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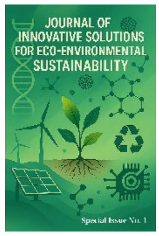

Review Article

Mitigation Strategies to Reduce the Climate Change Impact in Agriculture

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ARTICLE INFO

Keywords:
Adaptation
Climate change
Global warming
Greenhouse gases
Mitigation

ABSTRACT

Climate change and agriculture are closely interrelated and their effects on each other can be seen in the present-day agriculture. Global warming exerts a significant impact on agriculture because of rise in temperature, diminished precipitation, glacial melting, and uneven monsoon etc. Increment in the concentration of greenhouse gases (GHGs) has both impeding and valuable effects on crop yields. Therefore, in agriculture, a proper evaluation of unfriendly impact of climate change is required. An increase in temperature, shortage in rainfall, the incidence of flood and longer dry spells especially in non-ordinary pockets are confirmations of climatic dangers. Thus, appropriate mitigation strategies to reduce GHGs emissions and adaptation of resource conservation technologies (RCTs) are required to make the agriculture sector more resilient to climate change.

1. Introduction

Agriculture had started from ancient times but in the past few decades, it has attracted the attention of global researchers due to hug increase in its production and a drastic change in the gaseous distribution of earth's envelope [1]. Anthropogenic exercises prompting emission of greenhouse gases (GHGs), for example, methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) [2] (Table 1). The global warming potential of GHGs are in order of CFC > N_2O > CH_4 > CO_2. These GHGs trap the leaving infrared radiations from the earth's cover leading to an increase in temperature of the atmosphere which may bring adverse changes in the environment [1, 3].

Table 1.
Effect of anthropogenic activities on greenhouse gas emission

Parameters	CO_2	CH_4	N_2O	Chlorofluorocarbons (CFC)
Average concentration 100 years ago (ppb*V)	290,000	900	270	0
Current concentration (ppb V) (2007)	380,000	1774	319	3–5
Projected concentration in the year 2030 (ppb V)	400,000	2800–3000	400–500	3–6
Atmospheric lifetime (year)	5–200	9–15	114	75
Global warming potential (100 years relative to CO_2)	1	25	298	4750–10900

(Source: IPCC-2007 [2]) *ppb = part per billion

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https://doi.org/10.46991/JISEES.2025.01.1.13493
Received 4 September 2025; Received in revised form 27 October 2025; Accepted 17 November 2025; Available online 29 December 2025

At the end of the 20th century, the global mean annual temperature had increased by 0.4-0.7ºC, as a result, the concentration of GHGs increased. Intergovernmental Panel on Climate Change (IPCC) has anticipated the temperature increment to be between 1.1°C and 6.4°C by the end of the 21st century [4]. The past 50 years indicate a rise in temperature at the rate of 0.13°C/decade, whereas the rate of increase during the last one and half decades has been a lot higher [5]. For the years 2006-2015, the average global temperature was 0.87°C over a pre-industrial baseline [6]. Agriculture, Forestry and Other Land Use (AFOLU) also contribute to an estimated 23% of total anthropogenic GHGs emission, thus increase global warming. AFOLU activities accounted for about 13% of CO_2, 44% of CH_4 and 81% of N_2O emissions from anthropogenic activities worldwide during 2007-2016 [7]. Total annual emission of GHGs in term of CO_2 equivalent is 12,540 from the agriculture sector [8] (Table 2).

Table 2.
Greenhouse gas emissions from agricultural sector

Agriculture sectors	Annual Emissions million tonnes CO_2 equiv.	Green House Gases (GHGs)
Soil fertilization (inorganic fertilizers and applied manure)	2,130	Nitrous oxide
Gases from food digestion in cattle	1,800	Methane
Biomass burning	670	Nitrous oxide, methane
Flooded rice production (anaerobic decomposition)	620	Methane
Livestock manure	410	Methane, nitrous oxide
Industrial factors	1,010	-
Fertilizer production	410	Carbon dioxide, nitrous oxide
Irrigation	370	Carbon dioxide
Farm machinery	160	Carbon dioxide
Pesticide production	70	Carbon dioxide
Deforestation, at large	8,500	-
For agriculture and livestock	5,900	Carbon dioxide
Total	12,540	-

(Source: Bellarby *et al*. 2008 [8])

The local and worldwide changes in the pattern of rainfall, temperature, relative humidity, and soil moisture are crucial for the development and improvement of plants. Thus, appropriate mitigation and adaptation strategies should be pursued to diminish the helplessness of agriculture to climate change and making it more resilient [9]. Adaption capacity for the mitigation has its limitation in light of subsistence agriculture, lack of skill, low degree of formal education, and poor economic status of farmers [10]. Keeping these facts in view, it is necessary to develop a simple, economically feasible and socially acceptable model for the transfer of technology which is easy to adopt (Figure 1).

