Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.2760

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5 (4):** 381-394 (2017)

Review Article

International Journal of Pure & Applied Bioscience

OPEN ACCESS

Impact of Climate Change on Global Food Security- Challenges, Adaptation Measures and Mitigating Strategies

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Received: 27.03.2017 | Revised: 9.04.2017 | Accepted: 10.04.2017

ABSTRACT

Today's major global concern is the impact of climate change on land and water resources. Interference of anthropogenic activities with nature has seriously threatened the ecological balance and climate change. The global agricultural community is scared of catastrophic adverse effects that can take place in future due to climatic changes like increased temperature, deglaciation, sea level changes, atmospheric dynamics including evaporation and precipitation, global radiation balance on photosynthesis, ecological productivity, plant and animal community and many more. This review article focuses the challenges related to sustainability of food production as well as agricultural diversification faced by farming community. Following this, the paper highlights some of the technological and institutional (ICAR-IARI) innovations that have been developed to address such challenges. It also targets how climatic changes affect the food productivity, food security, yield gap and sustainable agriculture by exploiting modern techniques and methods. The transformation of the agriculture sector in India from the green revolution to 2017 is characterized by major breakthroughs in technological innovations and transformation, significant changes in diet, urbanization, globalization and enhancement in income. Serious challenges in agriculture caused by climate change offer opportunities to devise the diverse range of land management strategies having positive adaptation and mitigation synergies. It is recognized that agriculture and forestry offer significant cost-effective mitigation options, since many management techniques, are required to strengthen production systems, sequester carbon either above or below ground and reduce direct greenhouse gas emissions. These new trends will shape domestic and international policies, trading patterns, resource use, regional planning and the welfare of rural people especially in developing countries. Current crop research related strategies may respond positively to elevated CO_2*, impact of elevated temperature, altered precipitation patterns, and increased frequency of extreme events such as floods and drought, will likely combine to depress yields and increase production risks in many regions, thus widening the gap between rich and poor countries*[7,10,11]*. Predominance of agricultural sector in their economies scarcity of capital for adaptation measures and their heightened exposure to extreme events make developing countries more vulnerable to climate change than developed countries (where about 800–1000 million people are currently undernourished).*

Key words: *Resource, Climate Change, Resources, Global Agricultural Community.*

Cite this article: Singh, M., Sharma, N., Tiwari, N.K. and Kumar, N., Impact of Climate Change on Global Food Security- Challenges, Adaptation Measures and Mitigating Strategies, *Int. J. Pure App. Biosci.* **5(4):** 381-394 (2017). doi: http://dx.doi.org/10.18782/2320-7051.2760

INTRODUCTION

More than 65 percent of Indian population is directly or indirectly relying on agriculture as a source of livelihood. Total food grains production during 2014-15 was 252.23 million tonnes from 141 million hectare net sown area[4]. Agriculture is the most important occupation for most of the Indian families. In India, agriculture contributes about sixteen percent (16%) of total GDP and ten percent (10%) of total exports[5]. Over the last few decades there has been a global trend towards intensification in agricultural land-use and changes in farming methods have been paralleled by new industrial technologies. This has enabled the production of large amounts of cheap inorganic fertilizers and insecticides in order to meet increasing demands for food and other agricultural products. Accordingly, the pattern of fertilizer consumption has changed dramatically. Furthermore, through modern advances in technology, there has been a marked geographical expansion of agriculture regardless of the suitability of the land, and likewise the development of new crop genotypes, which has to be cultivated under marginal environmental conditions[3]. Such farming methods, which often are referred to as conventional farming, are very efficient and produce high crop yields but can have a profound impact on the environment. Modern farming methods employ large and highly efficient machinery, timing of nutrient and herbicide applications. The negative consequences are disaggregation of soil structure, increased soil erosion, oxidation of soil organic matter, soil degradation and disruption of soil organisms[17]. Agrochemicals were extensively used to increase yield of crops & to control weeds and pests often above recommended levels. Such agricultural intensification, is responsible for soil, water and air contamination, which in the past have been largely prevented by the use of less intensive farming methods[9]. In other words, advanced developments have led to negative consequences on environment. Intensive livestock production is also responsible for water and land quality problems by increasing the production of undecomposed residue and methane gas[27]. Major problems faced by modern agriculture include urbanization of farmland, water rights and usage, environmental concerns, and the procurement of government subsidies. With the substantial amount of crop residues and manure produced in farms, it is becoming difficult to recycle nutrients. Animal wastes cannot economically be returned to the land in a nutrient-recycling process because production systems are geographically remote from other systems which would complete the cycle. In many areas, agricultural waste has become a liability rather than a resource. Ecological diseases such as erosion, loss of soil fertility, depletion of nutrient reserves, salinization and alkalinization, pollution of soil and water systems, loss of fertile field lands to urban development, loss of crop, wild plant, and animal genetic resources, elimination of natural enemies, pest resurgence and genetic resistance to pesticides, chemical contamination, and destruction of natural control mechanisms have also been associated with the intensification of food production.

