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Impact of Climate Change on Vegetable Production and its Technologies for Mitigation

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Abstract

Agriculture sector is the most sensitive sector to the climate change because the climate of a region determines the nature and characteristics of vegetation and crops. A significant change in climate on global scale will impact vegetation and consequently affect the world's food supply. Vegetables play a crucial role in ensuring food and nutritional security, but they are highly perishable and their prices rise fast under changing climate conditions. Climate change is an unavoidable phenomenon of natural and anthropogenic origin against which mitigation is required to reduce the risk in vegetable production. For mitigating the impact of climate change various technologies such as developing climate resilient varieties, agronomic practices, integrated cropping systems, organic farming, cultural management, protected cultivation, forecasting and simulation models are used. Agronomic practices such as resource conservation technologies mitigate atmospheric greenhouse gases by reducing the existing emission sources and sequestering carbon through minimal soil disturbance. Organic farming, protected cultivation, carbon sequestration by cropping system and agroforestry provide a suite of possible strategies for addressing the impactof climate change on vegetable production. Screening the available germplasm for the heat tolerance, drought tolerance and salinity tolerance and using these tolerant genotypes in the breeding programme is one of the feasible options to combat climate change. In addition, weather forecasting models and growth simulation models can be used to predict the possible impact of climate change and to mitigate its effect on vegetable crop production.

Keywords: Climate change, mitigation, resilience, vegetable production

1. Introduction

Climate change is defined as a change in the climate that can be directly or indirectly linked to human activities that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods (United Nations Framework Convention on Climate Change UNFCCC). Climate variability is one of the most significant factors influencing year to year crop production, even in high yield and high-technology agricultural areas (Kang et al., 2009). Little change in the climate will disturb the whole ecology and in-turn the traditional pattern of growing vegetables (Bhardwaj, 2012). On a regional or global level, it is undeniable that our climate is changing, and its impacts are palpable (Kang et al., 2009). At present due to anthropogenic activities like industrialization, deforestation and automobiles etc. changes in the climate are being taken place, which will again turn detrimental to life (Bhardwaj, 2012) Conversely, the developing and least developed countries located in tropics and sub-tropics are more vulnerable to the harmful effects of climate change (Mendelshon et al., 2006, Mendelsohn and Massetti, 2017). Cultivation is playing a dual role. On one hand, being a climate dependent activity, it is adversely affected by the consequences of climate change and on the other hand, it is an important contributor to climate change (Ahmad et al., 2011, Koundinya et al., 2014). Farming is contributing to climate change in many ways, through tillage, use of chemical fertilizers, pesticides, fungicides and herbicides, and methane emissions from paddy fields and livestock (Kumari et al., 2018, Naik et al., 2013). In India, agriculture, including livestock, is one of the largest contributors of GHGs with a share of 17.6% of contributions next to energy and industry, whose share is 57.8% and 21.77%, respectively (Anonymous, 2014). Fertilized soils release more than 2 billion tree of CO_2 equivalent GHGs every year world-wide. When nitrogenous fertilizers are applied, it is expected that, in general, 1–2% of all the applied nitrogen is emitted as N_2O (Sartaj et al., 2013). Farming is the source of methane, nitrous oxide and carbon dioxide. It includes the use of chemical fertilizers, pesticides and herbicides produced by burning of fossil fuels (Milder et al., 2011). Fertilized soils release more than 2 billion tree of CO_2 equivalent GHGs every year worldwide (Smith et al., 2007, Ayyogari et al., 2014). Tillage accelerates the oxidation of soil organic carbon, thereby releasing high amounts of CO_2 into the air (Prior et al., 2000, La Scala et al., 2006). The opening of soil crust through tillage further makes the soil prone to soil erosion (Ahmad et al., 2011). Mislay of organic carbon either through oxidation or erosion leads to a reduction in fertility of soils, depletion of microbial activity and lower fertilizer use efficiency (FUE), which further necessitates more fertilizer requirement (Zajac et al., 2010). Various abiotic stresses like extreme temperatures (low/high), soil salinity, droughts and floods are detrimental to vegetable production (Raymundo et al., 2014). The different development phases like vegetative growth, flowering and fruiting are significantly influenced by the vagaries of climate. Increasing CO_2 caused an increase in mean global temperature (Houghton, 2001) leading to climate change with perturbations such as more frequent and more severe drought events across the globe (Mpelasoka et al., 2008). The temperature increase will alter the timing and amount of rainfall, availability of water, wind patterns and causes incidence of weather extremes, such as droughts, heat waves, floods or storms, changes in ocean currents, acidification, forest fires and hastens rate of ozone depletion (Minaxi et al., 2011, Kumar, 2012).

