Draft Report

Role of Climate Change and Agricultural Performance

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Preface

The recognition that the world's climate is gradually changing due to human actions is altering the way human beings envisage their future course of activities. Agriculture being a major economic activity in the country, India needs to build in climate change concerns into her agricultural development policy. Food security of the people and livelihood of the farmers have to be ensured even while the sector moves in line with the low carbon imperatives of growth and the capability to respond to events triggered by climate change has to be ingrained into the fabric of the sector. This study examines the linkages between climate change and agriculture, asks how agriculture can help India to meet the deemed obligation towards mitigation of greenhouse gas emissions and at the same time also take advantage of the opportunities provided by climate change. Whether and to what extent such objectives related to climate change are consistent with the existent objectives of agriculture and how Indian agriculture can cope with climate change are also dealt with in the report.

The study is conducted at the Institute of Economic Growth and I would like to thank our Director Professor Bina Agarwal for her encouragement and the Ministry of Agriculture for providing the opportunity to conduct a study on this important subject. I also thank Mr. P.C. Bodh and Mr V.P. Ahuja of the Ministry of Agriculture for their good coordination and support. I am indebted to Mr. M. Rajeshwor for his assistance with the literature review, data analysis and word processing. I also thank Ms Vanisha Jain for her help with the data.

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Content

Chapter 1

Introduction to Climate change and the Global initiatives

Climate change has become a major challenge to the world today. Human beings are as much the victims of its adverse impacts as they are the cause of it. India is especially vulnerable to the effects of global warming because of her tropical geography and also because large sections of the population are poor and rather indefensibly exposed to the onslaughts of natural calamities that can affect their livelihoods severely. Yet, many of the activities that drive India's growth are also causes of emission of greenhouse gases. While developed countries have greater moral accountability for their past actions, India's growing share in current emissions as well as her sensibility as a responsible nation would demand that India actively cooperates in the international endeavours of monitoring and controlling emissions and also revisits her development policy in light of the emerging concerns.

Agriculture with its exposure to natural events is at high risk relative to other sectors. The number of people directly or indirectly reliant on agriculture is very large and agriculture also serves the nation's most fundamental obligation, i.e., food security. India's stake in climate change ordains that adaptation is ingrained in the country's agricultural policy. Agriculture is also a major source of emission of greenhouse gases and interestingly, agriculture can also provide vital solutions to the problem. There is a critical need for appraising how far mitigation initiatives related to agriculture would be compatible with the objectives of food security and farmers' livelihood in India and how agriculture could contribute to abatement.

India's agricultural policy would increasingly need to fall in line with the climate related objectives in a way that is minimally damaging to the other basic objectives of the policy. The subject of climate change is known to be complex and cross-cutting. While text books and research customarily concentrate on a single discipline or even a subdiscipline, a comprehensive understanding of the subject and development of policy would require comparisons, coordination and interpretation of findings at a common and inter-disciplinary forum rather in stand-alone resolutions. Half-baked understanding of issues runs the risk of either diluting public seriousness by ‘crying wolf’ or instigating a fatalistic resignation. A clear perspective of the subject of climate change is a prerequisite for launching a new paradigm in agricultural planning policy.

1.2. Objectives

The subject of climate change is a very broad one. Contribution comes from a wide canvass of disciplines in the physical and social sciences and from observers and thinkers from the media and the civil society all of whom have their own specialized information base, tools of analysis and even language of communication. Yet the insights provided can be valuable regardless of the source disciplines and the cross-disciplinary reach of the subject makes communication of vital importance for the usefulness of such research.

This project is an attempt to contribute towards this assemblage of information gained on the associations that link Indian agriculture with the looming threat of climate change and to look for compatible solutions. This is done by making a comprehensive review of revelations made by scientists working in climate science, agro-science and soil chemistry and social sciences along with our own observations and analyses. The objectives undertaken in this report are as follows.

1. To understand how and in what way global warming can influence Indian agriculture
2. To list the farm practices that can possibly help in the sequestration of carbon and the control of emissions.
3. To chalk out strategies for an agricultural policy that takes care of climate concerns without compromising on the usual objectives of food and livelihood security.

The report is organized in the following way. Present chapter provides a background highlighting relevant issues, concepts and history. In chapter 2 the linkages between climate change and agriculture is discussed in a theoretical perspective. Chapter 3 as a prelude to the Indian context describes the highlights of India's climate and India's agriculture. Chapter 4 reviews the possible implication of climate change for Indian agriculture. Chapters 5 and 6 deal with the role of Indian agriculture in greenhouse emissions. Chapter 7 draws some inferences on possible policy direction in order to build in mitigation and adaptation objectives in agriculture.

1.3. What is climate change?

Climate change refers to a change in the statistical distribution of weather over reasonably long periods of time that is at least a decade, occurring either in a specific region or all across the earth. In environmental policy, the idea of a climate change is rather qualified. The United Nations Framework Convention on Climate Change (UNFCCC) defined climate change as a change of climate that is attributed directly or indirectly to human activity that alters the composition of global atmosphere and which is in addition to natural climate variability observed over comparable time periods. There is a scientific consensus that anthropogenic actions have contributed to global warming. The UNFCCC definition ties the concept of climate change with the emission of Greenhouse gases. Shorter period weather fluctuations and patterns constituting the El Nino Southern Oscillation (ENSO) phenomenon do not fall into this purview. It is important not to confuse the ENSO with climate change although longer term changes (like climate change) could well affect short term patterns. Appendix1 discusses the ENSO in some detail.

Climate changes have occurred over geological timescales due to natural reasons like tectonic changes and continental drifts, deviations from the earth's orbit and solar radiation. Human being have constructed past climates or what it would have been millions or thousand of years ago using proxies like glacial geology, sea levels, vegetations, archaeological evidences, settlements and agricultural histories and the collapse of civilizations. However, since the invention of the thermometer, as records began to be kept more methodically, information on climate became much more precise. Initially, temperature was measured from land surfaces and from ships on the seas. The instruments having to weather considerable exposure but later on the creation of the Stevenson screen made measurement more secure, comprehensive and straightforward. Standardization of temperature data was organized through the International Meteorological Organization that later became the World Meteorological Organization (WMO). Detailed temperature data since 1850 is accessible. The Hadley centre in the U.K. maintains comprehensive global surface temperature dataset and other archives include the NASA, US National Oceanic and Atmospheric Administration and National Climatic Data Centre. Further advancements occurred when satellite imagery enabled measurement of Tropospheric temperature since 1979 though approximate measures of the same from balloons are available since 1950s.

Natural factors continue to play a part in shaping the earth’s climate. For example volcanic eruptions affect climates several times in a century. The large eruption in Iceland known for disruptions international transportation recently by decreasing visibility is one such example. Eruptions intervene in the global carbon cycle by releasing carbon dioxide from the earth’s crust but, by blocking solar radiation for a long time, eruptions can also cause global cooling. A new factor that has become momentous in shaping global climates rather recently in earth’s time scales and especially in the last two centuries is human influence. The burning of fossil fuel, emission of aerosols, cement manufacturing, land use patterns, animal based agriculture, deforestation and modern industrial activities have been adding Carbon dioxide or other gases, collectively named Greenhouse gases, to the atmosphere. Their concentration has caused temperatures to rise over time especially since the industrial revolution transformed the type of industrial processing, led to greater use of external energy and subsequently revolutionized human living standards.

Meteorological observations show a tendency of global temperatures to rise since 1860 though this was not admitted for long time. The first person to note the recent warming trend and associate it with fossil fuel emissions was an amateur climatologist (Callendar, 1938) who grouped temperature data from reliable weather stations, and smoothing out the data, to find that global temperatures had increased by more than 0.2^{o}C between 1890 and 1935. He also inferred that the growing concentration of carbon dioxide was responsible for at least half the warming. The larger scientific establishment did not agree that the climate had changed radically in the preceding decades nor found the evidences of increasing carbon dioxide concentration convincing. Unfortunately, the menace of nuclear hazard was another dominant act of human ingenuity that was preoccupying the society in the aftermath of the World War II. By the 1950s technological advancements made measurement of carbon dioxide more precise and further evidences emerged to confirm the suspicion of the early proponent of the thesis. Experiments conducted at Mauna Loa observatory in Hawaii yielded continuous record of rising atmospheric carbon dioxide concentration from 315 ppm in 1957 to 386 ppm in 2009 along what has come to be known as the 'Keeling curve'. Gradually, major climate organizations recanted. A National research Council report 2006 estimated that global temperatures have increased by 0.6^{o}C during the last century, such a movement having been unprecedented in the last many centuries.

Land and sea measurements have now independently confirmed the warming. Apprehensions mounted in the year 2004-2005 which was the hottest on record affecting human health and food production and scientists believed there were chances that such a tendency would continue or even accelerate. Data also revealed that global temperatures and carbon dioxide concentrations have moved in conjunction. Indeed the co-movement of temperature and carbon dioxide, supported by theoretical understanding and verified by empirical evidences has already been known to have caused several rounds of global warming and cooling during the course of the earth's existence leading successively to the creation of life and the destruction of life forms. What especially pushed people to action was that this round of global warming was attributed to human generated emissions of carbon dioxide and other greenhouse gases. In 2005 even the leading oil company Exxon Mobil's report acknowledged that the 'accumulation of greenhouse gases' poses risks for society and ecosystems that justify actions. Other fossil fuel companies have followed suit since then showing the way for other responsible emitters to join the global endeavour to combat climate change. Figure 1 indicates that global warming continues.

Figure 1.1(a)

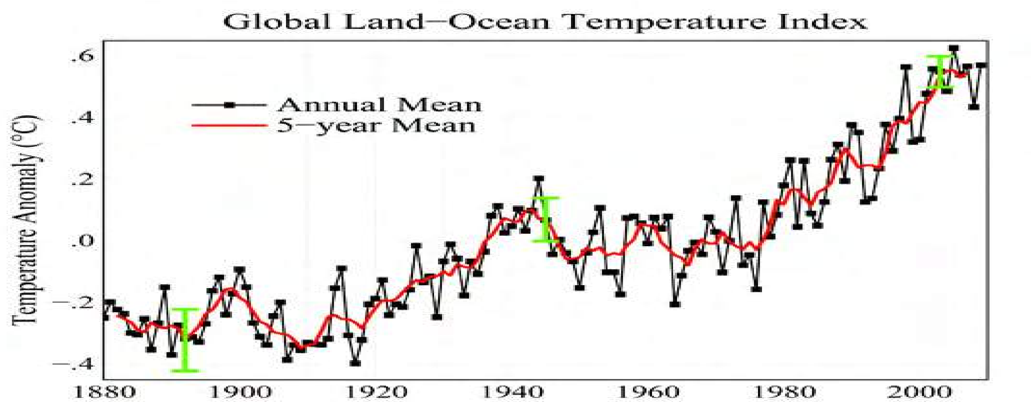

Figure 1.1(b)

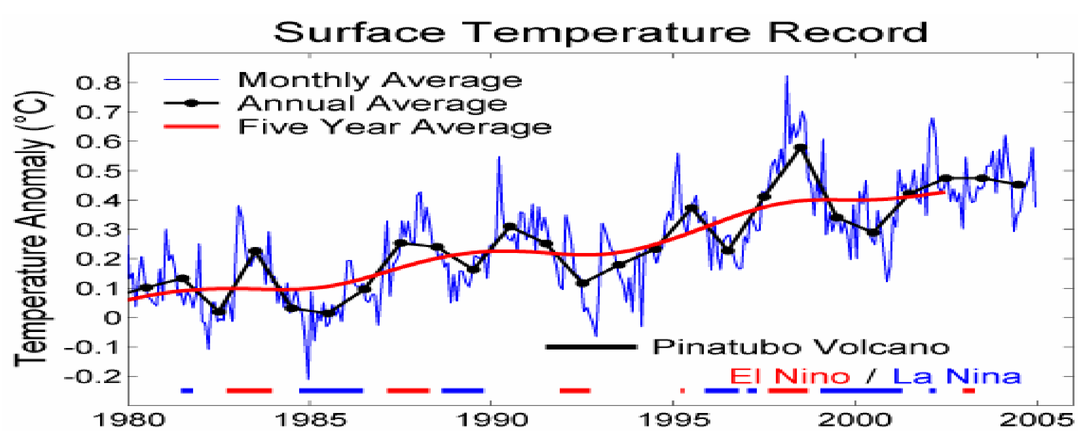

Figure 1.1 : Global Température Graph.

Sources: http://en.wikipedia.org/wiki/Image:Instrumental_Temperature_Record.png
http://en.wikipedia.org/wiki/Image:Short_Instrumental_Temperature_Record.png

1.3.1 What are Greenhouse Gases?

The chemical composition of the atmosphere assured the sustenance of life forms on earth. While 78% of the atmosphere consists of nitrogen that also forms part of organic tissues of living beings, oxygen which is essential for animals to survive constitutes 21%. Carbon dioxide, needed by plants for photosynthesis makes up a small 0.36%. The atmosphere is transparent to the incoming solar radiation that heats the earth's surface but part of the energy reflected back as long wave radiation by the earth and about 30% reaches back into space. Part of the remaining radiating energy is trapped by clouds and atmospheric gases that can retain heat. This is akin to, though not same as what happens in a greenhouse, which is a glass enclosure used for growing plants. The greenhouse gases help to maintain a temperature that is supportive of life on earth. If such gases were not present in the atmosphere, the temperature on this earth would have been much lower (by 33 ^{o} C) than it is now. Higher greenhouse gas concentrations would heat the earth surface and alter the wavelengths that escape and would raise the temperature beyond human tolerance range.

The greenhouse gases that are emitted due to human activity are an assorted lot of chemicals some of which may be present in the atmosphere even without human intervention. Water vapour is the most abundant greenhouse gas. Six other gases have been covered by international conventions as of now. Three of them Carbon dioxide, Methane and Nitrous oxide occur naturally in the earth system and their abundance may have been associated with historical events of natural climate change[i] but all of them are also released by burning fossil fuel and natural gas. Methane is also released by the decomposition of organic waste, from rice fields and livestock rising. All three gases experienced elevated concentration since the industrial revolution (Table1.1) The other three gases Hydrofluorocarbons, Perfluorocarbons and Sulphur-hexafluoride are synthetic substances emitted from a variety of industrial processes. Other fluorinated gases such as the CFCs known for depleting the atmospheric Ozone are emitted in small quantities but have global warming potentials. Ozone, whose depletion has been checked with all seriousness by the world community, is also a greenhouse gas. The emission of CFC is

[i] For example the abrupt release of methane, a powerful greenhouse gas, about 635 million years ago from ice sheets that then extended to Earth's low latitudes caused a dramatic shift in climate, triggering a series of events that resulted in global warming and effectively ended the last "snowball" ice age, a UC Riverside-led study reports.

regulated by the Montreal protocol (see Appendix 1.3). Water vapour concentration is not significantly affected by human action except at a local scale by activities like irrigation.

Greenhouse gases differ in their absorption properties with regard to electromagnetic waves, their concentration and chemistry (Table 1.2). All these gases take part in chemical reactions that limit their residence time in the atmosphere. The warming potentials of the gases are determined by their mean residence time and absorption characteristics. These reactions tend to chemically transform the gases to more benign forms and take place in what are known in literature as 'sinks'. Sinks are visualized as reservoirs that trap greenhouse gases, preventing them from adding to atmospheric concentrations and are also described as bodies that are net absorbers of GHGs. Nature provides both sources and sinks of greenhouse gases.

Table 1.1: Anthropogenic greenhouse gases

	Share in atmosphere %	Atmospheric concentration	Increase from pre-industrial revolution level	Emissions (Tg/year)
Carbondioxide	9-26	388ppm*	108	550
Methane	4-9	1745ppb**	1040	25
Nitrousoxide	3-7	314ppb**	44	5500

Note: 1 Tg= 10^{12} gram. *Parts Per million by Volume,**Parts Per billion, Source: Compiled from various sources.

Respiration and photosynthesis the vital reactions of certain life processes are the most elementary ways means of carbon dioxide emission and removal. Cellular respiration in animals and plants generates chemical energy necessary for maintenance and growth and involves the reaction of carbohydrates with oxygen to form carbon dioxide, water and energy. An alternative and anaerobic pathway to low energy generation involves the breakdown of carbohydrate to produce carbon dioxide, methane and chemical energy. The process of photosynthesis converts atmospheric carbon dioxide to carbohydrate and oxygen in the presence of water and sunlight by which green plants create high energy carbon from low energy carbon in carbon dioxide. Some of these products are stored as stable compounds like cellulose and lignin that do not decompose easily. In general plants pass on the carbon to the soil through vegetable residues to be stored as soil organic carbon (SOC). The two processes respiration and photosynthesis not only serve to preserve the basic balance between plant and animal lives on earth, they also maintain a carbon balance among the atmosphere, plants and the soil. An excess of photosynthesis over respiration in the living world would result in the accumulation of organic carbon in soil and vegetation and the depletion of carbon dioxide in the atmosphere a process termed as carbon sequestration. Although most human activities lead to emission, some of them also provide sinks and to the extent the absorption exceeds the emission, such activities are believed to mitigate global warming by the capture of greenhouse gases and by slowing down their accumulation in the atmosphere. These activities could be consciously promoted to control global warming.

Natural climatic changes cannot be dissociated with the history of the earth. In the relatively short period of 2-7 million years of human history, climate changes determined the spatial distribution, migration, vulnerability and social development of mankind and food availability and sometimes had a role in deciding the rise and fall of civilizations. While natural changes typically impinge over geological time scales, human induced changes could bring similar changes on the earth's climate but in a time span considerably shorter than what nature would take. That the implications could be adverse, radical and unimaginable at the current level of human knowledge needs no explanation.

Table 1.2: Properties of Greenhouse Gases

Attributes	Methane	Nitrous oxide	Carbon Dioxide
Annual growth rate%	3	0.2-0.4	0.4
Contribution to Atmospheric GHGs(%)	15	5	60
Global warming potential (Carbon dioxide equivalent)	21	310	1
Atmospheric life time year	10	170	100
Anthropogenic sources	Rice fields, cattle, landfills, fossil fuel production	Nitrogenous fertilizers, deforestation, burning biomass	Fossil fuel burning, land use change
Sinks	Oxidation in troposphere and in aerobic soils/rice root zones	Bacterial actions in soil, oxidation in stratosphere	vegetation , ocean ,soil
Emission (mill. Tonnes CO_2 equiv.)	28485	6408	3286

Source: Compiled from various sources.

1.4. Climate systems, Projections and Implications of Climate change

Forecasting of weather has been a part of the cultural systems in most early societies, especially in relation to the calendar for agricultural activities. This was traditionally an empirical science based on various associations that were observable to the interested observers. The significance of this function for India is demonstrated in the historical interest in weather demonstrated in the treatises of Varahamihara. The Old Farmer's Almanac has predicted the weather of continental United States since 1792. Over the years, scientific understanding of the determination of climate and measurement of variables facilitated by technological advances has improved the predictability of weather. Today weather forecasting is associated not just with agriculture and navigation but is quite intertwined with economic projections in general and with the daily lives of human beings. Weather forecasts are a part of any news report in the media.

While weather shows day to day or even hour to hour variability, climate is the expression of long term averages over weather variables. 'Climate is what we expect and weather is what we get' attributed to Mark Twain is an expression that clarifies the distinction between the two. Prediction of weather is a routine activity hinged on the knowledge of the climate supposing that the climate is stable. To study climate change or to predict climate is another matter, following the trends shown by the climate is far from easy. The number of parameters involved will be very large and changes in the parameters would be way too small in magnitude for easy discerning. The period of study would be fairly large and indefinite and above all it is difficult not to confuse between weather fluctuations and climatic changes. Moreover, interrelations among regions through atmospheric and oceanic movements make the subject dynamic as well as complex. The earth's climate is marked by significant spatial variations depending on a multitude of influences such as the latitude, the terrain, altitude and proximity to water bodies. Scientists have always tried to achieve broad classification of regions by climatic conditions despite the spatial interrelations and the temporal variations within a region. The most widely used classification is the Koppen climate classification (See Appendix2).

Predictions of weather can only be imprecise and subject to the performance of the methods used and the accuracy of the data used. In general predictions are made with broad ranges and reflect a large number of possibilities. For examples alternate scenarios can be based on estimates of heat trapping gases in the atmosphere, aerosol emission and assumption about future population, energy use, economic growth and land use changes. Given the limitations of understanding the natural interactions and also of measurements the performances of the models in reducing complex behaviour of climate to a few mathematical equations and in quantifying the indicators can still be far from precise.

1.4.1 Models for projection

Climate forecasting requires insight into the mysteries of the universe as well as actual observations and experiments. Experimental manipulation of actual events to measure the causality and impacts is often not possible due to the pace of events, large areas involved, inaccessibility of the regions of activation and above all prohibitive costs. Physical models or mathematical abstractions become the recourse. Early studies on atmospheric and oceanic circulation patterns examined simple physical models that were known as General Circulation Models (GCM). The limitation of the physical GCM to capture the intricacies of nature gave way to a search for mathematical GCMs. Digital computers made it possible to undertake the repetitive calculations involved in climate prediction. The GCMs became more sophisticated with the advancement of computing techniques, capturing the interactions of atmosphere, oceans, land surfaces and ice, analyzing and synthesizing information in spatial and temporal frameworks with several sub-models and depicting the earth's climate in its entirety so that the acronym GCM now stands for Global Climate model.