The fragile ecosystems which are more vulnerable to climate changes include mountain/Himalayan ecosystem (e.g. Nepal, India, Bhutan), mangroves, salt marshes, coral reefs (e.g. India, Bangladesh and Sri Lanka), semi-arid and arid dry lands (e.g. India and Pakistan). The low lying coastal regions would be affected due to Sea Level Rise (SLR) and increase in extreme climate events. Semi-arid tropics are vulnerable due to reduced rainfall, increased evapo-transpiration and drought. Small islands are extremely vulnerable due to high exposure of population and agricultural infrastructure to sea level rise (e.g. Maldives) and increased storms. The North Eastern shore region and the Magna Basin of Bangladesh are vulnerable to flash floods. Year 2012 was marked by extreme weather globally thus confirming the impacts of climate change on food security[26]. Global population is increasing at rate of 75 million people annually consequently increasing the level of CO_2 at the rate of 2.2 ppm. The major concern for sustainable agriculture is climate change and its uncertainties which lead to soil resource degradation, water quality and renewability and species diversity of soil flora and fauna, significantly low efficiency of energy-based inputs. The strong nexus between fossil fuel combustion, climate change, soil degradation and food security is widely recognized[1,19,20]. Furthermore, agricultural productivity and food supply is significantly affected by the impact of climate change and its induced soil degradation, drought and heat stress at different growth and development stages of plant. The population increase by an additional 2.4 billion people by 2050 and 3.8 billion by 2100 will necessitate extra food production for human and livestock diet[30]. Environmental sustainability in agriculture is no longer an option but an imperative. Currently, there are three crucial environmental challenges in the agriculture sector viz- conservation of biodiversity, mitigation of climate change and the global shift towards bio-energy. The production of food depends on the quality and management of soil resources and technological interventions. Therefore, the objective of this article is to discuss the importance and technological options of sustainable management under changing climate conditions to produce enough to meet food demand. The risk of hunger resulting from climate change is the result of both direct impacts on food systems and of indirect impacts that affect the different dimensions of food security. Table 2 provides an overview of the potential direct consequences of key climate change impacts on food systems. These are general examples however; the interactions between the climate and the food system are complex and vary greatly based on local circumstances[14]. Therefore, the climate change and its consequences need to be analyzed at the local level in order to plan appropriate interventions. In turn, the direct effects and their indirect consequences for all four dimensions of food security: availability, access, utilization and stability, are as shown in Table 2.

Table 2: Climate change impacts and consequences for food systems[14]

Climate Change Effects	Consequences
Increased frequency and severity of extreme weather events	• Crop failure or reduced yields • Loss of livestock • Damage to fisheries and forests • Destruction of agricultural inputs, such as seeds and tools • Either an excess or shortage of water • Increased land degradation and desertification • Disruption of food supply-chains • Increased costs for marketing and distributing food
Rising temperatures	• Increased evapotranspiration, resulting in reduced soil moisture • Greater destruction of crops and trees by pests • Greater threats to human health (e.g. disease and heat stress) that reduce the productivity and availability of agricultural labour • Greater threats to livestock health • Reduced quantity and reliability of agricultural yields • Greater need for cooling/refrigeration to maintain food quality and safety • Greater threat of wildfires
Shifting agricultural seasons and erratic rainfall	• Reduced quantity and quality of agricultural yields and forest products • Either an excess or shortage of water • Greater need for irrigation
Sea level rise	• Damage to coastal fisheries • Direct loss of cultivable land due to inundation and salinization of soil • Stalinization of water sources

Adverse impact intensive agriculture- Modern agriculture makes use of hybrid seeds, technologically advanced equipment, fertilizers, pesticides and advanced irrigation technology to produce large amounts of single crop.

