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Impact of Climate Change on Agriculture and Food Security

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Abstract

This paper takes a broader view and explores the multiple effects that global warming and climate change could have on food production and food security. Dealing with climate change would require strengthening the resilience of farmers and rural people and help them adapt to the impact of climate change. The research hence looks into how adaptation can go hand-in-hand with mitigation and how these measures can be integrated into the overall development approaches and agenda.

To understand the inter-linkages, the paper follows “Pressure-Impact-Response Framework” in order to analyse interrelationship between climate change and food security, and ways to deal with the new threat. The authors propose suitable mitigation strategies to lower the emission from the agriculture sector.

This paper also explores how adaptation activities can results in mitigation as co-benefits and also how these measures can be integrated into the overall development approaches and agenda. At the same time, it is important to assess inter-linkages between ecosystem services and food production and how ecosystem based adaptation will add to food security.

The study adds to the understanding of the impact of climate change on agriculture and produces a listing of adaptation and mitigation strategies to make agriculture sustainable on the face of global warming and improve livelihoods of farmers.

***JEL Classification**: Q01, Q2, Q54, Q28, Q29.*
***Keywords**: Global Warming, India, South Asia, Food Security, Agriculture.*

Executive summary

Temperature and its associated seasonal patterns are critical components of agricultural production systems. Rising temperatures associated with climate change will likely have a detrimental impact on crop production, livestock, fishery and allied sectors. It is predicted that for every 2^0 C (which has been predicted by 2030) rise in temperature, the GDP will reduce by 5 per cent. Accelerated warming has already been observed in the recent period 1971-2007, mainly due to intense warming in the recent decade 1998-2007. This warming is mainly contributed by the winter and post-monsoon seasons, which have increased by 0.80°C and 0.82°C in the last hundred years, respectively. The pre-monsoon and monsoon temperatures also indicate a warming trend.

Overall in India, it is predicted that, physical impact of climate change will be seen as **(1)** an increase in the average surface temperature by 2-4 degrees C, **(2)** changes in rainfall (both distribution and frequency) during both monsoon and non-monsoon months, **(3)** a decrease in the number of rainy days by more than 15 days, **(5)** an increase in the intensity of rain by 1-4mm/day and an **(6)** increase in the frequency and intensity of cyclonic storms.

Because of climate change, Indian agriculture is doubly vulnerable. First as around 60 percent of India's total agricultural areas are rain-fed, it is highly vulnerable to climate change impacts on monsoon. Secondly, more than 80 percent of farmers in India are small and marginal (having less than 1 ha of land) thus having less capacity to cope with climate change impacts on agriculture. India's 200 backward districts as ranked by the Planning Commission are distinguished for the large-scale practice of rain-fed agriculture. With the changing food habits and market conditions, farmers prefer wheat or rice in most parts of the country. In most agro-climatic regions, farmers have stopped cultivation of millets which are suitable to a particular agro-climatic region. Climate change is projected to have serious implications for these major crops especially wheat. The studies have already projected greater losses in *Rabi* season (e.g. in wheat yield) as compared to Kharif crops.

The key characteristics of Indian agriculture that could influence/increase its vulnerability to climate change are **(i)** the high level of subsistence agriculture with small land holdings **(ii)** majority of agriculture is rain-fed **(iii)** frequent occurrence of extreme weather events such as droughts and cyclones and **(iv)** the wide variation in agricultural productivity across the country.

Climate change will affect different parts of India in different ways. These differences are illustrated by the fact that, while large areas in Rajasthan, Andhra Pradesh, Gujarat, Orissa and Uttar Pradesh are frequented by drought, approximately 40 million hectares of land in the north and north-eastern belt is flood-prone. India may also be exposed to a greater number of floods due to the intensification of the Indian monsoon.

Food security is the outcome of food production system processes all along the food chain. Climate change will affect food security through its impacts on all components of global, national and local food production systems, which is projected to affect all four dimensions of food security, namely food availability; stability of food supplies; access to food and; food utilization.

Existing projections indicate that future population and economic growth will require a doubling of current food production, including an increase from 2 billion to 4 billion tonnes of grains annually. However agricultural production in many countries including India would be severely compromised by climatic variability and climate change.

Increase in frequency and patterns of extreme weather events will affect the stability of, as well as access to food supplies. Increasing the frequency of crop loss due to these extreme events may overcome positive effects of moderate temperature increases. In forests ecosystems, the increased risk of forest fires, insect/ disease outbreaks, and other forest disturbances may affect ecosystem services that support food production. These factors are likely to disproportionately impact smallholder farmers and artisanal fishers.

Until recently, most assessments of the impact of climate change on the food and crop sector have focused on the implications for crop production, with less consideration of other components of the food production system and how different food production systems are inter-related. In India livestock are an integral part of agriculture systems. Often cropping pattern is interlinked to availability of fodder for the livestock, an important component of food security in India and other South Asian countries.

Dealing with climate change would require strengthening the resilience of farmers and rural communities and to help them adapt to the impact of climate change. The key, to developing appropriate and targeted adaptation efforts, is to understand impact of climate change across different agro-climatic regions. The impact of climate change on behaviour of pests and diseases still remains largely unclear, while their economic implications are being increasingly felt.

This paper takes a broader view and explores the multiple effects that global warming and climate change could have on food production systems and food security. It also explores strategies for mitigation and adaptation to climate change in several key policy domains of importance for food security. The paper proposes suitable mitigation strategies to lower the emission from the agriculture sector. In addition, it also explores how adaptation activities can results in mitigation as co-benefits and also how these measures can be integrated into the overall development approaches and agenda. The paper assesses inter-linkages between ecosystem services and food production and how ecosystem based adaptation will add to food security and comes up with relevant policy recommendations.

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Impact of Climate Change on Agriculture and Food Security

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1. Climate change impact on diverse ecosystems in India

1.1. Semi arid agro-ecological region

Gujarat, the northern plains, the central highlands (Malwa), and the Deccan plateau are the semi arid regions in India. The climate varies among these regions. Some regions are characterised by hot, wet summers and dry winters, while others by dry summers and cool winters. With rising temperatures, semi-arid regions of western India are expected to receive higher rainfall, while central regions are likely to experience a 10 to 20% decrease in winter rainfall by 2050.[1] In North India, the average mean surface temperature is to rise between 3.5°C and 5°C by the end of this century. According to the Department of Agricultural Meteorology, Anand Agricultural University, these increasing temperatures and CO^2 concentrations are already havin g an impact on the yield of wheat and maize in these regions.[2] Furthermore, these semi-arid agro-ecological regions are already affected by water shortages, which impact agriculture. Although rice and sugarcane is grown where there are irrigation facilities, in some sectors of the central highlands, like Bundelkhand, less than 25% of the net cropped area is under irrigation.[3]

Another anticipated aspect of climatic change is the increase in the frequency and intensity of extreme weather events like cyclones. This will make agricultural (and human) losses higher. Adverse events combined with high population density and environmental degradation makes the Indo Gangetic plains an especially vulnerable area.

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[1] "Impacts of Climate Change: Western and Central India" Factsheet, Global Environmental negotiations. http://old.cseindia.org/programme/geg/pdf/western.pdf Accessed on 1 February 2012.

[2] *Trivedi Soumitra, "Global Warming may hit maize, wheat production" in* Business Standard.*http://www.business-standard.com/india/news/global-warming-may-hit-maize-wheat-production/283740/ Accessed on 02 February 2012*

[3] Gajbhiye. B.S. and Mandal.C., "Agro-Ecological Zones, their soil resource and cropping system" in *Status of Farm Mechnization in India*, Page.13. 01 January, 2000. http://www.indiawaterportal.org/sites/indiawaterportal.org/files/01jan00sfm1.pdf Accessed on 02 February 2012.

1.2. Arid agro-ecological region

Life in the deserts is made more difficult by the increasing temperatures. Excessive precipitation and floods in desert areas are also harmful because the water washes away the salt present in the sand, thereby making the water gradually becoming more saline and decreasing availability of fresh water. In addition, the Thar Desert experienced unusual flooding during August 2006. The unusual flooding of Barmer and other parts of western Rajasthan. The floods have already formed three large lakes covering about 7 to 8 square km in Kawas, Malwa, and Uttarlai, all in the Barmer district.[4] Which is destructive to the ecosystem and affects livelihoods adapted to live with water scarcity.