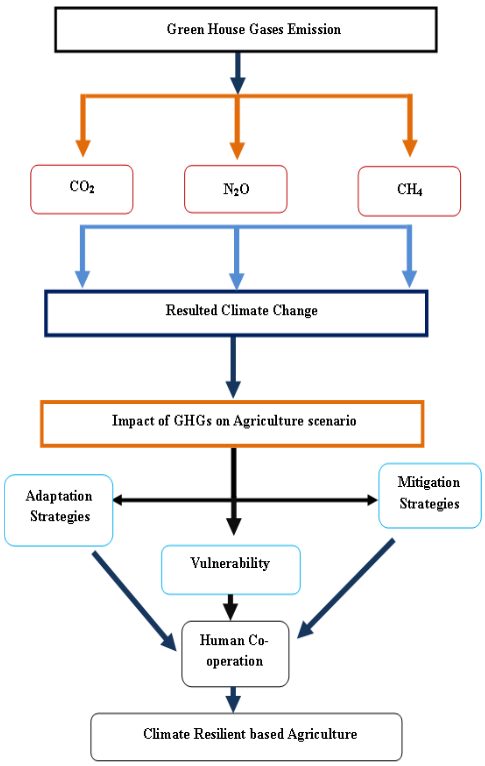

Fig. 1. Framework of climate change impact, mitigation and adaptation in agriculture

2. Climate Change and Its Impacts on Agriculture

Global climatic changes can influence agriculture by direct and indirect impacts on the soil, crops, domesticated animals, and pests [2, 11]. Climate change influences the quality and quantity of water and food, builds air contamination, modifies the circulation of pathogens/vectors and decreases eco-physical buffering contrary to severe climate and weather events [12, 13]. For example, India has to produce 300 metric tons of food grains by 2020 to fulfill the need of its growing population. The net cultivated land (142.5 Mha) is limited thus the pressure to produce more from the same area is mounting year after year; therefore, the maintenance of soil fertility is a prime issue for farmers. At present, agriculture is confronting a significant issue of continued decrease in soil nutrients from its reserve pool [14, 15]. The scientists reported that it may be due to changes in weather and climatic phenomena which are going from bad to worse [16].

An expansion in the atmospheric CO_2 level may have an impact on crops with the C_3 photosynthetic pathway and consequently will promote their development and productivity [17]. The temperature increase may results in increasing crop respiration rate, change photosynthetic apportioning to economic items, affect the survival and dissemination of pest populations, hurry nutrient mineralization in soils, the decline in fertilizer-use efficiencies and increase in evapotranspiration rate [18]. It might influence land use because of snowmelt, accessibility of irrigation water, recurrence of seasonal droughts and floods, organic matter transformations of soil, soil disintegration, and changes in pest profiles, decrease in arable regions and accessibility of energy [19]. Some of the climate change impacts on agriculture and livestock are described as under:

2.1. Carbon Dioxide and Its Potential Effect on Crop Yield

In the course of recent years, as the earth moved between ice ages, the atmospheric CO_2 changed between 180 ppm (glacial periods) and 280 ppm (interglacial periods). In 2009, CO_2 has expanded consistently to 384 ppm and the mean temperature has expanded by 0.76 °C, from their pre-industrial level of 280 ppm. An increase in the atmospheric concentrations of CO_2 has largely resulted in global warming and climate change during the past century [2, 15, 20]. The existing atmospheric level of major GHG *i.e.* CO_2 is 411 ppm, higher than whenever in the previous 800,000 years [6, 21].There is growing proof recommending that numerous crops, notably C_3 crops, may react emphatically to increased atmospheric CO_2 without other distressing conditions, yet the advantageous direct effect of raised CO_2 level can be offset by different impacts of climate change, for example, raised temperature, modified patterns of precipitation and higher tropospheric ozone concentration [22]. High temperatures lessen the net carbon gain in C_3 species by expanding photorespiration. The CO_2 enhancement is required to increase photosynthesis more at high temperatures, and therefore at least partially counterbalancing the temperature effects on yield [23]. The yield increments at high CO_2 ought to happen most frequently in regions where temperature is close to the optimum for crop growth. Then again, in regions where high temperature as of now is seriously restricting, further increments in temperature will discourage crop yield disregarding of changes in CO_2 [23].

Carbon dioxide is basic to plant development. Expanded CO_2 is relied upon to have positive physiological impacts by increasing the rate of photosynthesis. Right now, the measure of CO_2 in the climate is 384 ppm. In correlation, the measure of O_2 is 210,000 ppm. This implies that often plants might be famished of CO_2, being dwarfed by the photosynthetic contamination oxygen. The impacts of expansion in CO_2 would be higher on C_3 crops (*i.e.* wheat) than C_4 crops (*i.e.* maize), as the former one is more susceptible to CO_2 shortage [2]. The yield increase could reach 36% under optimum states of temperature and humidity if the levels of CO_2 are doubled. However, many studies additionally demonstrate an adjustment in harvest quality [24]. The growth improvement in C_3 plants could support vegetative biomass on grain biomass, in this manner prompting a reduction in grain yield. Some vulnerable change identified with CO_2 discharge will happen in the forthcoming era which may prompt a change in agricultural productivity [25] (Table 3).