Climate forecasting requires the predictability of forcing factors that influence earth's climate. While many of such factors are complex and require the use of probabilities, the future of greenhouse gas concentration in the atmosphere proves difficult to anticipate because of its strong dependence on human activities that are themselves difficult to predict. The projections made of climate change by the Intergovernmental Panel on Climate Change or the IPCC (see below, Appendix 1.3.3) are based on global scenarios of GHG emissions that are decided by various socio-economic factors and technological possibilities. Since anticipation of how human society is going to behave over long periods of time such as 100 years is far from easy, the IPCC uses a large number of possible scenarios published in the Special Report on Emission Scenarios (SRES). These scenarios follow distinct storylines such as rapid economic development, slow population growth and the use of fossil fuels/alternative fuels or regional autonomies as against international cooperation, slow technological adoption and sustained population growth. Yet another scenario would assume a worldwide shift to service and information economy, international agreements on clean and resource efficient technologies. Currently the IPCC (5^{th} Assessment) is developing a new set of 4 Representative Concentration Pathways (RCP).

How accurately these models can project the future may be questionable and depends on the modeling skills and the assumptions. Confidence in a particular model is gained only from assessing how well the projections represent the reality as observed from given climate and past changes. The GCMs have earned relatively high confidence based on the consistency of their projection with empirical evidences. If data is available the GCMs can be run to estimate the past, present and the likely future of the earth's climate. Verifying a GCM involves simulating the climate for some time past and comparing the model output with what actually occurred. Discrepancies between a GCM output and the climate record indicate problems with the assumptions, algorithms, initial conditions, coordination among the sub-models. The IPCC Fourth Assessment report presents results of many GCMs each under various assumptions. The best match for reconstruction of global temperatures over past 125 years was found when the model included both anthropogenic and natural forcings but anthropogenic forcings appear responsible for most of the $.5^{o}$ C rise in global temperature experienced from 1970 to 2000.

1.4.2 Implications of Global warming

The effect of global warming does not remain confined to temperature only. Climate change is associated with several identified effects on the earth's climate though yet many other effects may be unknown yet. Temperature directly changes the volume of water in the oceans as water expands in volume with temperature beyond 4^oC. The water levels are also affected by the flows in the rivers, lakes, ice-sheets, glaciers and ground water that sequester water that would otherwise be in oceans. Two independent approaches have indicated that sea level is rising at an average rate of greater than 1.7mm per year. That global warming will impact on rainfall is clear because temperature induced evaporation and condensation are directly associated with cloud formation and precipitation but the precise effect on rainfall is not understood. Annual global precipitation over land has increased by an average of 2% during the twentieth century along with tremendous regional variation. United States experienced a 7% increase but sub-Saharan Africa witnessed a 30% decline. Severe flooding and droughts have been experienced by various regions.

Warming of the earth surface increases the temperature gradient creating tropical storms like hurricanes, typhoons and cyclones. While the number of such storms has remained stable, the frequency of intense (high speed) storms doubled. Global warming is likely increase the severity of extreme events. There are other implications that either moderate the global warming or even feed back into it. Clouds have both positive and negative effects but a net cooling effect. The retreat of ice-caps will enhance heat absorption by the earth surface due to reduced reflectance. Removal of forest cover compromises carbon sequestration but greater reflection will counter the global warming. Melting sea ice may be altering the strength and direction of ocean currents that in turn influence the distribution of temperatures across the face of the earth. The symbiotic relation between the atmosphere and the soil biota could mean that a rise in temperature would activate respiration among soil organisms increasing the emission of carbon dioxide and methane.

In the Fourth Assessment Report of the IPCC anticipated an increase in globally averaged surface temperature by 1.1-6.4^{o} C over the 21st century relative to 1980-1999 for a full range of 35 SRES scenarios based on a number of state of the art global climate models. The projection says that all land areas, especially those in northern high latitudes will warm up more rapidly than global average. With unmitigated increases in GHG emissions coastal groundwater could become saltier, wetlands might be endangered, and precipitation patterns would significantly impact on already water scarce regions where rainfall would decrease. The implications for human life could vary from being favourable to stressful. Forest productivity would increase with a mild climate change but higher global warming would impose severe stress on plant life. Agricultural productivity can be favoured by climate change in certain limited geographical areas but it declines in tropical and sub-tropical zones, especially in developing countries. Small island states and countries that are close to sea and low-lying, as Bangladesh is, will be extremely vulnerable. Ecosystems will be profoundly affected as vegetation and animals respond to changes in their habitats leading to a redistribution of life forms. Not only is food security likely to be hit by climate change especially in Africa and Asia where people are already more exposed to malnutrition and hunger, but human health will undermined by heat stress, air pollution, falling water quality and infectious diseases. While greenhouse gas missions all over the world will be equally responsible for the climate change the effects will vary across regions and the consequences will probably be harder for countries and regions that are economically less developed regardless of where the emissions originate from in most cases.

1.5 Human initiative to control Global warming

Since the World Wars the human community has come together in dealing with various menaces that afflict mankind collectively whether uniformly or differentially such as wars, diseases, genocides, natural calamities and economic problems. Different countries deliberate, negotiate, agree or disagree at common forums democratically so that viewpoints and interests of the people of the respective countries are represented. Atmosphere is a global common property with no political boundaries and climates of various geographical regions are intricately related to one another. Such interdependency and interconnectedness across space would suggest that the United Nations Organization (UN) is the ideal umbrella body to designate specified international bodies to act as fora to deliberate over the problem of climate change, arrive at mutually acceptable solutions and implement them.

The First World Climate Conference sponsored by World Meteorological Organization (WMO) and held in Geneva in 1979 was probably the first major initiative to address the temperature graph that was hard to deny by that time. It established the World Climate Programme (WCP). The following decade of the 1980s witnessed much motivated activity in the same direction, as concerns about the threats associated with human activity induced (anthropogenic) emissions of greenhouse gases grew. Conventions and Protocols that resulted among world leaders were the expressions of these initiatives. While Conventions were agreements in encouragement of certain positive actions and reflected the countries' intentions, Protocols implied legal commitments but only when 'ratification' of individual countries came by. International bargaining and domestic politics are inevitable hurdles that Protocols have to overcome in order to succeed.

1.5.1 International agreements

While climate change is a calamity with severe implications of known and unknown dimensions that the crisis is not without a solution is a silver lining to this problem. Human initiatives are based on the premises that it is possible to adjust and modify human activities to reverse or at least mitigate the process. The success of the Montreal Protocol has amply affirmed the usefulness of international initiatives to tackle a global threat. Without it the ozone layer in the upper atmosphere would be 20-40% lower than they are today and the average temperatures at sea level would be $1^{O}C$ warmer in the Northern hemisphere. The first step in such a initiative is to admit that there is a problem. Economic cost benefit analysis then guides the way at each step. Economic analysis has revealed that the benefit of the Montreal Protocol has far exceeded its cost. Most countries both developed and developing find the measures to combat global warming costly and the cost is higher on the poor countries where the choice is often between climate change and poverty when it is apprehend that mitigation will compromise growth. The marginal cost-benefit analysis is also a difficult task because of the relatively unknown nature of the consequences. Nevertheless, precautionary principle suggests that efforts to prevent the projected events are advisable when their consequences are thought to be dangerous and irreversible even though scientific evaluation of potential damage is not possible[ii].

The conventions and Protocols conducted on environment under the aegis of the UN since the 1980s (details provided in Appendix) have made considerable achievement till date but have a much longer way to go in ensuring that human being mend their ways. The distribution of responsibility is a question that is not easily resolved. Greenhouse gas emission, regardless of where it is made affects the planet as a whole. Yet the severity of the problem created by global warming in a country is not proportional to the emission it creates. The developed countries that industrialized in the last centuries have been major contributors to the damage done in the past while the world's poorest countries that emit negligible amounts of greenhouse gas are often the major victims of changes in sea level, precipitation, storms, heat waves and diseases. The dynamics of the situation created by differential economic growth rates makes the case even more complex. While the industrialized countries with economic affluence have in recent decades been in a position to take appropriate actions to effect mitigation, developing countries that are now on track to grow and reduce poverty are generating higher emissions associated with increased economic activities. Moreover the multinational corporations are increasingly relocating operations associated with high emission to developing countries that can offer the supporting infrastructure but with less restrictive or costly regulations on emissions than developed countries. The distribution of current emission among countries is thus witnessing a shift that is becoming a component issue in international deliberations.

[ii] Calculations made subsequently in the Stern review 2006 showed the cost of compliance to be less than the cost of doing nothing.

1.5.2 Disagreements at the Kyoto Protocol

The Kyoto Protocol (KP) starkly demonstrated contentions that mark the international actions against climate change. The enforcement branch requires the Party (See details in Appendix 1.3) to submit a compliance action Plan and determines whether the ANNEX1 Party complies with its emission commitments during the commitment period. If the emission exceeds the assigned amount the Party is declared as a noncompliant and is penalized. Though a signatory and a Party of the UNFCCC, the US is the most prominent non-Party at KP[iii]. Australia too refused to ratify. India and China had reservations but finally ratified the treaty. The success of the KP was especially limited due to the non-ratification of the US which as a Party to UNFCCC continues to join the ensuing meetings as an observer raising hopes among other parties that it would re-engage in the process at some point. The KP entered into force only in 2005 i.e., about 8 years after the Kyoto meeting only when enough Annex I states (accounting for more than 55% of world emission of 1990) ratified it. As of 2009 October 187 States have ratified the KP and 38 of the 39 Annex I parties were among them. A meeting in Copenhagen sought to create a roadmap for the post KP era but met with little results. A meeting slated in Cancun further attempted to bring US to the table as also to negotiate funds. Limited success was achieved at this meeting in terms of fund allocation for adaptation.

[iii] Neither the Clinton administration nor the Bush administration following it sent the Protocol to the senate for ratification and the latter explicitly rejected the KP in 2001.

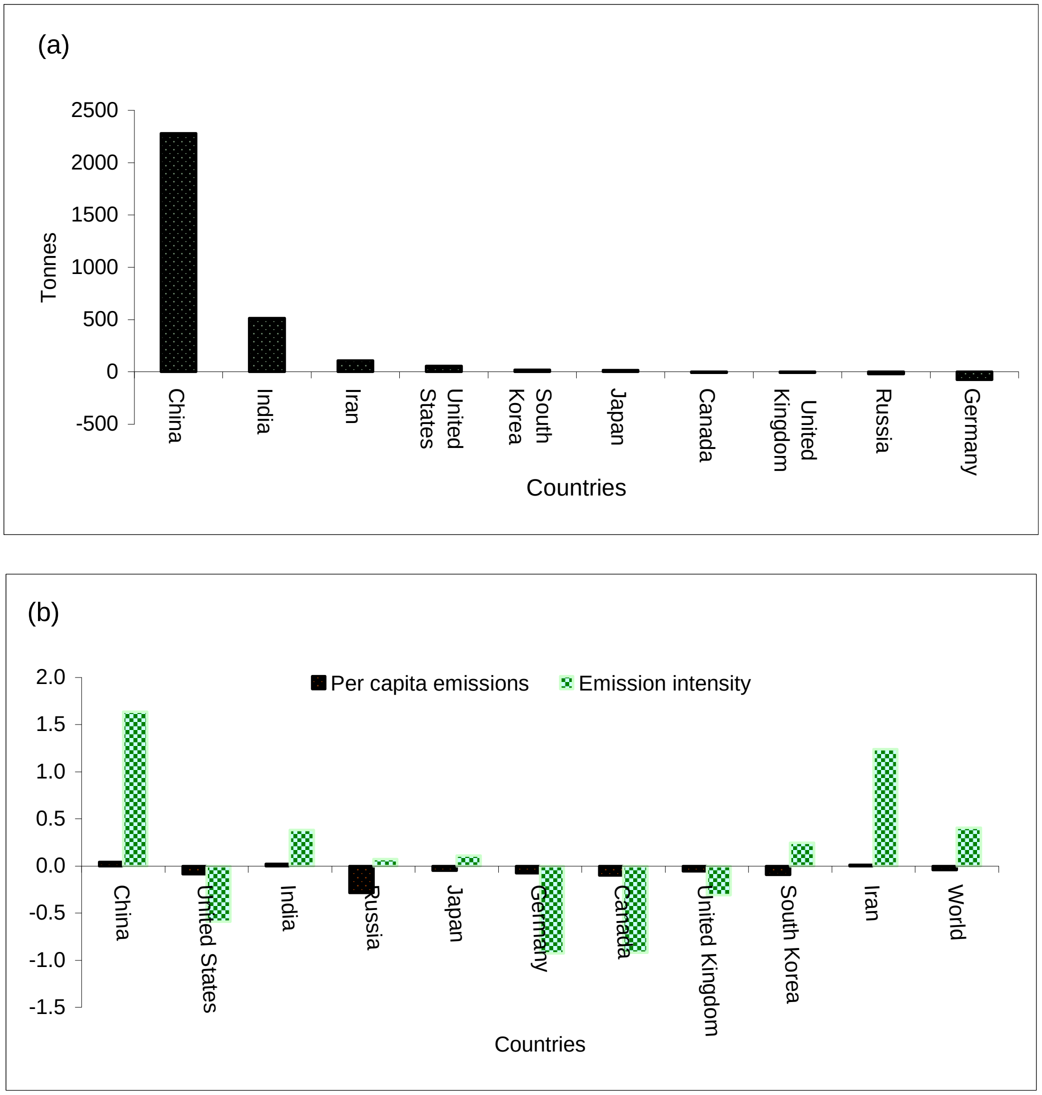

Figure1.2 :(a) Increase in Total Carbon dioxide emission between 2003 and 2007- Intercountry comparison
(b): Increase in per capita emission and emission intensity of Carbon dioxide between 2003 and 2007-Intercountry comparison , Source : http://earthtrends.wri.org.

1.5.3 GHG Inventories and IPCC Methodology Reports

Measurement of greenhouse gases and tracking their sources and removal (sinks) are an important part of the regulation process. The UNFCCC requires the Parties to prepare their inventories of GHG emission. A Greenhouse gas inventory is an accounting of the amount of GHG emitted to or removed from the atmosphere over a period of time. It also provides information on the activities that cause emissions or removals as well as a background of the methods used for the calculations. The National Greenhouse Gas

Inventory Program (IPCC-NGGIP) is instrumental in this initiative. The inventories so published can help in tracking emission, developing strategies and assessing progress in checking global warming. Monitoring, review and verification (MRV) of reduction commitments can be facilitated by the inventories.

The IPCC publishes internationally accepted inventory methodologies that serve as a basis for all countries making their own inventories ensuring that the methodologies are comparable and understandable. The Organisation for Economic Co-operation and Development (OECD) and the International Energy Agency (IEA) have cooperated since 1991 with the IPCC Working group in the inventory creation. The US Environmental protection Agency (EPA) that develops the country's official GHG inventory each year also works with developing and transition countries to improve the accuracy of their inventories.

1.5.3 Emission measurement

Historical and cumulative measures of emissions are useful for enabling comparison with pre-industrial levels in order to determine relative responsibilities of various countries. Between 1900 and 2005 the US supporting a mere 5% of the world population has been placed as the largest contributor responsible for a quarter of the Carbon dioxide emission. US was followed by the EU at 23% share, and China with a 14% share despite a population share of 16%. India's hare is 4% with a 15% share in population.

The current situation is dynamic and shorter time scales are required to measure and compare current performance. Table 1.3 shows that China, USA and India are the top three emitters in that order in 2007 but in terms of per capita emission India has a minuscule contribution in relative terms while China's place is slightly above the world average. Emission intensity of GDP puts both China and India alone the world average and countries like USA, Japan and Germany and both countries have increased their

Table 1.3: Carbon dioxide emission by major countries (Year 2007)

Country	Carbon(C)	GDP	Population	C/GDP	C/Population	Carbon share %	
						2007	2003
China	6538367	6091977	1328630	1.07	4.92	22.30	16.79
United States	5838381	13163870	305826	0.44	19.09	19.91	22.80
India	1612362	2740066	1169016	0.59	1.38	5.50	4.32
Russia	1537357	1868980	142499	0.82	10.79	5.24	6.14
Japan	1254543	4081442	127967	0.31	9.80	4.28	4.88
Germany	787936	2662508	82599	0.30	9.54	2.69	3.41
Canada	557340	1198654	32876	0.46	16.95	1.90	2.23
United Kingdom	539617	2003433	60769	0.27	8.88	1.84	2.16
South Korea	503321	1113038	48224	0.45	10.44	1.72	1.91
Iran	495987	694362	71208	0.71	6.97	1.69	1.53
World	29321302	60507273	6671226	0.48	4.40	67.07*	66.16*

Notes: Unites:- Carbon=000 metric tonnes, GDP= Mill. Int. $, Population=000, * sum of reported states
Source: Wikipedia, http://earthtrends.wri.org.

shares in global carbon emission between 2003 and 2007 while most developed countries reduced their shares. Figures 1.2 highlights the sharp differences in performances whether in terms of total emission intensities. While the per capita emissions of India and China are entailed by the relatively large population sizes of the countries, the performances over time in terms of even this indicator compare poorly with developed counties. The choice of a base year is imperative for measuring performances The IPCC has taken 1990 as a base in the Kyoto Protocol though controversies and disputes have not eluded this choice as it has amended the relative shares of the countries. In recent times a few large and fast developing countries not placed as Annexe 1 in the Kyoto protocol, (see Appendix1.3) such as Iran, China, Egypt and India have shown sharp acceleration in emission leading to a jump in the growth rate of emission from 1.1% per annum in 1990s to 3% in 2000, China being largest perpetrator. At the same time, measures effected by the western industrialized countries like the restructuring made in the energy sector and the collapse of the former Soviet Union have helped to stabilize emission. During the period 1990 to 2005 total emissions worldwide grew by 24%. The developing countries China, India and Turkey increased their emission by 65%, 54% and 76% respectively. While China and India have no legal commitment Trukey allowed itself to move to non Annex I parties and many western countries such as Spain, Canada, Greece and Portugal are not close to meeting their targets. The differential dynamics of

GHG emissions between developed and developing countries is analytically expressed in Figure 1.3.

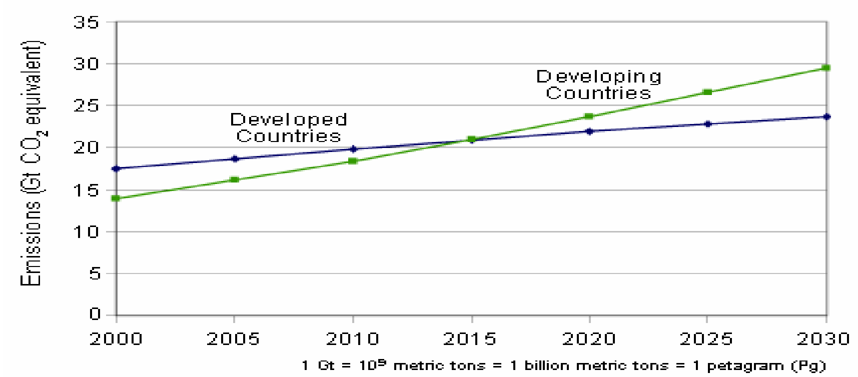

Figure 1.3: Total Greenhouse Gas Emissions by Region
Source: United states Environment Protection Agency,
http://www.epa.gov/climatechange/emissions/globalghg.html

1.6. Flexible mechanisms

Conventional methods of curbing emission involving compulsion, penalization, taxes and regulations, constitute the command and control measures. Imposition of ceiling on pollution emission of individual operators, monitoring them and dealing with each offender is a possible sequence of control that adds burden on the state administrative and judicial machinery. Besides, the use of coercion may be objectionable. An alternative and innovative approach is based by market based instruments that might potentially achieve the same ends with less cost and with voluntary participation of operators and countries for their own economic gain. The proposed carbon market or trading in emission which includes cap and trade and offset trading lies at the heart of such initiatives. The KP has provided for flexible mechanisms that offer market based, non-coercive and amenable ways of meeting targets that Parties have agreed to[iv]. This is based on an accounting system in which the commitment amount or the 'Assigned Amount' is divided into units, each unit equal to 1 tonne of carbon dioxide equivalent. The three pillars known as the Kyoto mechanisms that allow the new approach were the following, Emission trading or a carbon market, the Clean Development Mechanism(CDM) and the Joint Implementation (or JI).

[iv] These are further detailed in the 'Marrakesh Accords' of 2001.

1.6.1 Joint Implementation

This flexible mechanism defined in Article 6 of KP is designed to help rich (Annex I) countries meet their commitments using methods other than by directly cutting their own emissions. Under JI , an Annex I Party with a commitment may implement an emission reducing project or a project that enhances removal by sinks in the territory of another similarly listed country and count the resulting 'emission reduction units' (ERU) towards meeting its own target. Thus JI relates to two or more developed countries only.

