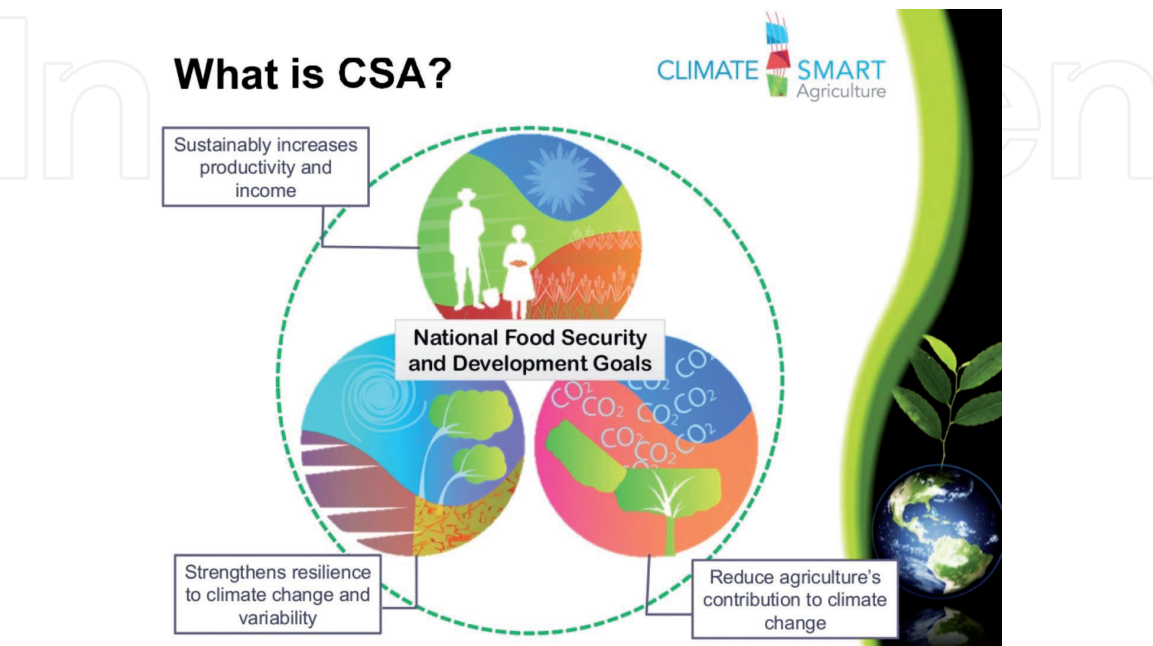


Figure 1.
Climate smart agriculture [7].

4. Objectives of CSA

CSA is striving to increase agricultural productivity in terms of climate smart crops, food security, and farmers' adaptive capacity and lowering greenhouse gas emissions as well [9]. The main objectives of CSA are given below:

- Sustainable increase of Food Security by agricultural productivity
- Building resilience and adapting to climate change
- Developing opportunities for reducing greenhouse gas emissions

4.1 Sustainable increase of food security by agricultural productivity

Agriculture is most important income source of around 75% of the world's poor living in rural areas. To improve the livelihood of this population, growth in the agricultural sector is highly effective that will increase food security in countries with a high percentage of the population dependent on agriculture [10]. Increasing productivity as well as reducing costs is important means of attaining agricultural growth which is possible through increased resource-use efficiency. "Yield gaps" is the difference between the yields that farmers obtain from their farms and the maximum yield potentials of that cultivar and such yield gaps are quite substantial for small farmers in developing countries [11]. Similar is the case with livestock productivity. Reducing these gaps by enhancing the productivity and efficiency of soil, fertilizer, water, livestock feed and other agricultural inputs, much higher returns can be obtained from this sector which in turn will reduce poverty and increase food availability. These same measures can often result in lower greenhouse gas emissions compared with past trends.

4.2 Building resilience and adapting to climate change

In the recent 5th assessment report by the Intergovernmental Panel on Climate Change (IPCC), it has been revealed that the impacts of climatic changes have been observed in different regions of the world. Results showed that drastic impacts of climate changes were more often as compare to the positive ones and underdeveloped countries have shown more vulnerability for the further negative effects of changing climate on agriculture [12]. In medium to long term, when average as well seasonal maximum temperature continuously increase, it led to a high average of rainfall, but these impacts are not distributed evenly as globally wet regions and seasons have higher rainfall as compare to the dry regions and seasons [13]. An increased frequency and intensity of extreme events like drought, high temperature, high rainfall and subsequent floods, have already been observed. Exposure of these increased climatic risks have already been observed in the different parts of the world, these risks put significant threat to potential for increased food security as well as reducing the poverty among the agriculture dependent populations having low-income. Formulation and implementation of effective adaptation strategies required to reduce and even to avoid these drastic impacts of climate change. According to the site-specific impacts of climate change, accompanied with a wide range of agro ecologic variations and farming, fishery system, and livestock, an effective adaption strategy will vary even with in country. For starting the development of an effective site-specific adaptation strategy, multiple potential measures have been identified already. These effect measures include enhancement of reliance of agro-ecosystems, through enhancing the ecosystem services by using

landscape approaches as well as principles of agro ecology. Decreasing the risk exposure by building an input supply system, using the diversification of incomes or production, and by extension services for timely and efficient use of inputs, use of stress resistant or tolerant varieties, livestock breeds, use of forestry species and fishes, are some of the examples of that can be used to increase resilience.