Table 3.
Per capita CO_2 emission and estimated impact of global warming (with carbon fertilisation) on agriculture productivity in some selected countries in 2080s

Country's Name	Per capita CO_2 emission (tones CO_2/capita/year)	% change in agriculture productivity
USA	18.9	+8
Canada	16.9	+13
Russia	10.8	+26
Japan	9.8	+8
Germany	9.6	+12
UK	8.9	+11
France	6.0	+7
China	4.9	+7
India	1.4	-29
Pakistan	0.9	-20
Sri Lanka	0.6	-8
Bangladesh	0.3	-10
Nepal	0.1	-4

(Source: Kumar *et al*. 2011[25])

There is an apparent increment in food grains, cereals, and some non-cereal commodities in India from 1971 to 2012 (Table 4) but an increase in the mean temperature over a threshold level will cause a decrease in agricultural yields. Temperature is an important climate element which has a crucial role in crop production. An adjustment in the minimum temperature is more essential than an adjustment in the maximum temperature. A little change in temperature may lead to a reduction in yield depending on the sensitivity of the crop to temperature [1]. Grain yield of rice, for instance, may decline by 10% for every 1°C increment in the developing season minimum temperature above 32°C [26]. In Punjab (India), the climate change effect on the productivity of rice has demonstrated that the increase in temperature at a rate of 1, 2 and 3°C with all other climatic variables remaining constant, would decrease the grain yield by 5.4, 7.4 and 25.1%, respectively [27].

Table 4.
Growth in food grains, cereal and some non-cereal agricultural commodities in India

Agricultural products	Year			Growth over the period from 1970-71 to 1990-91 (%)	Growth over the period from 1990-91 to 2011-12 (%)	Growth over the period from 1970-71 to 2011-12 (%)
	1970-71	1990-91	2011-12			
Food grains[a]	108.00	176.00	250.00	63	42	131
Cereals[a]	96.60	196.40	240.00	103	22	148
Pulses[a]	11.80	14.30	17.20	21	20	45
Oilseeds[a]	9.60	18.60	30.00	94	61	212
Potato[a]	4.80	15.20	46.60	217	206	870
Milk[a]	22.00	53.90	127.90	145	137	481
Egg[b]	6172	21101	66450	242	215	976

[a]Values in million tonnes, [b]Numbers in million (Source: Economic survey, GOI, 2012-13)

2.2. Irregularities in Drought, Monsoon, Flood and Cyclone

It has been found that various factors are responsible for change and the contribution to global GHGs emissions (Figure 2). Among the agricultural emissions, a share of enteric fermentation in CO_2 equivalent is highest (Figure 3). Crop yields scenario in agriculture is very reliant on the beginning, retreat and magnitude of monsoon rainfall, especially in the rainfed regions of the south, north-east, and east India [1].

Climate modelers and IPCC records have anticipated possibilities of expanding changeability in the Asian monsoon course in a warmer world. Global warming and altered precipitation patterns due to rising atmospheric CO_2 have been predicted to cause climatological drought events to become more widespread and severe [28]. Regardless of extension of the area under irrigation, droughts brought about by deficient and uneven circulation of rainfall, keep on being the most significant climatic distortions, which impact the agricultural production in India (Mall *et al.* 2006a; Mall *et al.* 2006b). In future, the occurrence of agricultural drought may be more common with new germplasm and farming practices with increased crop demand for water [29]. The severity of drought will increase in a warmer world. Extreme and incessant flooding because of climate change would be a noteworthy issue in the subcontinent countries (IPCC 2007; IPCC 2012).

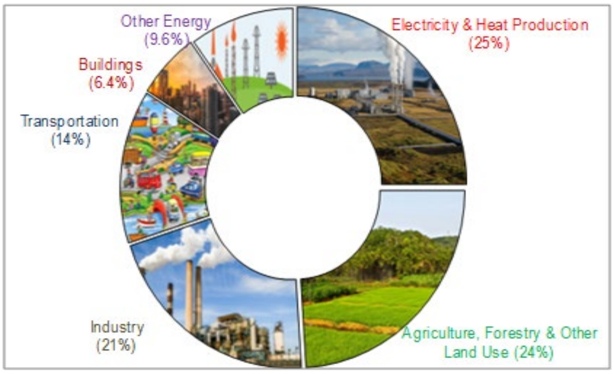

Fig. 2. Global GHGs emissions by economic sectors in 2010 (Source: IPCC [2])

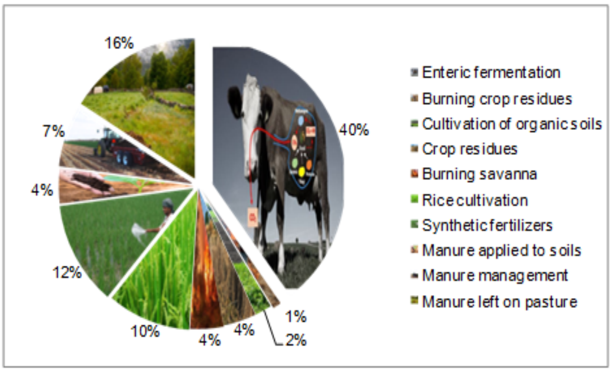

Fig. 3. Share of agricultural emissions in CO_2 equivalent in 2014 (Source: FAO)