Problems using fertilizers

- Micronutrient imbalance: Chemical fertilizers used in modern agriculture contain Nitrogen, Phosphorus and Potassium (N, P & K) which are macronutrients. Excess use of fertilizers in fields causes micronutrient imbalance. For eg. Excessive use of fertilizers in Punjab and Haryana caused deficiency of micronutrient Zinc thereby affecting productivity of soil
- Nitrate pollution: Excess Nitrogenous fertilizers applied in fields leach deep into the soil contaminating the groundwater. If the concentration of nitrate in drinking water exceeds 25 mg/L it leads to a fatal condition in new-born babies. This condition is termed "Blue Baby Syndrome".
- Eutrophication: The application of excess fertilizers in fields leads to wash off of the nutrient loaded water into nearby lakes causing over-nourishment. Their life is short; they die and pollute water thereby affecting aquatic life in the lake.

Problems in using Pesticides

In order to improve crop yield, pesticides are used indiscriminately in agriculture. Although these pesticides protect our crops from severe losses due to pests, they have several side-effects as listed below:

- Death of non-target organisms: Several insecticides kill not only the target species but also several beneficial not target organisms
- Pesticide resistance: Some pests that survive the pesticide generate highly resistant generations that are immune to all kinds of pesticides. These pests are called "superpests".
- Bio-magnification: Most pesticides are non-biodegradable and accumulated in the food chain. This is called bio-accumulation or bio-magnification. These pesticides in a bio-magnified form are harmful to human beings.
- Risk of cancer: Pesticide enhances the risk of cancer either by acting as a carcinogen or indirectly suppresses the immune system.

Water scarcity

Water-related problems occupy an important place. It can be said that water is the blood of an ecosystem. Water not only influences the plant's growth but serves as an important medium of transfer for nutrients into soil. It influences the soils physical properties, both directly and indirectly due to various biochemical processes. In water logged conditions, pore-voids in the soil get filled with water and soil-air gets depleted. In such a condition the roots of plants do not get enough air for respiration. Water logging also leads to low mechanical strength of soil and low crop yield. Water logging is caused by excessive water supply to the croplands, heavy rain and poor drainage

Water salinity

Water not absorbed by soil, is evaporated leaving behind a thin layer of dissolved salts in the top soil. This is called salinity of the soil. Saline soils are characterized by accumulation of soluble salts like sodium chloride, calcium chloride, magnesium chloride, sodium sulphate, sodium carbonate and sodium bicarbonates. Saline conditions are exhibited when pH is greater than 8.0.

Water Stress

Abstraction of water for agriculture reduces the availability of water for other users and uses (public water supply, industry, environment etc). For groundwater, sustainability implies not using more each year than the annual recharge rate while leaving enough water to support connected wetlands and rivers. Concerns have been raised over the potential impacts of water abstraction on the environment, particularly in catchments where irrigation abstractions are concentrated and where water resources are under pressure. Climate change is expected to intensify the hydrological cycle, leading globally to more floods and droughts on average[6].

Soil erosion and toxicity

In India, almost 130 million hectares of land, it is, 45 % of total geographical surface area, is affected by serious through sheet, rill and gully soil erosion , shifting cultivation, cultivated wastelands, sandy areas, deserts and water logging.

Water erosion

Raindrops hit bare soil with enough force to break the soil aggregates. These fragments wash into soil pores and prevent water from infiltrating the soil. Water then accumulates on the surface and increases runoff which takes soil with it. Well-structured soils are less prone to break up and the impact of raindrops is minimized if the soil surface is protected by plant or litter cover. The vulnerability of soils to water erosion depends on:

i. Rainfall intensity (erosivity)—High intensity rainfall creates serious risk as heavy drops on bare soil causes the soil surface to seal.
ii. Nature of the soil (erodibility)—Clay soils vary in their ability to withstand raindrop impact.
iii. Slope length—if a slope is long, water running down the slope becomes deeper and moves faster, taking more soil with it.
iv. Slope steepness—the speed of runoff increases on steep slopes, which increases the power of water to break off and carry soil particles.

Wind erosion

Wind erosion is a significant problem in the arid region. It is most likely to occur when strong winds blow over light-textured soils that have been heavily grazed during drought periods. It contributes to scalding, a process that forms smooth, bare areas on impermeable subsoil's. These areas, vary from a few square meters to hundreds of hectares, are difficult to revegetate due to lack of topsoil, low permeability and often saline surface. Sandy soils are more vulnerable to wind erosion because they cannot store very much moisture and have low fertility. Generally, wind erosion is not a serious issue in cropping areas.

It paves the way to animal abuse

In modern agricultures, animals are kept in small areas, pens or cages where they don't have the space to run around. They're usually kept indoors, which means they don't get to see the sun from the time of their birth until they're killed for their meat, fur, leather, and/or other products. Animals in intensive farms are also forced-fed substances that make them grow faster, get bigger, and/or become ready to reproduce earlier than what nature intended.