1.3. Tropical wet and dry agro-ecological regions

The tropical wet and dry agro-ecological regions comprising the south-eastern coastal plain from Kanyakumari to the Gangetic Delta have both rain-fed and irrigated agriculture. Rice is the predominant crop cultivated both in kharif and rabi seasons. After the rice is harvested pulses like black gram and lentil, and oilseeds such as sunflower and groundnut are cultivated using the residual moisture. Besides agriculture, coastal and brackish water fisheries are important economic activities.

Similar to other agro-ecological zones, these areas are also highly vulnerable to changes in climate. For example, in Orissa, seawater incursion has reached 2.5 kilometres inland over the previous two decades. This has negatively impacted more than 600 families and their livelihoods, primarily in the Satabhaya and Kanhupur areas.[5] Along these eastern coastal and inland areas, rainfall is now increasingly unpredictable and has become incompatible with established crop schedules. Evidence of this can be seen in the fact that only seven of the past 25 years have had normal rainfall. The remaining 17 years were characterised by deficient or delayed monsoon, causing an upheaval in rice production.

Furthermore, disasters related with extreme water events have spread to some areas that where earlier characterised by drought conditions. Drought prone districts such as Balangir, Kalahandi, Koraput, Bargarh and Jharsuguda have experienced frequent floods in the prior two decades. Extreme heat events are also being seen more often in coastal areas.

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[4] Nandi Palak, "After the deluge, Rajasthan desert looks blue from sky, its future green". In *India Express*, 2006 September 19. http://www.indianexpress.com/news/after-the-deluge-rajasthan-desert-looks-blue-from-sky-its-future-green/12998/0 Accessed on 02 February 2012

[5] Pattnaik Soumyajit, "Sea Gobbles up five villages in fifteen years" in *Hindustan Times*. 2007 May 18. http://www.hindustantimes.com/India-news/Bhubaneshwar/Sea-gobbles-up-five-villages-in-15-years/Article1-223440.aspx Accessed on 02 February 2012.

1.4. River deltas, costal areas, and mangroves

Some of the areas most vulnerable to climate change are the coastlines of tropical countries such as India. The river deltas are already facing the burden of climatic change and these adverse impacts are expected to increase in the coming century. For example, negative effects are already visible in the Sunderbans, the wetlands at the mouth of the Ganga and Brahmaputra river systems. The Sunderbans wetlands harbour one of the most globally important wildlife habitats, the largest mangrove forest. The Sunderbans wetlands have long been highly susceptible to seasonal ocean currents, tides, waves, winds, and cyclonic storm surges that cause rapid soil erosion on the one hand and salt deposition on the other. This leads to a constantly changing local ecology. Thus, the climatic uncertainty and high anthropogenic pressure resulting from climate change is exacerbating the already high pressures on this region.

One of the most vulnerable aspects of the Sunderban wetlands are its mangroves. Changes in temperature and CO_2 levels, changed rainfall patterns, frequency of storms, and rise in sea level directly threaten the mangrove ecosystems and diminish their ability to cope with changes. Mangroves will be able to adapt only if sea-level rise is slow and if there is space to expand. Ambient temperatures higher than 35°C will affect mangroves by reducing the rate of leaf formation, ultimately causing the population to weaken. If temperatures rise above 35°C, there will be acute thermal stress affecting the development of roots and seeds. At temperatures of 38-40°C, photosynthesis will stop, killing the mangrove population[6]. On the other hand, if it gets cooler, which can also happen with climate change, mangroves would be prevented from migrating north[7].

A decrease in rainfall is likely to cause a decrease in mangrove production, development, and reproduction, as well as affect its geographical distribution and biodiversity. An indirect effect of increasing temperature and CO^2 will be felt because of the degradation of coral reefs, which provide shelter to mangroves from wave actions[8]. An increased turbulence in water dynamics will impact mangrove health and composition due to changes in inundation, salinity, and extent of wetland sediments. Ultimately, the combination of extreme water events and sea level rise will lead to a steady destruction of mangrove populations[9]. Another example of an indirect threat is that a rise in sea level can increase demand for timber needed to create structures to protect coastline from seawater inundation.[10]. In this instance, mangroves will likely be the first casualty.

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[6] Mc Leod, E., Salm, RV. (2006). "Managing mangroves for resilience to climate change". *IUCN Resilience Science Group Working Paper Series – No 2.* Page 50.

http://data.iucn.org/dbtw-wpd/edocs/2006-041.pdf Accessed on 02 February 2012

[7] ibid pp 12

[8] ibid pp.52

[9] Ibid Page no.14

[10] Ibid Page no 22

The Sunderbans and its mangroves are not the only region that are vulnerable, as negative impacts will be experienced in other parts of the delta regions of peninsular India. River basins of the Krishna, Cauvery and Narmada iare estimated to be highly vulnerable to climate change. These basins are expected to experience regular water shortage. The river basins of the Mahanadi and Godavari, on the other hand are considered to be only moderately vulnerable [11].

In the long run, the most pressing threat from anthropogenic climate change in coastal areas will be the rise in sea level and increases in precipitation. There is no steadfast agreement on the extent of anticipated warming, but expectations are of 0.5°C – 2°C by the year 2030.[12] This is because a drastic cut in carbon emission is not expected to happen before a threshold is crossed in the next decade. In a worst case scenario, temperature increase would be between 1°C and 7°C by 2070.[13] This would translate into a 3 to 16 cm rise in sea level in the next two decades, 50 cm by 2070, and a 60 cm increase by 2100[14].

1.5. Forests

In India, a shift towards wetter forest types in the north eastern region and drier forest types in the north western region is predicted.[15] Current climate change scenarios predicting an increase of CO_2 concentrations of approximately 575 parts per million (ppm) to 740 ppm are expected to result in large shifts in Indian forests, affecting up to 80% of the forest by the end of the century. More than half the vegetation is unlikely to adapt to the new conditions and will become susceptible to biotic and abiotic stress.

Climate is an important determinant of vegetation patterns, and has significant influence on the structure and ecology of forests, meaning that specific plant communities are associated with particular climate zones. It is therefore expected that changing vegetation patterns will alter forest ecosystems significantly. As biodiversity and species composition in the forest changes, there will be unwelcome consequences for the livelihoods of people who are dependent on what they can collect from the forest. Given the severity of the estimated impacts of climate change on forest

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[11] "India's National Communication to the United Nations's framework Convention on Climate Change". 2004. Ministry of Environment and Forest. http://unfccc.int/resource/docs/natc/indnc1.pdf Accesed on 01 February 2012.

[12] "Climate change impact in the Asia/Pacific region." United Nations convention to combat desertification. http://www.ifad.org/events/apr09/impact/pacific.pdf Accessed on 01 February, 2012

[13] ibid

[14] "Climate change impact in the Asia/Pacific region." United Nations convention to combat desertification. http://www.ifad.org/events/apr09/impact/pacific.pdf Accessed on 01 February, 2012.

[15] Ravindranath, N.H., Joshi, N.V., Sukumar, R., Saxena, A. (2006). Impact of climate change on forests in India. Page no.354. *Current Science*, vol. 90, no. 3, 10 February. http://cs-test.ias.ac.in/cs/Downloads/article_39718.pdf Accessed on 02 February, 2012.

ecosystems and the people dependent on forest resources, it is urgently required to incorporate adaptation strategies in both short and long-term planning for the forest[16].

2. Impact of Climate Change on Agriculture

The uncertainties associated with climate change do not permit a precise estimation of its impact on agriculture and food production. However, what is happening already in terms of changing seasonal patterns and respective increases in temperature, moisture concentrations and CO_2 levels is likely to have diverse impacts on ecosystems--and therefore on crops, livestock, pests and pathogens.

The physiological response of crops to changing climate is expected to be varied. Although some positive outcomes are expected, the new climatic conditions are more likely to have negative impacts such as a rise in the spread of diseases and pests, which will reduce yields.A meta-analysis of experiments on crop performance shows that a potential increase of photosynthetic activity of plants under higher CO_2 concentrations is only realistic if linked with optimum temperature and favourable rainfall patterns. But the temperature and rainfall patterns are expected to change in future climate scenarios in unpredictable ways.

The nature of changes may be uncertain but what is certain is that changing environmental parameters are highly likely to affect ecosystems and the cultivation of crops. Examining these various parameters in turn provides a better picture of the challenges which global agriculture is facing in an era of climate change.