4.3 Developing opportunities to reduce greenhouse gases emissions

Agriculture as well as has land use changes become a major source of greenhouse gas emissions, almost a quarter of overall anthropogenic GHG emissions has been produced from agriculture sector. Agriculture mainly contributes in GHS emissions through crop and livestock sectors, also it is the major factor of increasing deforestation as well as degradation of peat land. Under the business-as-usual growth of agriculture, non-CO2 emissions of agriculture sector are expected to increase. But there are multiple ways to reduce the emission of these gases from agricultural sector. Sustainable intensification is one of the main strategies of agricultural mitigation can reduce the emission intensity (e.g. the CO2 eq/unit product) of these gases. But this process includes the application of new techniques that can increase the efficacy of inputs used so that agricultural outputs increased more as compare to the emission increase [14]. Another significant pathway to reduce the emission is high carbon sequestration rate from agriculture sector. Plants as well as soils have ability to remove the carbon dioxide from the atmosphere and store into their biomass, this phenomenon is called carbon sequestration. Carbon sequestration can be performed through increased tree cover in livestock and in crop systems (e.g. Agroforestry) and by reducing the soil disturbance (e.g. reduced tillage). Still this kind of emission reduction might not be permanent as stored CO2 can be released if trees are cut or soil plowed. In spite of following challenges, high carbon sequestration has a significant potential of mitigation, particularly when the agricultural practices which generates the sequestration have also been important role in adaptation of food security. CSA pathways based on impact of climate change on agriculture are given in Figure 2.

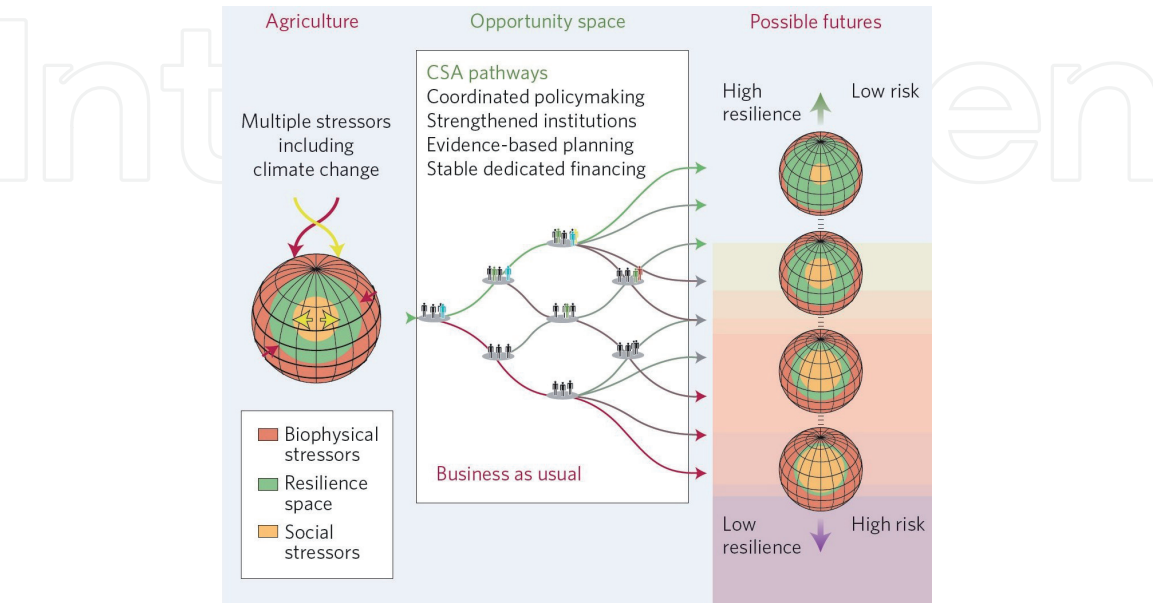


Figure 2. CSA agriculture pathways [15].

5. Climate-smart food system and supply chain

Climate change effects on crop production have shown to have a strong and consistent global trend, which may have implications for food supply. Because of short-term supply fluctuations, the reliability of whole food systems could be jeopardized because of climate change. At regional scales, however, the potential effect is less obvious, but climate instability and transition are likely to intensify food insecurity in areas that are already vulnerable to hunger and malnutrition. Similarly, it is expected that food access and use will be influenced indirectly by collateral effects on household and individual incomes, and that food consumption will be hampered by a lack of access to drinking water and health problems. The evidence suggests that significant investment in adaptation and mitigation measures is needed to create a "climate-smart food system" that is more resilient to the effects of climate change on food security [16]. Food chain from pre-production to consumption has been elaborated in **Figure 3**.

6. Impacts of climate change on crop production

Due to climatic changes overall crop production system has affected, ultimately causing a challenge to global food security. But the more severe impact of these changes has been observed in underdeveloped countries. Over the next decade it is predicted that billions of people, particularly from underdeveloped countries may encountered with water as well as food scarcity, accompanied with a high risk to the life and health due to climate changes. Developing countries are more prone to the changing climatic conditions as these countries lack in social, financial as well as technological resources, which required facing the climate change [17].