2.3. Diseases and Pests

Individual farmers and consumers are expected to be affected greatly by climatic changes. The agricultural sector of developing and developed nations needs to understand what is at stake and judiciously prepare for the change. Despite of advancements in technology, crop productivity still remains highly dependent on climate. Infestations by pests and plant diseases, as well as irrigation demands are again influenced by climate. Alterations in the patterns of weather thus make the crops more susceptible to infections, choking weeds and pest infestations. The influence of climate on the development of plant diseases has been observed for over 2000 years. The ancient Greeks in fact pointed out that cereal crops grown at higher altitudes had lower incidence of disease in comparison to cereal crops of lower altitudes [30]. The most important climate-change factors which probably influence the severity of plant diseases and spread include: increased atmospheric CO_2, unseasonal rains, increased humidity, drought, and warmer winter temperatures [31]. Since the beginning of the Industrial Revolution, there have been a significant rise in the concentration of atmospheric CO_2 and is in fact estimated to double its current level by the end of this century. The increase in green house gases will lead to increased CO_2 emissions and global temperature. As a result, global weather patterns will change in turn raising the ocean levels thereby affecting the biological functions. Plants are among the most exposed organisms to changing climatic conditions and will be affected severely. The increasing CO_2 concentrations will directly affect the interactions between plants and diseases which have been even shown for major food crops infected with plant viruses [32].

Climate change and variability are significant drivers for epidemiology of plant disease. Changes in climatic seasonality may disturb the synchrony between crop phenology and disease patterns. If the situation continues to remain same, crops will require spraying of chemicals for disease control [33]. Further, farmers may have to select the most favourable site for their crop species or they may introduce new crop species which would be beneficial for elevated levels of atmospheric CO_2 [34]. Besides the possible benefits from planting new crop species, the risk of new pathogens accompanying new crop species will increase [35]. The influence of future predicted temperatures on virus titre of Barley yellow dwarf virus (BYDV-PAV) was studied on wheat grown in western Victoria. The study showed higher titre of the virus under elevated temperatures in early growth stages. The viral symptoms were visible earlier in wheat at higher temperature as compared to ambient temperature [36]. Thus, in times of quickly changing atmosphere and unsteady weather, the forecast of disease outbreaks will be more difficult. Ecological unsteadiness and expanded frequency of extreme weather may lessen the viability of pesticides on targeted pests or result in more damage to non-target organisms [1].

2.4. Water Deficiency

Climate change is an unavoidable event either of natural or human origins to which reduction and adaptation are crucial to lessen the extent of its influences and damages [37]. It is in fact one of the biggest environmental challenge of 21st century with negative impact on different human communities, economic sectors, natural resources, and biodiversity [38]. Reduced rainfall and elevated temperatures would result in changes to water fluxes and stores in groundwater systems [39]. The increase in temperature would bring about more water deficiencies and the irrigation water demand would rise. Increment in air temperature will prompt more potential evapotranspiration in the areas of the south to 40º N [40]. In India, water deficiencies because of climate change would result in about twenty percent net decrease in the rice yields. So, water scarcity is also a prime issue in agriculture and to overcome this issue we have to utilize the water feasibly [4].

2.5. Decline in Soil Fertility

Climate is an active factor of soil formation which governs the properties of soil. The change in environment will reflect a change in properties of the soil up to a certain level [41]. Maintenance of soil fertility is a prime issue to sustain crop productivity. To achieve the food demand, 45 million tons of nutrients are required out of which 35 million tones are estimated to be supplied by chemical fertilizer and remaining by organic sources. The present-day agriculture is confronting an issue of continuous decrease in soil nutrients reserve and a decrease in organic matter content of soil [42]. Carbon and nitrogen are the main ingredients of soil organic matter. Organic matter is meaningful for various soil properties like formation and maintenance of soil structure, cation exchange capacity, water holding capacity and nutrients supply to the soil ecosystem [17]. Soil temperature influences the organic matter decomposition rates and nutrients release. However, nutrient accessibility will increase for the time being but organic matter substances will decrease in the long haul at high soil temperatures, thus decreasing soil fertility. The organic matter substance of Indian soils which is now very low would turn out to be still lower and in this manner soil quality might be altered [43]. The crop residues will have higher C: N proportion under the raised CO_2 concentrations resulting in the reduction of their decomposition rate and supply of nutrients. An increase in soil temperature will raise nitrogen mineralization, however, its accessibility may diminish because of the increase in gaseous losses due to denitrification and volatilization processes [1].

The soil framework reacts to the long duration changes like chemical and physical weathering and experiences short duration changes like episodic infiltration of precipitation because of climate change. Global climate change results in the potential shift of factors responsible for soil formation [26]. As an extent, the sodic soil will lead to an increase in salt content due to arid conditions thus making nutrients unavailable to plants. The extreme events of either rainfall or temperature may enhance the leaching of nutrients and accelerate the rate of mineralization which directly correlated with a decline in the fertility status of the soil [42].

2.6. Sea Level Rise

About 10 percent of the regional rice production in East, South East and South Asia, which is sufficient to feed 200 million people, is from the areas that are sensitive to a 1 m rise in the sea level [2, 4]. Direct loss of land joined with the less ideal hydraulic situation may decrease rice yields by 4 percent if no adaptation measures are taken, threatening the food security of at least 75 million people. Saltwater interruption because of ascending sea level resulting in soil stalinization are other concerns for agricultural productivity [44].