2.1 Water

According to the 2006 Human Development Report of the UNDP, 2.5 billion people in South Asia will be affected by water scarcity by the year 2050[17]. Rising temperature, changing precipitation patterns, and an increasing frequency of extreme weather events are expected to be the main reasons for reducing regional water availability and impacting hydrological cycles of evaporation and precipitation. This will drastically affect agriculture production in a region where over 60 percent of the agriculture is rainfed, such as in India. On the other hand, climate change can also increase the occurrence of floods, as was seen in the arid regions of Rajasthan in 2006.

A decrease in water storage coupled with increased evaporation would further widen the gap between water supply and water demand. In addition to increased agricultural demand for water, water availability is further exacerbated due to escalating urban, industrial, and environmental demands for water coupled with poor water management.

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[16] ibid

[17] UNDP (2006). Beyond scarcity: Power, poverty, and global water crisis. Human Development Report. UNDP

Already the global use of water exceeds the renewable supply, with 15-35% of total water withdrawals for agriculture estimated to be unsustainable.[18] Evidence of decreased water availability in India is already apparent. Between 2002 and 2008 water levels in northern India fell by 40.5 mm per year and overall more than 109 cubic km of groundwater has disappeared from aquifers[19]. More evidence comes from Uttarakhand where over the previous decade, 34% of 809 perennial water streams have become seasonal or have dried up completely[20]. Further, in Kashmir the average water release from streams has dropped by two thirds[21].

2.1.1. Melting glaciers

Glaciers play an important role in climate and weather regulation. They are important for maintaining ecosystem integrity and in feeding rivers, thus providing water for agriculture. Apart from the monsoon rains, India relies heavily on the Himalayan Rivers for its irrigation. The hydrological characteristics of Himalayan watersheds have already undergone significant changes as a result of climate change and anthropogenic activities. This has resulted in increased variability in rainfall and surface water runoff, more frequent hydrological disasters, and the pollution of lakes. Melting glaciers will impact certain areas more than others and in different ways. The increase in temperature resulting in more rainfall instead of snow is a direct consequence of Himalayan glacial melt. More rain and less snow fall increases the availability of fresh water in the short term but decreases water availability in the long run since moisture is not stored in frozen form. The retreat of Himalayan glaciers reduces water flow into the rivers. A reduced water flow from the melting glaciers changes the watershed distribution and the ecological parameters of rivers causing the temperature of river waters to rise. This further affects the oxygen dissolved in the water, negatively affecting aquatic flora and fauna which are very sensitive to oxygen concentration.

The India government has plans to combat challenges posed by Himalayan glacier melt. The government has established the National Action Plan on Climate Change (NAPCC) to deal with domestic climate change issues. The NAPCC includes a National mission for Sustaining the Himalayan. The concerned research organizations and institutes are making attempts to reduce the threat to the region through mitigation strategies and have put in place monitoring system.

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[18] "Water: Facts and Trends" in World Business Council for Sustainable Development Page.3. http://www.unwater.org/downloads/Water_facts_and_trends.pdf Accessed in 01 February 2012.

[19] "NASA Satellite unlock Secret to Northern India's vanishing water" NASA 08/12/09 http://www.nasa.gov/topics/earth/features/india_water.html. Acessed on 02 February, 2012.

[20] McDermott Mat, "Climate change induced drought causing crop failure, Livestock Problems in Indian Himalyas" in *Treehugger*. 19 November, 2009. http://www.treehugger.com/natural-sciences/climate-change-induced-drought-causing-crop-failure-livestock-problems-in-indian-himalayas.html Accessed on 01 February, 2012.

[21] Warming shrinks Kashmir's rivers, streams in Reuters. 24 September 2007. http://in.reuters.com/article/2007/09/24/idINIndia-29694120070924 Accessed on 01 February 2012.

2.1.2. Disruption of rainfall patterns

The disruption of established precipitation patterns negatively impacts Indian agriculture since agriculture systems have developed cropping patterns dependent on regional weather conditions. Across regions, precipitation patterns are changing with wet years becoming wetter and dry years become drier. The development of crops is also affected by increase in intra rain fall variability. This change could result in a greater number of heavy rainfall events a decrease in the overall number of rainy days, and longer gaps between rains, as well as increased rate of evapo-transpiration. This would disturb established cropping patterns. Heavy rainfall combined with a decrease in the total number of rainy days is occurring over a major part of India. Annual rainfall variability is increasing.. Estimates show that the rise in mean surface temperature will not only affect the post-monsoon and winter weather, but it is likely to lead to a 70% decline in summer rainfall by 2050[22]. These changes are altering the seasons and changing the distribution of fauna and flora. They are also affecting the emergence and spread of pathogens which affect crop yields.

2.1.3. Flooding

Changes in the rainfall pattern leading to a more frequent occurrence of intense weather events will lead to an increased risk of flooding. In tropical areas extreme events will impact agriculture that is already vulnerable to floods and environmental hazards such as drought, cyclones, and storms. For example, in 1962 and 1988 Bangladesh lost about half a million tons of rice due to floods, which amounted to nearly 30% of the country's average annual food grain import[23]. While most rice varieties can withstand submergence for about 6 days, after this period approximately 50% of the plants will die. When submergence lasts for 14 days or longer then mortality will reach 100%[24]. Indian agriculture and food production is particularly susceptible to flooding since one third of the country's flood prone area is used for agricultural purposes.

2.1.4. Droughts

In certain vulnerable arid and semiarid regions, increased temperatures have already resulted in diminished precipitation. Notably, precipitation in Southern Asia and

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[22] Johny Stanly, "Climate Change and Economy: In search of fine balance". In *Zee News.* http://zeenews.india.com/EarthDay/story.aspx?aid=617794 Accessed on 21 February 2012.

[23] Kelka Ulkar and Bhadwal Suruchi, South Asian Regional study on climate change Impacts and Adaptation: Implication for Human Development. Human Development Report 2007/2008 Ocassional Paper. http://hdr.undp.org/en/reports/global/hdr20078/papers/Kelkar_Ulka%20and%20Bhadwal_Suruchi.pdf Accessed on 12 February 2012.

[24] N.V.Nguyen, Global Climate change and rice food security. International Rice Commission, FAO. http://www.fao.org/forestry/15526-03ecb62366f779d1ed45287e698a44d2e.pdf Accessed on 12 February 2012.

Western Africa has decreased by 7.5% between 1900 and 2005[25]. Increased temperatures cause an intensification of the water cycle with more extreme variations in weather events and longer-lasting droughts. Furthermore, the expected temperature increase is likely to exacerbate drought conditions during sub-normal rainfall years. Large areas in Rajasthan, Andhra Pradesh, Gujarat, and Maharashtra and some areas of Karnataka, Orissa, Madhya Pradesh, Tamil Nadu, Bihar, West Bengal, and Uttar Pradesh are already experiencing recurrent drought with several regions currently experiencing water deficits.

In dry land areas, marginal cropland could convert to range-land, and some crop-land and rangelands could no longer be suitable for food and fodder production. More frequent drought would necessitate greater multi-year reservoir storage capacity, in which India is currently deficient. Water conservation and management practices, as well as water storage will need urgent attention.

2.1.5. Monsoon

Monsoons are the lifeline of Indian agriculture so it is not surprising that the changes occurring in monsoon patterns are damaging crop yields. The timely arrival of the monsoon is of crucial importance to food production in the country and changing patterns in the monsoon are a threat to agriculture, food security, and the overall economy. The onset of the summer monsoon in India is getting delayed and disturbed. This affects crop cycles and cultivation in rainfed areas. Monsoon delays and failures inevitably lead to a reduction in agricultural output, thereby deepening food insecurity.

Pre-monsoon rainfall disruption can be just as big problem however. For example, the Chattisgarh region in the past years has received half its usual amount of water during the months of May and June, seriously affecting rice production.

2.2 Soil

While it is natural to expect precipitation patterns to be impacted by climate change, soil processes are also heavily affected. This is because changes in temperature and precipitation influence water run-off and erosion, affecting soil, organic carbon and nitrogen content and salinity in the soil,. This in turn has a major impact on the biodiversity of soil micro-organisms. These parameters are very relevant to soil fertility.