Environmental conditions always cast an impact on either the succession or failure of crops, while the management of stresses caused due to these changes has been part of multidisciplinary studies. Global crop production system has shown continuous susceptibility to the risks of changing climatic conditions. Now farmers have been facing severe challenges than the normally experienced, due to changing climatic conditions. Global climatic conditions became extreme like, warmer temperatures, increased coastal waters, heavy precipitation, and geographical shifts in drought as well as storm patterns [18].

It is estimated that climatic changes may cause a considerable decrease in maize production in southern Africa. It may also cause up to 10% decrease in staple crops of south Asia, including rice while more than 10% decrease in millet and maize production [19]. With a slight increase of 1-3°C in the mean local temperature of some moderate- to high latitude areas, productivity may also be increased, depending on

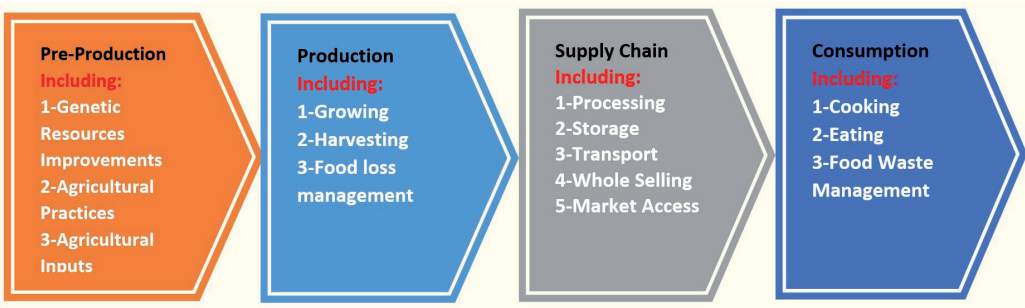


Figure 3.
Food chain from pre-production to consumption.

| Event | Potential impact |
|---|--|
| Day and night temperature increased over most of the land areas as cold periods become shorter and warmer (virtually certain) | High yields in low temperature areas; while in high temperature areas yield reduces; increased outbreaks of different new insect pests as well as pathogens causing notable effect on crop production. |
| High frequency of precipitation over most areas (very likely) | Crop damages; soil erosion; waterlogged soils making land unable for cultivation |
| Increased drought affected areas (likely) | Soil erosion and degradation; reduced yields due to crop failure or damage; arable soil loss |
| Increased tropical cyclone frequency (likely) | Crop damage |
| Extremely increased level of sea water (excludes tsunami) (likely) | Saline irrigation water, fresh and estuaries water systems; arable land loss. |

Table 1.
Impacts of climate change on crop production [22].

the crop. In contrasting, in areas of lower latitudes productivity of crop decreased with the even slightest change in relative temperature range [20].

Unpredictable seasonal as well annual, fluctuations have been observed in crop production system due to the abrupt outbreaks of disease and pest and other extreme events. This require an efficient adaptable management response towards these changing scenarios [21].

Agriculture crop production is facing a number of impacts due to climate change in the components of weather/climate such as temperature, precipitation, cyclones, sea level etc. (**Table 1**).

7. Modern tools of climate smart crop production

Climate change, which includes high temperatures and drought, is projected to have a detrimental effect on plant agronomic conditions as well as soil nutrients, diseases, and pests. As a result, climate-resilient varieties with broad spectrum and long-term tolerance to both biotic and abiotic stresses are required. The new genetic engineering method for crop enhancement is precise genome editing [23]. Climate change has put a pressure on researcher, farmers and scientists working in the field of agriculture to adopt new technologies to cope with the prevailing issues (**Figure 4**). For targeted genome editing in plants, several techniques have been developed, including zinc finger nucleases (ZFNs), TAL effector proteins (TALENs), RNA directed nucleases (RGENs), and CRISPR (clustered regularly interspaced short palindromic repeats)/Cas9 (CRISPR associated protein 9. Both of these approaches depend on the creation of double stranded breaks at particular loci and the activation of the DNA repair system [24].

7.1 Genome editing

Crops with higher yields and greater resistance to abiotic stress are needed to meet the demands of a growing global population and the effect of climate change on agriculture. Traditional crop improvement through genetic recombination or random mutagenesis, on the other hand, is a time-consuming process that cannot keep up with rising crop demand. Genome editing techniques including clustered regularly interspaced short palindromic repeat (CRISPR)/CRISPR-associated protein (CRISPR/Cas) allow for selective alteration of almost any crop genome