1.6.2 Emission trading

Emission trading allows countries to meet their reduction commitments under KP in a cost effective way by utilizing the free market mechanism (see Appendix1.4). The participants in carbon trading buy and sell contractual commitments or certificates relating to emissions allowance. The method also ensures that good behaviour in regard to emission is rewarded monetarily and the developed countries pay for their emissions. For an institution emission trading has as yet a relatively short span of life, the successful achievement of the Acid Rain programme of the US being the first demonstration. Given the interest shown by investors in the Carbon market there are attempts at having voluntary trading also in countries that have is no commitment to abatement.

1.6.3 The Clean Development mechanism (CDM)

Coming as the entry point for developing countries (non-Annex I) into the KP, the CDM allows governments or private entities in rich countries to set up emission reduction projects in developing countries with the intent to promotes sustainable development in developing countries while also helping the Annex I countries to meet their commitments. Unlike the JI, the CDM is an interaction between a developed and a developing country. The developed countries can invest in low-cost abatement opportunities in developing countries and receive credit from the reduction in emissions thus bringing down the need for cut-backs within the border. A typical CDM project would be substituting fossil fuel based power generation with renewable energy or a project that would improve existing energy efficiency levels. Participation in CDM is voluntary and nations need to designate a national authority to deal with CDM. The projects must result in 'real, measurable and long-term benefits' with 'additionality' i.e., over and above what would have happened in a business as usual scene. The World Bank has the role of a referee in the international fund flows.

In the course of KP negotiations in 1997, CDM arose as a controversial proposal and it was the US government that later retracted, which desired that there be flexibility in emission reduction. The CDM benefits both developing and developed countries and provides a vehicle through which investment flows to climate friendly technologies and projects in developing countries. A criticism remains that the CDM would allow the investing countries to sell their technologies while continuing to pollute at home.

1.7. Mitigation, Adaptation and Development policy

Since climate change relates to a complex interaction between climatic processes on the one hand and a broad range of environmental, economic, political, institutional, social and technological processes on the other, the problem of climate change cannot be addressed in isolation of broader societal goals. Mitigation and adaptations are ways in which climate change enters into the centre of overall policy making.

Mitigation involves all the actions that try to decrease the intensity of 'radiative' forcing driving climate change or to diminish the severity of the global warming. Such actions target both sources and sinks of GHGs. Fuel efficiency, shifts to cleaner fuels, re-engineering and modulation of practices are methods by which the sources are addressed to bring down emission from the same level of activity. In addition, consciousness and responses in consumption patterns to the problem can also achieve mitigation by bringing down certain activities associated with emission. Yet it is hard to visualize a world devoid of emission and the adverse impact of controlling emission could be very severe on certain countries and peoples. The UNFCCC therefore imposes certain conditionality on the GHG stabilization programme such as the protection of food security and the progress of sustainable development, differentiated time frames of commitment and exemptions from commitment extended to developing countries. Since greenhouse gases can be transformed into more benign forms, mitigation also involves removal of greenhouse gases already in the atmosphere by the expansion of carbon reservoirs called sinks. Such removals also can be instrumental in maintaining the balance between emission and removal. The IPCC defines mitigation as an anthropological intervention to reduce the sources or enhance the sinks of GHG.

Adaptation, on the other hand, involves methods that teach how to tolerate the effects given that even with mitigation, global warming is yet unavoidable due to past human activities and currents constraints on mitigation. Adaptation is a broad subject related to the understanding of how individuals, groups and natural systems can prepare for and respond to changes in climate or their environment (Mitchel and Taneer 2007). IPCC defines adaptation as adjustment in natural and human systems in response to actual or expected climate stimuli or their effects. An adaptation process seeks to moderate the harm or exploit the benefits of climate change.

Mitigation and adaptation both are costly in terms of finance and socio-economic implications and they are mutually interactive strategies. More the mitigation, less the consequences we have to live with and adjust to. Also greater the preparedness less will be the adverse impact of any given degree of climate change. Nevertheless, they are desirably not treated as alternatives. While it can cause irrevocable damage to compromise on mitigation even if adaptation is possible, it is difficult not to recognize that emissions or the effect of past emissions cannot be totally eliminated given the socio-economic demands of society so that the imperative of adaptation remains. Mitigation and adaptation thus constitute twin processes. There has been a call for exploiting the synergies between the two approaches, arising when the measures to control GHG concentration also reduce the adverse effects of climate change or vice versa creating a win-win situation. With the two strategies being inherently different[v] in temporal and spatial reach and in their focus and measurability such a joint strategy has also been strongly criticized (Klein et al 2005).

A more appealing option could be to exploit the synergies between the development policy and adaptation policy of a nation and to incorporate adaptation into decision making. The linkages between adaptation and sustainable development can be exploited wherever possible so that the capacity of countries and community to adapt to climate change can be interface in a larger interface available. Many developing countries facing poverty and food insecurity have already developed indigenous and planned methods of coping with natural calamities to protect the vulnerable population. The knowledge base provided by the experiences as well as the available institutional frames can be explored to accommodate the additional burden imposed by climate change. The World Summit on Sustainable Development in Johannesburg in 2002 provided an impetus to explore the concept of climate 'mainstreaming' which can ensure more efficient and effective use of financial and human resources compared to having a climate policy separate from development policy. This report will argue that mitigation can also enter the realms of development policy where the objectives will now include minimization of emission along with other developmental aims. This implies a much more radical revisualization of the development strategies and the launch of new paradigm involving switches in fuel, material, technology, management practices and even life styles even while meeting the usual goals. A low emission growth path would require greater research and experimentation at identifying and moderating the sources and sinks of greenhouse gases.

[v] The spatial and temporal scales are much larger for mitigation where emission reduction in a point on earth could benefit any other place on the earth and over long periods compared to adaptation that typically acts at the local or regional level and at small periods of time. Mitigation is also more point specific, concentrated in energy and transportation sectors and the costs can be estimated more precisely whereas the benefits of adaptation is diffused, embrace actors representing varied sectors of activity and are hard to measure

1.8. How serious is the issue of Climate change; The Indian context

That the emission of greenhouse gases on account of human developmental actions is liable to cause global warming is a scientific finding that has hardly been disputed. However, how imminent or how catastrophic is the predicament is not totally clear to people at large. Evidences of outcomes that are used by policy advocates are often subject to speculation and clear linkages with climate change are not necessarily borne out. Estimates provided by the climate scientists are sensitive to the assumptions made. Climate change is also a staggered process in which the adverse effects become 'immediate, obvious and widespread enough to stimulate universal action' long after the dangerous level of emission is crossed (Hodder and Martin, 2009). Certain projections made in the Fourth Assessment report of the IPCC have met with justified criticisms but perhaps in the process some the faith put on such projections have been shaken. Alarmism and the 'language of fear' creates confusion between depicted disaster and the observable physical reality of today (Weber, Elke U., 2006) and contradictions in the scientific world weaken the resolve shown by the common man and the policy maker. There is a compelling need for caution in treading the path.

The tendencies for questioning the seriousness of prophesies, especially among the governments and their political oppositions in various countries are not surprising because of the large trade-offs that exist between national development and the reduction of emission. Threats such as war, civil unrest, poverty, unemployment, HIV aids and other diseases and inequality that could kill people demand immediate attention. Development demands the generation of energy the benefits of which may be share by the poor. Even developed countries have faced the challenge of prioritizing between climate change and other exigencies. The non-participation of the U.S. is an illustration.

India, a party to global negotiations portrays the friction between development and climate change in is strongest form. In a OECD publication titled' Climate change: India's perceptions, Positions Policies and Possibilities' Parikh and Parikh (2002) ascribed the responsibility for the threat of climate change on the unsustainable consumption patterns of the rich industrialized nations pointing out that 25% of the global population emit more than 70% of global carbon dioxide and consume 75-80% of other world resources. In contrast at the per capita level the Indian citizen emits only 0.25 tonnes of carbon per year against a figure of 5.5 tonnes attributed to the US citizen. The findings were well received in the UNFCCC which recognized the rights of developing countries to economic development. India's case was also defended by pointing out the proved unreliability of data on methane emission from India. It was argued that emission by poor who live on the margin of subsistence should be considered a basic human right and should not be counted when ascribing responsibilities for emission (Aggarwal and Narain, 1991). On the other hand the adverse impacts due to temperature increases, sea level rise and frequency of extreme events' occurrences merit serious consideration Undoubtedly, to the extent this influential paper manifested India's stand in the climate change deliberations, the emphasis was on the negotiation strategy and the argument went in favour of a freedom to decide which type of energy was used by the country, how power was generated and how methane emission was reduced and so on.

Growth of the economy carrying along vast sections of people at various income levels is awarded supreme importance in India's policy. India's National Action Plan in Climate Change (NAPC, Government of India, 2008) clearly states the overriding priority of maintaining high economic growth rates and identifies measures that promote development objectives while also yielding co-benefits for addressing climate change effectively. A national mission under this Plan will have in the agenda the socio-economic impact of climate change. For addressing climate change effectively National Mission for sustaining the Himalayan ecosystem, National Mission for a Green India and for Sustainable Agriculture. India's stand emphasized that the country's per capita GHG emissions will at no point exceed that of developed countries.

Yet, it is a matter of concern for India, a leading victim of climate change that negotiation have slowed down significantly and India can play an active role in opening up the discourses again and facilitating the flow to take effective directions. To what extent

India can remain exempt from commitments shared by developed partners will depend on India's growth momentum negotiations as well as associated economic ramifications of the growth process. India's share in global GHG emissions provided in Figure 1.4 shows the weight of methane that is generated on account of the country's food production followed by carbon dioxide that is associated with the provision of power to a large underdeveloped predominantly rural country. Also, with the asymmetric situation prevailing in the world, industries have been relocating to developing countries where emission is less restrictive or less costly. The current dynamic situation may not rule out a situation when the MRV provisions will be extended to developing countries as well (Dasgupta, 2010). Moreover, India's active involvement in the mitigation process will also help in comprehensive information gathering on emissions and the efficacy of mitigation measures. The right to emission on grounds of poverty can also be replaced by an alternative system where the right is legally sanctified with a monetary value so that the poor is compensated for not being able to exercise the right. Such compensations can be funded through the public budget, international resource pools and also through innovative financial mechanisms. Adaptation and mitigation both involve resources but climate change also offers India ways of raising the resources through climate services that were not available earlier. Such services are in most cases not inconsistent with our development objectives and as we shall in the course of this study in the subsequent chapters, the emerging financial institutions will possibly open up ways of pursuing development objectives that were hitherto unfulfilled for lack of resources even while the climate change adversities can be combated simultaneously.

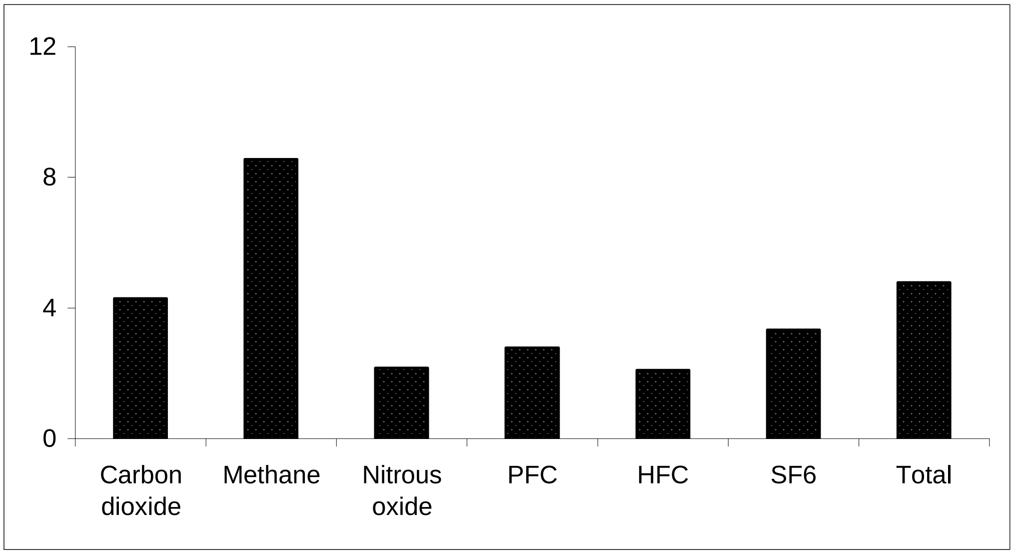

Figure 1.4: Share (%) of India in world GHG emissions.
Source: Ministry of Environment and Forest Government of India.

Appendix 1.

1.1 ENSO: short run climate phenomena

El Nino Southern Oscillations (ENSO) is the strongest known natural climate pattern observed at relatively short intervals running up to a decadal scale. It originates over the tropical Pacific region due to ocean-atmosphere interaction and spreads westward and eastward. The ocean gets warmed as the trade winds die down and the warm waters migrate outwards. ENSO has two components, an ocean temperature component and an ocean atmosphere component. The two well-known phases associated with ENSO are the warm oceanic phase or the El-Nino and the opposite and cooling phase or La-Nina. The La-Nina phase begins generally after one year of the El Nino. Coupled together, the two components create 'quasi periodic' climate patterns associated with floods, droughts, weather disturbances in many regions.

ENSO dependent climate patterns increase the likelihood of extreme events like freezes and floods (during El Nino) leading to crop failure (Nadolnayak, vedenor, Norakk, 2008) in the US, severe tropical cyclones in the Pacific and weakened monsoon in South Asia. El-Nino can cause intense rainfall in some areas and droughts in others. It affects countries like Indonesia and Australia severely. Incidences of water borne and vector borne diseases in the world are also linked to ENSO. Although the effects could be beneficial as well as catastrophic, the adverse effects merit attention in developing regions. Whether and to extent the ENSO is related to climate change is not fully understood and is debated. Different theories are used to predict their patterns in context of the climate change. Modeling climate data has suggested that more frequent and stronger ENSO events could be triggered by global warming as sea surface temperature anomalies increase. Some theories also see the possibility of a reduction in the oscillations and even associate greater global warming with a continuous ENSO state.

1.2. Climate classification and the Koppen System

First published by a German climatologist by the same name the Koppen System, used since the 19th century this system is based on five primary classifications (1) Tropical, (2) Dry, (3) Mild mid-latitude, (4) cold mid-latitude, (5) polar. Further there are a number of secondary classifications. The classified climatic regions include Rainforests characterized by high rainfall, Monsoon where seasonal prevailing winds blow for several months often bringing rain as in parts of Americas and in East Asia, Tropical savanna, Mediterranean, Sub-arctic and Polar ice cap among others. The Koppen system is based on solar radiation and precipitation while evapo-transpiration is another component added in an alternative system named Thornwate system. Further, the Bergson and the Spatial Synoptic classifications also take account of air masses.

1.3. International Conventions and Agreements

Convention on Long term Trans-boundary Air Pollution (LRTAP)

Held in Geneva in 1970 this forum addressed the human induced menace of pollution for the first time. The convention aimed that the Parties should develop policies and strategies to combat the discharge of air pollutants through exchange of information, consultations, research and monitoring. A special emphasis was placed on East Europe, the Caucasus, Central Asia and South east Europe.

1.3.1 The Vienna Convention and the Montreal Protocol

The concern over the atmospheric concentration of Chlorofluorocarbons or CFCs was aroused by the studies conducted by scientists Rowland and Molina of the University of California. They showed that the atoms of these compounds remained stable in the atmosphere till they reach the middle of the stratosphere and subsequently they are broken down by Ultraviolet (UV) rays releasing chlorine atoms that in turn are expected to break down the ozone molecules in the atmosphere. Rowland and Molina were awarded the Nobel Prize in Chemistry in 1995. The depletion of the ozone layer and reduced protection from UV rays in turn have been linked with the growing incidence of skin cancer.

The Vienna Convention for the Protection of the Ozone Layer was a Multilateral Environmental Agreement agreed upon at the Vienna Conference of 1985 and came into force in 1988. It acts as a framework for the international efforts to protect the ozone layer but does not include legally binding reduction goals for the use of CFCs, the main chemical agents causing ozone depletion. The Convention however led to the more celebrated Montreal Protocol.

1.3.2. The Montreal Protocol

Montreal Protocol on Substances That Deplete the Ozone Layer or the Montreal protocol in short, following the Vienna Convention, was an international treaty to protect the ozone layer by phasing out the production of a number of substances believed to be responsible for the ozone depletion. The treaty was opened for signature on September 16, 1987, entered into force on January 1, 1989 and was followed by a numer of meetings (Helsinki, 1989, London, 1990, Nairobi, 1991, Copenhagen, 1992, Bangkok, 1993 Vienna, 1995, Montreal, 1997 and Beijing, 1999) and seven revisions in the treaty. It is believed that if fully adhered to the Ozone layer would be recovered by 2050. The international cooperation in observing this treaty, structured around the halogenated hydrocarbons commonly called the CFC, has been remarkable and Montreal protocol has been described as the ‘single most successful international agreement to date’.

1.3.3. Intergovernmental Panel on Climate Change (IPCC)

Following the heels of the Montreal protocol, the establishment of the Intergovernmental Panel on Climate Change (IPCC) by the joint initiative of the United Nations Environment Programme (UNEP) and the WMO in 1988 was a landmark step in the decade. The IPCC became the leading body for the assessment of climate change to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences. It reviews and assesses the most recent scientific, technical and socio-economic information produced world wide that is relevant for understanding climate change. It does not itself conduct research nor does it monitor data or parameters but bases its assessment mainly on peer reviewed and published scientific literature. Review is the essential process by which the IPCC attempts its objective assessment reflecting differing view points existing in the scientific community. The IPCC is an intergovernmental body open to all member countries of the UN and WMO and governments are involved in the work as well. In 1988 the UN General Assembly outlined the IPCC's task of preparing a comprehensive review with its recommendations.

The first assessment report of the IPCC was brought out in 1990. The study concluded that human activities were largely responsible for climate change and the topic indeed deserves a political platform among countries. The report predicted that under a "business as usual" (BAU) scenario, global mean temperature will increase by about 0.3 ^{o}C per decade during the 21st century. They judged that global mean surface air temperature had increased by 0.3 to 0.6 ^{o}C over the preceeding 100 years perid. The submission of this report was followed by the Second Climate Conference also held in Geneva the same year. The Conference reviewed the WCP and though the declaration it made was not universally welcomed, the IPCC Report and the Conference together contributed to the creation in 1992 of the United Nations Framework Convention on Climate Change (UNFCCC), a key international treaty to reduce global warming and to cope with the consequences of the climate change. The Kyoto protocol was result of the UNFCCC.

As an update of the First Assessment Report was (AR1) a supplementary report brought out in 1992 in context of the Earth Summit in Rio but no further improvement of the fundamental understanding of GHG effect was indicated. In 1995 the IPCC's Second Assessment Report (2AR) was tabled. Attempting a disaggregated view to climate change along with the social and economic dimensions, mitigation and adaptation were the two major imperatives that report brought into focus. Considerable progress over the 1990 report was explicit in the 2AR of the IPCC. A clear distinction between natural and anthropogenic influences on climate made in the report provides a richer understanding of human influence on global climate.

Still, the Second Assessment Report was controversial in its treatment of the economic value of human life in rich and poor countries and many governments were unhappy over the cost benefit analyses made. The Third Assessment Report (AR3) tabled in 2001 predicted that the average surface temperature is projected to increase by 1.4 to 5.8^{o} Celsius degrees over the period 1990 to 2100, and the sea level is projected to rise by 0.1 to 0.9 meters over the same period. The wide ranges in predictions is based on scenarios that assume different levels of future CO_2 emissions and each scenario then has a range of possible outcomes associated with it. The most optimistic outcome assumes an aggressive campaign to reduce CO_2 emissions; the most pessimistic is a "business as usual" scenario. Other scenarios fall in between. This report was criticised for certain aspects of modelling (the Global Climate Models) used. The Fourth Assessment Report (AR4) was brought out in 2007 the same year that IPCC got the Nobel prize. The Fifth Assessment report is under process, As a first step, experts, governments and organizations involved in the Fourth Assessment Report have been asked to submit comments and observations in writing.

1.3.4. The Earth Summit

In 1992 a historic summit named the UN Conference on Environment and Development (UNCED) also known as the Earth summit was held in Rio de Janeiro in Brazil where 172 governments participated with the following objetcives.

1. To scrutinize the patterns of production and the production of toxic components such as lead, poisonous or radioactive wastes.
2. Replacement of fossil fuels with alternative sources of energy.
3. New reliance on public transportation system to reduce pollution congestion, emission and health problems.
4. To address the growing scarcity of water.

The Summit also created a Convention on Biological diversity and an agreement not to carry out activities on lands of indigenous people that would cause environmental degradation and were culturally inappropriate. An Agreement on Climate change was also important achievement of the Summit.