Higher air temperatures will increase soil temperature and with it, increase the speed of organic matter decomposition and other soil processes that affect fertility. Experiments

[25]"Spatial Pattern of Percipitation Trends" in *Climate Change 2007:Working Group I: The Physical Science Basis.* IPCC Fourth Assessment Report (2007). http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch3s3-3-2-2.html Accessed on 02 February, 2012..

show that global warming will have the effect of reducing soil organic carbon by stimulating decomposition rates.[26] At the same time increasing CO_2 can also have the effect of increasing soil organic carbon through net primary production[27]. According to researchers, a small increase in temperature in low carbon soil results in higher carbon dioxide emissions as compared with medium and high carbon soil.[28] This phenomenon makes low carbon soil more vulnerable to warming.

Another example which looks at the complex and often ambiguous effect climate change has on soil focuses on nitrogen. It has been shown that soil nitrogen availability is reduced in drier soil conditions[29]. This is because dry soil affects root growth and the decomposition of organic matter that affect the activity of nitrogen fixing bacteria. Reduced nitrogen fixation in turn reduces soil fertility.

Increasing the use of chemical fertilisers to compensate for soil degradation and fertility loss is commonly thought of as a solution to decreased soil fertility. However, this practice not only contaminates ground water, but also decreases natural soil fertility in the long run. Excessive, chemical fertilisers destroy the living processes of the soil and make it more vulnerable to climate variability. At the same time, they contribute to emission of nitrous oxide, a potent greenhouse gas.

An increase in the rate of soil erosion and land degradation will lead to desertification and climate change will contribute to the expansion of arid zones. The impact of climate change has already resulted in the contraction of several million hectares of fertile growing land. Flooding will cause soil erosion, and in severe instances, landslides which cause extensive damage to livelihoods and habitations. In India, it is likely that intense rainstorms may become more common and lead to more frequent floods, further reducing the amount of arable land, especially in low-lying areas such as fertile river deltas. In order to reduce the expected increase in runoff and soil loss, it is necessary to increase and improve rainwater management

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[26] Kirschmbaum Miko., "Will changes in Soil organic carbon act as a positive or negative feedback on global warming?" in *Biogeochemistry* Vol. 48, No. 1, Controls on Soil Respiration: Implications for Climate Change (Jan., 2000), pp. 21-51. Published by Springer http://www.jstor.org/stable/1469551 Accessed on 02 February,2012.

[27] ibid

[28] Aggarwal.P.K. edt, "*Global climate change and Indian agriculture, Case studies from the ICAR Network Project.*, Indian Council of Agricultural Research, New Delhi.. Page No.viii

[29] Cynthia Grant and Fernando Selles, "Nitrogen Behaviour Under Dry Soil Conditions" . Agriculture and Agri-Food Canada, Brandon Research Centre. http://umanitoba.ca/afs/agronomists_conf/proceedings/2006/grant_nitrogen_behaviour.pdf Accessed on 01 February 2012.

2.3. Biodiversity

The fourth IPCC Report (2007) states that by the end of this century climate change will be the main cause of biodiversity loss. If there is an increase of the average global temperature by 1.5-2.5 ° C, then approximately twenty to thirty percent of known plants and animal species will be threatened by extinction[30]. Climate change will increase the pressure on land degradation and habitat loss, as well as genetic erosion which is already intensifying because of the growing uniformity in agricultural systems across the world. By mid-century, most species could lose half of their geographical range and size because of habitat fragmentation. According to the Food and Agricultural Organisation (FAO), three-quarters of the global crop diversity is already lost[31]. This is particularly problematic as the loss of genetic diversity, both in natural ecosystems and domesticated crops, is exacerbating the impact of climatic change. Only a fraction of the total genetic variability of crop plants is currently stored in gene banks. Diminished genetic diversity, especially if combined with poor human and financial resources, will make adaptation to climate change that much more difficult.

Changes in the climate pattern also favour the diffusion of invasive alien species which are considered to be second only to habitat destruction as threats to global biodiversity and ecosystems. Invasive alien species are able to conquer new territories when changed eco-climatic zones become favourable for their breeding.Future biodiversity scenarios show a steady rise in the number of invasive alien species in many regions. Since these species constitute a large majority of the weeds in agriculture, they pose a growing threat to food production. Alien invasive plants often replicate faster by vegetative means (roots, stolons etc) and are usually more responsive to increases in atmospheric CO_2 concentrations[32].

2.4 Crop productivity

Most studies on the impact of climate change on agriculture come to the same conclusion that climate change will reduce crop yield in the tropical area. According to the IPCC, the next few decades of climate change are likely to bring benefits to higher latitudes through longer growing seasons, but in lower latitudes, even small amounts of warming will tend to decrease yields[33]. The regional inequality in food production resulting from climate change will have a very great implication for global food politics. Even without the challenge of climate, food security is an issue in the tropical

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[30] IPCC (2007(1)). The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

[31] "The State of the world's Plant Genetic Resources for Food and Agriculture" in *Food and Agriculture Organization* (FAO) Report, 2010. .

[32] H. H. Rogers,* G. B. Runion, S. A. Prior, A. J. Price, and H. A. Torbert USDA-ARS D. H. Gjerstad, "Efects of Elevated Atmospheric CO2 on Invasive Plants: Comparison of Purple and Yellow Nutsedge (Cyperus rotundus L. and C. esculentus L.)" Published in *J. Environ. Qual. 37:395–400 (2008)*

[33] IPCC (2007). Summary for Policymakers. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

areas considering that almost 800 million people in the developing world are already suffering from hunger[34]. The effects of global warming could leave no room for manoeuvre since in many parts of India, and other developing countries, crops are already being cultivated near their maximum temperature tolerance. This is especially true in the dry land, non-irrigated areas, where vulnerabilities are high. In these regions even moderate warming of 1°C for wheat and maize and 2°C for rice will reduce yields significantly.[35]

It is known that many agricultural systems are seasonally dependent and thus sensitive to climate change. Crop and livestock production need a specific range of weather conditions at particular times, for optimal growth. Changes in the climate can shift these optimal windows. The most vulnerable agricultural systems are the arid, semi-arid, and dry sub-humid regions of the developing world. In these regions high rainfall variability and recurrent drought/flood cycles disrupt crop development, particularly where crops are grown in marginal lands with low inputs.

Extreme high and low temperatures cause physical injuries to crop plants and damage the grain. Injuries are inflicted by high temperatures on the exposed area of plants, scorching leaves and dehydrating the plant. Young seedlings also dehydrate quickly when soil temperature rises. Temperature rise in lower latitude regions accelerates the rate of respiration, excessively leading to sub optimal growth. For example, rice productivity is estimated to decrease under climate change due to its sensitivity to temperatures that cause damage to the plant, thus affecting yield.[36]

Increased temperatures have multiple impacts on crop productivity depending on the biological characteristics of the specific crop and the time of the heat stress in relation to its development. Higher daytime temperature accelerates plant maturity and results in reduced grain filling, while higher night temperatures increase yield losses due to higher rate of respiration. Episodic heat waves can reduce yields, particularly when they occur during sensitive developing stages, such as the reproductive phase which increases sterility.[37] Higher level of ozone in the lower atmosphere (troposphere) also limits growth of crops[38].

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[34] 2020 Vision: Sustainable food security for all by 2020. Proceedings of an international conference. 2001. International Food Policy Research Institute. http://www.ifpri.org/sites/default/files/pubs/pubs/books/2020conpro/2020conpro.pdf Accessed on 1 February 2012.

[35] Smallholder Farming in Transforming Economies of Asia and the Pacific: Challenges and Opportunities. International fund for Agriculture Development, 2009. http://www.ifad.org/events/gc/33/roundtables/pl/pi_bg_e.pdf Accessed on 01 February 2012

[36] Geethalakshmi, V,Palanisamy.K,, Aggarwal.P.K., and Lakshmanan.A. 'Impacts of climate on rice, maize, and sorghum productivity in Tamil Nadu' in Page no.18 . In *Global climate change and Indian agriculture, Case studies from the ICAR Network Project.*, Indian Council of Agricultural Research, New Delhi.

[37] M. Moriondo · C. Giannakopoulos·M. Bindi, "Climate change impact assessment: the role of climate extremes in crop yield simulation. In Climatic Change (2011) 104:679–701. DOI 10.1007/s10584-

2.5 *Diseases and pests*

The severity of diseases caused by fungi, bacteria, viruses, and insects are anticipated to increase with global warming. The spur in the population of pests and other vectors is related to the interplay of different factors such as increases in temperature, changes in moisture concentration, and a rise in atmospheric CO_2.[39]

2.5.1. *Temperature*

Changes in environmental conditions are likely to result in the northward extension of certain diseases and pests, more generations of pathogens per season, and a better capacity to survive the winter, thus increasing their prevalence and range. Further compounding the problem is that as farmers change crops and cropping patterns to adapt to the changing climate, their crops will be exposed to new kinds of diseases and pests.