2. Impact of Climate Change on Vegetable Production

Climate change may have more effect on small and marginal farmers, particularly who are mainly dependent on vegetables. Vegetables are regarded as protective foods due to their capacity to prevent diseases by supplying vitamins and minerals, and additionally, their nutritional quality is determined by soil factors, temperature, light, and CO_2 so, a little change in these parameter will bring a drastic change in the quality, there by the nutritional value of the vegetables may be reduced or increased. For example, increase in the level of CO_2 improved the vitamin C, sugars, acids and carotenoids in tomatoes. The more frequent extreme weather events under climate change may damage infrastructure with damaging impacts on storage and distribution of vegetables. Besides low yields, change in nutritional quality, severe postharvest losses, the climate change also affect the pest and disease incidence, host-pathogen interactions, distribution and ecology of insects, time of appearance, migration to new places and their overwintering capacity.

2.1. Temperature

All vegetable needs an optimum temperature for their proper growth and development, but optimum temperature required varies from crop to crop in addition to this, temperature limits the range and production of many crops. With changing climate the crop will be exposed to increased temperature stress. High-temperature stress has been reported to decrease vitamin C, starch, sugars and many antioxidants especially anthocyanins and volatile flavor compounds in fruits. Among the vegetable crops potato required exact temperature and day length for tuber formation and flowering, so it will be adversely affected by climate change. An increase in temperature of above 21°C cause sharp reduction in the potato tuber yield, at 30°C complete inhibition of tuber formation occurs (Sekhawat, 2001). Effect of high temperature on different vegetable crops are shown in table 1, 2 and 3.

Table 1: Effect of heat stress on vegetables

Crop	Effect	Reference
Tomato	√ Shorter crop duration with small fruit size	Rylski, 1979.
	√ Reduction in pollen production, reduced ovule and pollen viability	
	√ Degradation of lycopene (>27°C)	El-Ahmadi and Stevens, 1979
Cucurbits	√ Germination will not occur at 42°C in watermelon, summer squash, winter squash and pumpkin seeds. √ Fluctuations in the temperature delays fruit ripening	Kurtar, 2010
	√ Poor production of female flowers thereby leading to low yield	
Okra	√ Poor germination (spring summer season), Flower drop above 42°C.	Dhankhar and Mishra, 2001
Cole crops	√ High temperature causes bolting (not desirable for vegetable purpose	Ayyogari et al., 2014.

Table 2: Physiological disorders of vegetable crops caused by High Temperature

Crop	Disorder
Asparagus	High fiber in stalks
Bean	High fiber in pods
Cauliflower, Broccoli	Hollow stem, leafiness
Lettuce	Tip burn

Table 3: Effect on breeding systems in some crop species

Species	Response to Elevated Temperature
Carrot	Reduced male sterility at 26°C
Brussel sprout	Breakdown of male sterility above 17°C
Radish	Breakdown of self-incompatibility at 26°C

(Source: Hampton et al., 2016)

2.2. Drought

Drought is the most important factor that cause famine and affect the world food security. Being succulent in nature vegetables are highly affected by water stress (shown in table 4). High temperature coupled with low precipitation resulting from climate change will reduced the availability of irrigation water and at the same time evapotranspiration will be increased. So, this will leads to severe crop water stress resulting low yield and quality of vegetables. Drought increases the salt concentration in the soil and affects the reverse osmosis of loss of water from plant cells. This leads to an increased water loss in plant cells and inhibition of several physiological and biochemical processes such as photosynthesis, respiration etc., thereby reduces productivity of most vegetables (Pena and Hughes, 2007).