It pollutes the environment

The animals and crop residue in intensive farms produce a large amount of waste that the farmers can't handle. As a result, many of them opt to dump the wastes in rivers and streams and end up polluting these of water bodies. These wastes can still pollute the air and leach into the surrounding land and water tables.

It contributes to health problems

Intensive farming jeopardizes people's health in two major ways. One of these is through the pollution that they produce, which harm the health of the people and make them more prone to developing illnesses. Another is through the antibiotics that they inject into their animals to make them "immune" to the unsanitary conditions they live in and prevent them from falling ill. These antibiotics work in the short term, but they promote the evolution of bacteria and the rise of drug-resistant pathogens. These can be transmitted to people from the meat and other animal food products they eat, causing a wide range of illnesses that can't be easily treated with antibiotics.

It can produce low-quality food

Synthetic compounds including insecticides, fungicides, herbicides, rodenticides, molluscicides, nematicides, plant growth regulators and others contributed greatly to pest control and agricultural output. Ideally, pesticides are not only lethal to the targeted pests, but also to non-target species, including man through food chain. Animals in large farms are kept in unsanitary conditions, they can develop illnesses that may not be treated by antibiotics and pass these on to the people who consume them. Many of these animals are bred through artificial processes and/or raised in an environment that stresses them out, both of which can also lead to food products that have poor quality.

Impacts of Agriculture in climate Change

Carbon Dioxide **-**The main sources of carbon dioxide emission are decay of organic matter, forest fires, eruption of volcanoes, burning of fossil fuels, deforestation and land-use changes. Agriculture is also a contributor to CO_2 emission but is not considered a major source of green house gases (GHG). Within agriculture, soil is the main contributor with factors such as soil texture, temperature, moisture, pH, available C and N, influencing CO_2 emission from soil. Emission of CO_2 is more from a tilled soil than from an undisturbed soil (no tillage). Temperature has a marked effect on CO_2 evolution from soil by influencing root and soil respiration. It may be mentioned that plants, oceans and atmospheric reactions are the major sinks of carbon dioxide.

Methane- Methane is about 25-times more effective as a heat-trapping gas than CO_2. The main sources of methane include wetlands, organic decay, termites, natural gas and oil extraction, biomass burning, rice cultivation, cattle and refuse landfills. The primary sources of methane from agriculture include animal digestive processes, rice cultivation and manure storage and handling. Methane is also produced in the soil by the metabolic activities of a small but highly specific bacterial group called 'methanogens'. Their activity increases in the submerged, anaerobic conditions which develop in the wetland rice fields and thus limiting the transport of oxygen into the soil and also the microbial activities thereby rendering the water-saturated soil practically devoid of oxygen.

Nitrous Oxide- As a GHS, nitrous oxide is 298-times more effective than CO_2. Forests, grasslands, oceans, soils, nitrogenous fertilizers, and burning of biomass and fossil fuels are the major sources of nitrous oxide, while it is removed by oxidation in the Stratosphere. Soil contributes to the largest amount of nitrous oxide emission. The major sources are soil cultivation, fertilizer/manure application and burning of organic material and fossil fuels. From an agricultural perspective, nitrous oxide emission from soil represents a loss of soil nitrogen thus reducing the nitrogen-use efficiency. **Adaptation measures**

Land and water management

Adaptation is an essential feature of agriculture to ensure long-term sustainability of food production. A large number of farm-level management practices are already available as a basis for devising climate change response like growing new cultivars, which are more adapted to altered thermal and hydrological conditions. Need of today is to put in place the observing and monitoring systems capable of informing and supporting decision-making for both autonomous and planned adaptation by public and private sector collectively. Therefore, planned adaptation, therefore, including changes in policies, institutions and dedicated infrastructure will be needed to facilitate and maximize the long-term benefits of adaptation responses to climate change. Several simulation studies suggest the possibility of relative benefits of adaptation with low-to-moderate warming, although several response strategies may place an extra stress on water and other environmental resources as warming increases. Increase resilience in agricultural systems requires better reconciliation of biodiversity and agricultural production techniques[7]. Methods that help in management of production systems to deal with projected climatic changes include:

a) changed inputs, varieties and species for increased resistance to heat shock and drought, flooding and salinization
b) changed input rates to maintain grain or fruit quality
c) changed amounts, depth, method and timing of irrigation
d) changed the sowing timing or seed rate of crops according to changed conditions
e) diversifying towards rotation systems,
f) making wider use of integrated insect pest and pathogen management

g) increased use of climate forecasting to reduce production risk
h) matching livestock stocking rates and grazing to pasture production, altered pasture rotation,
i) changed growth and rotation periods shifting to more productive areas under new climate conditions,
j) adjusting fire and pest control management systems