However, it is also possible that physiological changes in the host (like more acidic sap) results in higher disease resistance[40]. On the other hand, resistance can be quickly overcome by more rapid pathogen life cycles when temperatures are high. Ultimately, rapid life-cycles will lead to a greater chance of mutations and selected resistant populations.

Due to the ambiguity in the expected changes, planning and preparing for new and varied pathogen and pest profiles is a complicated and oftentimes impossible task to undertake. For example, the favourable temperature range for the development of the rice gundhi bug is 13°C -35°C [41]. If the temperature exceeds the upper threshold of the favourable range, the development rate and the survival capacity of the bug will be reduced. As the impact of climatic change will likely vary in different agro-climatic zones, the behaviour of the rice bug population sswill also vary making it difficult to forecast its evolution. Strategies for the biological control of pests will have to undergo

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010-9871-0.https://www.uni-hohenheim.de/fileadmin/einrichtungen/klimawandel/Literatur/Moriondo-etalCC2011.pdf Accessed on 01 February 2012.

38 "Agriculture and Food Supply" in Climate Change- Health and Environmental Effects. US Environmental Protection Agency. http://www.epa.gov/climatechange/effects/agriculture.html Accessed on 01 February 2012.

39 Chander, S., Reji, G., Aggrawal, P.K. (2009). Assessing impact of climatic change on rice gundhi bug using a population dynamics simulation model in *Global climate change and Indian agriculture: case studies from the ICAR Network Project*. Indian Council of Agricultural Research, New Delhi.

40 Ho Won Chung, Timothy J.Tshaplinksi, Jane Glazebrook, and Jean T,Grenberg "Priming in Systemic Plant Immunity" in Science 3 April 2009: Vol. 324 no. 5923 pp. 89-91 DOI: 10.1126/science.1170025

41 ibid.

a change to adapt to changes in the development patterns, morphology and reproduction of the targeted pests.

2.5.2. Moisture

Moisture also plays an important role in the activities of the pathogens as optimal breeding conditions are usually created when moisture is high. Simultaneous increase in temperature and moisture creates especially favourable conditions and affects both hosts and pathogens in various ways.

2.5.3. Carbon Dioxide

Similar to temperature and moisture levels, increased CO_2 levels can impact both host and pathogen in multiple ways. An increase in CO_2 stimulates the growth vegetative parts like leaves and stems in plants. Increased foliage leads to denser canopies and higher moisture levels that favours pathogen development. When plant matter decomposition is low under higher CO_2 concentrations, the presence of intact plant residue enables organisms to overcome winter. Ability to survive winter means more fungal spores and higher level of infections in the next growing season.

2.5.5. Plant-based contaminants

Another aspect is that the occurrence of plant-based toxic contaminants can be influenced by changes in climate. For example, aflatoxin a metabolite of the fungal species Aspergillus, is a dangerous contaminant that infects food grains and is harmful for human and animal health. Climatic changes including increased prevalence of drought and unseasonal rains, changes in relative humidity, and shift in temperature will affect the population of aflatoxin-producing fungi.

Compounding this problem is the fact that changes in climate may allow the increased population of fungal pathogens to have increased opportunities to attack food grain crops. For example, dry conditions during grain filling and maturity enhance the probability of cracked grains, which can get more easily infected by this fungal pathogen. Heavy rains during or after the harvest can lead to incompletely dried crops before storage, causing proliferation of the fungus during the storage period.

2.5.6. Livestock

Poultry, livestock and other farm animals will suffer due to climate changes because higher temperatures will increase the number of new diseases directly or indirectly affecting them. For instance exposure to drought and excessive humidity or heat renders cattle more vulnerable to infections. Also, alternating drought and heavy rainfall cycles provide a good environment for midge and mosquito vectors that are linked with outbreaks of vector-borne livestock diseases. Poultry is similarly affected by excessive heat or rainfall.

2.6. Weeds

Weeds are another aspect of agriculture likely to be affected by climate change. This is important since the dynamics of crop-weed competition ultimately decides crop output. The higher genetic diversity in weeds gives them flexibility to adapt to new environments through quickly responding to the changes with higher rates of growth and reproduction. Hence, a larger number of weed species are found associated with respective major crops. It is estimated that 410 weeds species are associated with 46 major US crops[42]. Often the worst weeds of crops are their wild relatives, for example, red rice is a weed in rice cultivation and Johnson grass a close relative of sorghum is a weed in sorghum fields. In almost all cases of weed/crop competitions where the plants have similar photosynthetic pathways, weed growth is favoured as CO_2 increases, posing a challenge to the crop.

It is shown that in a CO_2 enriched environment, weeds transfer significantly more carbon to roots and rhizomes than to shoots[43]. This improves their root growth and increases their chances of survival. More vigorous roots lead to more viable plants and higher reproduction with more seeds. Weeds with stronger roots are more competitive and more difficult to control with traditional weed management techniques or herbicide which attack the foliage rather than the roots. Adaptable weed systems will lead to higher crop losses in several crop cycles, under adverse climatic conditions.

Similar to changes in insect, pest, and pathogen profiles, changes in the climate can affect the geographic and temporal scope of different species of weeds. Weeds can migrate to new areas under higher temperatures where earlier they were unable to prosper because of the cold.

2.7. Pollen

For good grain formation, there needs to be a high percentage of germinated pollen grains followed by vigorous growth of the pollen tube to the ovule. Yet, these factors are all very sensitive to environmental changes. Any fluctuation in temperature during the flowering season can be deleterious to effective pollination and subsequent grain development.

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[42] Ziska, L.H. Climate change impacts on weeds. Climate change and agriculture: practical and profitable responses. Page no.1. Fact Sheets. http://www.climateandfarming.org/pdfs/FactSheets/III.1Weeds.pdf Accessed on 1 February 2012

[43] Ibid pp 4

Scientists have shown that in rice and wheat, changes in normal temperature around flowering had a significant effect on fertility of the pollen grains.[44] High temperatures lasting just 1-2 hours during anthesis induces sterility in rice pollen. While Basmati varieties are particularly susceptible to high temperature, above 32°C , pollen germination decreases dramatically in all rice varieties[45]. In wheat on the other hand, it is low temperature around anthesis that can be detrimental for pollen viability and successful fertilization.[46] Changes in the climate with increasing temperature fluctuations can have serious implications for reproductive mechanisms with the potential to diminish crop yields. Since the extent of damage depends on the particular variety, crop genetic diversity is an indispensable resource which allows farmers to adapt to climate change[47].

3. Impact and vulnerability of Indian Agriculture to Climate Change

Indian agriculture today is faced with the challenge of having to adapt to the projected vagaries of climate change. It must develop mechanisms to reduce its vulnerability. The Indian Council of Agricultural Research (ICAR) has already begun research to assess the likely impact of climate change on various crops, fisheries, and livestock. A sector wise analysis is given below.

3.1 Cereal Crops

The Asia-Pacific region is likely to face the worst impacts on cereal crop yields. Loss in yields of wheat, rice and maize are estimated in the vicinity of 50%, 17%, and 6% respectively by 2050[48]. This yield loss will threaten the food security of at least 1.6 billion people in South Asia. The projected rise in temperature of 0.5°C to 1.2°C will be the major cause of grain yield reduction in most areas of South Asia[49].

3.1.1. Wheat

India is considered to be the second largest producer of wheat and the national productivity of wheat is about 2708 kg/ha. The Northern Indian states such as Uttar Pradesh, Punjab, Haryana, Uttaranchal and Himachal Pradesh are some of the major

[44] Chakrabarti, B., Singh, S.D., Nagarajan, S., Aggrawal, P.K., Prasad, H., and Chaudhary, H.B. (2009). "Impact of high temperature on pollen sterility and pollen germination in rice and wheat". Chapter 10 Page 43. Page no. 43. in *Global climate change and Indian agriculture, Case studies from the ICAR Network Project*., Indian Council of Agricultural Research, New Delhi

[45] ibid

[46] Ibid "Wheat" pp. 43

[47] Ibid pp, "Wheat" no.43.