2.7. Livestock Management

Climate change will influence fodder production which ultimately affects the nutritional security of livestock. An increase in temperature would boost lignifications of plant tissues, decreasing the edibility of feed. An increase in water shortage would likewise diminish feed and fodder production. The main effects on vector-borne diseases will be through the extension of vector populations in the cold regions [2]. The variations in rainfall patterns may likewise impact the extension of vectors during humid years, prompting huge outbreaks of diseases. Global warming would enhance water, safe house and energy prerequisite of animals for ensuring the projected milk demands. Climate change is probably going to disturb the heat stress in dairy livestock, antagonistically influencing their reproductive performances thus the climate change adversely affects the human being as well as livestock [4].

2.8. Loss of Biodiversity

To a great extent because of climate change as a result of human exercises, many species of flora and fauna are evaluated to vanish at a rate that would be around 100 times quicker than the historical record [1]. An itemized evaluation of the 394 species of primates from Indonesia to South America has shown that 29 percent are in risk of endangering because of climate change, hunting and habitat loss [1, 45].

3. MITIGATION Strategies to Green House Gas Emission

It is a well-established fact that excess emissions of GHGs are the major culprit for climate change. An increase in Soil Organic Carbon (SOC) stocks is a regularly mentioned alternative to mitigate emissions of greenhouse gases [46]. Organic amendments and suitable mineralogical conditions play a key role in enhancing soil carbon stabilization [47]. Under climate change, SOC reduced by 1.3% of original stocks and microbial respiration expanded by 17% because of an expansion in annual minimum and maximum temperatures [48]. The approaches for alleviating methane emission from rice cultivation could be done with change in water management and developing organic matter management by improving aerobic deterioration through composting or integrating it into the soil during a draining period or offseason. Utilization of rice cultivars with some ineffective tillers, high harvest index, high root oxidative movement and use of fermented manures such as biogas slurry instead of unfermented farmyard manure are some other mitigation approaches [49]. Biomass has frequently been viewed as a capable renewable energy asset to mitigate the change in climate [50]. Methane discharge from ruminants can be decreased by modifying the feed content, either to decrease the rate which is changed over into methane or to improve the meat and milk yield. The most adequate management process to decrease the emission of nitrous oxide is site-explicit *i.e.* effective nutrient management [51].

The emission could likewise be decreased by utilizing nitrification inhibitors, for example, dicyandiamide (DCD) and nitrapyrin. Some plant-derived organics are there such as neem cake, *Karanja* seed extricate and neem oil which can likely act as nitrification inhibitors. Adams *et al*. [52] identified that mitigating the emission of CO_2 from agriculture can be accomplished by expanding carbon sequestration in the soil through the handling of soil temperature and moisture, reclamation of soil carbon on depraved lands and putting aside excess agricultural land. Soil management activities like manuring, reduced tillage, micro aggregation, residue adding, mulching and enhancing soil biodiversity can take significant roles in carbon sequestration in soil. A few advances like site-specific nitrogen management, irregular drying, etc. can be effectively adopted by the farmers without extra venture, while other advancements need policy support and economic incentives [49]. In India, the neem coating of urea has become compulsory. It has twin benefits, apart from increasing N use efficiency; it also had less N_2O emission when contrasted with uncoated urea. Polymer coated urea is also being tested to mitigate the N_2O emission [42].

3.1. Adaptation Strategies to Reduce the Accelerated Effect of climate change

A proper strategy should be endorsed to cope up with the conflicting effect of climate change on living and non-living things on earth [1, 2]. The efficient adaptation strategies are improving crop management activities, better weather forecasting, adopting RCTs, promoting cultivars tolerant to salinity and heat stress, improving pest management, resistant to drought and flood, utilizing the indigenous technical knowledge of farmers, modifying water management, crop insurance and crop diversification [4]. Some of these techniques are explained as under:

3.2. Climate Smart Crop (CSC)

Crop production is fundamental to worldwide food security and is being influenced by climate change everywhere throughout the world [53]. The adoption of improved cultivars is a significant approach to adjust to the negative inference related to climate change and inconstancy [54]. Improvement of new high yielding crop cultivars and resistance from different stresses such as flood, drought and salinity will be the way to manage yield stability. Development in germplasm of essential crops for tolerance against heat-stress ought to be one of the objectives of the breeding program. Additionally, it is necessary to create a tolerance for numerous abiotic stresses as they happen in nature [55]. The concept of the climate-smart crop is ground approach base with little scientific modification in technology.

CSC = Sustainable Crop + Resilience – Emissions Climate-smart crop is a new practice to achieve the yield in adverse conditions by adopting a certain principle. The key points to be followed in the cultivation of CSC to achieve higher yields are:

- ✓ Keep soil healthy to enhance the services related to soil ecosystem and crop nutrition
- ✓ Planting a broad range of varieties and species in associations, sequences and rotations
- ✓ Adopting seeds of good quality
- ✓ Using planting materials of high yielding and well-adapted cultivars
- ✓ Practicing the integrated management of weeds, diseases and pests
- ✓ Efficient water management

The availability of nitrogen and other nutrients is essential for increasing crop productivity. This can be achieved using the cultivation of legumes crop, use of crop residue, slow-release nitrogenous fertilizer such as neem coated, and polymer-coated urea leading to less emission of GHGs under traditional sector where subsystem farming is being practiced and soil is poor in nutrients. Emerging nanotechnology-based inputs such as zinc oxide nanoparticles can further improve nutrient uptake and stress tolerance in crops [56, 57]. The problem can be addressed by intercropping, crop rotation, agroforestry, and use of green manuring legume crops [37].