1.3.5. United Nations Framework Convention on Climate Change

This treaty was opened for signature at the UNCED or Earth Summit of 1992 with the objective of stabilizing GHG concentration in the atmosphere at a level that would prevent ‘dangerous anthropogenic interference with the earth’s climate system’. The treaty did not enforce any madatory limits on emission for countries nor have any mechanism for enforcement but provided for updates or ‘protocols’ of which the Kyoto Protocol has become the most famous. In an explicit recognition of the ‘common and differentiated responsibilities’ so that responsibility fell dominantly on the developed and industrialized countries that were identified in the Annex I of the UNFCCC, the treaty aimed to stabilize emissions at 1990 levels by the year 2000. The 154 signatories committed the governments to a voluntary ‘non-binding’; aim to reduce GHG concentration in the atmosphere. One of the first tasks was to create national GHG inventories for emission and removals. Such inventories are to be regularly updated. Having received the required number of ratifications the UNFCCC entered into force in 1994.

Annex I (40 countries):

Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States of America

AnnexII (23 countries):

Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, United States of America

1.3.6. Kyoto protocol

As part of the UNFCC the Kyoto protocol (KP) was a treaty aimed to stabilize GHG concentration in the atmosphere. Adopted in 1997 by the Conference of parties of the UNFCCC, in Kyoto, Japan this controversial and intensely negotiated treaty came into force after a long gap in 2005 when 187 countries ratified it. This committed the industrialized countries and some central European economies in transition all included in Annex I of UNFCCC to collectively reduce emissions by 5.2% from 1990's level. Thus Europe is to reduce emissions by 7% below the 1990 level, US by 7%, and Japan by 6% during the KP period 2008-12. Though the commitment is legally binding, a Party can withdraw with a 12 month notice period. KP however imposes no obligation on the developing countries including India and China. The reduction of emission is facilitated by the Flexible mechanisms mandated in the KP.

The modalities of the KP were worked out in a series meetings especially the so called COP or the Conference of Parties, the Kyoto meeting being one such COP, and those meetings held subsequently in Bonne (2001), Marrakesh (2001), Johannesburg (2002), Bali (2007) and Copenhagen (2009) being others. The countries specified in Annex I committed to reduce their emissions via reduced allocation of funds to operators within their borders though these operators could use other permissible mechanisms to supplement their allocations. Annex II countries which are a subset of the Annex I countries but exclude the transition economies and also Turkey (that exempted itself later) were recognized as developed countries that would pay for the cost of emission in developing countries. The developing countries also take part in mitigation as they get finance and technology from the Annex II countries for moving to low carbon technologies.

Several doubts and unresolved issues constituted the KP's limitations:

(a) The split between the Annex I and the developing countries was seen to be unfair by some who felt both needed to reduce emissions unilaterally.

(b) Some including the US claimed that the cost of following the Convention would stress the economy.

(c) The choice of base year for benchmarking was also subject of debate. A uniform base year of 1990 would increase the marginal cost of those countries that had made efforts to reduce emissions relative to other so that countries that subsidized over consumption of energy would be at an unfair advantage.

(d) What constituted a safe level of concentration called for value judgment and could be contested.

In parallel developments, in 2007 leaders at the 33rd G8 summit announced their aim to halve global emissions by 2050, in 2007 the Vienna Talks under the UNFCC opined that energy efficiency could significantly reduce emissions at a low cost. In 2007 the United Nations Climate Change Conference at Bali, Indonesia negotiated on a successor of the KP, prepare a 'roadmap', a time table and 'concrete steps for the negotiations' with a view to reach an agreement by 2009. The EU proposed a decline of 'well below half' of the 2000 level by 2050 for the developing countries and for developing countries to achieve emission levels 20-40% below 1990 levels by 2020. The US and some other countries strongly opposed the numbers. The compromise mandate being only 'deep cuts in global emission targets' raises questions on the significance of the achievements.

1.3.7. Copenhagen

The Conference was slated from 7th December 2009 but on 14th November of the year, the New York Times announced that President Obama and other world leaders decided to put off the difficult task of reaching a climate change agreement and to make it a mission of the Copenhagen conference to reach a less specific 'politically' binding agreement.

The meeting was attended by 192 countries and civil society organizations but even the incumbents in the Annex I countries were found reluctant to fulfill commitments under the KP.A political accord was signed that included the US and China among the incumbents, but this accord fell outside the UNFCCC. Commitments on funds by developed countries were discussed and negotiation on extending the KP beyond 2012 remained unresolved. Long term options on climate financing are discussed within the UN Secretary General's High Level Advisory Group on Climate Financing, a report being due in November 2010.

1.3.8. Cancun

The Cancun meet in end 2010 was not significantly path-breaking or constructive than the preceding ones. The countries converged on the significance of climate change as a threat. There was some progress on creating a global fund for adaptation and technology and Bolivia promised some steps forward.

1.4. Carbon offsets

Theoretical considerations and computer simulations made National Air Pollution Control Administration which later gave way to the EPA in USA in the 1960s are the highlights of the inception of this innovative market. The potential of the method was first demonstrated to the world by the success of the Acid Rain programme in the US. The trading of sulphur dioxide emissions under the ARP of 1990 Clean Air Act in US not only succeeded in reducing emissions but also achieved this at a reduced cost than other possible strategies. Trading mechanisms have since been applied in various cases in the US and other countries. Trading of volatile organic compounds in Illinois state in 2000 and trade in carbon dioxide emissions for power generators (Regional Greenhouse gas Initiative or RGGI) in New York State launched in 2009 and NO_X budget trading for power plants and other large combustion sources in eastern states in 2003 and a proposed project in California state which would address manure management, forestry, building energy. SF_6 and landfill gas capture are examples. In 2007 US and four Canadian provinces joined in an initiative for regional GHG emission trading system. The Chicago Climate Exchange provides a platform for trading emission allowances since 2003. Outside US too, trading is under trial. In Japan although a nationwide cap and trade programme saw little success, efforts are on and the city of Tokyo which is very in terms of energy consumption has launched a programme overseen by its metropolitan government to cut the city's carbon emissions by 25% from 2000 level by 2020. The European Union Emission Trading Scheme is the largest multi-national trading scheme in the world having commenced operation from 2005 now covering 25 of the 27 members as participants. Australia and New Zealand have also trading programmes in process or under near future plan. Trading of emissions has mostly covered power generators as of now though coverage is expanding. Coverage of agriculture is at an initial stage. Though a potentially powerful tool carbon trading is still in an inception stage it does encounter several imitations and designing insufficiencies and the coverage is yet to expand beyond significantly beyond power and transport sectors.

Creation of a market for emissions is an innovative method that has been on trial for several years now and is based on the basic microeconomic principle of equating marginal cost and benefit. Trading is a possibility in the case of emissions because the marginal abatement cost of emissions (MAC) is different across entities and countries. Such a market can operate in an individual country or even a single state or city and also internationally across countries. The trading is initiated by a central authority setting an upper limit or cap on the amount of pollutants or emissions so that emission trading is also known as cap and trade method. The operators or firms are required to hold a number of permits or credits that represent their right to emit or discharge a specific volume if pollutants but they can exceed this allocation by acquiring more permits at a cost as trading of permits take place. Those who reduce emission need fewer permits and sell them to those who require discharging more emissions. The Clean development mechanism (CDM) of the KP creates an opportunity for developing countries to participate in the international carbon market as of now and the Joint Implementation facilitates collaborations among the developed countries.. The emission or cap and trade market along with the JI and the CDM make up the possibility of an international market for carbon trade where a price of carbon will be determined by free market forces. The market allows the price of emission to be determined by market forces influenced by factors like the level of cap and abatement costs and development needs in various countries rather than arbitrary State stipulation.

Chapter 2:
Links between Agriculture and Climate change

The relations between agriculture and climate change are manifold as well as multi-directional where agriculture is both a cause and a victim of climate change. Moreover, given the diverse kinds of impacts and the feed-back effects supplementing or offsetting such effects, the effect of climate change can be adverse as well as or favourable for agriculture in a region. The linkages that tie crop husbandry and global warming are also complex, diffused and generally difficult to measure. This sets agriculture quite apart from other activities that are commonly associated with climate change such as power production and fishing where the culpability and vulnerability are well understood and can be empirically estimated by means of specific coefficients. In this chapter we review the literature that examines some of the cause and effect relations that bind agriculture and climate change. Sections 2.2 and 2.3 survey how climate change can possibly affect agriculture touching on both the physical and the social dimensions of the effects. The impact of agriculture on climate is discussed through the sections 2.4 to 2.6 and in section 2.7 a review is made on model based exercises on the subject in order to capture the agriculture-climate change linkages.

2.2. How Climate change can affect Agricultural production

Global warming, the evidence of which has already emerged, presents a future scenario of the global climate that can alter human being's regular way of life and affect various activities including agriculture. The effect will neither be uniform across the earth nor always be predictable in tendency. While global warming is directly related with the rise of average surface temperatures, the warming effect can in turn generate changes and shifts in other parameters of climate of which precipitation is of major interest.

2.2.1. Signs and significance of Global Climate change

The broad changes in climate parameters that are indicated by theory and associated features emerging from modeling exercises are listed as following.

(1) Temperature rise: Temperature rise is the central manifestation of climate change. Global surface is anticipated to warm by somewhere between 1.5^{O}C and 6.8^{O}C from 2000 to 2100 depending on human activities. Though the temperature effect will vary spatially, no region is expected to cool. Experts also infer that landmasses will warm more than oceans. The arctic regions will warm more than other regions, leading to melting of ice and greater reflectance or 'albedo' that will further intensify global warming.

(2) Changing precipitation: Global precipitation is likely to increase on the whole since global warming will enhance evaporation but the distribution and incidence of rainfall will vary across regions. Some regions will receive more rainfall but others will be drier making floods and droughts simultaneous and frequent occurrences in various places. Water availability will be affected profoundly due to the moderations in rainfall, snow covers and river flows. However these effects are only incompletely understood and need more research.

(3) Sea level: Sea level will rise due to melting of polar ice and less sequestration of global waters in landmasses. The expansion of sea water due to higher temperature will also add to this process. Some of the GCM results suggest that the sea level will rise by 0.2m to 0.5 m between 2000 to 2100 but if the observed acceleration of glacial flows in Greenland is factored in, the rise could be up to 1.2 m higher than 2000. The effect of the rise in sea level will be undoubtedly adverse to small island countries and in coastal areas where the ingress of sea water could cause soil salinity, water logging and displacement of human beings and their economic activities. Global warming is expected to make the ocean waters more acidic affecting marine life also.

(4) Storm: Storms are empowered by the high temperature on the sea surface and larger temperature gradients. Storms with greater intensity of fury could become more frequent.

(5) Forest Fires: Hotter and drier weather becomes a trigger for forest fires that in turn lead to greater emission and feed back into the global warming process.

(6) Feedback effects of climate change: Climate change can be self-propelling because of certain circularities of effect. Global warming will cause polar ice to melt but the resulting decrease in reflectance will further intensify global warming. The rise in temperature is known to accelerate decomposition of organic carbon in soil leading to further emissions of greenhouse gases. Dry and hot conditions by inhibiting biomass production will also slow down global carbon sequestration. Climate change is a lingering process and the effect may be felt for many years after the emission is actually made. This is both because greenhouse gases have fairly long atmospheric life time and because the carbon dioxide that is accumulated in the oceans can be released into the atmosphere at a slow rate.

(7) Finally, it may not be appropriate not to consider the chief causal factor, the increased concentration of carbon dioxide in the atmosphere as another change in the ambience. Both animal and plant lives are sensitive to this concentration though in different ways and degrees. Beyond a level the growing concentration can create difficulties of breathing for human being though the projected levels may not be of serious worry. At present the concentration is estimated to be 380 ppm as compared to 260 pmm that prevailed 150 years ago. The concentration is projected to go up to 550 ppm by 2050 due to greenhouse gas emissions.

One does not have to go far to realize that the complex and profound changes in the climate parameters that are expected to occur in coming times will have grim implications for agriculture. Agriculture is an activity the success of which is intimately related to the temperature, rainfall, sunshine, humidity, air and sub-surface soil resources.

Availability of water in terms of both quantity and quality as ground water or as surface flows is a crucial effect on the choice of crops and the performance of crops. The quality of soil measured by its content of nutrients, carbon and biota is another critical component of agriculture and we will see that even this has complex ties with the atmosphere and its changes. Hot and dry weather would lead to greater evaporation and transpiration affecting plant life while storms and flooding are shocks that can make agriculture highly unpredictable and even economically unviable if the frequency of these events increases. Submergence in water and soil salinity might displace the activity altogether in some regions. Even if such adversities can be minimized by the use of suitable adaptation measures, protective measures will add to the cost of cultivation under usual circumstances and profitability of crop cultivation can be severely compromised rendering the profession non-remunerative. Even if the financial impact can be compensated by able financial management and public policy, it is far more difficult to restrain the physical effects on food security. The food security effects will be a continuous concern for the governments that are committed to protect the welfare of the people and are vulnerable to political unrest and electoral shocks. In a globalized world the food security effect can spill over from one country to other countries and the inflicted hardship is likely to be the cruelest for the poorest countries. Both the climate induced shortage and the costly adaptation responses can lead to food price rises.

Admittedly, the climate change effect on agriculture and food security need not only be adverse. The number of snow-free days being more under global warming than without it can be beneficial to agriculture in cold regions helping to bring more area under cultivation and improving crop yields. Similarly greater amount of rainfall in drier areas if that is a consequence of global warming can help crop cultivation and irrigation. Thus it would be an overstatement to say that the effect of climate change is necessarily adverse. Indeed the impact of climate change may range from beneficial to adverse but much would depend on the capacities of the affected countries to make use of the advantage and to overcome the calamity. Moreover, neither the distribution nor the temporal incidences of the effects can be predicted with surety. Agriculture is an economic activity of human beings and as such the social effect of climate change coming through agriculture could far exceed the immediate technical effects that would be felt by crop production. There is little doubt that the impact on the choice of activities, locations, timings, products, the incomes and well-beings of farmers and the welfare of consumers and obligations of the governments could be considerable.

2.2.2. Temperature effect on Crop yields and food quality

Grain maturation is sensitive to the specific weather conditions at various points of the growth cycle of the plants. Biologists projects that the effect of increased temperature on crop growth would largely be negative because of increased respiration and shortened vegetative and grain-filling periods. Reduced floral reproduction, causes sterility due to stomatal closure and reduces (Satake and Yoshida, 1978, Nishiyama and Satake, 1981). Each phenol-phase of plants has its own demands and its reduced duration due to higher temperature may induce forced maturation.

Several crops like wheat, mustard and a large number of fruits are raised in tropical countries only in winter because they thrive and germinate in relatively cold conditions. The winter temperature thus presents a threshold for the fruition of these cold-climate crops and any minor warming can make these crops unsuitable for these regions. The same feature can however benefit wheat production in temperate regions where the excessively low temperatures and frost are existing impediments. High temperature is also known to undermine the quality and nutrient content of the crops by interfering with the chemical process even if yield quantity is conserved.

Evidence has emerged that rice yield is also affected by the rise in night-time (minimum) temperature that by the greenhouse gas emission can trigger. Yoshida and Parao (1976) showed that above the optimum temperature (22-23^{O}C) rice yield declined linearly with an increase temperature up to 30^{O}C caused by shortening of crop duration followed by a sharp decline thereafter owing to spikelet sterility. Theoretically, the effect of nighttime temperature would be adverse on yield probably because of intensified respiration. Factors that are yet less understood till now are also responsible. Increase in maximum temperature on the other hand can damage chloroplasts. In tropical and sub-tropical Asia impacts of both minimum and maximum temperatures jointly (Welch et al, 2010) are important. Moreover, radiation is another significant influence for rice. Evidences of stronger warming at night and significant trends in temperatures and radiation are noticed in these regions. Model results suggested that yield rates at most sites would have grown more rapidly without the trends and the resultant of the quantum latent losses that occurred due to warming are presented in Table 2.1.

Table 2.1: Predicted changes in annual growth rate of rice yield if observed weather trends at the ends of the 20th century had not occurred at it site. (Kg. per hectare per year.)

Season and Site	T_{min}	T_{max}	Radiation	Net impact
High yielding seasons				
China	0.0	0.0	0.0	0.0
India	6.3	-12.6	4.1	-2.2
Indonesia	12.0	0.0	0.3	12.3
Philippines	21.8	0.0	-2.3	19.5
Thailand	11.7	0.0	0.0	11.7
Vietnam (Hanoi)	16.6	0.0	6.2	22.8
Low yielding seasons				
China	9.8	-14.0	0.0	-4.1
India	7.2	-10.7	0.0	-3.5
Indonesia	7.1	0.0	0.0	7.1
Philippines	12.5	0.0	0.0	12.5
Thailand	0.0	-10.9	-6.8	-17.7
Vietnam (Hanoi)	0.0	0.0	-11.8	-11.8
Source: Welch et. al. (2010)				

2.2.3. Water stress and Irrigation

Water is a most vital component of all life forms. Agriculture traditionally is organized in sync with the rainfall pattern of the specific site. Over the past decades there have been visible changes in the incidences of rainfall, with polar and tropical regions becoming wetter and mid-latitude regions drier. Theory suggests that higher surface temperature would steepen global temperature gradients, increase the quantum of evaporation taking place in oceans both because of the higher temperature and the enhanced quantum of water. Global warming is expected to strengthen monsoon circulation although the regional incidences of rainfall vary and are difficult to predict till now and can be altered with climate change. There are clear indications that the onset of monsoon will become more variable. The higher temperatures also tend to increase evaporation from ground and transpiration from leaves generating severe water stress for plants. So the effect of climate change on water resources can be bidirectional.

Water demands of plants are biologically determined and need to be adequate and timely. The limited land area available on earth is proving increasingly insufficient to feed the growing world population creating an obligation to generate more output from a given unit of land both by way of higher productivity and multiple cropping. Both these routes create greater demand for water so that the seasonal availability of natural water supply is no longer enough. Agriculture accounts for the largest part of water consumption of human beings but demand to fulfill other uses have also increased. Soil water gained by accumulated natural precipitation is supplemented by irrigation that makes use of surplus water collected at a different location or at a different point of time.

Global climate is a key factor deciding water supply for agriculture because it affects not only the rainfall level and its distribution but because this effect in turn also determines the levels in surface and sub-terranian domains that supply water for irrigation. Excess proliferation of canal irrigation without the conjoint use of ground water creates water logging that too has implications for plant growth. Without proper drainage, surface water irrigation leads to soil salinity that disturbs the process by which plants draw nutrients and water. Intriguingly, even this case of water abundance can simulate a drought like condition for the plants. Excessive reliance of groundwater also hurts the ecology and long term sustainability. Agriculture is benefited by timely and optimum supply of water, abundance, scarcity and untimeliness of water supply being detrimental. Thus the management protocol for irrigation also needs to respond to the climate change.

Many rivers that form the life-line of various countries and are harnessed to provide irrigation via canals are derived from the precipitation that occurs in the mountains as rainfall and snow. Melting of glaciers that feed the rivers are the key strengths for food production and agricultural performance. Sierra Nevada in the USA and the Himalayas are two main examples, the latter feeding most major rivers in Asian countries like India, Pakistan, China and Vietnam. Global warming will diminish the water stored in the snows and mid-elevation snows are anticipated to disappear. While the snows provide the supplies for the rivers throughout the year, the significance of rainfall as the source of river water will increase.

The river flows may improve with the melting ice but the period of flow is likely to shorten creating excess load on the river basins, causing periodic floods alternating with water shortage. Also, the ice as the source will gradually be exhausted as snows disappear. As surface waters do not suffice, ground water is increasingly drawn up for irrigation. This can cause more emissions due to use of energized pump-sets, adding to climate change. The replenishment of ground water is a slow process. Water stress has already reached a point of crisis in many developing countries in the current scenario. China is faced with a plateauing agriculture and scarcity of water is a major concern. Although China expects to receive more precipitation in the coming decades because of climate change, given that evaporation will also increase, a food crisis may not be averted. India has also faced several droughts in the last two decades and droughts in some parts of the country have been accompanied by devastating floods in other. Excess or untimely rainfall has also been marked

2.2.4. Favourable effects of Climate change on production

There are also reasons to believe that climate change can favourably affect crop productivity even outside the temperate zones. One major converse possibility is the so called carbon fertilization. Plants require carbon dioxide for their growth and the increased carbon dioxide in the atmosphere could promote photosynthetic activities and add to biomass production and improve grain yield provided however that water and nutrients are adequately available. The hypothesis is based on the understanding that plants can sense the change in concentration and respond through photosynthesis and stomatal conductance. The implications will differ between plants classified as C3 and C4 (see Appendix2.3). Potentially the carbon fertilization effect could even outweigh the negative effect of higher temperature. On the contrary, research shows that elevated concentration of carbon dioxide can slow down nitrogen fixation and in this deprived state the nutritive value of plant product can also be impaired. Wheat, rice and potato plants receiving normal levels of nitrogen fertilizer is found to have 10% less grain protein under carbon dioxide enrichment. The IPCC projects that the gains due to climate change on account of carbon effect would be negative in the tropical regions and positive in temperate ones but when averaged across the global total crop yield will rise. Further, the increase in carbon sequestration from the atmosphere due to accelerated photosynthesis, if confirmed, will portray a favourable effect of global warming on agriculture and indicate an internalized balance.