Table 4: Effect of drought on vegetables

Crop	Effect	Reference
Tomato	√ Reduction in tomato fruit size thereby reducing the locular size	Stevens, 1979
Onion, Okra	√ The germination of seeds seriously affected.	Arora et al., 1987
Potato	√ Reduction in tuber yield and sprouting of tubers affected.	
Leafy vegetable	√ In amaranthus, palak and spinach, the drought conditions reduce their water content thereby reduce their quality.	

2.3. Salinity

Elevated soil salinity is very threatening to the vegetable production particularly in irrigated croplands and its main root cause is the drought. Plant sensitivity to salt stress is reflected in loss of turgor, growth reduction, wilting, leaf curling and epinasty, leaf abscission, decreased photosynthesis, respiratory changes, loss of cellular integrity, tissue necrosis, and potentially death of the plant (Lopez et al., 2011).

2.4. Flooding

Vegetable production is also threatened by heavy rainfall. Flooding reduces the oxygen level in the root zone inhibiting aerobic processes. Under flooded condition tomato plants accumulate endogenous ethylene that causes damage to the plants. High temperatures coupled with flooding causes rapid wilting and death of plants. Floods can make the spread of water-borne pathogens easier, droughts and heat waves can predispose plants to infection, and storms can enhance wind-borne dispersal of spores (Pautasso et al., 2012).

3. Mitigation

Mitigation is essential component of addressing climate change. Mitigation is defined as 'An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases'.

3.1. Strategies to combat climate change in vegetable growing

In the developing countries of the world, nearly 70% of people live in rural areas where agriculture is the largest supporter of livelihoods (Easterling et al., 2007). The majority of India's population is in the country side and its livelihood is agriculture. The service sector's contribution to the Indian GDP has overtaken that of agriculture, but the number of families that depends on farming for survival remains almost the same. Hence, one can say that climate change poses a grave threat to the livelihoods of the rural farming community. In this perspective, mitigation strategies should be planned in such a way that they reduce the risk and uncertainty in Indian agriculture and ensure sustainable livelihoods in rural communities. Under mitigation following practices can be followed to combat climate change.

3.1.1. Developing Climate resilient varieties

Breeding vegetables crops for climate resilience-one of the cost-effective and reliable methods. First step is the screening of germplasm for biotic and abiotic stress resistance in open-field conditions or in controlled conditions. The resistant/tolerance germplasm then be used in breeding programs to incorporate resistance (table 5, 6 and 7)

3.1.2. Agronomic practices

Agronomic practices like resource conservation technologies (RCT), carbon sequestration by agroforestry and cropping

Table 5: Some varieties of vegetables to mitigate the harmful effect of heat and cold (Selvakumar, 2015)

Crop	Varieties	Tolerance
Tomato	Pusa Sadabahar, Pusa Sheetal, Pusa Hybrid-1	Tolerance to high and low temperatures
Radish	Pusa Chetki	Better root formation under high temperature
Carrot	Pusa Vrishti	Form root at high temperature
Early cauliflower	Pusa Meghna	can form curd at high temperature

Table 6: Source of disease/insect resistance in vegetables

Crop	Disease/insect	Resistant source
Tomato	TYLCV	S. pimpinellifolium S. pimpinellifolium
	Insect resistance	S. pennellii.
Sweet pepper	Fungi and viruses	Capsicum chinense, C. baccatum and C. frutescens.
Cucumber	Powdery mildew	Poinsett, Sparton Salad, Cucumis ficifolia, C. Anguria
	Downy mildew	Chinese Long and Poinsett
	CMV	TMG-1, Tokyo Long Green, Chinese Long and Table Green

(Source: Naik et al., 2013)