[48] "Impact of Climate change on Agriculture-Factsheet on Asia" in Asian Development Bank, *Addressing Climate Change in the Asia and Pacific Region*, 2009

http://www.ifpri.org/publication/impact-climate-change-agriculture-factsheet-asia Accessed on 01 February, 2012.

[49] ibid

wheat producing states. Here the impact of climate change would be profound, and only a 1°C rise in temperature could reduce wheat yield in Uttar Pradesh, Punjab and Haryana. In Haryana, night temperatures during February and March in 2003-04 were recorded 3°C above normal, and subsequently wheat production declined from 4106 kg/ha to 3937 kg/ha in this period[50].

An assessment of the impact of climate change on wheat production states that the country's annual wheat output could plunge by 6 million tonnes with every 1°C rise in temperature.[51] However, utilising adaptation strategies such as changing the planting dates and using different varieties, it is possible to moderate the losses. By adapting certain agronomic strategies it was estimated that at a 1°C rise, 3 million tonnes could be restored.[52] The assessment also found that the impact of climate change on wheat production varies significantly by region. North India and other areas with higher potential productivity were less impacted by a rise in temperature than the low-productivity regions. If there is no mechanism or strategy to cope with rainfall variability, then rainfed crops will be more heavily impacted than irrigated ones[53]

3.1.2. Rice

Research conducted by Indian Agricultural Research Institute (IARI) has shown that the grain yield of rice is not impacted by a temperature increase less than 1°C. However from an increase of 1-4°C the grain yield reduced on average by 10% for each degree the temperature increased[54]. Thus, higher temperatures accompanying climate change will impact world rice production creating the possibility of a shortfall. We have seen already that basmati varieties of rice are particularly vulnerable to temperature induced pollen sterility, and thus to lower grain formation.

Rainfall pattern is a very important limiting factor for rain-fed rice production. Higher variability in distribution and a likely decrease in precipitation will adversely impact rice production and complete crop failure is possible if severe drought takes place during the reproductive stages. In upland fields, if the rice crop receives up to 200 mm of precipitation in 1 day and then receives no rainfall for the next 20 days, the moisture

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[50]Cooshalle Samuel, "Extreme climate risk" in *Hindustan Times*. 17 December, 2007. http://www.hindustantimes.com/News-Feed/India/Extreme-climate-risk/Article1-263575.aspx Accessed on 02 February 2012

[51]Aggarwal, PK and DN Swaroop Rani. 'Assessment of climate change impacts on wheat production in India. Page no.9. In *Global climate change and Indian agriculture, Case studies from the ICAR Network Project.*, Indian Council of Agricultural Research, New Delhi.

[52] ibid

[53] ibid pp .9

[54] Singh.S.D., Chakrabarti Bidisha and Aggarwal.P.K. "Impact of Elevated Temperature on Growth and Yield of some Field Crop". Page no.47 in In *Global climate change and Indian agriculture, Case studies from the ICAR Network Project.*, Indian Council of Agricultural Research, New Delhi.

stress will severely damage final yields[55]. Assessments predict a decrease in the rice production in tropical regions, but an increase of rice production outside tropical regions.[56] This shift is of particular concern to India because lower rice production will immediately create a hunger situation on a large scale.

Studies on the impact of night time temperature rise on rice yields indicates that the warmer nights have an extensive impact on the yield of rice, "Every 1°C increase in night time temperature led to a 10 percent reduction in yield,"[57]

The eastern region of India has diverse physiographic and agro-climatic land which supports genetic resources. According to a study done by the Indian Agriculture Research Institute the impact of climate change with increased temperature and decreased radiation will lead to decrease productivity in rice in the North Eastern region[58].

3.1.3. Maize

Maize (Zea mays L.) is the third most important cereal crop in India and has a major role to play in food security especially in mountain and desert regions. Maize production in arid and semi arid tropical regions is particularly sensitive to weather conditions, especially rainfall. Therefore, variation in the rainfall as well as maximum and minimum temperature during the south-west and north-east monsoon period will negatively impact maize crops. In Tamil Nadu, assessments indicate a reduction in yield by 3.0%, 9.3%, and 18.3%, in 2020, 2050 and 2080 from current yields[59].

In terms of maize production, two important shifts are predicted to occur. First, maize yield during the monsoon season is expected to decrease as a consequence of increase in temperature; though this can be partly offset by increase in rainfall. Secondly, maize yield during the winter season can decrease in the mid Indo-Gangetic Plains and Southern Plateau as a consequence of increased temperature. On the other hand, in the

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[55] Nguyen..N.V. "Global Climate changes and Food insecurity in *FAO, International Rice Commission* Part 1, Overview, Page no.27. http://www.fao.org/forestry/15526-03ecb62366f779d1ed45287e698a44d2e.pdf Accessed on 21 February, 2012.

[56] Ibid pp27

[57] Vaiadyanathan Gayathri, "Warmer Nights Threaten India's Rice Production" in *Scientific American, 05 May, 2010.* http://www.scientificamerican.com/article.cfm?id=warmer-nights-india-rice. Accessed on 01 February 2012.

[58]"Climate change Impacts on Agriculture in India" in *Keysheets 6 IARI.* http://www.decc.gov.uk/assets/decc/what%20we%20do/global%20climate%20change%20and%20energy/tackling%20climate%20change/intl_strategy/dev_countries/india/india-climate-6-agriculture.pdf. Accessed on 01 February, 2012.

[59] Geethalakshmi, V,Palanisamy.K,, Aggarwal.P.K., and Lakshmanan.A. 'Impacts of climate on rice, maize, and sorghum productivity in Tamil Nadu' in Page no.18 . In *Global climate change and Indian agriculture, Case studies from the ICAR Network Project.*, Indian Council of Agricultural Research, New Delhi.

Upper Indo-Gangetic Plain characterised by low winter temperature, the maize yield can increase up to a 2.7°C rise in temperature[60]. High temperatures plays a greater role in affecting maize yield as compared to rainfall, which may not have a major impact on winter yields as the crops in the Gangetic belt are well irrigated. Maize yield during monsoon could be reduced by up to 35% in most of the Southern Plateau regions and up to 55% in Mid Indo-Gangetic Plains, whereas the Upper Indo-Gangetic Plain is expected to be relatively unaffected[61].

3.2. Vegetables and legumes

Most vegetables are sensitive to environmental extremes, thus periodic high temperature and soil moisture stress conditions are likely to reduce yield, on average. But research also shows that higher CO_2 concentration could offset the negative effect of higher temperature especially in the case of leafy vegetables that would benefit from increased rates of photosynthesis.[62]

3.2.1. Chickpeas

Short duration vegetables and legumes could perform better under higher concentration of CO_2, especially crops such as chickpeas which have a well developed carbon sink capacity, due to their ability to utilise additional photo-assimilates more effectively.[63] Chickpeas grown under elevated concentration of CO_2 (up to 550ppm) showed better performance compared to plants grown under current CO_2 concentrations of 370ppm.[64] There was greater shoot elongation and leaf expansion under elevated CO_2 and an 18% increase in the number of seed in some varieties. Nevertheless, an increase in temperature is likely to reduce the beneficial effect of increasing CO_2[65].

3.2.2. Onion

Elevated CO_2 (550 ppm) leads to higher number of leaves and to larger bulb size in onions. The pseudo stem length, number of leaves and leaf area are higher at bulb initiation and bulb development stages than at ambient CO_2 levels (370ppm).[66] The

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[60] Byjesh, K., Kumar, S.N., Aggrawal, P.K. (2010). "Simulating impacts, potential adaptation and vulnerability of maize to climate change in India". *Mitigation and Adaptation Strategies for Global Change*, 15. pp 413 – 431.

[61] ibid

[62] Pal Madan and Khetarpal Sangeeta, "Impact of levated Carbon fioxide concentration on Growth and yield of Chickpea' . Page no 28 in *Global climate change and Indian agriculture, Case studies from the ICAR Network Project.*, Indian Council of Agricultural Research, New Delhi.

[63] Ibid pp 28

[64] Ibid pp.29

[65] ibid

[66] Rao MKS, Laxman RH., Bhatt RM. (2009). "Impact of elevated carbon dioxide on growth and yield of onion and tomato", Chapter 8.Page, 36. *In Global climate change and Indian agriculture, Case studies from the ICAR Network Project.*, Indian Council of Agricultural Research, New Delhi.

enhanced accumulation of dry matter translates into big size bulbs with an average diameter of 75.02mm under elevated CO_2 levels compared to 65.67 mm under ambient levels[67].