The tolerance mechanism against abiotic stress is a quantitative character in plants. Germplasm having higher oxidative stress tolerance is one such example where the defense system of plant targets few abiotic stresses. Analogous to the research endeavors on alteration of rice from C_3 to C_4 crop, steps ought to be taken for development in the radiation-use efficiency of some other crops also [19]. Enhancement in nitrogen-use and water-use efficiencies expect more importance in perspective on climate change, as water assets for agriculture are probably going to decline in the future. Make use of more drought versatile rice cultivars and better irrigation framework may lessen the effects in the regions where food security and living of low-income farmers might be compromised in the coming couple of decades by climate changes (Singh *et al.* 2019).

3.3. Diversification in Crops and Its Growing Pattern

The capacity to build productivity even with the moisture and temperature stresses is to be achieved through diverseness of crop varieties [4, 58]. Diversity in the composition and genetic structure of seed has been perceived as a powerful defense contrary to disease and pest outbreak and climatic threats. Furthermore, demand for food items having high value such as vegetables, fruits, eggs, fish, dairy, and meat is expanding due to the urbanization and growing income [55, 59]. This is decreasing the demand for staple foods like wheat and rice. This diversification towards high-value commodities from wheat-rice will increase income and resulting decrease in fertilizer and water use [55]. Despite, there is a need to evaluate the effects of crop diversification on soil health, GHGs emissions, water use, employment, and income. A critical restriction of diversification is that it is expensive in terms of income opportunities [18].

3.4. Alteration in Land Use Management Practices (LUMP)

Alteration in land-use related activities like moving production far from marginal areas, relocating production among livestock and crops, adjusting the intensity of pesticide and fertilizer application can help decrease dangers in farm production from climate change [1, 4]. Land-use consequences for soil fauna are similarly solid under vast and future climatic circumstances [60, 61]. Climate change has a more noteworthy effect than land use on water maintenance, but land-use change greatly affects nitrogen export, phosphorus export and soil retention [62-64]. Modifying the cropping sequence that includes altering the timing of planting, spraying and harvesting to exploit the changing term of growing seasons is one more choice [55]. Changing the sowing or planting time can likewise control the growing season length to superiorly fit in the climate change. Change in the irrigation time or split application of fertilizers could also mitigate a part of GHGs emissions. Mineral amendments such as zeolite enhance nutrient retention and water-use efficiency [65]. Methane emissions can be avoided by utilizing fermented manure, such as biogas slurry to reduce the emission [66]. The monoculture of cereals promotes the deficiency of monovalent ions from the soil. It is advisable to include pulse along with cereals crops in rotation. Pulses being nitrogen fixers and less exhaustive help to improve soil fertility [18].

The agroforestry system helps improve the fertility of the soil, increasing the productivity of crops and helps diminish vulnerability and make the agriculture system more climate smart. Tree and shrubs not only protect to mitigate extreme weather events for example windstorm, drought, flood and heavy rain but also increase the income of the farmers by providing a protective layer against crop failure. Hedging is a feasible versatile measure against the climate change instigated water deficiency at the Pong reservoir in the Indus Basin Beas River, India [67]. Inclusion of tree crop enriched biodiversity reduced soil erosion, increase infiltration rate of soil moreover the legumes tree and shrubs can fix atmospheric nitrogen which reduced the dependence on chemical fertilizer. It has been observed that the maize yield increase by 1.3 to 1.6 ton/ha/year in the agroforestry system of Africa [68]. In central Kenya, farmers traditionally use fodder trees and shrubs such as *Calliandra* and *Leucaena* capable of reducing the need for extreme feeds [69]. Bamboo is developing a financial situation of farmers by using cultivable wasteland and helps in the mitigation of climate change by controlling deforestation, carbon sequestration and afforestation [70].

3.5. Adjust the Crop According to Its Suitable Season

Terminal rain and heat in India are appearing as a new menace both in *kharif* and *rabi* seasons causing substantial yield loss in rice and wheat crops. Change of planting dates to reduce the impact of temperature increase initiated spikelet sterility which can be utilized to decrease yield instability by escaping the flowering time to concur with the hottest period. There are various models in use to predict the appropriate date by which the loss of crop in terms of yield could be minimized [71, 72]. Adjustment measures to decrease the negative impacts of expanded climatic changeability as ordinarily experienced in semi-arid and arid tropics may incorporate shifting of the cropping schedule to exploit the wet period and to keep away from extreme weather occasions like storms and typhoons in the growing season [4]. Cropping systems may have to be altered by cultivating suitable varieties, increasing crop intensities or planting various categories of crops. Farmers should adjust to changeable hydrological systems by changing crops [73].