Table 7: Source tolerance against drought

Crop	Genetic resources for draught tolerance
Tomato	*S. pimpinellifolium, S. hirsutum, S. cheesmanii, S. chilense,S. lycopersicum var. cerasiforme, S. pennellii, S. peruvianum, S. habrochaites*
Brinjal	*S. microcarpon, S. macrosperma*
Chilli	*C. chinense, C. baccatumvar. pendulum,* ArkaLohit
Potato	KufriSheetman, KufriSindhuri
Okra	*A. tuberosus, A. rugosus*
French bean	*P. acutifolius*
Watermelon	*Citulluscolocynthis*(L).
Onion	Arka Kalyan, *A. fistulosum*

(Source: Kumar et al., 2012)

systems may decrease GHGs by increasing their intake and their storage of C in biomass, wood and soil. Agronomic practices globally can mitigate 0.39 t CO_2 equivalent ha^{-1} year^{-1} under a dry climate, and 0.98 tonne CO_2 equivalent/ha/year under a moist climate (Smith et al., 2007; Milder et al., 2011). The main strategies to sequester carbon and to reduce GHG emissions through agricultural practices are enriching soil carbon, minimizing the use of inorganic fertilizers, restoring degraded lands and preventing deforestation. Multiple cropping systems, such as crop rotation, intercropping, cover cropping and agroforestry systems play a critical role in optimizing carbon sequestration in agriculture by influencing optimal yield, and increasing carbon sequestered with biomass and in the soil.

3.1.2.1. Resource conservation technologies

Resource conservation practices in cultivation could decrease the net emission of carbon dioxide in many areas (Uri and Bloodworth, 2000). It can help to mitigate atmospheric GHG by reducing the existing emission sources and sequestering carbon through minimal soil disturbance by combining no-till, permanent organic soil cover and crop rotation. These techniques result in healthier soil, enhanced carbon sequestration, decreased erosion as well as reduced use of water, energy and labour. Precision farming, another RCT, includes site-specific nutrient management through the judicious application of fertilizers as per the soil nutrient status, thereby reducing the excess use of fertilizers.

3.1.2.2. Integrated cropping systems

Integrated cropping systems in association with cropping practices have the ability to sequester atmospheric carbon, thereby helping in the formulation of mitigation choices of climate change. Intercropping, mixed cropping, relay cropping and strip cropping helps in increasing the yield and productivity of crops. Under changing climatic situations, crop failures, reduced yields, reduction in crop quality and increasing pest and disease problems are common, and they render vegetable cultivation unprofitable (Koundinya et al., 2014). Under such circumstances, multiple cropping systems are more beneficial than monocropping as the loss due to the failure of one crop can be compensated by the yield from another crop. Cropping systems also aim at increasing the farm income by crop diversification, thereby reducing the risk and uncertainty as a result of climate change. Intercropping of vegetables can be a possible and reliable measure to cope with these problems as it is a more productive system and a less risky technology. Intercropping with legumes has been becoming more stable and dependable than sole cropping systems in vegetable cultivation. Intercropping of baby corn with okra, brinjal and chilli during summer (Adhikary et al., 2015a) and with tomato, brinjal, chilli and pea during autumn-winter (Adhikary et al., 2015b) is a more highly profitable and productive system than sole cropping.

Also intercropping prevents the spread of vector-borne diseases, which are becoming aggravated due to climate change (Koundinya et al., 2014). Adhikary et al. (2015a) found that intercropping of okra plants with baby corn reduces the spreading of yellow vein mosaic virus in okra as the baby corn plants act as a barrier to whitefly, the vector for this virus. Crop rotation with legumes helps in fixing atmospheric N, thereby, reducing the burning of fossil fuels for the production of chemical fertilizers. Growing cover crops is an effective approach to improve carbon sequestration and soil organic carbon storage. Moreover, cover crops assist in moisture conservation in soil by preventing the loss of moisture through evaporation, thereby cover cropping forms an important adaptation strategy against drought or moisture stress.