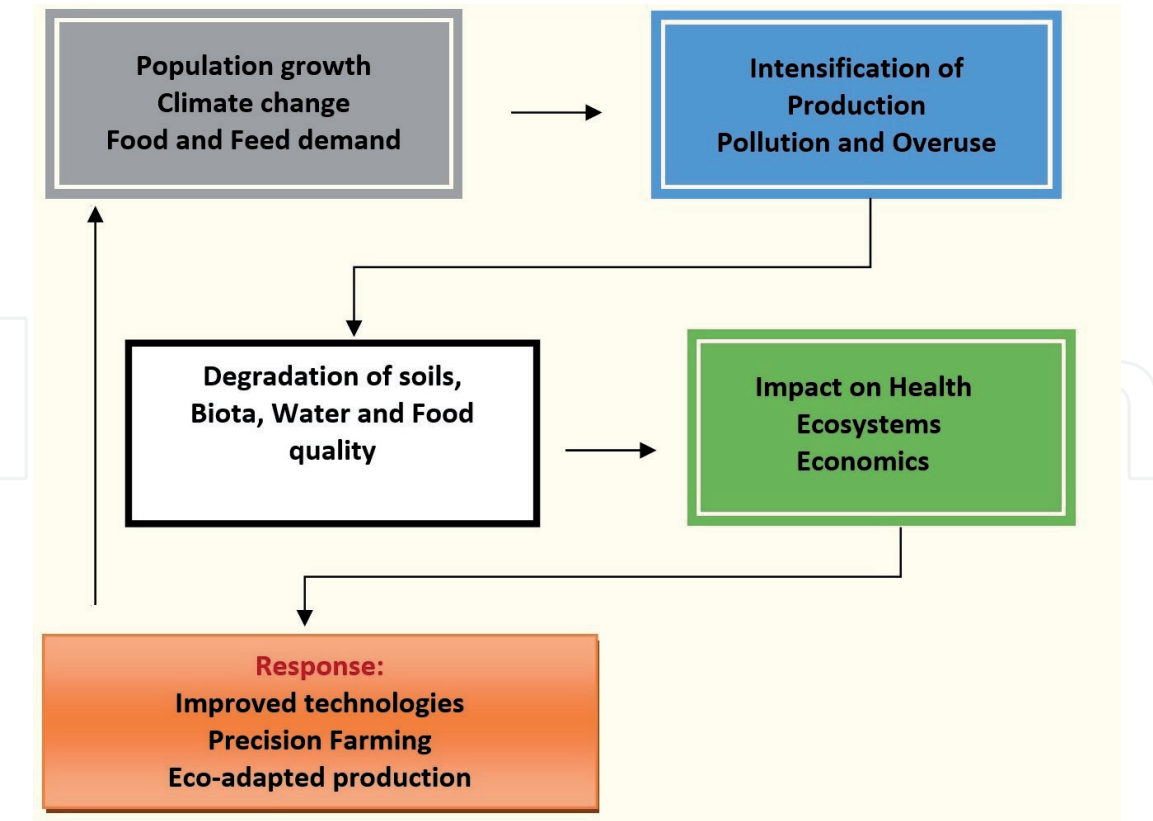


Figure 4.
Impact of climate change on agriculture.

sequence to generate novel variation and speed up breeding efforts. We anticipate a gradual transition away from conventional breeding and toward selective genome editing cycles in crop improvement. Crop enhancement by genome editing is not limited by existing variation or the need to pick alleles through several breeding generations. However, the lack of full reference genomes, a lack of awareness of possible modification goals, and the legal status of edited crops restrict current crop genome editing applications. We believe that overcoming the technological and social barriers to genome editing's implementation will allow this technology to produce a new generation of high-yielding, climate-ready crops [25]. At our lab, we are using different online platforms such as CHOPCHOP, CRISPR-P, MultiTargetor etc, and reagents provided by Addgene, Vectorbuilder, GeneCopoeia, Nootropics Frontline etc. for genome editing in crops.

7.2 Gene silencing

Gene silencing is a method of down regulating (or 'turning off') specific genes via the over expression of RNA sequences (RNAi), which prevents a gene's functional expression. Even though it has been available for many years, it is increasingly being used as a method for shutting off specific genes. Future food protection applications may involve shutting off pathogen attack receptors or stress response elements, which could be extremely useful in the face of climate change. Gene editing is a technique for making precise, targeted changes in genomes at a scale of one or a few nucleotides. Using clustered regularly interspaced short palindromic repeats (CRISPR) and the CAS9 nuclease, transcriptional activator-like effectors' nucleases (TALEN), two alternative systems currently provide state-of-the-art protocols for achieving these small-scale genomic adjustments. Precise genomic modification using CRISPR has been likened to a 'find and replace' function [26]. To precision edit genomes, TALENS employs a nuclease system based on the fusion of transcription

activator-like effectors with target DNA binding domains and an endonuclease cleavage domain. Variable DNA binding domain sequences, like CRISPR/CAS9, enable different genomic targets to be addressed. In rice and wheat, the TALENS system has been effective in conferring powdery mildew resistance [27].

To monitor plant responses or stimulate pathogen resistance, RNA spraying technology typically applies complex synthetic RNA to surfaces, such as plant leaves. RNA spraying technology is known to be under investigation by a number of agricultural biotechnology firms. Since there is no alteration to the plant genome, RNA spraying eliminates the need for genetic modification in such applications. Instead, plant cells take up the sprayed synthetic RNA, temporarily silencing specific genes before the effect wears off, which can take anywhere from a few days to three months [28].