Advantages of adaptation will vary with the type of crop and with changes in temperature and rainfall[18]. For wheat, the potential benefits of management adaptations are similar in temperate and tropical systems (17.9 percent versus 18.6 percent). The benefits for rice and maize are smaller than those for wheat, with a 10 percent yield benefit when compared with yields when no adaptation is used. Several significant caveats need to be applied on the above positive results of impacts and adaptation. Changes in pest and disease incidence, increased air pollution, the actual strength of CO_2 responses in real field situations, increased climate variability and the frequency of extremes may lessen farmers' ability to adapt. Furthermore, capacity to implement needed adaptations may not be available, particularly in developing regions where subsistence agriculture is predominant. On the other hand, inclusion of a broader range of adaptations including more significant and systemic change in resource allocations would presumably increase the benefits, particularly if those adaptations included alternative land-use and alternative livelihood options.

Climate resilient crop varieties and genetically modified crops

Climate change will have negative effects on crops yield across irrigated areas in India both due to increase in temperature and changes in water availability. While rainfed agriculture primarily due to rainfall variability and reduction in number of rainy days[28]. Shift in seasons, increase in temperature and change in rainfall pattern are already being observed. In view of these, the crops may encounter extreme weather events like drought, flood, heat and cold during its life cycle, resulting in yield reduction. The yield reductions are likely to be caused by shortening of growing period, negative impacts on reproduction, grain filling and decrease in water availability at critical growth stages. The negative impacts due to terminal heat in the month of January/February, increased water stress and reduction in number of rainy days on yield of wheat and paddy are already being felt[25]. The year 2005, witnessed destructive hurricanes/cyclones across the globe with some major floods in India[29]. During 2006, the states of Rajasthan, Andhra Pradesh witnessed floods while, it was a drought year for North Eastern States of the country. The increase in frequency of heavy rainfall events in last 50 years over Central India points towards a significant change in climate pattern in India[15]. The development and identification of climate resilient crop varieties, with enhanced tolerance to heat, drought, flooding, chilling and salinity stress is essential in order to sustain and improve crop yields to cope with the challenges of climate change. It is essential to bridge the yield gaps, enhance the productivity and profitability, minimize risk and improve the livelihoods of millions of people dependent on agriculture. While, abiotic stresses such drought, heat or cold may trigger a series of responses in plants that include changes in gene expression, signal transduction pathways, metabolic and molecular mechanisms as well as cumulative manifestations of these in terms of source and sink relations for adaptation. The major biotic and abiotic stresses affecting crops that limit crop productivity (Figure 1 and Table 1). Among various abiotic stresses, drought, heat, salinity, cold and flooding is the major factors that adversely affect plant growth and productivity[31]. The contribution of genetically modified crops can make in adaptation to climate change is controversial. Nevertheless, recent examples such as the identification of the gene responsible for rapid stem elongation in deepwater rice may contribute to rice breeding in lowland areas and ultimately lead to reducing the devastation of rice crops caused by monsoon flooding in India and Asia to boost rice production in flood-prone areas.