3.1.2.3. Agroforestry

The adoption of agroforestry practices like windbreaks and riparian forest buffers, which incorporate trees and shrubs into ongoing farm operations, represents a potentially significant sink of greenhouse gases. Agroforestry significantly stores carbon in plant biomass (Smith et al., 2007). Use of some legume and nitrogen-fixing trees in agroforestry systems supports the fixing of atmospheric nitrogen in the soil), which reduces the need for application of nitrogenous fertilizers to the intercropped crops in case of silvi–pastorial, horti–pastorial systems. Agroforestry globally can mitigate 0.3 t CO_2-equivalent ha^{-1} year^{-1} under warm dry climate and 0.7 tonne CO_2-equivalent ha^{-1} year^{-1} under warm moist climate (Smith et al., 2007, Milder et al., 2011). Agroforestry systems avoid long-term vulnerability as trees act as an insurance against drought, insect pest outbreaks and other threats (Rathore, 2004). As well, they provide socio-economic benefits to the farming community, thus helping to minimize the risk and uncertainty in agriculture under a climate change situation.

3.1.3. Cultural management

Various crop management practices such as mulching and use of shelters and raised beds help to conserve soil moisture, prevent soil degradation, and protect vegetables from heavy rains, high temperature and flooding.

3.1.4. Mulching

Mulching helps to conserve soil moisture, prevents soil degradation and protects vegetables from torrential rains, high temperatures and flooding. Both organic and inorganic mulches are being used in the cultivation of vegetable crops like okra, brinjal, round melon, ridge gourd, bottle gourd and sponge gourd, under stress conditions. Mulching reduces soil moisture evaporation, moderates soil temperature, restricts weed growth and reduces soil runoff and erosion. Moreover, organic mulches like rice straw, fenugreek, cluster bean and grasses help in improving the soil fertility and add organic carbon to the soil as they are allowed to degrade after their use. Inorganic or plastic mulches do not add organic matter to the soil, but conserve soil moisture and reduce weed growth. Some coloured plastic mulches also help in controlling pest and diseases, which are being provoked by the climate change.

3.1.5. Organic farming

Organic farming mitigates climate change because it reduces greenhouse gases, especially nitrous oxide, as no chemical nitrogen fertilizers are used and nutrient losses are minimized. Organic farming stores carbon in soil and plant biomass by building organic matter, encouraging agro-forestry and forbidding the clearance of primary ecosystems. It minimizes energy consumption by 30–70% unit^{-1} of land by eliminating the energy required to manufacture synthetic fertilizers, and by using internal farm inputs, thus reducing fuel used for transportation.

Organic farming helps farmers adapt to climate change as it prevents nutrient and water loss through high organic matter content and soil covers, thus making soils more resilient to floods, droughts and land degradation processes. It preserves seed and crop diversity, which increases crop resistance to pests and disease. Maintenance of diversity also helps farmers evolve new cropping systems to adapt to climatic changes. It minimizes risk as a result of stable agro-ecosystems and yields, and lower production costs.

3.1.6. Irrigation and fertilizer management

Irrigation water management is a critical adaptation strategy under varying climatic conditions. Water is one of the most important requisites for crop production, a vital component in all biological systems, and climate change directly hits its sources and reduces its availability. Climate change affects and delays the monsoons and often causes crop failure. The delay or failure of the monsoons results in water shortage and below average crop yields (Koundinya et al., 2014). Timely irrigation and conservation of soil moisture are critical components of irrigation water management under climate change. Micro irrigation systems such as sprinkler and drip irrigation are already proven technologies of water conservation and increasing WUE and crop yield. In Florida, when need-based irrigation is given to tomato crops by recognizing soil moisture content through sensors, it saves 15–51% irrigation water over conventional drip irrigation (Zotarelli et al., 2009). It also takes part in the mitigation strategy as micro irrigation avoids soil disturbance and reduces the soil surface runoff, which are common problems with surface irrigation methods. Water harvesting for dry land is a traditional water management to ease future water scarcity in many arid and semi-arid regions.