The extent and reliability of the hypothesis around carbon fertilization is rather unresolved although controlled experiments have shown positive results in case of certain staples (Kimball et al 2002, Ainsworth and Long 2005). The experiments are caught up in practical difficulties. Unlike temperature, carbon dioxide concentration has hardly any spatial variation and it is not easy to alter the concentration experimentally. As a result, most information about crop responses to elevated carbon dioxide is obtained from studies in greenhouses and laboratory controlled environment chambers where released carbon dioxide can be stored and easily controlled. These settings have provided the basis for making the projections mentioned on major food crops maize, rice, sorghum, soyabean and wheat. The development of ‘Free air concentration Enrichment experiment’ (FACE) technology has enabled large scale experiments to be conducted in fully open-air field conditions in recent times. A review of experimental results however found that the elevation effect on photosynthesis was about 50% less in case of FACE experiment than the enclosure studies for all the crops and for C4 crops the results were consistent with the absence of any direct effect (Long et al, 2006).

Table 2.2. Relative change in yields of selected grains at elevated versus ambient Carbon dioxide concentrations					
Crop	Range of Values	Mean ChamberA	Mean FACEB	Number of Studies	Reference
Wheat	-20 to +80	+10	+7	50	Amthor 2001
Soya bean	-20 to +100	+24	+15	58	Ainsworth et al,2002; Morgan et al. 2005
Rice	+4 to +71	+15	+12	6	Baker et al. 1992; Ziska et al. 1997; De Costa et al, 2003; Baker 2004; Vannayan eta al. 2005; Weerakoon et al. 2005
Maize	-35 to +93	+29	=0	57	Rogers and Dahlman 1993; Leakey et al. 2004
Sorghum	-4 to +31	+31	+6	2	Chaudhuri et al. 1986; Ottman et al. 2001
Source : Bloom, 2010					

Secondly, there is also a possibility that with litter fall and plant decay, the biomass generated through carbon fertilization can mix with the soil and the resulting soil carbon accumulation will enrich the soil quality. The implications depend on the response shown by respiration which is also provoked by the biomass generation (see Section2.4). The abundance of biomass transferred to the soil expands the population of soil micro-organisms whose respiration may balance or even offset the carbon sequestration. In general, most biochemical reactions display a typical temperature response. They proceed slowly near freezing, accelerate exponentially with rising temperature and level off somewhere between 15^{O} C and 35^{O} C and crash at temperatures higher than 40^{O}C. Photosynthesis that removes atmospheric carbon and respiration that replaces the same follow this pattern but the critical temperatures at which these reactions peak differ, the critical temperature being higher for respiration. Carbon assimilation in soil depends on this difference. To predict the exact result is not an easy task because decomposition rates differ with the kind of organic materials formed in the soils. The soil composition varies widely between sites but with longer exposure the emission tapers off as the decomposition of labile components approaches completion.

Thirdly, the effect on water use and nitrogen assimilation, if any, will help to increase crop productivity. For the rising atmospheric carbon dioxide concentration to stimulate plant growth the availability of nutrients must also keep pace and the supply of water must be adequate. Nitrogen is the mineral element that organisms require in greatest amounts as it constitutes a vital part of organic compounds. Although abundantly found in the atmosphere, it is inert or ‘noble’ and needs to be ‘fixed’ to achieve a reactive form such as ammonia and nitrate. Certain organisms like the blue-green algae and synergic microbes like the rhyzobium can fix atmosphere naturally but in modern agriculture artificially fixed nitrogen has to be applied also. However whether the increased carbon dioxide content in the atmosphere would influence the assimilation of nitrogen is also a critical question that arises in the context of climate change.

Soil nitrogen is derived from biological fixation and nitrogen mineralization. By and large these processes are neutral to atmospheric carbon dioxide concentration but nitrogen fixation may in fact decrease with carbon dioxide enrichment. Also, the increased growth, leading to greater soil organic materials, is a reason for soil organisms to become extremely active, removing more nutrients from the soil than normal. As a result nitrogen immobilization increases. Evidences suggest that the assimilation of nitrogen by plants will also be especially inhibited when the nutrient is in the nitrate form. The enriched condition however makes plants more efficient in water uptake by appropriately adjusting their stomatal aperture but whether plants will be able to pick up the carbon dioxide signal under a higher background level has been questioned casting doubt even on this favourable route. That profound impacts of atmospheric changes on the evolution of species are possible has been demonstrated in the past history of the earth and analogous possibilities raise serious uncertainties about life on earth. Thus while there are indications of positive effects due to carbon dioxide concentration in the air, the complexities make the relation highly uncertain to make a firm conclusion of the hypothesis.

2.3. Social Implications for agriculture

2.3.1. Change in habitat

Each living organism can function at a certain range of temperature and this range depends on the bio-physical tolerance of the organic system. The changes in the timing of the different seasons can have many broad biological consequences. Survival and functioning of species will depend on the suitability of the habitat. Very cold climate is a formidable barrier to life because chemical reactions slow down and eventually cease at low temperatures. This means that warming can make cold places more habitable. Similarly, biochemical reactions integral to life processes also crash at high temperatures. Models predict that 20-30% of all species face the threat of extinction in this century of which a large section consists of vegetation in temperate, tropical and coniferous forests. Many animals may be migrating to more suitable habitats to avoid extinction but this likely to create new complexities for human beings and problems of new pest infestation for agriculture. A general northward shift in the distribution of flora and fauna involving the migration of temperate organisms to higher altitudes and latitudes is expected.

Agriculture is determined by the climate of a place which shapes the choice of crops, determines the crop calendars and crop cycles and influences the planning of irrigation, crop rotations and other operations. Productivity and income potential of farming also depend on the climate. In this context, profound changes resulting from global warming may be anticipated in terms of geography, seasons, crops and varieties of same crop as well as competitive advantages in agriculture.

Global warming is disruptive to those species that have narrow geographical distributions. Crops whose survival is associated with certain specific conditions of soil and climate will be more affected than others and farmers growing these crops would increasingly resort to shifts in cropping patterns and alteration of crop calendars to adjust to the changing scenario. As a result acreages under some crops will dwindle, geographical distribution of such crops may alter structurally, more crops will be treated as exotic in a nation and probably some food products will become rare or even extinct. In this context the plight of winter crops like wheat in tropical areas become questionable. Undoubtedly, this process may be balanced by the rise of new or till now less significant crops and development of new producing and processing technology. The temperature rise will also change in the population of pests and intensity of the pest problem. All this is in the realms of unknown and is difficult to predict. Needless to say the whole disturbance to the existing system will have a profound effect on the markets, changing relative prices and trading directions and flows.

2.3.2. Volatility, shocks and uncertainty

Global warming will lead to greater incidences of extreme events such as droughts, floods and cyclones. This is likely to create wide fluctuations in crop production besides human anguish. These ups and downs in production will generate volatility in prices of food and make food management a difficult task for the governments and international communities. These incidents not only result in crop losses but the damage of properties and deaths of cattle add to the woes of farmers. The financial catastrophe can necessitate the sale of farm properties and borrowing of funds at high interest rates and create debt traps. The volatilities are reflected not only on the income instability of farmers but also on the welfare instability of consumers and are particularly harsh on the poor. Food price rise affects industrial wages and pushes up general price levels hurting all sectors. In the process the shocks suffered generates other socio-economic and long drawn responses like migration, loss of health and education and asset liquidation. It can lead to unrest and even political uprisings. Farming becomes uncertain resulting in agriculture becoming an unattractive occupational choice. Existing risk mitigation methods that evolved through past experience will become insufficient impairing also the banking system’s health. Insurance schemes need to be redesigned.

2.3.3. .Problems of Coastal Areas

Countries or regions that are located near the sea are more vulnerable to climate change than other regions. The rise in sea level can led to submergence of arable land and intrusion of sea water leading to salinization of groundwater in coastal regions and small island states. Agriculture and fishing will probably be the worst victims besides tourism. The outcome could make agriculture completely unviable in extreme cases. The livelihood loss will provoke people to move out of the areas in search of alternative livelihoods. In this way the effect of climate change not only affects the coastal areas but spills over to surrounding area and even neighbouring countries that draw the migrants. Climate migrants would increasingly become an international burden. Fertile land under crops will be lost in the process. The countries have to rise to the situation in creating infrastructure for the protection of coastal areas, plan crop and natural vegetation patterns in these areas and in worst cases work out sustainable rehabilitation plans.

2.3.4. Conflicts

Climate change is an external factor that can show up in conflicts within societies that apparently evolve around specific issues. Alarmingly, conflicts appear as political blame-games and it may not always be easy to link them to their root cause. So while people look for misplaced solutions, the conflicts drag on. Water shortage is one such crisis that creates competition and contention among community groups. Flows in rivers become a subject of dispute between rival territories which can take inter-province and even international dimensions. This problem is of special relevance when not only does the river flow through two different provinces or countries but when the source of the river is situated in a country that is different from the one where the major part of its course lies. Precipitation occurring in the source country then affects the economic prosperity of the other and any upstream intervention on water use such as the building of dams or reservoirs can stimulate disputes with downstream areas while understanding of the issues could have encouraged cooperative projects. Receding ground water as a result of decreased river flows or enhanced evaporation creates disputes within communities, deprivations and class conflicts even in a small territory, especially since it is difficult to define water rights. Food price rise on account of crop failures is known to find resistance from political oppositions and create tension in industrial relations and disputes between trading countries are common when exporting countries impose restrictive measures to address domestic food problems.

2.3.5. Inequalities

Examining the implications it becomes clear that impact need not necessarily be adverse in all regions or to all sections. For example Model results suggest that even without adaptation European countries, including East European nations and former USSR and China in Asia may witness a rise in GDP from agriculture. Africa, already reeling under food insecurity will be the most hard hit. Global inequalities are likely to increase raising the probability of conflicts and political tension. Also, the extent of adverse effect would depend on the adaptation measures taken by the countries whether by the government or the farmers themselves and effective strategies could turn the effect from adverse to favourable. Given the global income distribution this fact only tends to accentuate the inequality inducing effect and a case arises about creating an institution for the transfer of resources from rich countries to poor countries to facilitate adaptation.

2.4. How Agriculture affects the climate

Although agriculture has serious implications for greenhouse gas concentrations in the atmosphere, such effects are often compounded by feedback effects so the effect of climate on agriculture is as much part of the topic. Agriculture accounts for 16% of the global greenhouse emissions net of land- land use change effect (Figure 2.1). Within agriculture animal husbandry contributes 32% and manure management 7% so that crop cultivation accounts only for 61% of the green house gas emissions from agriculture (Figure2.2). Figure2.3 also shows that methane and nitrous oxide are the two main green house gases emitted by agriculture. Carbon dioxide the most perturbing emission in today's world does not result in any significant degree from agriculture. Nevertheless, we will discuss that agriculture still has to play an important role in mitigating carbon dioxide emissions.

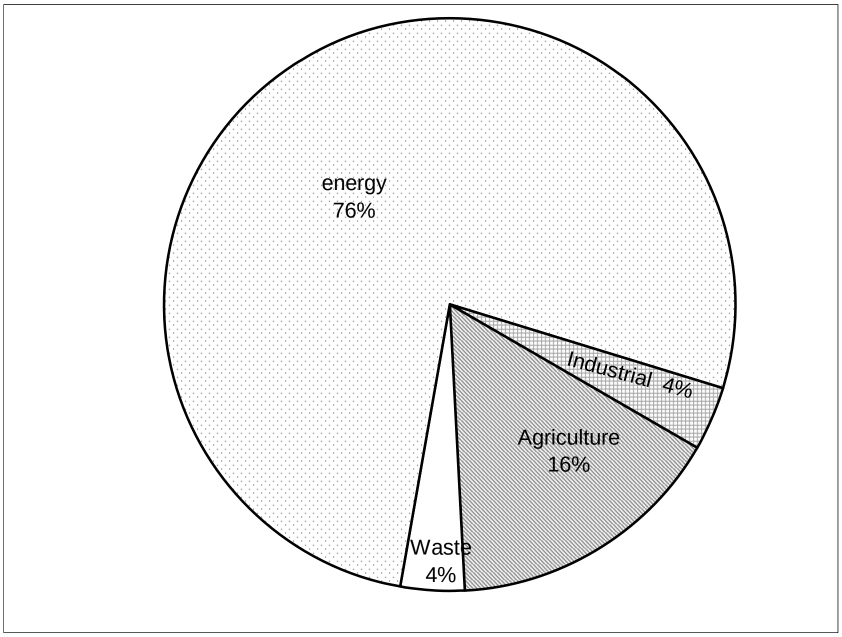

Figure2.1: Contribution to GHG emissions by sectors in WORLD
(Excl. Excl. LULUCF), Source:gtz, 2008

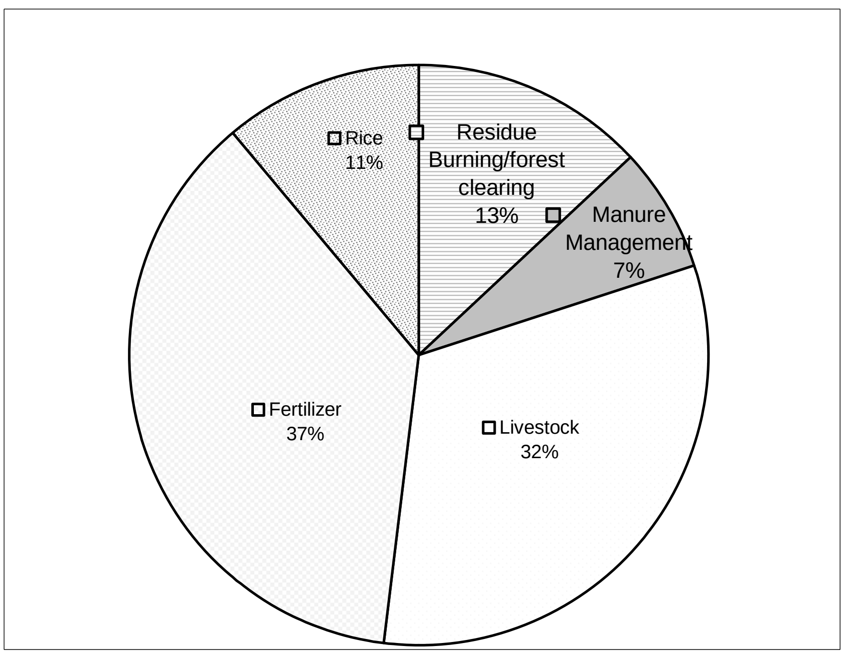

Figure 2.2.: Emissions from Agriculture by sources within the sector WORLD

2.5. Major Emissions from Agriculture: Methane and Nitrous oxide

The presence of a combustible gas commonly known as ‘marsh gas’ in mines, swamps, marshlands and low-lying rice growing areas, often popularly described as ‘will-o-the-wisp’ or ‘corpse lantern’ in the west and ‘aleya’ or ghost light in eastern India has been subject of folk lore and myths. Historically remembered for Davy’s safety lamp[i], methane, a compound that is highly inflammable, is used as a constituent of natural gas used by human beings as a fuel. The understanding that methane is a potent GHG with a high global heating potential and knowledge of its long atmospheric life time have brought methane emission into the centre of global concern too. A further cause of unease apart from its status as a GHG is the possibility that methane concentration may affect the chemistry and the oxidation capacity of the atmosphere through its reactions with ozone, hydroxyl ions and carbon monoxide unleashing unknown catastrophes.

A trace gas in the atmosphere, nitrous oxide is also historically associated with Humphrey Davy who first suggested its analgesic properties for medical use. It was commonly known as the ‘laughing’ gas. Concentration of this gas in atmosphere probably has grave consequences because of its ability to destroy stratospheric ozone which in turn is associated with the incidence of skin cancer[ii]. The Montreal Protocol of the UN during the 1980s had addressed the menace of the depleting ozone layer with utmost seriousness as a result of which emission of the CFCs was curbed around the world[iii]. The global warming potential (GWP) of the two gases methane and nitrous oxide based on a 100 year time horizon are 21 and 310 respectively as compared to carbon dioxide. Nitrous oxide emission has been strongly associated with the use of

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[i] Sir Humphrey Davy’s safety lamp was an illuminative device for miners’ use when the presence of methane made lighting a dangerous challenge inside the mines.

[ii] A doubling of the atmospheric nitrous oxide could decrease the ozone layer by 10% that would increase ultraviolet radiation reaching the earth surface by about 20% (Cutzen and Enhalt, 1977) while it is also shown that every 1% drop in the ozone could increase the incidence of skin cancer by 4-6% (Shea, 1988)).

[iii] Generated by human activities Chlorofluorocarbons or CFCs are compounds that are identified strongly with the break-down of the ozone molecules in the atmosphere.

nitrogenous fertilizers to agricultural soils and therefore any effort to improve crop productivity for food security cannot afford to be made without adequate concern for the implications of this critical GHG. Similarly, reduction of methane emission can potentially undermine rice production. Soil and agriculture major sources of emission of methane and nitrous oxide, despite the stamp as GHGs both have other useful properties and in both cases the soil system acts not just as a source but also as a sink. Emissions are associated also with other anthropogenic sources (Table1.2) and unlike carbon dioxide, non-anthropogenic or natural sources are significantly accountable for their emission. Rice fields are said to account for 11% of world's GHG emissions (methane) from agriculture which contributes 13% of total emissions (World Resource Institute 2008, USEPA, 2006)

Nitrous oxide constitutes the largest part of emissions from crop cultivation and accounts for 6% of the anthropogenic warming. Nitrogenous fertilization of soil through synthetic or organic additions or even natural fixation is the key source of this emission. Nitrous oxide emission is deeply associated with intensive cultivation of crops especially where both fertilizer and irrigation are applied. Since fertilizer and irrigation are the main sources through which the food needs of the growing population are going to be met at the presnt state of technology, the strong linkage that this form of emission has with the growth imperatives of agriculture provide enough reason to consider the issue seriously.

Nitrous oxide is only an intermediate product in the biotic chains of soil chemical reactions known as nitrification and denitrification and as such these activities also make soil a sink for nitrogen in more stable terminal forms than nitrous oxide. The problem of nitrogen emission is rather complex because all the nutrient that is applied for plant growth does not generally turn out as crop output is terms of grains or foliage. Nitrogen added to soil tends to leach out or runoff to other sites or are redepsited after volatilization to the atmosphere making this form of emission intractable. Most nitrous oxide is derived from denitrification which represents the respiration of microbes that generate energy by using nitrogen compounds rather than oxygen. Measurement of nitrous oxide emission has remained difficult mostly due to the indertiminacy of its production in the chain reactions and the diffused location owing to its mobility in soil. Nitrous oxide production is an outcome of a complex geo-chemical process influenced by different physical conditions (see chapter 5).

Modern agrarian technology has succeeded in producing more food by the addition of artifically synthesized nitrogenous fertilizers. In turn this has imposed huge costs on procuring the fertilizers that are produced from fossil fuels and have replaced the application of organic fertilizer that are also rich sources of carbon that the substitution has displaced. Excess use of nitrogen in relation to its uptake by plants and utilization by plants to generate biomass, specifically the harvests, implied ineffeiciency of nitrogen use leading to high pecuniary costs and pollution of water. Emission of nitrous oxide is another adverse effect that is promoted by excessive use of nitrogen. Research has recently focused on improving nitrogen use effeiciency (NUE) in context of the conservation of soil health though improved varieties of cultivars, fertilizer products and application protocols.

Methane is formed in wetlands by the action of methanogenic microbes in oxygen-free ambience. Methane emission in mostly associated with rice cultivation and is a particular concern in Asian countries where rice is transplanted and cultivated in submerged conditions. In this method rice is first planted in nursery from where the seeding is transferred after…. to a land under feet water. This is land puddling as against the alternative of direct-seeding of rice. While methane production is part of a complex process in soil affected by temperature, texture, moisture and a soil property called the redox potential, emssion is also inhibited in the submerged conditions by resence of oxyen in pockets of the wet soil causing oxidation of methane before its release (Neue,1993). Methane is a hazardous as a greenhouse gas and for its unknown effects on the chemistry of the atmosphere but it can serve as a useful fuel, being the main constitutent of natural gas.

2.6. Agriculture as a Carbon Sink and source

Sinks are reservoirs where the transformed carbon (or other GHGs) is stored for various periods of time running up to millions of years. A typical example of a terrestrial sink is the fossil fuel that contains carbon that is trapped away from the atmosphere for thousands of years deep beneath the earth surface. It is human action that has turned fossil fuels from their status of natural sinks to being sources of emission. When burnt they constitute net addition to the carbon cycle because the carbon released would have been removed millions of years ago. Specifically, coal deposits represent the carbon sequestered from atmosphere by towering forests that flourished about 360 to 290 million years ago in the Carboniferous period. This sink is of little use for humans as the conversion is quite irreversible given the prolonged periods of time and the exacting conditions of heat and pressure that create fossil fuels. Perhaps the sink that has received the most policy attention is the tree or collectively the forest. Over the years the trees absorb carbon dioxide and through photosynthetic mechanism create and store carbon in their living tissues as carbohydrates or in more complex forms. Trees too are potential sources of emission as the stored carbon reverts to the atmosphere when the tree dies. In the absence of human interference, however the two roles of a tree as a source and a sink are in balance and the emission need not entail net removal of carbon dioxide. Soils that support vegetation becomes a sink of enormous significance as the biomass created by plants get transferred through leaf-fall and root decay into the soil and the organic matter trapping the carbon in different stable forms remain in the soil for years. They are mostly reverted back to the atmosphere in sizable quantities when human beings intervene insensitively by clearing forests, inflicting other soil disturbances and exposing the soil to degradation, erosion and intense organic respiration. In this way soil too becomes a source of carbon emission due to human behaviour.