8. Use of genetic resources for climate smart crop

The sustainable use of plant genetic resources can help in adapting and mitigating the effects of climate change.

8.1 Genetic resources for climate change adaptation: a sustainable use

The sustainable utilization of plant genetic assets includes evaluation of genetic traits; identification of desirable traits; plant breeding, including epigenomics; variations in crop production; advancement and commercialization of hybrids; sustainable seed production and supply chain system; and establishment of new business sectors for the distribution of local varieties and related products. These exercises can play a key role to address the effects of climate change on sustainable crop production.

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In their local production environments, farmer varieties and landraces are well adapted to current conditions and proved to be a successful source for adaptive genes in crop improvement [29]. However, they may lose this adaptation in the changing climatic conditions [30]. It may not be a practical solution to introduce more suitable crop varieties from elsewhere [31]. For this purpose, the only viable solution may be the breeding of new varieties. More genetic vulnerability renders crop potentially more susceptible to the impact of climate change. By incorporating novel traits into cultivars, this genetic vulnerability may be reduced. These novel traits are often found in wild relatives of the crops [32]. Pre-breeding is a source of introduction novel alleles from wild cultivars into crop varieties [33]. In this technique, intermediate materials are generated that are used as parents in plant breeding. Diversity and geographical locations of crop wild relatives and landraces can remotely be determined by using predictive characterization tools based on eco-geographic and climate data [34]. This method is known as the Focused Identification of Germplasm Strategy. In the changing climatic conditions, it would be a challenge for breeders and geneticists to increase the yields of major food crops or even maintain them that will definitely depend on their ability to improve local varieties by introducing adaptive traits through breeding [35]. It is also of

much importance for the farmer community to actively participate in the varietal development process to increase the adoption rates of new varieties [36]. Use of a wide range of methodologies is required to develop crop varieties that are tolerant toward climate change induced stresses [37]. These methodologies include induced mutations, biotechnological applications, including cell and tissue biology, marker assisted selection and genetic engineering; and novel plant breeding techniques, including genome editing procedures. With the help of such techniques, Scuba Rice, a flood-tolerant variety of rice was developed for the flood prone areas, such as those found in Bangladesh, India and the Philippines. This is an excellent example of the successful breeding of a crop variety that supports climate-smart agriculture. In these areas where such extreme challenges are faced by crops, adoption of climate-ready varieties is expected to increase because of climate change. There are many neglected and underutilized edible plant species that are resilient and adapted to marginal areas [38]. For example, Moringa (*Moringa oleifera*), Yam bean (*Pachyrhizuserosus*) and Bambara groundnut (*Vigna subterranea*) etc. It would be strategically important to replace staple crops such as maize, with drought-resistant crops, such as cassava and millets in drought-prone regions of the world. However, this climate-smart agricultural adaptation strategy would only be possible if farmers are willing to adopt these new crops. Farmers can only get benefit from this strategy if the seed and planting materials of such crops are available in right quantity and quality and at an acceptable cost. The effectively availability of such resources is much important for these diverse crops and crop varieties to contribute to climate change adaptation and sustain rural livelihoods [39]. Variety approval and release procedures, seed production, quality control, and its marketing are important components of seed delivery systems. These systems usually fall under national and international policies and regulations, that involve diverse actors, such as government authorities, community-level cooperatives, private firms, input dealers, and contracted growers.

8.2 Genetic resources for climate change mitigation: a sustainable use

As compared to climate change mitigation, the contribution of plant genetic resources to climate adaptation process is more result oriented. However, to mitigate climate change, a number of strategies can improve the sequestration of greenhouse gases. More cultivation of C4 plants may be one of these strategies to maintain or increase carbon content in plants, such as maize, sugarcane, millets and sorghum [40]. It is found through various studies that increased carbon sequestration capacity through improved photosynthesis, is a heritable and it can be improved through conventional breeding [41].

Through breeding, improved varieties have been developed that are more productive and sequester more carbon. Legumes crops including pulses such as lentil, garden pea, chickpea, pigeon pea, groundnut etc., have diverse nitrogen-fixing capacity. Improved nitrogen fixation is also correlated with increased carbon sequestration, that's why cultivation of pulses and other legumes would provide additional support for the mitigation of climate change [42].

9. Climate smart crop production: practices and technologies

9.1 Sustainable crop production intensification

Crop production system has continuously been evolving from beginning of domestication of different crop species, almost 10,000 years ago. Crop production

has improved and still improving through different means including, varietal selection, improved irrigation and crop planting methods, efficient use of cropping patterns and fertilizers, using the wild plants and wild relatives. In recent times crop production has relatively enhanced significantly which ultimately provides more food for a continuously increasing global population.

Green revolution has been a best and well documented example of improvement in crop production which revolutionized the crop production system almost in all developing countries during 1960s. Planting high-yielding varieties of crop and also using chemical and improved irrigation methods were the main components of green revolution. In the result of this, production of cereal food crops was increased over 2.2 billion tonnes from 800 million tonnes during the period from 1961 to 2000. It is estimated that almost one population of one billion was saved from famine due to this green revolution, but it costs a high price in the long run. Intensive cropping for several decades has caused a loss of fertility of agricultural soils, ground water depletion; induce resistance in pests, decreased biodiversity as well as air, soil and water pollution. But now this paradigm should be shifted to a new, as intensive cropping systems has not been sustainable and this is what Save and Grow – i.e. sustainable crop production intensification – is about [43].