3.1.7. Fertilizer management

Fertilizer management, another input management approach in crop production under climate change, mainly forms the mitigation strategy. Integrated nutrient management (INM) makes use of organic manures, inorganic and biofertilizers and thereby reduces the dependence on chemical fertilizers (Anonymous, 2009). Nutrient management has global GHG emissions mitigating potential up to 0.33 t CO_2-equivalent ha^{-1} year^{-1} in a moist climate and 0.62 t CO_2-equivalent ha^{-1} year^{-1} in a warm climate (Smith et al., 2007). Complex (NPK) and customized fertilizers, fortified micro-nutrient fertilizers, can supplement up to 20–25% of chemical fertilizers usage in the country (Anonymous, 2016). Leaf colour chart (LCC) is an easy-to-use and inexpensive tool for determining nitrogen status in plants. Use of the LCC promotes timely and efficient use of N fertilizer to save costly fertilizer.

Fertigation helps in the judicious application of nutrients, reduces wastage and increases FUE of crops. Planting fast-growing trees in degraded areas, converting them to biochar and subsequent addition to the soil as a source of nutrients provides a way for carbon sequestration. Application of silicate amendments helps in the conversion of CO_2 into bicarbonates besides reversing the acidification of soils.

3.1.8. Protected cultivation

Protection of crops from unfavorable environmental conditions is an age-old agronomic practice. Under varying weather, cultivation of crops under protected structures is becoming compulsory to protect them from high and low temperatures, drought and flooding situations and soil pH stresses. The climate inside the greenhouse can be regulated by using various devices such as heating and cooling systems, CO_2 emission and absorbing systems, automated need-based irrigation and nutrient supplying systems. Soilless cultivation (hydroponics and aeroponics) avoids the problems associated with soil cultivation like weeds, salinity, alkalinity, acidity and soil borne pest and diseases (Eng, 2010).

3.1.9. Grafting

Grafting of a susceptible scion cultivar onto a resistant rootstock is another way of utilisation of plant biodiversity to adapt to climate change (Koundinya et al., 2014). It offers an opportunity to overcome several biotic and abiotic stresses (Koundinya and Kumar, 2014), which are a major setback to vegetable production and are becoming intensified by climate change. High and low temperature tolerance in tomato was achieved by grafting onto *Solanum melongena* EG203 and *Solanum habrochaites* LA1777 rootstocks (Venema et al., 2008), respectively. Grafting onto *Solanum melongena* rootstock helped in bacterial wilt and flooding tolerance in tomato. Rootstocks from *Cucurbita* species were more tolerant to salt than rootstocks from *Lagenariasiceraria* (Matsubara 1989). Interspecific rootstocks like *Solanum lycopersicum*X *S. habrochaites* provided low soil temperature (10–13°C) tolerance to their grafted tomato scions and *S. integrifolium*×*S. melongena* rootstocks provided low soil temperature (18–21°C) tolerance to eggplant scions, respectively (Okimura et al., 1986).

3.1.10. Potential role of underutilized indigenous vegetable crops in the changing climatic scenario

There are various advantages of Indigenous vegetables such as they could be introduced elsewhere for greater crop diversification and increased productivity. Provide balanced year round nutrition, new market opportunities and enhance farm income. Also use of locally available indigenous crops can adapt to climate variability and change, while supporting sustainable diets and food systems. Cultivation of indigenous crops suited for local environments could provide nutritional diversity for communities, an option for crop rotation for farmers, harnesses and protects local knowledge and agro-biodiversity, opportunities for farmers to disrupt pest and disease cycles, replenish nutrients through improved contributions and support of nutrient cycling.

Crops such as cowpea, faba bean, chilli, yams, colocasia etc. are adapted to extreme weather (drought and heat stress) and poor soil conditions. Research has shown that several indigenous crops require less water and have relatively high water use efficiencies (Chibarabada et al., 2017). They can also be grown in marginal and fragile environments. Therefore, land that has been condemned as unsuitable for cultivation of major crops may be suitable for cultivating adaptable indigenous crops. With the risk of a shrinking food basket under climate change, mainstreaming indigenous crops into local food systems will mitigate malnutrition, which is also predicted to increase under climate change. However, despite this reported potential, indigenous crops still face significant obstacles with regards to being mainstreamed into the dominant agricultural landscapes and food systems.