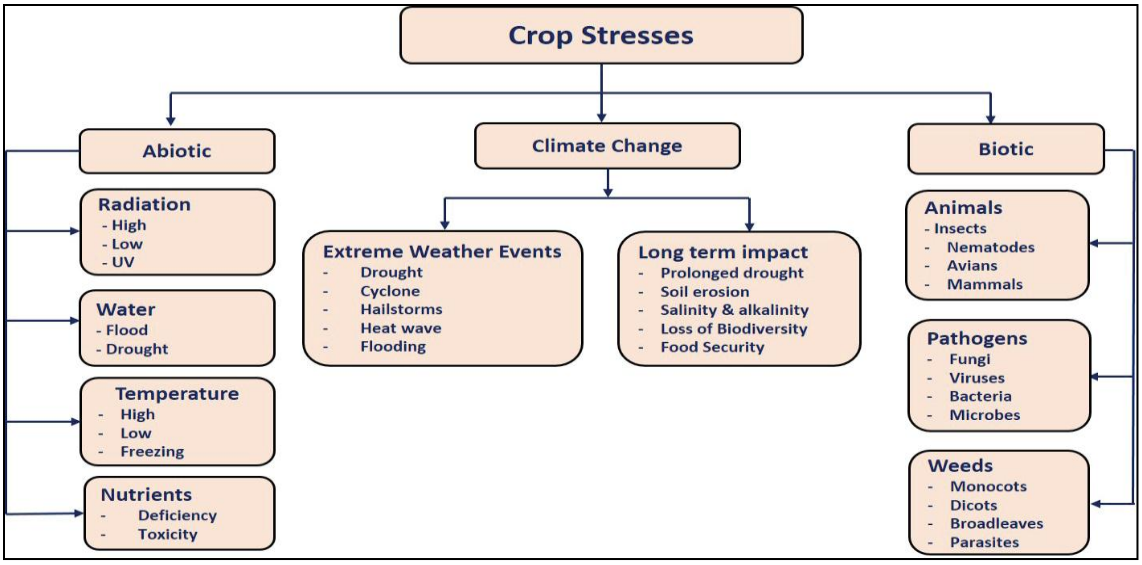

Fig. 1: The major biotic and abiotic stresses affecting crops that limit crop productivity

Water management

Practices of water management are a critical component of adaptation in different climatic conditions that may provide significant adaptation potential for all land production systems under future climate change. Moreover improvement in irrigation schedule and water management are critical to ensure the availability of water both for food production and for competing human and environmental needs[13]. A number of adaptation techniques and approaches are specific to water management for agriculture. These include:

- adoption of varieties or species with increased resistance to heat shock and drought
- modification of irrigation amount, timing or technology
- adoption of water-efficient technologies to conserve and harvest soil moisture (e.g. retention of crop residue, mulching, etc.)
- improved water management to prevent water logging, erosion and leaching
- modification of crop calendars, i.e. timing or location of cropping and agroclimatic conditions
- conjunctive use of surface water and groundwater and
- adoption of structural and nonstructural measures to cope with floods and droughts.

Adaptation practices that involve increased irrigation water use will likely place additional stress on water and environmental resources as warming and evaporative demand increase[18]. Technological options for enhanced R&D include both traditional breeding and biotechnology for improved resistance to climate stresses such as drought and flooding in crop, forage, livestock, forest and fisheries species.

Reducing food system vulnerability by increasing food production

Past increases in agricultural production have occurred altering natural ecosystems to generate products and intensification producing more of the desired products per unit area of land already used for agriculture[16] with simultaneous alteration in natural ecosystem. In future, intensification will be the dominant means for increasing production, although the cultivation of new land will be important in some regions for cereal production by 2020[2]. Increased yields per unit area, with a smaller contribution from an increased number of crops grown in a seasonal cycle, is expected to be the main way in which crop production will rise to meet demand. In the recent past, such increase have been achieved by a 'unique conjunction of three innovations', namely cheap nitrogenous fertilizers combined with semi-dwarf genotypes of cereals, effective weed control with herbicides and the expansion of irrigation[12]. For the future, continued technological developments are anticipated to facilitate the adaptation of crops to changing environments.

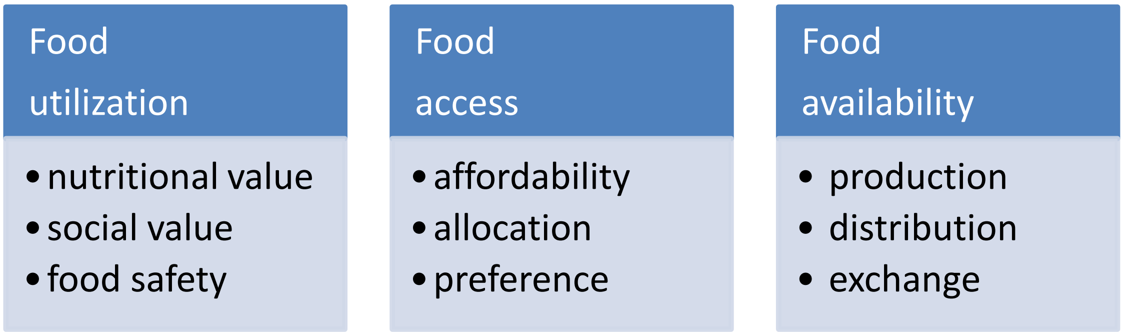

Fig. 2: The major factor s affecting food security

Food systems are defined as a set of dynamic interactions between and within the bio-geophysical and human environments which result in the production, processing, distribution, preparation and consumption of food. They encompass components of:

(i) food availability (with elements related to production, distribution and exchange)

(ii) food access (with elements related to affordability, allocation and preference)

(iii) food utilization (with elements related to nutritional value, social value and food safety (Figure 2).