2.6.1 Carbon Sequestration Potential

Thus although agriculture may not be a significant factor for emission of carbon, it can play a valuable role in offsetting carbon emitted elsewhere through the carbon flows taking place among the soil, the vegetation and the atmosphere and thereby the sequestering power of its soils. Trees and plants absorb carbon dioxide from the atmosphere for photosynthesis generating organic biomass that eventually gets transferred to the soil as roots, litters, decayed parts and dead plants. Thus vegetation as green plants by their own survival process form a route for the passage of carbon dioxide to the soil which stores the carbon as different compounds for various periods of time. The soil also returns carbon and other GHGs to the atmosphere through root respiration, decomposition of dead organic matter and the respiration of a large body of soil

organisms and other chemical reactions that release carbon dioxide. In the carbon balance, balance between photosynthesis over respiration determines the status of soil as a sink. Soil is a sink of considerable significance storing more carbon than atmosphere and forests. The global soil organic carbon (SOC) inventory is estimated to be 1200-1600 Pg as compared to 550-700 Pg (petagram = 10^{15} grams)) in vegetation and 750 Pg in atmosphere (Post et al, 1990, Paustian et al, 1997). Alternative estimates based on vegetation zones or soil maps are 1456 Pg SOC (Schlesinger, 1977), 1395Pg (Post et al, 1982) and 1576 Pg (Eswaran et al, 1993).

Carbon sequestration (CS) is defined as the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere. The rapid increase in the world's agricultural area over the past 300 years was responsible for large emissions in the past three centuries. Historical net carbon loss due to conversion of native ecosystems to agriculture has been worked out as the differential between virgin and cropped soils at 54 Pg providing a reference level for carbon sequestration potential (Paustian et al, 1997). The temperate grassland soils by far present the highest potential at 24% as a single source (Figure 2.4). Janssens (2003) estimates net positive uptake of carbon in the soils in Europe but there is a net flux in the case of peatlands (Figure 2.5). Drainage of large peat areas of Europe for pasture, cropland and forestry purposes coupled with the extraction of

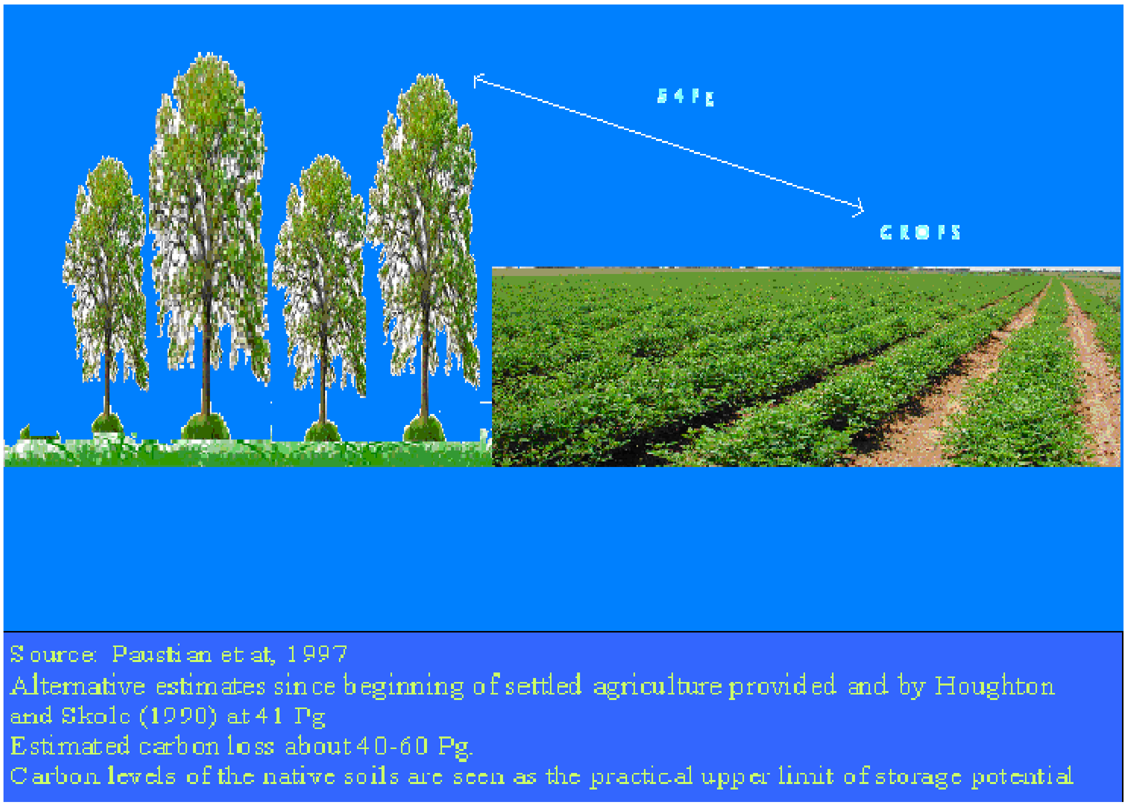


Figure 2.3: Carbon Sequestration Potential of Global soils

peat for use in horticulture and energy sectors generates more carbon losses than is sequestered in undisturbed state. Positive flux is also noted in the case of croplands. Such carbon losses are not attributable to land use changes but reduction of carbon returns due to harvests and emissions resulting from management practices, the net carbon uptake being negative at 300Tg C/acre (1 terragram=1 million tones).

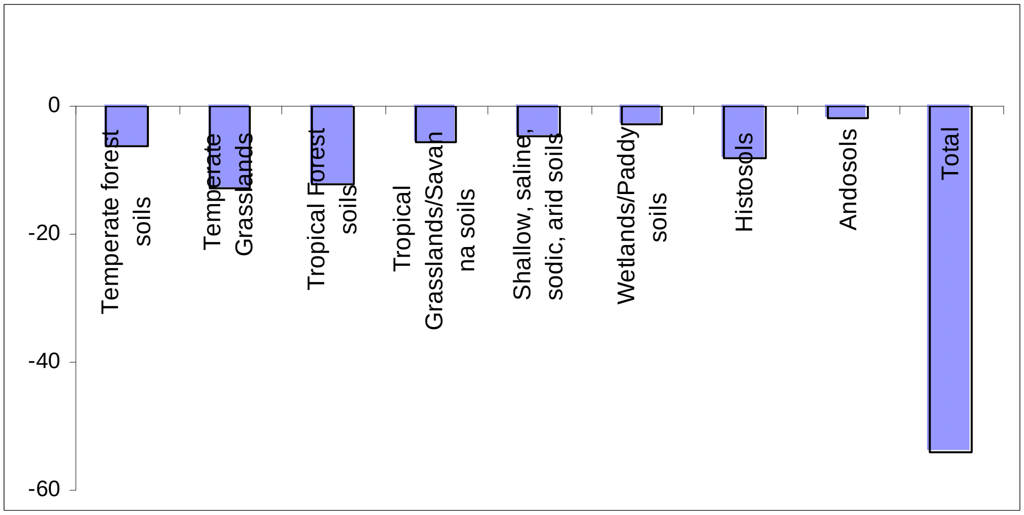


Figure 2.4: Organic carbon Loss due to Cultivation (Pg-C), Source: Pautian et. Al. (1997)

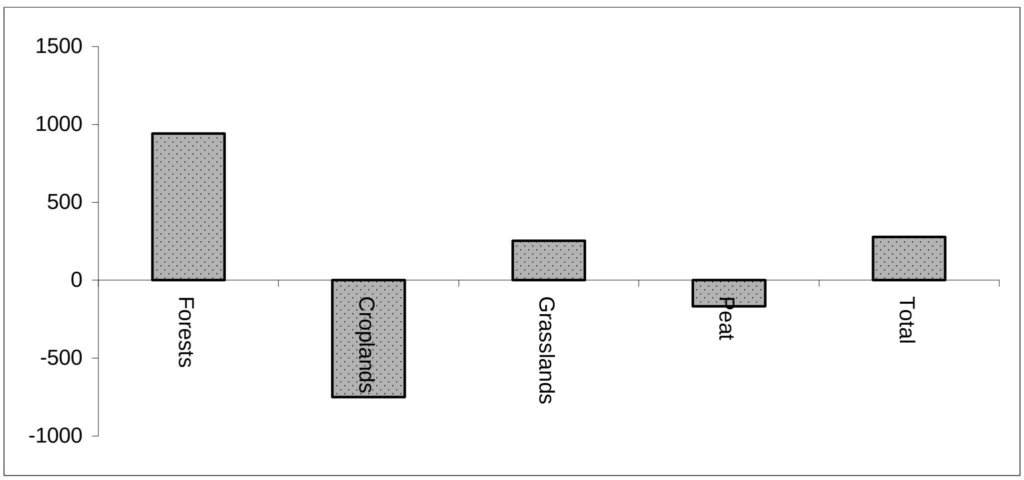


Figure 2.5: Net Carbon uptake in Tg C per acre, Source: Janssens, et al. 2003.

2.6.2.Feedback effects

Greenhouse gas concentration in the global atmosphere can also change the rate of modulating effect of agriculture leading to a feedback effect. The feedbacks are mostly on account of inherent non-linearilties of relations that make the results disproprtionately more than the stimuus.For example agricultural emissions increase with GHG emissions induced higher temperatures due to intensified soil respiration so that global warming becomes self-intensifying. Greater carbon dioxide concentration by increasing the rate of photosynthesis would remove some of the carbon dioxide and help providing a balance.

Biomass generation leads to soil carbon sequestration and in turn more photosynthesis and crop growth but on the other hand increases emissions by accelerating soil respiration.

2.7. Results of model based simulations

Food production is an essential eco-service that is aided by both human enterprises that shape the technological drivers such as plant nutrient application, irrigation and seed selection and by natural elements like agronomic and climatic conditions. While the natural determinants have generally been considered as beyond human control, the emerging reality convinces us that both these conditions are influenced by human practices and can be modulated by consciously planned human decision. The evidences on anthropogenic forcings on climate and understanding of their indirect impact of soil strengthen this belief. In order to probe into the unknown world of what would be the future and what could have been the past under alternative trajectories of history, mathematical models supported by field experiments are proving extremely useful. Global climate models help in understanding the possibilities given the complex web of implications that human actions have for the climate. These models can be combined with agricultural production models to further project the levels of food production.

2.7.1 The gtz review

Model based frameworks have been developed that forecasts short and long term impacts on food systems. A majority of the models investigate regional impacts especially in North America and Europe with a relatively fewer models dedicated to the impacts on developing countries. Together these models are integral to highlighting the possible disparities between the developed and the developing countries (Fischer, 2005). Some of the results presented by a review conducted by the gtz (2008) are summarized below.

(1) GDP from Agriculture: Estimates produced by Tol (2002) presented in Table 2.3 suggest that adaptation could change the direction of changes on agricultural GDP from

negative to positive for most regions. Even otherwise these projections find the impacts to be mostly benign for most of Europe, former Soviet Union and Centrally Planned China. Latin America, Asia and Africa are adversely affected in the absence of adaptation.

Table2.3 : Global impacts on agriculture for a 2.5 degree Celsius increase in global mean temperature					
Regions	Without Adaptation		With Adaptation		Mean
	Best Guess SD	Best Guess SD	Best Guess SD	Best Guess SD	
Latin America	-0.8	0.6	0.6	0.7	-0.1
South & South-east Asia	-0.7	0.3	0.6	0.3	0.0
Middle East	-0.4	0.4	0.6	0.5	0.1
Africa	-0.2	0.2	0.5	0.3	0.1
OECD-P	-0.2	1.6	0.8	1.6	0.3
OECD-A	-0.3	1.3	1.0	1.3	0.4
OECD-E	0.6	1.0	2.1	1.1	1.3
Eastern Europe & Former SU	0.9	1.2	2.7	1.1	1.8
Centrally planned Asia	1.7	1.0	3.1	1.0	2.4
Note: Figures are percent change from reference projection of GDP Source: Tol (2002)					

(2) GDP from Agriculture: A model developed by FAO/IIASA for agro-ecological zones combined with the global Food model (IIASA Basic Linked System or BLS that represent major economic sectors with agriculture imbedded in the economies interacting with other sectors) has generated the following projections:

(i) Globally aggregated impacts are small (-1.5% to +2.6% in changes in GDP) which is not much different from Tol.

(ii) Agricultural GDP will be benefited in developed countries

(iii) Developing countries would face decreases in agriculture GDP, Asia at -4% with high rate of emission scenario, Africa at up to -9% while Latin America could be an exception.

(iv) North America and former USSR can gain in all the scenarios but Western Europe will lose.

(3) Crop yields: A 69 sector synthesized model created by Easterling et al (2007) takes account of the effect of temperature changes along with carbon fertization and finds that yields of crops increase in mid to high latitude areas but the effect diminishes when

temperature changes are greater than 3 ^{o} C but yield depressing effects are found in tropical and sub-tropical regions for all crops along with lower temperature thresholds. Though the magnitudes are yet debatable, carbon fertilization effects have been incorporated and the results are widely varying across regions. The yield depressing effect could come down to the range 30-50 million tones from 200-450 million tones (Parry et al 2004). Measured as net revenue changes for disaggregated global regions, agricultural productivity in developing countries is expected to decline by 9-21% due to global warming but could increase by up to 8% with carbon fertilization in industrialized countries (Cline, 2007). Thus climate projections indicate that agriculture in developed countries may be benefited by global warming but only up to a point (3^{o} C) but yield depressing effect will be strong in tropical and sub-tropical regions and worst in Africa. The models however do not consider other stressors like pests, so actual results could be further depressing.

(4) Cereal imports: Cereal imports can increase in developing countries by 10-40% by 2080.

(5) Food security: Food security will be hurt by climate change although it must be recognized it is greatly influenced by other factors like trade policy, storage capacity and food aid. Food security impacts can be addressed by integrating trade policy and other socio-economic development indicators in the GCM although such studies are scarce till date. One synthesis of these models finds an estimate of an additional 5-170 million people who will become malnourished depending on the scenario. Africa will become a region of highest population of food insecure accounting from 75% of world total by 2080 (Schmidhuber and Tubiello, 2007). Based on possible yield changes due to climate change and the importance in diet considerations, ‘climate risk hot-spots’ are identified in terms of crops and regions (Lobell, 2008).

2.7.2. Crops vulnerable (Climate risk hot-spots)

The gtz review also provides the hot-spots of food insecurity potential identified by the model results as given below.

Wheat: Caribbean and Central America(20), Central Africa (43), Andes (36), Southern Africa (41), ,Brazil (55), South Asia (3), West Asia (10), South-east Asia (17).

Rice: Caribbean and Central America(42), Central Africa (35), China (4), Andes (57), West Africa (30), Brazil (62), South Asia (1), West Asia (63), South-east Asia (2).

Maize: Central Africa (18), Andes (62), West Africa (48), East Africa (8), Southern Africa (9), Brazil (67), South Asia (24), West Asia (69), South-east Asia (35).

Cassava: Central Africa (7), South-east Asia (35).

In the above list (drawn from Lobell, 2008) only the crops that are projected to witness yield decline on the average are mentioned and the figures in parentheses indicate rank in terms of number of people malnourished and the calorie drawn from the crops. Rice is a case of concern projected to see a decline in most regions (all but Southern Africa and it is of no consequence in East Africa) and most notably in South Asia and in South-east Asia which hold the first two ranks. Wheat yield will also decline in these two regions. Maize holds the top ranks in East and Southern Africa where its yield is projected to decline but cassava which occurs in the list in only seven regions will gain in Central America Andes, West Africa, East Africa, Southern Africa and lose in Central Africa and South-east Asia.

2.7.3. Projections for China

Using Global Social Economic Climatic Impact Model (GSCIM) based on IPCC (1992) scenarios temperatures in China and East Asia are projected to rise by 0.88 ^{O}C in 2030, 1.4 ^{O}C in 2050 and 2.95 ^{O}C in 2100 and precipitation by 2.6%, 4.2% and 8.9% in the corresponding periods (Futang, 1995). Temperature change due to human activities is more obvious than precipitation change. Simulations find a northward temperature shift by 1-3 ^{O} of latitude, the shift being more in north-east China. The shift is less visible in respect of precipitation. Despite the projected increase in precipitation, combined with temperature induced enhanced evaporation, the climate is likely to get drier.

Vegetation is likely to follow the climate change, maintaining its equation with climate resulting in shifts in vegetation types. The model simulates cold temperate coniferous forests either to be restricted only to Siberian borders or to disappear completely, area potentially suited to tropical monsoon rainforest in South China increasing, the Alpine vegetation in Tibet coming down and vegetation type in northwest China turning to warm hot desert type. The intermediate forest zones are stable in size despite being shifted northward. Not being able to identify possible new future vegetation types is the limitation of the model.

The effect of agriculture ranges from being moderately adverse to favourable. More natural vegetations will turn into arable land with the rise in temperature in cold regions. Less area will be single cropped while triple cropped area increases by 22.4 % in 2050. Cropping pattern will become more diversified as climate becomes favourable for crops. The area suitable for rice and wheat will increase though mean yield may fall due to reduced water availability. In cold regions of northeast China crop yield will rise but the effect in east China will be unfavourable.

2.7.4. Projections for India

In India the dynamics observed in food production has been explained by factors like fertilizer consumption, area under HYV seeds, irrigation and credit as also the total factor productivity (TFP). By mid-eighties technological changes and gains due to technical efficiency contributed only around 15% of aggregate agricultural growth (Kalirajan and Shand ,1997) the remaining growth using from input use but subsequently output growth per unit increase in input decelerated (Kumar and Mittal, 2006). Estimates of supply projections of food for India are 270.4 million tones in 2020 when the deceleration of TFP is factored in (Kumar et al, 1995, Goyal and Singh, 2002 and the 309 million tones when policy intervention is assumed. Another projection made by the International Food policy Research Institute (IFPRI)'s IMPACT model finds the estimate at 256 million tones (Rosegrant et al, 1995). On the other hand, estimated food demand for cereals in 2020 broadly centres around 225 miilion tones and (Chand, 2007, Bhalla et al, 1999). While these projections arouse comfort and even complacency, this is contrary to the evidences of hunger and under-nutrition being present in the society. The available studies on demand and supply do not account for the impact of climate change and emerging evidences suggest that in the long run, the likely impact of climate change on food productivity can constrain attainment of food security from domestic production (Dasgupta and Sirohi, 2010).

Climate change effects on agriculture can be studied by combining climate models with agronomic and economic models. The process raises several uncertainties, that related to climate scenarios being the major ones. At lower altitudes the crop productivity decreases projected for temperature rise by the IPCC raise a spectre of hunger prevailing in developing countries. High temperatures are expected to reduce yields of desirable crops while encouraging weeds and pest proliferation and changes in precipitation patterns increase the likelihood of short run crop failures and long run production decline, threatening global food security (Nelson et al, 2009). Lack of more precise regional models for South Asia comes in the way of pushing for pro-active policy initiatives in the region. The 30% decrease of crop yields in South and Central Asia by mid 21st century needs to be investigated (Chopra, 2007).

In a detailed study on India, Kumar and Parikh, (2001a and 2001b), considering a range of equilibrium climate change scenarios projected a temperature rise of 2.5-4.9^{O}C for India and predicted that yield losses for rice and wheat at respectively 32-40% and 41-52% without considering carbon fertilization effect. They also showed that consideration of carbon fertilizer will reduce the effect but not change its direction. Even with farm level adaptation and using an alternative methodology the impacts were projected to be significant. They estimate that with +2^{O}C temperature change and accompanying precipitation change of 7% farm level net revenue will fall by 9% whereas with +3.5^{O}C temperature rise and precipitation increase by +15% the fall will be nearly 25%. Since these are large changes for a developing country, the authors conclude that a +2^{O}C increase of temperature will be intolerable for India while other countries like Bangladesh will be even more vulnerable. Submergence of coastal zones will further bring misery and create large numbers of refugees moving away from low lying delta regions. A one meter rise of seal level is believed to be capable of displacing 7 million persons in India (ADB, 1995) and with 35% of land in Bangladesh facing submergence prospects under this scenario, the humanitarian problem can be enormous. Building walls along the vulnerable zones being a solution, the question raised was 'who will pay Bangladesh or India for such walls?'