It means a productive agricultural system not only conserve but also enhances the natural resources using an ecosystem approach which exploits the natural biological processes and inputs. This system not only reduces the negative impact on our environment but also enhances the flow of ecosystem services as well as natural capital. SCPI has also been contributing in the increasing of flexibility of system which is a critical factor, particularly under the aspect of climate change. SCPI can be achieved using better farming practices which are based on the improved efficiencies and well managed biological processes. It has been based on the agricultural production systems as well as management practices which include:

- maintaining the soil health to increase soil-related ecosystem services as well as crop nutrition.
- cultivate a diverse range of species and varieties with associations, rotations, and sequences.
- use of quality planting materials and seeds of high-yielding, and well adapted, varieties.
- integrated management of pest, diseases, and weeds; and
- efficient use of water.

SCPI has climate smart approaches and practices of crop production. Sustainable crop production systems have presupposed to address the vulnerabilities as well as risks caused by the climate changes. CSA has same purpose of achieving food security as the sustainable agriculture, using its own perspective of climate change. From crop production to preparation of land, crop planting and harvesting are basic parts of a farming system which ultimately form a broader agro-ecosystem and landscape. An actual crop is only one part of this agro-ecosystem. But crops may also be the integral part of other production systems like, agroforestry, rice-fish system and integrated crop livestock system. Other parts of agro-ecosystems include soil, biodiversity as well as ecosystem services.

9.2 Integrated pest management

Climate changes have been affecting the spread as well as the formation of different types of disease pests, and weeds. This phenomenon has a large consequence of change in the distribution as well as health of the naturally occurring plants, natural predators, hosts and adaptive variations in agricultural management. With an increase of globalization of trade as well as germplasm exchange, following changes present the pest control with new challenges. Integrated pest management (IPM), an ecosystem approach used for crop production as well as crop protection. This technique has based on the considerations of all possible pest control techniques. IPM considers the use of all possible and appropriate means, to prevent the development of pest population ultimately maintaining the levels of pesticide to economically justifiable limit. Thus, decreasing the risks to human health as well as to the environment through minimize agricultural ecosystem disturbance. Making comprehensive decisions at the field level have been essential for effective IPM [44].

9.3 Sustainable soil management through conservative agriculture

Conservative agriculture is technique which involves the covering of maintained land, reduced soil disturbance, and diversifying crop production. Even though conservation agriculture approach was developed to minimize soil erosion as well as to restore the degraded soils, but it also provides strategic initial base point for adaption against climate changes. Conservative agriculture focusses on the reproducing most stable soil ecosystem which can be attain in any agricultural ecosystem to minimize the dependence of producer on the external inputs to full fill the plant nutritional requirements and pest control (**Figure 5**). BY covering the soil, loss of soil moisture can be minimized; soil temperature can be stabilized, low erosion by water and wind, restoration of the soil carbon through plant debris breakdown and also provide the food material for beneficial soil organism. Using crop rotation and diversification technique disease and pest population will be minimized and soil nutritional value increase. Populations of different soil dwelling animals like earthworms, millipedes, and mites can be flourishing by avoiding mechanical tillage. These micro faunae will take over tillage and improve soil structure by building soil porosity. Conservation agriculture includes the surface organic matter. Soil aggregate improved through the excrement of these soil organisms, while worms create vertical channels which help in the removal of excess water. Soil micro fauna introduce their organic matter which helps in improvement of soil organic quality, structure and capacity to store water ultimately helping to survive under longer drought periods. Conservation agriculture system has ability to mitigate the climate change as untreated soil can work as carbon sink by storing and sequestering carbon. Untreated soil may also reduce the quantity of agriculture required to produce crops, ultimately reducing the fuel consumption [45].

9.4 Sustainable land management SLM

Both public as well as private benefits can be obtained through SLM innovations, making them a potential tool of finding the 'win-win' solutions for poverty, environmental issues and food scarcity. Farmers as a private beneficiary of SLM will get an increased productivity, lower costs, better production stability through growing as well as conserving natural capital (like water resources, soil organic matter, and different types of biodiversity). Through SLM practices soil fertility improved by using large quantity of biomass, reducing the soil disruption, conservation of water and soil, an increased activity as well as diversity of soil fauna, and supporting the