Food systems, involve much broader considerations than productivity and production alone. They underpin food security, which is the state achieved when food systems operate such that 'all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life'[13]. Food security is diminished when food systems are stressed. Access to culturally acceptable food by individuals and communities, or means for its procurement, is increasingly being elaborated into human rights legislation[21]. Climate change is an injustice, as the people least responsible suffer the brunt of its impacts. Cooperative for Assistance and Relief Everywhere[8] approach to adaptation is focused on increasing the capacity of people, particularly the most vulnerable groups, to adapt to climate change. This includes support for climate-resilient livelihoods, disaster risk reduction and empowerment, advocacy and social mobilization to address the underlying causes of vulnerability, including poor governance, gender inequality and inequitable access to resources and services. CARE[8], approaches to climate change adaptation and to food security share objectives of empowering socially excluded groups to reduce their vulnerability and increase their resilience. Adaptation necessarily addresses food security as a key challenge facing climate-vulnerable populations, while food security programming will in many cases contribute to people's capacity to adapt to climate change, particularly when climate change is explicitly taken into consideration in the design of programmes. They are mutually supportive approaches. In places where people are vulnerable to both climate change impacts and food insecurity. Increasingly adopting an integrated approach which addresses resilient livelihoods, risk reduction and the underlying causes of vulnerability and food insecurity. Following are the examples of strategies that will contribute to the mutually supportive objectives of climate change adaptation and food security:

- Increasing agricultural productivity, climate resilience and sustainability, particularly for small land holding farmers (for example, by promoting conservation agriculture practices, restoration of degraded soils and agricultural biodiversity)

- Promoting rights of vulnerable people, particularly women, to critical livelihood resources such as land and water
- Integrated water resource management
- Sustainable land use management and ecosystem services
- Technology transfer (irrigation, conservation and sustainable agriculture, biogas technology, etc.)
- Disaster risk reduction strategies
- Enhancing government capacity to implement social protection schemes
- Linking emergency food assistance to longer term food security responses
- Promotion of savings and insurance schemes
- Assessing vulnerability to and impact of climate change on the different dimensions of food security
- Improvement of food security monitoring to incorporate indicators related to gender equality, nutrition and climate variability and change
- Partnerships with other humanitarian, development and environmental organizations, research institutions, governments and the private sector to identify practical and effective responses to climate change and food insecurity
- Knowledge management and sharing across sectors, communications and awareness raising

Mitigation strategies for sustainable environmental condition

1. **Land-use Management Practices-** Changing land-use practices such as the location of crop and livestock production, rotating or shifting production between crops and livestock, shifting production away from marginal areas, altering the intensity of fertilizer and pesticide application as well as capital and labour inputs can help reduce risks of sustainability of the farm production.
2. **Climate-ready Crops-** Development of new crop varieties with higher yield potential and resistance to multiple stresses (drought, flood, salinity) will be the key to maintain yield stability. Improvement in germplasm of important crops for heat-stress tolerance should be one of the targets of breeding programme. The research efforts on conversion of rice from C_3 to C_4 crop, steps should be taken for improvement in radiation-use efficiency of other crops as well. Exploitation of genetic engineering for 'gene pyramiding' has become essential to pool all the desirable traits in one plant to get the 'ideal plant type' which may also be 'adverse climate-tolerant' genotype.
3. **The resource-conserving technologies (RCTs)-** encompass practices that enhance resource- or input-use efficiency and provide immediate, identifiable and demonstrable economic benefits such as reduction in production cost thus savings in water, fuel and labour requirements; and timely establishment of crops, resulting in improved yields. RCT minimize unfavorable environmental impacts, especially in small and medium-scale farms. Resource conserving practices like zero-tillage (ZT) can allow farmers to sow wheat sooner after rice harvest, so the crop heads and fills the grain before the onset of pre-monsoon hot weather. As the average temperatures in the region rise, early sowing will become even more important for wheat. Field results have shown that the RCTs are increasingly being adopted by farmers in the rice-wheat belt of the Indo-Gangetic Plains because of several advantages of labour saving, water saving, and early planting of wheat. The RCTs in rice-wheat system also have pronounced effects on mitigation of greenhouse gas emission and adaptation to climate change[23].
4. **Agricultural diversification-** , Demand for high-value food commodities, such as fruits, vegetables, dairy, meat, eggs and fish is increasing because of growing

income and urbanization. Diversification of crop and livestock varieties, including replacement of plant types, cultivars, hybrids, and animal breeds with new varieties intended for higher drought or heat tolerance, being advocated as having the potential to increase the yield to meet the rising demand.