Most of the simulation studies on Indian agro-climatic conditions have projected adverse effects of rising temperatures on food productivity (Aggarwal, 2000, Aggarwal and Sinha, 2003 and Rao and Sinha, 1994). Findings from various model based simulations are documented by Dasgupta and Sirohi, 2010 (see also chapter 4). Models like WHTGROWS, INFOCROP and CERES indicated that in north India a 2^{o} C rise in mean temperature reduced potential grain yields of rice and wheat by 15-17% (Aggarwal and Sinha, 1993, Hundul and Kaur, 2007). At the all India level a substantial reduction in wheat production is likely to occur for the scenarios of climate change. The wheat output is expected to fall significantly short of its projected value under business as usual. Beyond 2020 the yield increases expected on the basis of input growth are not likely to materialize under climate change and production will come down. Some studies incorporated the interaction of biotic interference (pests, insects and weeds) and found further aggravation of the effect (Kaur and Hundal, 2008).

A study conducted by the International Food policy Research Institute (IFPRI) combined the Institute's own IMPACT model and DSSAT model on five crops rice, wheat, maize. Soyabean and Groundnut. They used two scenarios from different models (NCAR and CSIRO) based on A2 of IPCC Fourth AR. There were substantial differences between the two scenarios, NCAR being wetter of the two. Their results show yield decreases in most crops and a severe effect on South Asia (see Appendix table 2.1A). They also projected price rise for most crops and a higher feed price, decreased cereal consumption and average calorie intake lower than even 2000 level in the developing world. The IFPRI Spatial Analysis Model covering area, yield and production of crops at sub-national level, irrigation, prices, rainfall, evapotranspiration, temperature, slope, elevation and soil characteristics are combined with results from Pathak (1999) and Bhatia et al (2004) to explore mitigation options for three sources of agricultural GHG release, namely methane from irrigated rice production, nitrous oxide emissions from the use of nitrogenous fertilizers and the release of carbon dioxide from energy sources used to pump groundwater for irrigation. Based on Pathak study it was shown that with 120 Kg of Urea based nitrogen and 60kg nitrogen from farmyard manure, rice fields under continuous flooding has higher grain yield and greater nitrogen uptake than fields under one mid-season drying but emissions of carbon dioxide and methane would be lower (see also Chapter 6). Nitrous oxide emission would be higher under the midseason drying system but there are promising indications that fertilizer type and crop choice influence emissions. The potential benefits of fertilizer use efficiency, use of biofertilizers, manure management and use of compost cannot be quantified. Irrigation is supplied in India mostly by ground water with deep tubewells proliferating. Wells are powered by diesel or electricity generated from coal fired plants. Carbon dioxide emission from the wells will depend on the efficiency of power transmission and pumping process and the carbon density of the energy source. Deep tube-wells are the largest single source of carbon dioxide emission from irrigation. They accounted for 65% of carbon dioxide emission in India and 5% of all GHG emissions. Model projections showed under different scenarios of transmission losses emissions from shallow electric and shallow diesel will stabilize but that from deep electric wells will increase three-folds till 2050 but by 2040 the growth stops. This is when the increased efficiency of water use offsets demand arising from higher production demand. Finally the study not only expresses the impossibility of producing reliable climate effects under given information, the reliability of the data available for use has also been admitted to be not above questioning.

Table 2.4: Some model results on Climate change effect on Agriculture		
Tol 2002	Global	1. Adaptation could change the direction of changes on agricultural GDP from negative to positive for most regions. 2. Impacts mostly benign for Europe, former Soviet Union and Centrally Planned China. 3. Latin America, Asia and Africa are adversely affected in the absence of adaptation.
FAO/IIASA (Global Food model)	Global	1. Globally aggregated impacts are small (-1.5% to +2.6% of changes in GDP) 2. Agricultural GDP will be benefited in developed countries. 3. Developing countries would face decreases in agriculture GDP, Asia at -4% with high rate of emission scenario.
Easterling et al (2007),(Cline,2007), (Schmidhuber and Tubiello, 2007)	Global	1. Crop yield depressing effects found in tropical, sub-tropical regions for all crops. 2. Net revenue changes for disaggregated global regions in developing countries expected to decline by 9-21% due to global warming 3. Africa will become a region of highest population of food insecure accounting from 75% of world total by 2080
Futang 1995	China	1. Vegetation to maintain its equation with climate resulting in shifts in vegetation types. 2. More natural vegetations will turn into arable land in cold regions. 3. Less area will be single cropped 22.4% rise in triple cropped area by 2050. 4. Cropping pattern more diversified 5. The area suitable for rice and wheat will increase though mean yield may fall due to reduced water availability. 6. Favourable effect on crop yield in (cold) northeast China but unfavourable effect in east China. 7. Model not able to identify possible new future vegetation types.
Supply-Demand models	India (without climate change)	1. Modern technology and total factor productivity important for dynamics. 2. Supply projections 256 mt ((Rosegrant et al, 1995).), 270.4 mt with decelerating TFP and 309 million tones with increased public investment ((Kumar et al, 1995, Goyal and Singh, 2002) 3. Comfortable projections but climate change not factored in
Kumar and Parikh, (2001a and 2001b)	India	With +2^{O}C temperature change and precipitation change of 7% farm level net revenue will fall by 9% whereas with +3.5^{O}C temperature rise and precipitation increase by +15% the fall will be nearly 25%. These are large changes for a developing country
(Aggarwal and Sinha, 1993, Hundul and Kaur, 2007).	India (climate model with agronomic models)	In north India a 2^{o} C rise in mean temperature reduced potential grain yields of rice and wheat by 15-17%
International Food policy Research Institute (IFPRI) combined the Institute's IMPACT model,	World	Negative impact on world cereal (rice, wheat, maize) production by 12-14%, 23-27% and -.2-0.4 0.% but in South Asia by 14-15%, 44-49%, 19-9%.
Source: Compiled from various sources.		

Appendix 2

2.1. Fossil fuel

A typical example of a terrestrial sink that first comes to mind is undoubtedly the fossil fuel, specifically the coal. Carbon is trapped away from the atmosphere for thousands of years in these fossil fuels which are buried by nature deep beneath the earth surface. They are thus potential sources of emission that have been brought out of their remote abodes by human intrusion and burnt to give human beings a better life, unleashing the locked up carbon back to the open air. When the trees evolved with relatively developed vascular system to draw water and nutrients from soil, the earth became covered with towering forests. This period is known as the carboniferous period because the carbon deposited from the decay of the tress changed into coal stocks under the earth surface. This carbon that was sequestered by the trees long ago therefore became far removed from the atmosphere. Thus it is human action that has turned fossil fuels from their status of natural sinks hidden in their remote abodes to being sources of emission.

Being derived from carbon that was removed by prehistoric times organisms, when burnt, they constitute net addition to the carbon cycle. This attribute distinguishes the fossil fuel from other sinks. Specifically, coal deposits represent the carbon sequestered from atmosphere by towering forests that flourished about 360 to 290 million years ago in the Carboniferous period. This sink is of little us for humans as the conversion is quite irreversible given the prolonged periods of time and the specific conditions of heat and pressure that are required for the formation of fossil fuels

2.2. Forests

Perhaps the sink that has received the most attention in policy changes is the tree or collectively the forest. The life process of the tree stands out in contrast and in synergy to that of the animal in that the tree takes in carbon dioxide and by and large gives out oxygen that is so precious for animal life. Over the years the trees absorb carbon dioxide and through photosynthetic mechanism create and store carbon in their living tissues as carbohydrates or in more complex forms. Trees too are potential sources of emission as the stored carbon reverts to the atmosphere when the tree dies. In the absence of human interference, however the two roles of a tree as a source and a sink are in balance and the emission need not entail net removal of carbon dioxide. Since unlike the fossil fuel, the process of removal can be accentuated and emission curbed by purposive afforestation and deforestations forests have been instrumental in offsetting carbon emission in other activities to maintain the carbon balance. However, forests take up space that is required for alternative uses like agriculture and urban development and they have an inherent limitation to serve as sinks. Trees are temporary as sinks and conservation of forests becomes essential to keep the carbon from reverting to the atmosphere again. Forest fires resulting from human actions, natural reasons and even global warming can end up in releasing considerable carbon to the atmosphere and also eliminating the pathway of carbon sequestration. Even after a tree attains its full growth potential only conservation can ensure that the stored carbon remains undisturbed and after a tree dies careful and useful disposal is essential.

2.3. C3 and C4 Plants

In C3 crops (like rice, wheat, soyabean) rising carbon dioxide increases net photosynthetic carbon dioxide uptake whereas C4 plants (like maize. Sorghum) may not show direct effect of photosynthetic activity but in either case increased water use efficiency can increase yield.

Human beings consume more rice than any other cereal (540 million tonnes). Rice grown on 150 million hectares worldwide mostly on wetlands. The cultivation involves planting on shallow standing water and increasing the water level till the crop matures when the land is allowed to dry. Puddling the land helps to control weeds, keep water in reserve and improves nutrition to some extent. The respiration of certain microbes that cannot survive in oxygen breaks down carbohydrates in biomass to methane and carbon dioxide. This process known as methanogenesis emots 700 Kg of carbon equivalents per hectare which 1.5% of the world's greenhouse gas emissions from human activities. Methane emission depends on the availability of biomass in the soil which again is stimulated by nitrogenous nutrition and inefficiency of nitrogen would be a positive effect on methane emission.

Table2.1A: Climate Change effect on crop Production, no Carbon dioxide fertilization				
	South Asia	Developing	Developed	World
Percentage Change Projected (2000-2050) with no climate change				
Rice	41.0	17.4	-0.3	16.5
Wheat	97.9	75.6	23.6	57.3
Maize	15.7	73.1	69.6	71.4
Percentage change due to Climate Change, 2050 (CSIRO)				
Rice	-14.3	-11.9	-11.8	-11.9
Wheat	-43.7	-29.2	-7.6	-23.2
Maize	-18.5	-10.0	11.5	0.2
Percentage change due to Climate Change, 2050 (NCAR)				
Rice	-14.5	-13.6	-10.6	-13.5
Wheat	-48.8	-33.5	-11.2	-27.4
Maize	-8.9	-2.3	1.8	-0.4
Source: Nelson et al, 2009				

Chapter 3:
Climate and Agriculture in India

As a prelude to the discussion in the following chapters we present an overview of Indian climate (section 2) and its tendencies if any and provide a vista for Indian agriculture (section 3), highlighting its spatial properties, the crops grown, water resources and land use. Climate change effects may be intrinsically related to these aspects.

3.2. Indian Climate

Agriculture has always been the mainstay of Indian's economy and rulers, court advisors and common people have been interested in weather since ancient times. The India Meteorological Department (IMD) was formally established in 1875 and its functioning developed with the creation of a network of 90 weather observatories for systematic observation and research. Their work was complemented by institutions in other climate associated sectors like agriculture, forestry and hydrology. The Agricultural meteorology directorate was created in 1932. In the recent past Automated Weather Stations (AWS) and ground-based remote sensing techniques have provided input from satellites and modern observation platforms strengthening the process. Several Ministries like that of Environment and Forestry, Earth Sciences, Science and Technology, Human resources, Health, Energy along with scientific organizations like the Indian Space Research Organization (ISRO) and the Institute of Economic Growth (IEG) have coordinated and cooperated in the build up of data and understanding of Indian climatic processes and their implications for Indian economy and society. The IMD established a Glaciology Study research Unit in 1972 to determine natural water balance in river catchments as well as to study the snow-melt run-off and Himalayan climatology in order to explore reservoir regulation options and facilitate better management of water resources. The IMD has also created an archive of weather data and regularly analyses and monitors

India's climatic parameters. Forecasts of weather are made regularly for agricultural and other purposes.

3.2.1. Overview of Indian climate

Indian climate is predominated by the monsoon, a phenomenon affecting the climate of many countries most of which are located in Asia. The monsoon is typified by the seasonal winds that are reversed due to the earth's revolution around the sun and generated by the earth-ocean-atmosphere interactions and it brings rain to landmasses in these countries. In India the incoming monsoon described as the South-west Monsoon (SWM) referring to the direction from which the wind blows, is the source of the largest share, about 35%, of rainfall that occurs in the country. This period lasts from June to September but may continue up to October. Besides the main monsoon season, the broad seasonal classifications made by IMD are the pre-monsoon, the post-monsoon and the winter seasons.

In the pre-monsoon season (March-May) temperatures start to rise all over the country and by April reaches 30-35^{O}C in peninsular India and to 40^{O}C in some Central Indian locations. The daily range can become very high. In May the temperature can reach at least 45^{O}C but heat creates low pressures leading to cyclonic storms that rises from the Bay of Bengal towards the northwest. Temperature conditions also give rise to local winds and storms in various parts of the country. The following four months (June-September) is the season of southwest monsoon that lasts from 75 days (Western Rajasthan) to 120 days in the southwest. The SWM starts over Kerala coast on 1st June and advances in a regular manner overrunning the entire country by the first part of July. Although the onset and distribution of SWM rainfall are by far regular events in monsoonal India, that the inter-annual and intra-annual variations are marked is also a steady feature of the climate. The monsoon is influenced by factors like the El-Nino, northern hemispheric heating, sea-surface temperature and snow cover. The SWM is characterized by active spells, 'breaks' and monsoon-depression induced cyclones but it becomes feeble and withdraws from the north-west in September. The period October-

December is termed as the post monsoon or north-east monsoon season marked by falling temperature, reduced humidity and clear skies but during this time parts of Andhra Pradesh, Tamilnadu, Kerala and South Karnataka also receive rainfall due to the coastal geography and the retreating monsoon winds. In January and February winter prevails in India. Temperatures fall, the mean daily minimum temperatures coming down to 22^{O}C in extreme south, 10^{O}C in northern plains and 6 ^{O}C in Punjab. Cold air masses from the Siberian region and western disturbances and their associated troughs bringing rain to north-western India and western Himalayas are common.

Indian climate is generally assessed by the occurrences of events like droughts, floods and tropical storms and also by the monsoon performances demonstrated by the timing of onset, quantum of rainfall and delayed or early withdrawal of monsoon where monsoon refers to SWM (more detailed discussions are available in the Appendix3.1). The rainfall in this season is the main source of water for the kharif crops in the country, for the recharge of water-bodies and for replenishing the soil moisture after a parched summer, all of which are important influences for the rabi crops crop grown when the SWM has withdrawn itself. The rainfall received from the north-east monsoon and western disturbances are also important for rabi crops.

The IMD provides detailed data on rainfall by 36 meteorological sub-divisions and temperature data recorded as daily maximum and minimum temperatures for seven zones namely western Himalayas, north-west, north-central, north-east, interior peninsular, east coast and west coast as well as all India. The rainfall scenarios are classified as light to heavy (0-64.4mm), heavy (64.4-124.4 mm) and very heavy to exceptionally heavy (>124.4 mm) the last category being identified as extreme rainfall event. Information on droughts, cyclones and floods are provided classified analogously by their extent of severity. A long period average of rainfall which is a moving average over a long period of time is often used as a comparison base. The IMD has made analysis of India's climatic behaviour with past data exploring tendencies in various parameters and the tendency for climate change, the details of which are provided in the Appendix 3.1.

3.3. Climatic tendencies 1975 onwards: An analysis

Based on our sample period 1975 to the latest data available we have worked out broad trends in temperature and rainfall and their variations. For temperature both minimum and maximum daily temperatures are studied at the temperature zone level. The zones are western Himalayas (WH), north-west (NW), north-central (NC), north-east (NE), interior peninsular (IP), east coast (EC) and west coast (WC). In the case of rainfall using the met-sub-division level data (36 in number), state rainfall level is worked out for 14 major states as the weighted average of the met-region level rainfalls R_m relevant for state s, using district level net sown area as weights. Thus R_s is the rainfall at the state level obtained by the formula.

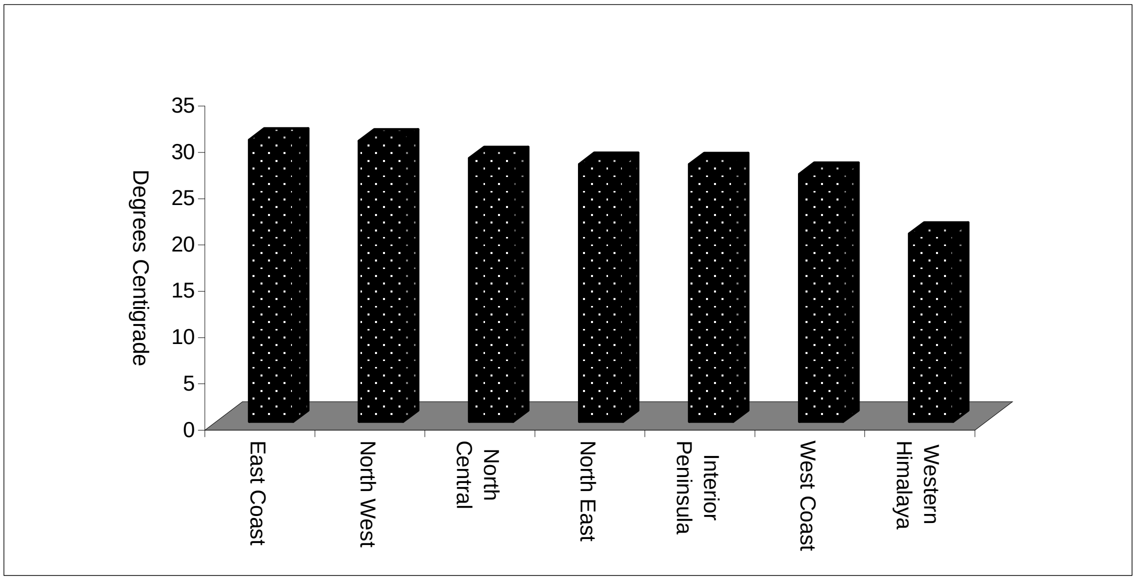
$R_s = \Sigma\ (wt_{ms} * R_{ms})$ where the summation is over all the met-regions m that fall in the state and

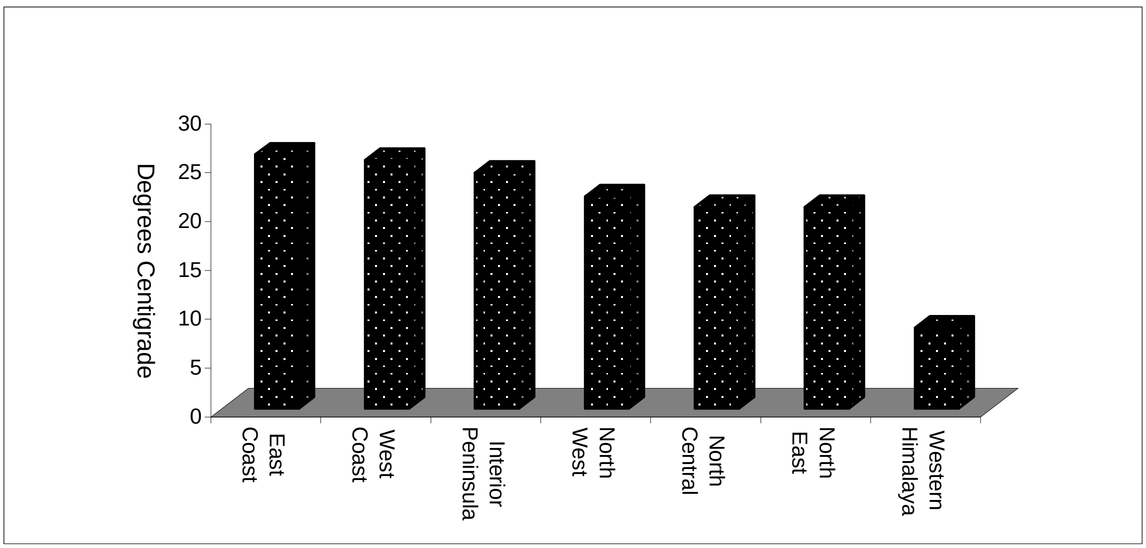
$Wt_{ms} = (NSA_{ms}/NSA_s)$

And $NSA_{ms} = \Sigma(NSA_{dms})$ where NSA_{dms} is the net sown area of the district d in state s falling in m-th met-region, the summation is over all the districts of the state that fall in the m-th met-region, NSA_s is the state total of NSA to arrive at the Wt_{ms} , the weight for the m-th met region is s-th state..

3.3.1. Temperature patterns and changes

Figures 3.1 (a) and 3.1(b) provide the relative ranking of the temperature zone in terms of temperatures recorded during the two main cropping seasons. The average daily temperature is calculated as the average of the minimum and the maximum temperatures and the plot is for three year average of temperatures. The EC and the WH have respectively recorded the highest and the lowest temperatures in both the season. The NW, NC and NE zone have second, third and fourth ranks in monsoon season temperature but IP and WC have higher temperatures in the post-monsoon season.





Figures 3.1: Average temperatures in (a) South West monsoon (June-September) and (b) Post Monsoon (October-December) seasons (Average of years 2001, 2002, and 2003). Average temperature is Average of Minimum and Maximum daily temperatures. Source: Based on data presented by Indian Institute of Tropical Meteorology (IITM).

The plots of the all India level temperatures (Figure 3.2) both minimum and maximum show positive trends more pronounced since 1990s. The reason for the rising tendency may be linked to global warming but the apparent shift in 1990 has hint that industrial development or geopolitical developments such as the gulf war and other environmental disturbances could be also contributive factors. The minimum temperature is highest in the monsoon season followed by the pre-monsoon (summer) season and then by the post-monsoon season while the winter records the lowest minimum temperature. In respect of the maximum temperature, the picture is similar except that pre-monsoon season is hottest followed by the monsoon.