3.2.3. *Tomato*

Tomatoes are positively influenced by elevated CO_2 levels (550ppm). Plant length, number of secondary branches and leaf area increase at elevated levels of CO_2, as compared to ambient levels. At elevated concentrations of CO_2 the fruit yield is higher. The yield increase is mainly due to increase in the number of fruits per plant with a mean of 74 fruits per plant, compared to 56 fruits per plant under current ambient conditions[68].

3.2.4. *Castor*

Elevated CO_2 resulted in an increase in the dry matter production and the total yield of castor [69].

3.2.5. *Coconut*

Coconuts, like other plantation crops, have to deal with the impact of climatic variability even within a single generation. Coconuts require an average temperature of 29°C with a diurnal variation not exceeding 7°C.[70] They further require annual rainfall of at least 1,800mm evenly distributed throughout the year for optimum production.

Research shows that coconut productivity in India is likely to decline in the eastern coastal areas of Andhra Pradesh, Orissa, Gujarat, and parts of Tamil Nadu and Karnataka as a result of climate change. Conversely, yields are likely to increase up to 4% by 2020, up to 10% by 2050, and up to 20% by 2080 due to a positive impact of climate change in the western coastal areas of Kerala, Maharashtra, Tamil Nadu, and Karnataka. [71]. Nevertheless, the yield projections can vary depending on availability of water, even when climate conditions are favourable.

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[67] Ibid

[68] Ibid pp.37

[69] Vanja M., Reddy PRR., Maheswari M., Lakshmi NJ., Yadav, Rao MS., Rao GGSN. (2009). "Impact of elevated carbon dioxide on growth and yield of castor bean". Chapter 7, Page no.32. In *Global climate change and Indian agriculture, Case studies from the ICAR Network Project*., Indian Council of Agricultural Research, New Delhi.

[70] Kumar, SN, Aggrawal PK, 2009. "Impact of climatic change on coconut plantations". Chapter 5, Page 24, in *Global climate change and Indian agriculture, Case studies from the ICAR Network Project*. Indian Council of Agricultural Research, New Delhi.

[71] Ibid pp.25

3.2.6. Apples

The NationalNetwork Project of ICAR suggests that, changing climate is thought to be the main reason for the current decline in apple production in Himachal Pradesh. Apple trees develop their vegetative and fruit buds in summer and as winter approaches, the buds become dormant in response to shorter day lengths and cooler temperatures. Once buds have entered dormancy, they become tolerant to sub-zero temperatures and will not grow in response to mid-winter warm spells. These buds remain dormant until they accumulate sufficient chilling units (CU) of cold weather. Only when they have accumulated enough chilling, the flower and the leaf buds are ready to grow in response to warm temperatures. Hence, if the buds do not receive sufficient chilling temperatures during winter then trees will express delayed foliation, reduced fruit set, and increased buttoning[72].

This is problematic since data collected over two decades shows that minimum temperatures in Himachal Pradesh increased from November to April; and maximum temperatures increased from April to November. Decreased snow fall during winter months led to low chilling hours in the region. Data on cumulative chill units for the coldest months show a decline of more than 17.4 chill units every year due to increase in surface air temperature at Bajura and Shimla in Himachal Pradesh[73]. These ongoing climatic changes are negatively affecting the state's apple production, an important livelihood activity and contribution to the state GDP.

3.3. Fisheries

3.3.1. Marine fish

Climatic changes are likely to impact the geographic distribution and mortality of marine organisms. Depending on the mobility of the species, the area they occupy might expand or shrink. Any distributional changes will directly affect the nature and abundance of fishes. Fish spawning is especially sensitive to temperature, and several species of marine fish are known to spawn only at a particular water temperature. Climatic changes are already affecting the availability, behaviour and distribution of some commercial fish.

One good example is the changes seen in the spawning timing of the threadfin breams *Nemipterus japonicus* and *N. mesoprion*[74]. These threadfin breams are found at depths

[72] Bhagat Rajiv Mohan, Rana Ranbir Singh and Kalia Vaibhav, "Weather changes related shift of apple Belt in Himachal Pradesh" Chapter 12. Page no.48. In *Global climate change and Indian agriculture, Case studies from the ICAR Network Project*. Indian Council of Agricultural Research, New Delhi.

[73] Ibid pp.50

[74] Vivekanandan E., Ali MH., Rajagopalan M. (2009). „Impact of rise in seawater temperature on the spawning of threadfin beams". Chapter 21, Page no.93 in *Global climate change and Indian agriculture, Case studies from the ICAR Network Project*., Indian Council of Agricultural Research, New Delhi.

ranging from 10 to 100m along the entire Indian coast. They have a lifespan of about 3 years, are fast growing, and highly fertile. They are an economically important species as the annual threadfin bream catch along the Indian coast was 1,11,345 tonnes during 2006, comprising 4.7% of the total fish catch [75].

It has been observed that there is a positive relationship between the sea surface temperature and spawning activity of threadfin breams.[76] Data shows that the April to September sea surface temperature in Chennai increased from 29.07°C in 1981-85 to 29.38°C in 2001-04 (+0.31°C). Between October and March of the same period the temperature increased from 27.86°C to 28.01°C (+0.15°C). The frequency of spawning, of threadfin breams was found to decrease with increasing temperature from April to September, however, it increased from October to March when there is a slight increase in sea surface temperature[77]. The fish were shifting their reproductive activities to a period where the temperature is closer to their optimum. The changes in reproduction patterns will play an important role in the availability of these fish and the livelihoods and incomes of fisher folk.

Changes in behaviour directly linked with climatic changes are also visible in oil sardines, a coastal, schooling fish with a high reproductive rate.[78] Its distribution is restricted to the Malabar region along the southwest coast; however, it plays a crucial ecological role in the ecosystem both as a plankton feeder and as food for large predators. It has economic importance in that the annual average production is 3.8 lakh tonnes which comprises 15% of India's total catch. It is also important in terms of food and nutritional security as it is a good source of protein, serving as a staple food for millions of coastal people[79].

Due to the current warming of the Indian Ocean, the oil sardine has already spread to the northern and eastern boundaries of its original distribution in the Indian ocean.[80] From 1950-2005 the surface temperature of the Indian ocean has increased on an average of 0.03°C to 0.18°C per decade. Further, the predicted increase in the surface temperature is expected to rise to approximately 3.0°C in the 2000-2010 decade[81]. While the oil sardine and threadfin breams are two important examples, changes in the temperature of the seas will have an overall impact on many of the types of fish available, affecting not only the value of Indian commercial fishing but the food and livelihood security of many coastal communities.

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[75] ibid pp 93

[76] Ibid pp.95

[77] Ibid. pp. 95

[78] Vivekanandan, E, Rajagopalan, M., Pillai, N.G.K. (2009). « Recent trends in sea surface temperature and its impact on oil sardine".Chapter 20, Page no.89 in *Global climate change and Indian agriculture, Case studies from the ICAR Network Project*., Indian Council of Agricultural Research, New Delhi

[79] ibid pp 89

[80] Ibid pp.92

[81]Ibid., pp .89

3.3.2. Fresh water fish

Changes in the quality and quantity of water in inland water bodies will affect fresh water fish. Many fish in the Ganges breed during the monsoon because of their dependence on seasonal floods. These floods inundate the Gangetic flood plains and are essential for the ' feeding and reproduction of many fish types. Changes in the rainfall pattern, especially decreases in precipitation, can alter the necessary flow and turbidity of the water thereby affecting the breeding patterns of various species of fish.

One example is the Indian Major Carps, which are the most important fish found in both rivers and confined water bodies. Monthly rainfall data records show that the percentage of the total rainfall in the peak fish breeding period between May and August has declined by 5% whereas it has increased by 7% in the post-breeding period[82]. This shift is a major factor responsible for disturbances in breeding and the drastic reduction in the critical numbers of young fish, necessary to maintain the population.

Changes in rainfall pattern and higher temperature have also led to a shift in distribution of fish in the Ganges.[83] Warm water fish species that were earlier available only in mid-river are now available in the more upper, colder regions near to Haridwar. On the other hand, phytoplankton population which predominantly inhabit the cold waters near the mountains have become insignificant[84]. Because all species are interlinked with each other, variation in the distribution of one set of organisms can affect the functioning of the entire ecosystem with large economic and environmental consequences.