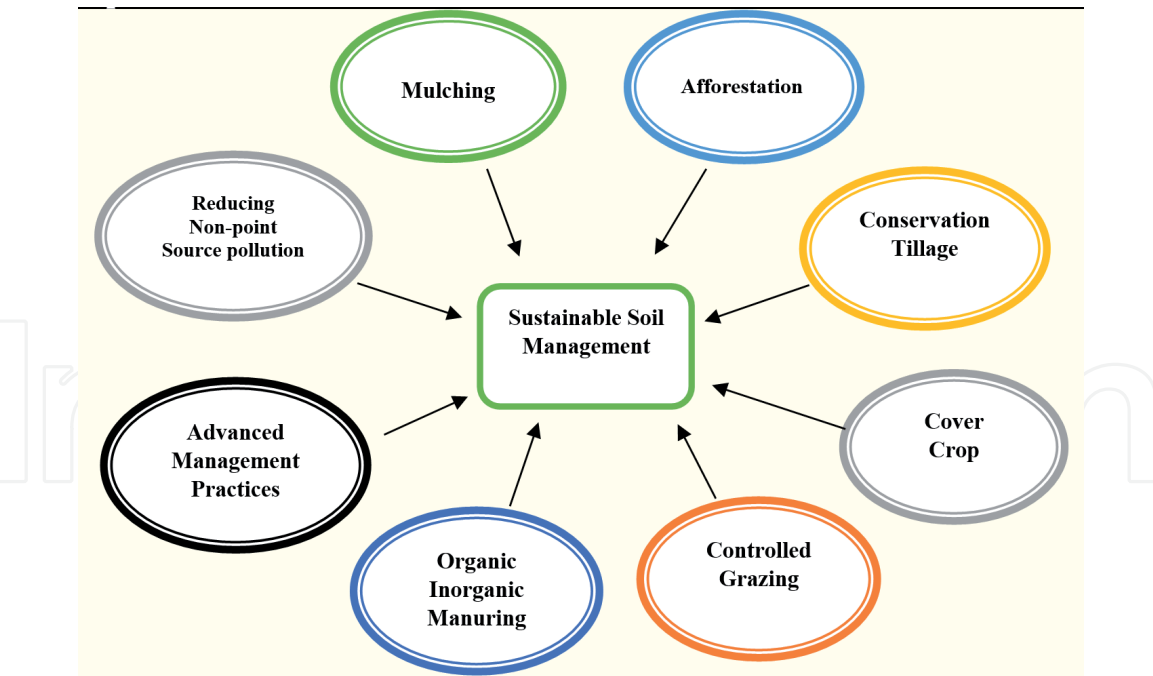


Figure 5.
Sustainable soil management.

elemental cycling mechanism. All this led to improved plant nutritional quality, high water retention ability, and improvement in soil structure contributing to increased yields as well as high resilience, ultimately resulting in improved food as well as livelihood [46].

9.5 Improved water management system

Loss of water can be countered and an improved water management can be achieved by the means of water and soil conservation; either by reduce irrigation which helped to maximize the yield per volume of water used; or through using more efficient irrigation technologies that can minimize the unproductive water loss through evaporation. Buy to attain a high irrigation efficiency and addition energy costs also required, because expansion of irrigation should have to be accompanied by the precise energy technologies (e.g. solar pumps). Strategy development and decision making for the water management and control should be accompanied with the water balance analysis, as for understanding of the impact of changes in water usage in agriculture on the water cycle, a precise assessment of water balance is required for both filed as well as catchment levels. But in upstream areas, introduction of rainwater harvesting technique on a large scale could adversely affects the downstream water users by affecting the groundwater recharge and flux.

9.6 Agro-ecosystem based cropping system approach

Changing climate, sustainable crop production and mitigation in agriculture are linked with each other. The management of ago-ecosystems for production of food, fodder and fuel as well as for management for adaption and mitigation to the chang- ing climate have same fundamental principles and can also work together to attain the same goal: by ensuring the availability of enough, nutritious food for present as well as for future. A resilient ecosystem required for adaption and mitigation to changing climate as well as for crop production, this can be attain using practices and approaches basically based on the ecosystem services and sustainable manage- ment of biodiversity (**Figure 6**).