3.1.11. Forecasting

Technology to improve the quality and accessibility of data on crop production under climate change has been developed. Forecasting is the prediction of future value based on past data. Weather forecasting models (WFM) provide the advantage of daily forecasting of weather information through remote sensing, validation of different land-use products and dissemination of information. The crop growth simulating models (GSM) predict crop growth and yield under future climatic conditions using various parameters which include future weather scenarios predicted by weather forecasting or global circulating models. These can be used to predict the possible impact of climate change on crop production and also help in framing necessary adaptation measures.

Different pest and disease forecasting models (table 8 and 9) have also been developed to predict the appearance of pest and diseases in advance to allow preventive actions to be taken. Luck et al. (2011) used three global climate

Table 8: *Examples of crop growth simulation models and experiments under modified environment*

Sl. No.	Crop growth simulation models	Application	Case study examples
1.	DSSAT: Decision Support System For Agrotechnology transfer	A software application that includes crop simulation models for 42 crops	Potato DSSAT-SUBSTOR (Raymundo et al., 2014)
2.	WOFOST; World Food Studies	A mechanistic model which explains crop growthbased on the underlying physiological processes,such as photosynthesis, respiration and theinfluence of environmental conditions on theseprocesses	Potato SWAP-WOFOST
3.	INFOCROP	A generic crop model that simulates the effects oncrop growth, yield, soil carbon, nitrogen and water, and greenhouse gas emissions byweather,soils, agronomic practices (crop husbandry) andmajor pests	INFOCROPPOTATO (Singh et al., 2005)
4.	APSIM: Agricultural Production Systems Simulator	A simulation of systems which deals with a range of plant, animal, soil, climate and management interactions.	APSIM-Potato (Brown et al., 2011, Lisson and Cotching, 2011)
5.	CropSyst: Cropping Systems Simulation Model	An analytical tool to study the influence of climate, soils, and crop management on cropping systems productivity and the environment	CROPSYSTVB CSPOTATO

Table 9: Experiments under modified environment

Sl. No.	Crop growth simulation models	Application	References
1	MLT (Multi Location Trial)	To find out the genotypes or varieties with high adaptability to different locations	Thinh et al., 2017 in Chinese Yam
2	FACE: Free Atmospheric CO_2 Enrichment	To Study the crop growth and yield in response to high atmospheric CO_2	Miglietta et al., 1998 in Potato
3	FATE: Free Atmospheric Temperature Elevation	To Study the crop growth and yield in response to high atmospheric temperature	
4	T-FACE: Temperature: FACE	A combination of FACE and FATE	

models (EH5OM, HadCM3Q and CCAM-Mark 3.5) and two regional climate models (RegCM3 and PRECIS) for prediction of potato yields in India, Bangladesh and Australia. They also used the Hyre model, Smith model, Wallin model, Blitecast, Fry model, Hartil and Young models for the prediction of late blight disease incidence in potato under changing climatic conditions. Another way of assessing the possible impact of climate change on crop production is by conducting the experiment in a modified environment condition that includes high temperature, and high CO_2 and other GHG concentrations. For example, growing crops in a CO_2 enriched environment helps attain a better understanding of crop growth and yield under elevated CO_2 conditions. These types of environments can be created in a closed environment like greenhouses and growth chambers or an open environment like FACE, FATE. Most of such studies are performed in closed environments, but the experiments conducted in an open environment are more representative of field conditions as a closed environment misses several other factors such as plant competition. From the huge amount of literature on crop production under the influence of climate change, it is understood that climate change threatens crop production and its impacts will continue in the future, causing global food security to worsen. It necessitates the framing up of needs-based sustainable adaptation and mitigation strategies that can effectively combat climate change, avoid risk and uncertainty in agriculture, and also ensure sustainable livelihood.

4. Conclusion

The time has come to initiate intensive research on climate change specific to agriculture at national and international levels. Establishment of a strong cooperation between public sector institutions and private NGOs, which are working on climate change, is much needed. A well-organized extension system should be developed to help farmers become aware and to keep them well informed regarding climate change and its effects on crop production, to prepare them to face uncertainty and to provide information about new regulatory structures and government policies.

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