3.4. Livestock

The livestock sector has already been impacted by climate variability. This is a major concern considering the potential of livestock in poverty reduction efforts, especially for landless farmers. Disruptions in the seasonal patterns affect the biological rhythms of organisms and the regulation of their biological-cycles[85]. Examples of factors that regulate the biological rhythm are temperature, the light and dark cycle, noise, and

[82] Das, M.K., 2009. "Impact of recent changes in weather on Inland Fisheries in India". Chapter 23, Page no.102 in *Global climate change and Indian agriculture, Case studies from the ICAR Network Project*., Indian Council of Agricultural Research, New Delhi

[83] ibid

[84] ibid

[85] Upadhyay.R.C., Ashutosh, Raina.V.S. and Singh.S.V. "Impact of Climate change on Reproductive Functions of cattle and Buffaloes. Chapter 25 Page.107. In *Global climate change and Indian agriculture, Case studies from the ICAR Network Project*. Indian Council of Agricultural Research, New Delhi.

interaction with members of the same species. For many livestock species, the most important factor is the 24 hour cycle of light and darkness. [86]

In livestock, their biological clock enables them to synchronize their reproductive behaviour with the most favourable environmental conditions for raising their young ones. Ambient temperature plays a major role whereas increased temperatures and humidity levels causes the animals to have increased body temperatures, which results in declined feed intake, disturbed reproductive functions, and low milk yield. High temperature and increased thermal stress also negatively impact ovarian activity, especially in buffalo, and crossbred cows that are known to have a poor capacity to dissipate heat from the skin. Limited availability of water could further impact reproductive functions and also milk production.[87]

Currently the impact of climate stress on milk production of dairy animals is estimated to be 1.8 million tonnes.[88] Models based on different climatic scenarios suggest that milk production will decrease by 1.6 million tonnes by 2020 and by more than 15 million tonnes by 2050.[89] North India is likely to experience greater climate related reduction in milk production of both cows and buffalos compared to other areas[90].

Therefore, adaptation strategies need to be developed to maintain the viability of the dairy sector. One possible solution is to promote the use of indigenous cattle breeds which are more tolerant to thermal and moisture stress, and thus better able to cope with anticipated changes in the climate.

4. Adapting to Climate Change

Adaptation strategies to climate change will have to be based on sustainable agriculture practices. Such practices are better suited for local climatic variability. To develop sustainable agricultural systems it is crucial to include the knowledge of farmers at every level. A knowledge intensive, as opposed to input intensive, approach needs to be adopted to develop sustainable adaptation strategies. Strategies used by farming communities to cope with climate crises in the past will be instrumental in finding solutions to address the future uncertainties of climate change. [91]

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[86] ibid

[87] ibid

[88] Upadhyay.R.C., Sirohi.S., Ashutosh, Singh.S.V.,Kumar.A. and Gupta.S.K., "Impact of Climate change on Milk Production of Dairy animals in India" Chapter 24, Page no. 105 in *Global climate change and Indian agriculture,*

[89] ibid

[90] ibid

[91] Sahai, S. (2010). Recommendations. National Conference on climate change and food security. *Gene Campaign.* http://www.genecampaign.org/Publication/Pressrelease/Food-Security-Climate-Change-Press-release-24.html Accessed on 02 February, 2012.

Given that climate change will have far reaching effects on Indian agriculture and food security, it is important that the country prepares itself to adapt to these changes and does so quickly.

Coping with the impact of climate change on agriculture will require careful management of resources like soil, water and biodiversity. Making agriculture sustainable is key, and is possible only through production systems that make the most efficient use of environmental goods and services without damaging these assets. If climate change impacts can be incorporated in the design and implementation of development programs right away, it will help to reduce vulnerability, stabilize food production and better secure livelihoods. A large scale climate literacy program is necessary to prepare farmers, who are today bewildered by the rapid fluctuations in weather conditions that affect their agriculture. Their traditional knowledge does not help them to manage these recent anthropogenic changes.

Developing countries face a substantial decrease in cereal production potential. In India, rice production is slated to decrease by almost a tonne / hectare if the temperature goes up to 20°C. By 2050 about half of India's prime wheat production area could get heat-stressed, with the cultivation window getting shorter, affecting productivity. For each 10°C rise in mean temperature, wheat yield losses in India are likely to be around 7 million tonnes per year, or around $1.5 billion at current prices[92]. To cope with the impact of climate change on agriculture and food production India will need to act at global, regional, national and local levels.

4.1. Specific Recommendations

Apart from the obvious focus on soil health, water conservation and management, and pest management; there are some specific action areas which will be crucial to making agriculture and food production more sustainable and ecologically sound so as to better adapt to climate change turbulence.

A special package for adaptation should be developed for rain fed areas based on minimizing risk. The production model should be diversified to include crops, livestock, fisheries, poultry and agro forestry; homestead gardens supported by nurseries should be promoted to make up deficits in food and nutrition from climate related yield losses. Farm ponds, fertilizer trees and biogas plants must be promoted in all semi-arid rainfed areas which constitute 60 percent of our cultivated area.

Aggrawal PK. (2010). "Possible strategies for adapting to and/or coping with the impacts of climate change on agriculture". *National Conference on ensuring food security in a changing climate.* New Delhi. http://www.genecampaign.org/Publication/Pressrelease/Food-Security-Climate-Change-Press-release-24.html Accessed on 02 February, 2012.

[92]Sahai Suman 2012. "Multiple Cropping Zones to protect agro-ecosystem. In DNA http://www.dnaindia.com/opinion/comment_multiple-cropping-zones-to-protect-agro-ecosystem_1417598 Accessed on 01 February 2012.

A knowledge-intensive, rather than input-intensive approach should be adopted to develop adaptation strategies. Traditional knowledge about the community's coping strategies should be documented and used in training programs to help find solutions to address the uncertainties of climate change, build resilience, adapt agriculture and reduce emissions while ensuring food and livelihood security.

Therefore conserving the genetic diversity of crops and animal breeds, and their associated knowledge, in partnership with local communities must receive the highest priority.

Breed improvement of indigenous cattle must be undertaken to improve their performance since they are much better adapted to adverse weather than high performance hybrids. Balancing feed mixtures, which research shows has the potential to increase milk yield and reduce methane emissions, must be promoted widely.

An early warning system should be put in place to monitor changes in pest and disease profiles and predict new pest and disease outbreaks. The overall pest control strategy should be based on Integrated Pest Management because it takes care of multiple pests in a given climatic scenario.

A national grid of grain storages, ranging from Pusa Bins and Grain Golas at the household and community level to ultra-modern silos at the district level, must be established to ensure local food security and stabilize prices.

The agriculture credit and insurance systems must be made more comprehensive and responsive to the needs of small farmers. For instance, pigs are not covered by livestock insurance despite their potential for income enhancement of poor households. A special climate risk insurance should be launched for farmers.

In each of the 128 agro-ecological zones of the country various support structures needs to be established. Firstly, there needs to be a Centre for Climate Risk Research, Management, and Extension. The Centre should prepare computer simulation models of different weather probabilities, and develop and promote farming system approaches which can help to minimize the adverse impact of unfavourable weather, while maximising the benefits of a good monsoon.

Secondly, there needs to be the establishment of Farmer Field Schools (FFS) to house dynamic research and training programs on building soil health, integrated pest management, and water conservation along with its equitable and efficient use. The FFS should engage in participatory plant and animal breeding. Similarly, there should be a focused research program to identify valuable genetic traits, such as pest resistance, disease resistance, and drought, heat, or salinity tolerance, that are available in region's agro biodiversity.

Thirdly, there is need for Gyan Chaupals and Village Resource Centres with satellite connectivity from where value-added weather data from the government's Agromet Service should be reached to farmers through mobile telephony. This will give them valuable information on rainfall and weather in real time.

Finally, there needs to be further development of a network of community level seed banks. These should have the capacity to implement contingency plans and alternative cropping strategies depending on the behaviour of the monsoon. Based out of the seed bank network, there must be the establishment of decentralised seed production programs involving local communities to address the crisis of seed availability. Seeds of the main crops and contingency crops (for delayed/failed monsoons or floods), along with the seeds of fodder and green manure plants suitable for the agro-ecological unit, must be both produced and stocked.

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