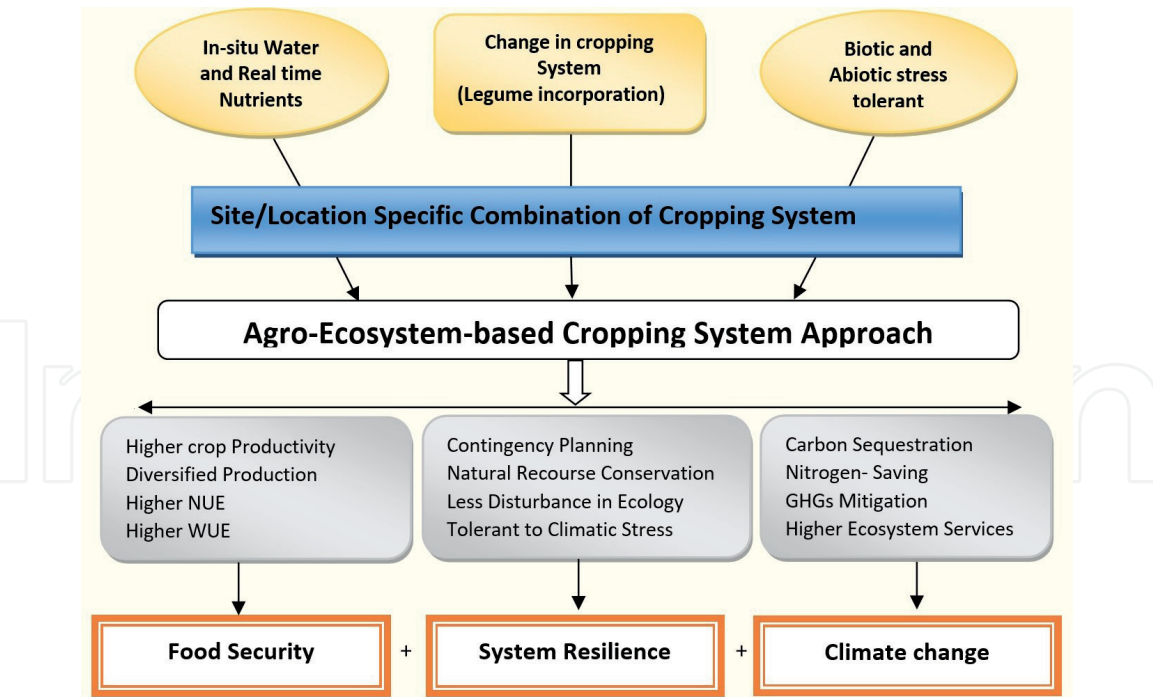


Figure 6.
Agro-ecosystem-based cropping system approach.

Climate smart crop production system is same as the sustainable crop production system as both concerned with climate change. Different opportunities for adaption to climate change and mitigation through contribution to the maintenance and delivery of different public goods like clean water, flood protection, carbon sequestration, ground water recharge and landscape amenity has been provided by sustainable agriculture system. Sustainable agriculture system has been less vulnerable to the stresses and shocks. Productive and sustainable agriculture systems make of the best crop varieties, livestock breeds as well as their biodiversity, agroecological and agronomic management [47].

The drastic impact of climatic changes on crop productivity has already been felt by agriculture sector. For example, in India, production of rice has been decreased 23% during the period of 2001-2002 due to water scarcity [48]. In Indonesia, about 1 344 million tonnes production of rice has been lost due to flooding [49]. While in Mississippi state of the USA, an estimated loss of up to US\$ 8 billion were recorded due to flooding before the harvest season in 2008 [50].

For the security of future food production, crop production system needs to be adopted and mitigated the climate changes. To contrast the impacts of climate change, a better understanding of biological processes (below and above ground) which are involved in farm management practices, is needed. For this purpose, ecosystem management should integrate the different measures for building the resilience and mitigating risk in agriculture. All these elements have become critical under the changing climatic conditions. Biodiversity is essential to maintain the key functions of ecosystem (its structure and process) and to provide vital ecosystem services. It's a significant regulator of agro-ecosystem functions, not only due to its impact on production, but also for filling a variety of needs of the farmers as well as society at large. Biodiversity not only can increase the resilience of agro-ecosystems, but also act as means of risk reducing and adapting to the climate change. Agro-ecosystem managers, including the farmer, can enhance, build upon and manage the essential ecosystem services which have been provided by the biodiversity their efforts for a sustainable agricultural production system.

9.7 The conservation and enhancement of biodiversity

Sustainable farming practices have support both above and below ground cropping systems as well as management of ecosystem services. The nature of associated diversity (plant, microbial animals) can be influenced by the diversity and composition of planned biodiversity (e.g. selected crops) ultimately affecting delivery of ecosystem services. An ecosystem approach means that, to integrate the planned biodiversity that has been maintained through associated diversity e.g. more soil coverage and perennial cultivation, high on-farm plant diversity throughout the agro-ecosystem (e.g. resistance against noxious species).

10. Conclusion

Crop production plays a vital role under climate change by providing opportunities in adapting and mitigating the effects of climate change. Both the principles of sustainable crop production and the approaches for climate change adaptation and mitigation are in line. Climate-smart agriculture actually moves the agriculture from an unstable system towards a more efficient, resilient and sustainable system with the help of naturally auto-control mechanisms. Practices and approaches of climate smart crop production can be utilized by farmers, but the implementation of climate change adaptation and mitigation options not only rely on purely technical basis, but they also depend on social support from the population involved. It is very important to facilitate the farmers by giving the opportunities that are sustained by research institutions and policy. Well-built agricultural policies and research institutions at country level are crucial to counteract the effects of climate change in agricultural production systems and generating the income of the rural population, especially in developing countries. Strong government commitment is a dire need of the moment to formulate or adapt agricultural policies to overcome or minimize the impacts of climate change on crop production. Climate-smart systems are not only important in responding to changing climates especially to the increased unpredictability but can also contribute to mitigate any further change in the climate, thus making these systems more efficient, sustainable and productive. A production system can only be a climate smart, if it is productive and sustainable at the same time.

Modern technological tools such as gene editing, gene silencing and DNA sequencing have revolutionized crop improvement programs in terms of production. Information can be revealed that how plant responses towards stress by using genomics tools and this information can be translated to climate resilient crop. With the help of genomics, molecular markers that are linked to important agronomic traits can be identified; thus, helping to improve crop varieties in terms of quality production, stress tolerance and disease resistance. All these technologies will help to make the world more food secured.

An integrated approach is required to face the challenges of food security under climate change from global to local level as well as from research to policies and investment level. The whole agricultural sector can be shifted onto climate smart agriculture pathways with right policies, practices and investments. It will increase the food security by decreasing the impacts of climate change to global food security on long term.

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