3.6 Adequate Utilization of Assets

The RCTs incorporate practices that amplify input- or resource-use efficiency and give quick, recognizable and demonstrable economic advantages like savings in water, decrease in production costs, fuel and labor prerequisites and timely formation of crops, bringing about improved yields [4]. Wheat yields in water and heat-stressed environments can be expanded significantly by using RCTs, which reduce adverse environmental effects, particularly in small and medium-scale fields. Reducing the carbon footprint of energy-intensive agricultural systems is essential for climate mitigation [74]. Zero-tillage which is a resource-conserving technique can enable farmers to plant wheat just after harvesting of rice, so the grain filling in crop starts before the beginning of pre-monsoon [2]. Using enhanced organic management and reduced soil tillage can balance the negative effect of climate change on soil carbon [75]. Early sowing will turn out to be more meaningful for wheat, as the normal temperature in the area rise. Field results have demonstrated that the RCTs are progressively being followed by farmers in the rice-wheat areas of the Indo Gangetic Plains (IGPs) given benefits of water-saving, labor-saving and early sowing of wheat. The RCTs in the rice-wheat pattern additionally have a clear-cut effect on the mitigation of emission of greenhouse gases and adaptation to climate change [76]. Water and soil management is significant for adaptation to climate change [1, 2] . Water will additionally turn into a rare asset with a change in rainfall distributions and higher temperatures. Farmers must be motivated and trained for micro-irrigation schemes for improved water-use efficiency and adopting techniques on-farm water conservation. Farmers should be advised to adopt the practices for decreasing soil evaporation with the utilization of crop residues mulch, reducing runoff with the utilization of ridges, contours, vegetative hedges and improving water infiltration with progress in soil aggregation [4].

3.7 Shifting of Crops to Suitable Regions

Climate change in premises of CO_2 concentration, droughts, increased temperature and floods would influence crop production [3]. But this effect will be diverse over regions and crops. So, there is a need to find out the regions and crops that are more conscious of changes in climate and shift them to those suitable areas. Suitable areas that would emerge as convenient for such crops from quality perspective should be recognized and evaluated for their appropriateness. For instance, it is found that higher temperature would influence the quality of the crop, especially some significant aromatic crops like tea and basmati rice [55, 59].

3.8 Farmers' indigenous technical knowledge (ITK)

South Asian farmers, generally poor and marginal, are trying different options with climatic changeability from the centuries. There is an abundance of information on the scope of measures that can benefit in establishing technologies to conquer climatic problems [55]. The opportunity has already come to grab that knowledge and utilize it to fit the modern demands. Sociological and anthropological investigations have featured the significance of social learning and community-based resource management to improve their ability to adapt to future climate change effects [1, 2]. Knowledge setup of hill and tribal are abundant with potential indigenous activities utilized for crop production, nutrient management, weed management, rainwater harvesting, and plant protection. Their judgments have efficiently helped in the forecasting of weather and risk balance in the cultivation of crops. During the course of their residence, the indigenous people of the Himalayan terrain area have devised methods of decreasing their defencelessness to natural calamities through experimentation, their experience and aggregated knowledge [3].

3.9 Improved pest management

Changes in temperature and fluctuation in rainfall would influence the occurrence of disease and pests in major crops [77]. It is because climate change will efficiently influence the weed/pest-host relationship by influencing their population, population of the host and their interactions. Some of the adaptation approaches are:

- ✓ Establishing alternative crops and production systems that are resistant to invasions and different risks
- ✓ Adoption of integrated pest management with more attention on modifications in cultural practices and biological control
- ✓ Developing diseases and pest's resistant cultivars
- ✓ Management of diseases and pests by using resistant cultivars, viral and bacterial pesticides, natural pesticides, pheromones for disturbing pest reproduction, etc.
- ✓ Pest forecasting based on recent techniques like simulation modelling
- ✓ Bio agents viz. Trichogramma, Trichoderma, Nuclear Polyheterosis Virus (NPV), etc. have a decisive

contribution to the management of pest, subsequently, activities which enhances natural enemies and improving their habitat, multiple cropping, crop rotation, release of parasites and predators, and encouraging flowering strips and beetle banks ought to be incorporated in pest management activities. Decrease being used of pesticides will likewise help in decreasing carbon emission.

3.10. Better Crop Insurance Schemes and Improved Weather Forecasting

Government policies had a significant impact on current agriculture and will continue to do so. Early warning setups and weather forecasting will be exceptionally helpful in minimizing the dangers of climatic changes. Information and Communication Technologies (ICT) could enormously support the analysts and administrators in creating alternate plans. Efficient crop insurance schemes ought to be formulated to help the farmers in decreasing the crop failure risks because of climatic changes. Both public and private as well as formal and informal insurance schemes should be set up to assist the reduction in income losses because of climatic impacts [55]. Ease in access to financial related services could be a favour for helpless farmers. Developing a system of portable communication such as mobile could further accelerate SMS based financial services and benefit the farmers in having a good relationship with financial organizations. Nonetheless, contrasted with micro-finance, micro-insurance developments and their accessibility are limited. There is a demand to improve sustainable insurance setup, whereas there is a need to educate the rural poor [78].