5. **Reduction in use of pesticides-** Management of pests and diseases with use of resistant varieties and breeds alternative natural pesticides, bacterial and viral pesticides, pheromones for disrupting pest reproduction, etc. could be adopted for sustainability of agricultural production process. Bioagents have a crucial role in pest management, hence practices to promote natural enemies like release of predators and parasites, improving the habitat for natural enemies, facilitating beetle banks and flowering strips, crop rotation and multiple cropping should be integrated in pest management practices. Some of the potential adaptation strategies could be:
    i. developing cultivars resistance to pests and diseases
    ii. adoption of integrated pest management with more emphasis on biological control and changes in cultural practices,
    iii. pest forecasting using recent tools such as simulation modelling, and
    iv. developing alternative production techniques and crops, as well as locations.
6. **Conservation Agriculture (CA)-** is a term encompassing farming practices which have three key characteristics:
    1. Minimal mechanical soil disturbance (i.e. no tillage and direct seeding),
    2. Maintenance of a mulch of carbon-rich organic matter covering and feeding the soil (e.g. straw and/or other crop residues including cover crops) and
    3. Rotations and associations of crops including trees which could include nitrogen-fixing legumes.

    It also contributes to sustainability of environment by reducing crop vulnerability. The protective soil cover of leaves, stems and stalks from the previous crop shields the soil surface from heat, wind and rain, keeps the soil cooler and reduces moisture losses by evaporation. In drier conditions, it reduces crop water requirements making better use of soil water and facilitates deeper rooting of crops; in extremely wet conditions, CA facilitates rain water infiltration, reducing soil erosion and the risk of downstream flooding. Conservation Agriculture also contributes to protect crops from extreme temperatures. Crop rotation over several seasons also minimizes the outbreak of pests and diseases. CA thus offers opportunities for climate change adaptation and mitigation solutions, while improving food security through sustainable production intensification and enhanced productivity of resource use.
7. **Direct seeded rice-** The upland, aerobic soil does not produce methane. Water management, therefore, plays a major role in methane emission from soil. Altering water management practices, particularly mid-season aeration by short-term drainage as well as alternate wetting and drying can greatly reduce methane emission from rice cultivation. Improving organic matter management by promoting aerobic degradation through composting or incorporating into soil during off-season drain-period is another promising technique. Appropriate crop management practices, which lead to increased N-use efficiency, hold the key to reduce nitrous oxide emission. Site-specific

nutrient management, fertilizer placement and proper type of fertilizer supply nutrients in a better accordance with plant demands, thereby reducing nitrous oxide emission[24].

CONCLUSION

Intensive agriculture made us not only self sufficient but also increased the produce for export in food grains, Despite all this, it can also lead to several drawbacks. Reforming the food production system is essential for reduction in degradation of soil, water and air. Agro-ecological methods, infrastructure distribution, energy efficiency, recycling, packaging and storage facilities, right technological solutions combined with the right policy directions for the future can effectively contribute to a sustainable and equitable global food system. A new global food system should assure that everybody has access to sufficient food and that poverty should be reduced significantly without doing damage to the natural environment. Despite of environmental disasters that attend it, agriculture is still potentially a renewable enterprise. In every century on a global scale, agriculture is seen as potentially renewable and fundamentally different from the industrial sector of society. It is only in the last 50 years, with the expansion of industry and the chemicalization of agriculture, that the inherently extractive economy has acted as though the renewable resources that support agriculture are fair targets for exploitation in industrial terms. That is what makes the modern era different. Enhancing resilience of the farming community to climate risks to ensure sustainability over a period has to be focused on climate resilient agriculture in the country. Thus, the focus is on adaptation to climate variability, which entails appropriate strategies to contingent situations. Issues related to managing trade-off between risk and expected returns in vulnerable areas to weather aberrations including drought, flood, heat and cold waves etc. also need urgent attention. Another important dimension of utilizing the present information on climate resilient varieties is that, these could be utilized as potential genetic resources for further advancement using tools of both conventional as well as marker assisted selection and other cutting edge science tools. These stress tolerant cultivars can play an important role in coping with climate variability as well as enhancing the productivity. Location specific conservation techniques, water harvesting and efficient management of water resources and other adaptation strategies as well as enabling policies on crop insurance, along with robust early warning system and weather-based advisories will further facilitate enhancing the resilience of Indian agriculture to climate change and climate variability.

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