3.11. Soil management by sustainable key factors

Biochar application enhances carbon sequestration, soil fertility, and microbial activity play a vital role in maintaining soil structure and nutrient enrichment (Singh [72, 79]. Green manuring improves soil organic matter and nutrient cycling, supporting long-term sustainability [18]. Declining soil fertility is now a day's primary global concern that should be managed for attaining proper soil health. Soil is facing various kinds of problems concerning major issues for gaining sustainable yield. The sustainable key factors that are helpful for proper maintenance of soil health in a sustainable manner are noted in Figure 4. The figure clearly shows that there are some key factors that are responsible for declining soil fertility continuously but at the same time if we follow sustainable key factors then soil health could maintain till prolong time [24, 80].

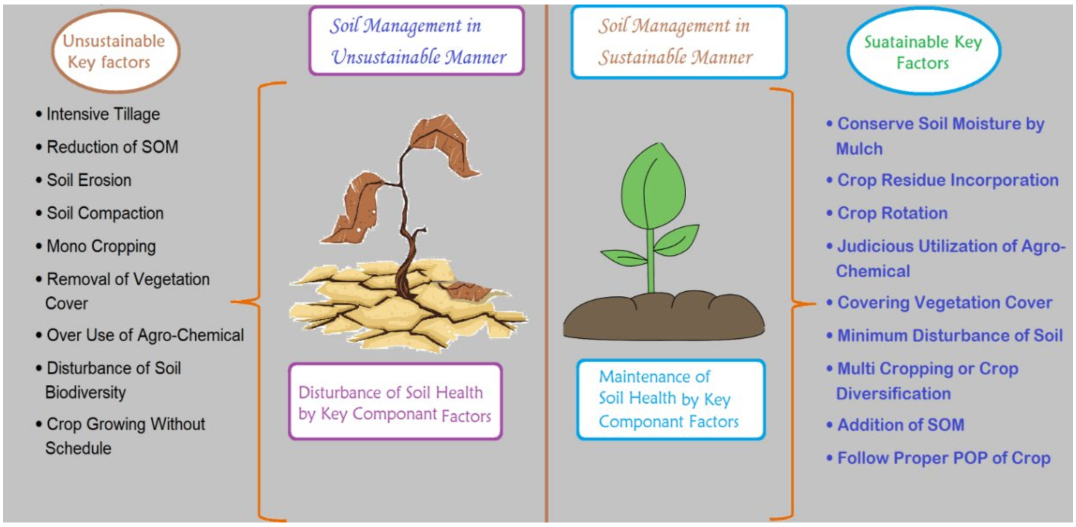

Fig. 4. Management of soil health by sustainable key factors

4. Future Outlook and Research Gaps

Although major progress has been made in identifying mitigation and adaptation strategies, several knowledge gaps remain that limit the practical implementation of climate resilient agriculture. Future research should focus on integrated studies linking soil, crop, and atmosphere interactions under multiple stresses such as heat, drought, and salinity. Long-term field experiments and modelling approaches are required to clarify the combined effects of temperature, rainfall, and CO_2 enrichment on soil carbon dynamics and nutrient cycling. Technological gaps persist in the quantification of greenhouse gas emissions from different management systems. Developing region specific emission factors, adopting sensor-based monitoring, and using remote sensing, GIS, and machine learning tools can strengthen accuracy and real time forecasting. Further attention is needed to evaluate trade-offs among productivity, profitability, and environmental quality using life cycle and systems-based assessments. From a socioeconomic perspective, low adoption rates of climate smart practices highlight the need for participatory technology development, capacity building, and accessible financial mechanisms such as micro insurance or carbon credit incentives. Integrating indigenous technical knowledge with modern innovations will also enhance local adaptability and acceptance. Research on sustainable practices should explore the synergistic benefits of biochar, organic amendments, microbial inoculants, and conservation tillage for improving soil fertility and reducing GHG emissions. Parallel efforts in genetic improvement through stress tolerant and resource efficient cultivars will further support food security in variable climates. Looking ahead, the pathway toward resilient agriculture depends on cross disciplinary collaboration, data sharing, and evidence-based policies that combine ecological, technological, and social dimensions. A unified framework connecting researchers, policymakers, and farmers will be vital to transform agriculture from a carbon source into a driver of climate mitigation and sustainable development.

5. Conclusion

Climatic changes and rising climatic inconstancy are probably going to disturb the issues of future food security. There are tons of vulnerabilities about the impact assessment, adaptation and mitigation of climate change in agriculture. Climate change, as acknowledged through patterns of the rise in temperature and increase in CO_2 level, is a major issue. The tremendous genetic diverseness in crops gives a stage to develop appropriate drought and heat tolerant varieties for sustained productivity in this changed climatic era. Recognition of appropriate agronomic management activities can be a potential key for enhancing agricultural production. To have a general evaluation of soil health with the change in climate, the potential modifications in soil physical, biological, and chemical properties should be considered. Intensive cultivation in a country like India has just begun giving indications of yield stagnation, raising the alarm of sustaining the yields. An increase in the frequency of floods and droughts in the recent scenario, as foreseen in the climate change situations, alert us to recognize suitable "no regrets and no risks" management alternatives to confront the situation. The crop, pest and weather interaction investigations, led previously, should be carefully examined for building a sub-routine to interface with the crop growth models to provide the practical estimates. Socio-economic parts of climate change are moderately feeble, and future scenarios should be achieved for different agro-ecological regions.

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