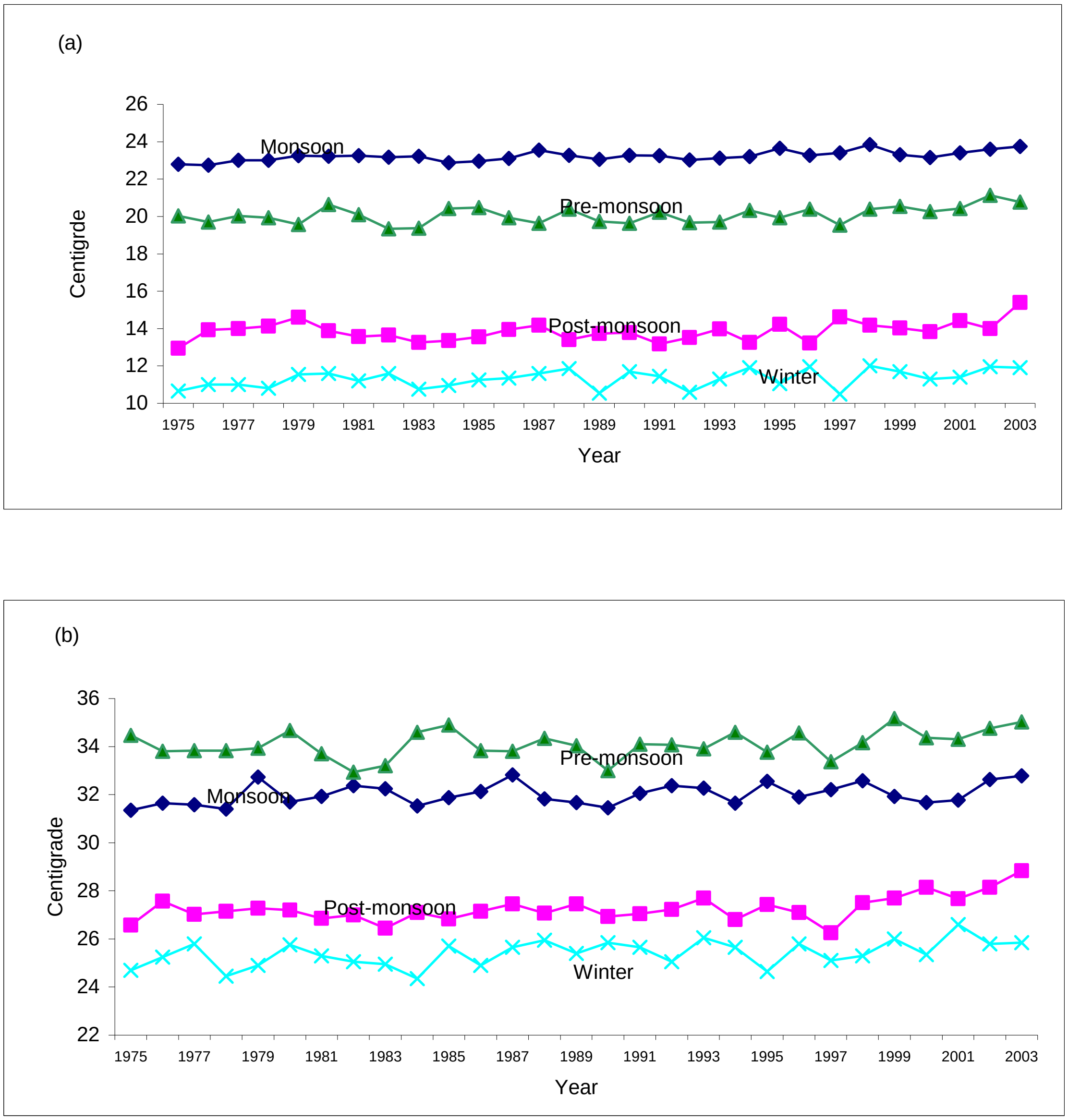


Figure 3.2: All India (a) Minimum and (b) Maximum Temperatures for the four seasons plotted over the years 1975-2003. Source: Based on data presented by Indian Institute of Tropical Meteorology (IITM)

Logarithmic trends have been estimated for the data on temperature since 1975-76 onwards using data available in IMD site (Table 3.1). The trend has been uniformly positive and barring a few exceptions (the IP minimum temperature, NC maximum temperature both in the pre-monsoon season, NC maximum temperature in the monsoon, IP, EC and WC minimum temperature in the post-monsoon and NC and NE maximum temperatures in the winter), and the trend is also significant mostly at 1% level. Although the findings are anything but contradictory to the hypothesis of a global warming, whether greenhouse gas emission are the cause of this tendency and how far other factors like industrial and other types of pollution are responsible are questions that these regression results cannot answer. Temporal convergence of zonal temperatures has been indicated by the negative signs of the coefficients of the standard deviations in the case of both minimum and maximum temperatures in pre-monsoon season and also in the minimum temperature in the monsoon season and the maximum temperatures in the post-monsoon and the winter seasons.

Table 3.1: Temperature trends in India (1975-2003)

	Pre-monsoon (March-May)		Monsoon (June-Sep)		Post-Monsoon (October-December)		Winter (January-February)	
Zones	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
All - India	0.001**	0.001*	0.001***	0.001**	0.002*	0.001***	0.002**	0.002**
Western Himalaya	0.008***	0.004**	0.004***	0.001***	0.017764	0.007***	0.003*	0.013***
North West	0.002**	0.001**	0.001**	0.001**	0.002*	0.002***	0.003*	0.002**
North Central	0.001*	0.00057	0.001***	0.000287	0.002*	0.000532	0.002*	0.00034
North East	0.001***	0.0000	0.001***	0.000343	0.002***	0.001***	0.002**	0.00041
Interior Peninsula	0.000314	0.000286	0.001***	0.000502	0.000333	0.001*	0.0007	0.001**
East Coast	0.001**	0.000446	0.001***	0.0005*	0.000503	0.001**	0.0009	0.001***
West Coast	0.001*	0.001***	0.001***	0.001**	0.000604	0.001***	0.001**	0.001***
S D across the seven Zones	-.002**	-.003***	-.003***	-0.001	-0.001	-.004***	-0.001	-.003***

Notes: Log linear trends functions are used. The last row gives the trends of the standard deviation (SD) of temperature across the seven temperature zones. Source: Based on data presented by Indian Institute of Tropical Meteorology (IITM)

3.3.2. Rainfall patterns and changes

Global warming can also be associated with the levels and patterns of precipitation occurring in India. We will be attempting to explain the possible nexus later in a later chapter. The SWM is the major source of rainfall in India, concentrated in the four months June, July, August and September (Figure 3.3) although the pre-monsoon and the north-east monsoon seasons account for some rainfall from retreating monsoon and other disturbances but the incidence is very small in comparison.

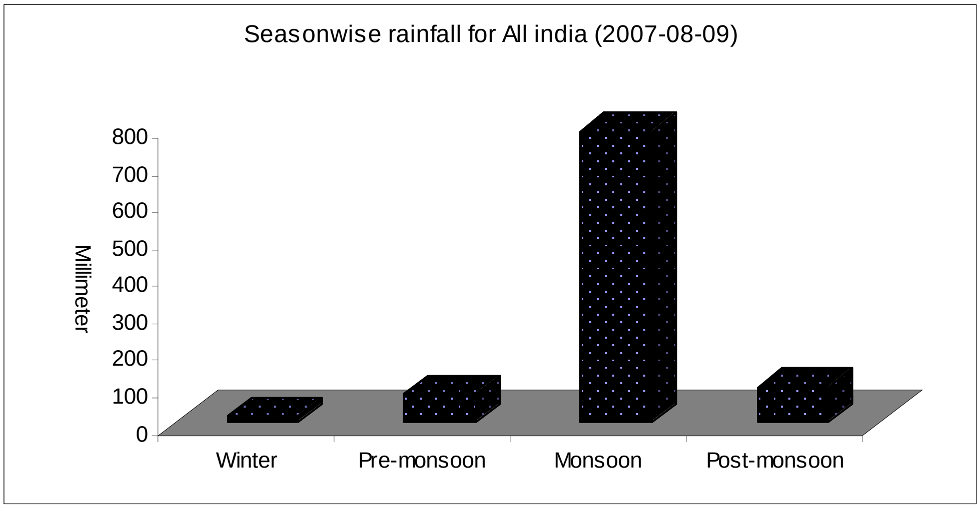
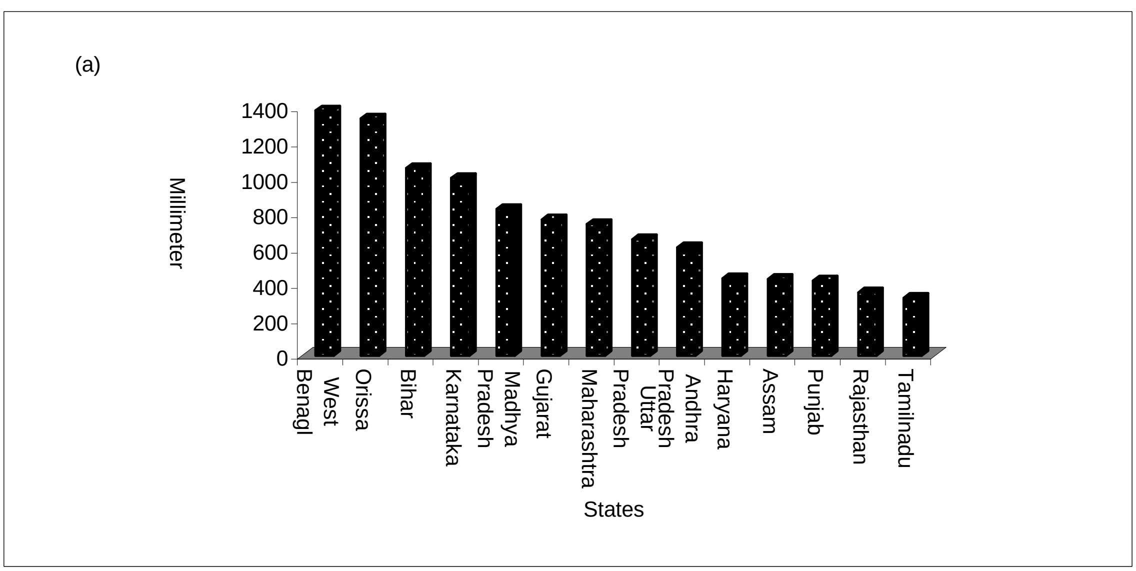


Figure 3.3: Rainfall distribution among the four major seasons in India.
Source: Based on data presented by Indian Meteorology Department.

The average SWM rainfall plot in Figure 3.4 shows the three eastern states West Bengal, Orissa and Bihar among the top recipients among the states considered and Haryana, Punjab, Rajasthan and Tamilnadu among the driest in that order. In the post-monsoon season, the southern states Tamilnadu, Andhra Pradesh and Karnataka receive more rainfall than others.



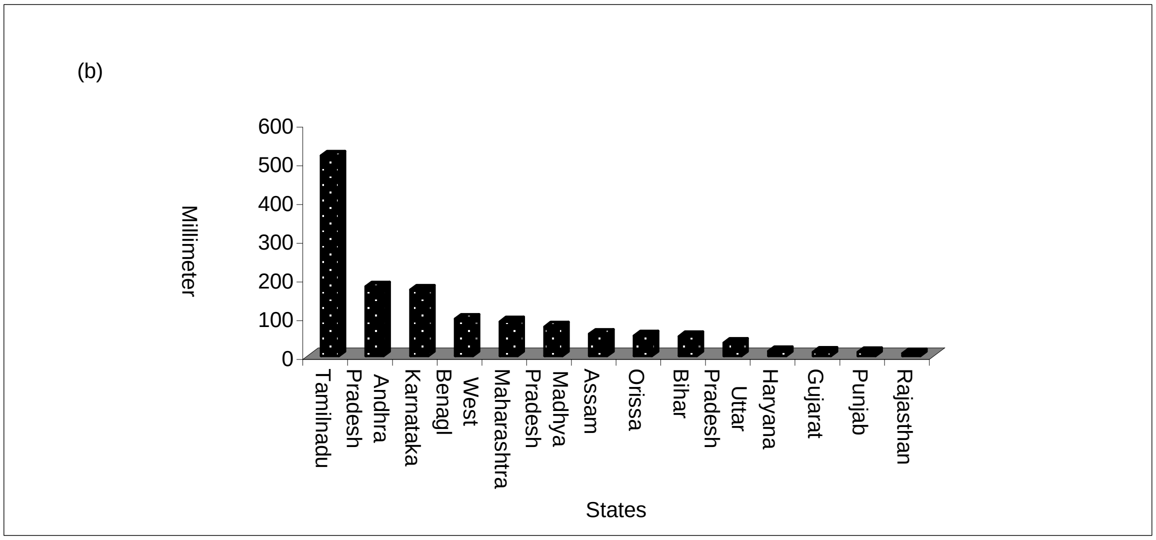


Figure 3.4 Average Rainfall in major states (average of 2007, 2008, and 2009), (a) South west Monsoon season (b) Post Monsoon season. Source: Based on data presented by Indian Meteorological Department (IMD).

Table 3.2 provides the time trends of rainfall worked out for the states in the sample period 1975-2009. Unlike in the case of temperature there is no clear indication of trend. Negative and significant trends are indicated in respect of winter and monsoon seasons in Karnataka, Rajasthan and Uttar Pradesh, positive and significant trends in Madhya Pradesh and Tamilnadu in pre-monsoon season and negative significant rends in Gujarat and Rajasthan for post-monsoon season. In most cases the estimated trend coefficients are not statistically significant but the sign is negative in a number of cases in the winter season, post-monsoon and the monsoon season also. Thus there is yet little indication of a secular increase in rainfall. The statistically not significant trend of the standard deviation suggests that regional variation of rainfall has been by and large stable. July accounts for the heaviest part south west monsoon rainfall and together with June also two sowing months of agriculture accounts for half of the seasonal rainfall in south west monsoon are normal (Table 3.7A). However no correlation is marked between the monthly rainfall (Table 3.8A) that appears independent within the monsoon season. There is also no apparent indication that seasonal rainfall has become more variable over the year (Table 3.9A)

Table 3.2: Rainfall trends in India(1975-2009)				
	Winter (Jan-Feb)	Monsoon (Jun-Sep)	(Pre-monsoon) Mar-May	Post—monsoon (Oct-Dec)
States	Coefficient	Coefficient	Coefficient	Coefficient
Andhra Pradesh	0.008	-0.004	0.007	-0.002
Assam	0.005	-0.003	0.001	-0.003
Bihar	-0.012	-0.003	-0.003	-0.011
Gujarat	0.019	0.001	0.016	-0.06**
Haryana	-0.001	-0.001	0.015	-0.003
Karnataka	-0.046*	-0.006*	0.001	0.000
Maharashtra	-0.009	-0.001	0.015	-0.009
Madhya Pradesh	-0.004	-0.004	0.023**	-0.013
Orissa	-0.026	0.003	0.006	0.006
Punjab	-0.003	-0.003	-0.004	-0.019
Rajasthan	-0.041*	-0.01*	0.000	-0.043*
Tamilnadu	0.028	-0.003	0.014**	0.003
Uttar Pradesh	-0.033**	-0.007*	-0.001	-0.022
West Bengal	-0.017	0.004	0.01145*	0.004
S D States	-0.002	0.003	0.005	0.004

Notes: Log linear trends functions are used in all cases. The last row gives the trend of the standard deviation (SD) across the 14 states. Source: Based on data presented by Indian Meteorological Department (IMD).

3.4. Climatic events

India has always been a victim of extreme climatic events that have brought hardship to different sections of people. Floods have been a recurrent calamity in many parts of India, especially in eastern India and causes extensive damages and disruption to human life. From times immemorial people have taken measures to prevent floods and to reduce the damages. The building of dams and reservoirs has been one such attempt that was stepped up in post independence days. However how far the engineering intervention served its purpose or even unleashed greater devastations in extreme circumstances was questioned. Figure 3.5 shows that the ravage of floods in terms of crop area affected rose during 1960s and 1970s and subsided since the 1990s. Appendix table 3.6A gives an indication of the catastrophic effects of floods in 1978 and 1979. More modest measures include zoning of flood prone areas, containing the development in vulnerable areas in order to minimize losses and most significantly developing the technology, infrastructure and institution of flood forecasting and advance warning. However, it remains to be said that a complete solution has till now eluded the system and even the engineering solutions may deserve a re-look in the current technological perspective (Sengupta, 2008).

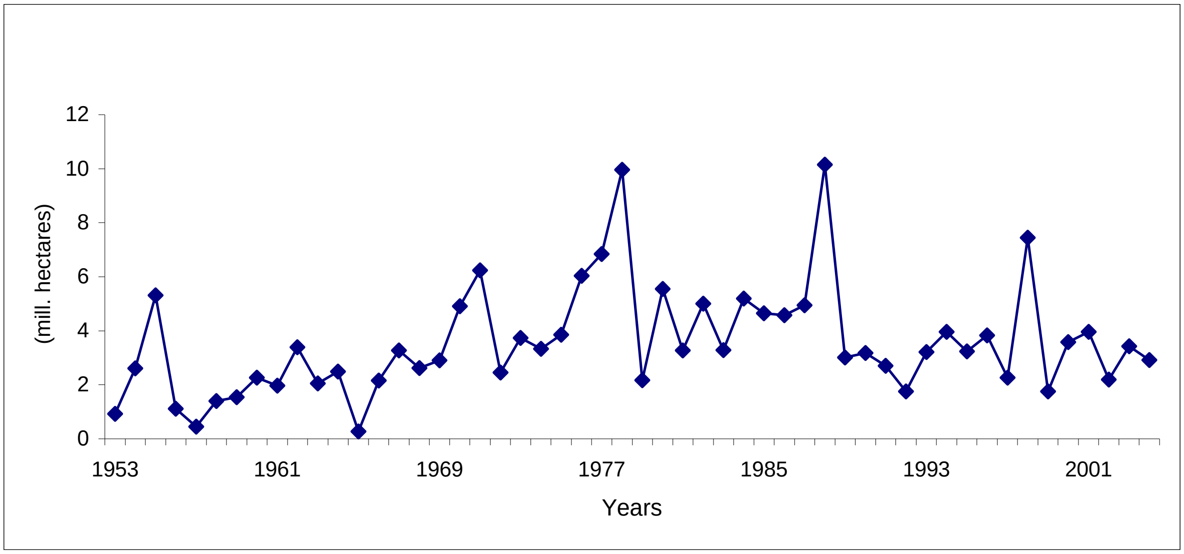


Figure 3.5: Crop area affected by floods in India, Source: Computed.

Droughts are another regular event that occurs in some part of the country in most years, their incidences being concentrated towards the country's northwest. While localized droughts caused hardship to the local population without turning into a national calamity, when drought affects large parts of the country agricultural production and food security is affected adversely. Some of the worst years in terms of rainfall failure written in recent Indian history are 1979, 1987, 2002 and 2009. The year 2002 was one of the worst experiences in recent times when 29% of the country's area faced drought conditions and 10% faced severe drought. Apart from floods and droughts, cyclonic disturbances often in the post-monsoon season can cause havoc in parts of the country by causing storms with high speed winds that damage crops and other properties. Coastal areas are more vulnerable to floods and cyclones that other areas and tidal waves are an added insecurity. About 32.8% of the country's net sown area is in the drought prone districts, 1.8% of area in the country is vulnerable to floods. The recent devastation by the Tsunami in 2004 is one such example. Appendix 3.1 provides more detailed accounts of the extreme events in India's climate.

Table3.3: Drought incidence in 2002 and 2009 in a relative perspective									
	2001	2002	2003	2004	2005	2006	2007	2008	2009
Districts affected (%)	32	61	23	44	28	40	28	24	59
Rainfall shortfall*(%)	8	19	-5	14	1	1	-5	2	23
* Shortfall with respect to the long period average rainfall. Source: Computation based on IMD data.									

3.5. The Diaspora of Indian Agriculture

The following Sub-sections will present some salient features that mark Indian agriculture. These aspects not only determine the extent and course of agricultural development but will possibly have intimate interaction with climate change emerging either as casual or as an impact of the process.

3.5.1 Land utilization

India is a large country with a geographic area covering 328 million hectares. Utilization of this land is largely reported by the Government of India, barring few inaccessible pockets. Of the reported area of 305 million hectares land under net sown area (NSA) constitutes 141 million hectares (47%) and another 25 million hectares are fallow land both making up arable land of India (Figure 3.6). Thus NSA makes up the largest share of the reported area. Even the cropped area is not fully utilized given that most agricultural crops take about four months from sowing to harvest and only a few crops like sugarcane require to be on the field for a year or more. In principle therefore it is possible to raise multiple crops on the same land although there are various constraints that keep the cropping intensity of land low. The extent of land under-utilization in India shows that 15% of the arable land is fallow and 85% under crops and of the cropped area only 38% is under multiple cropping while 62% of the net cropped area is single cropped.

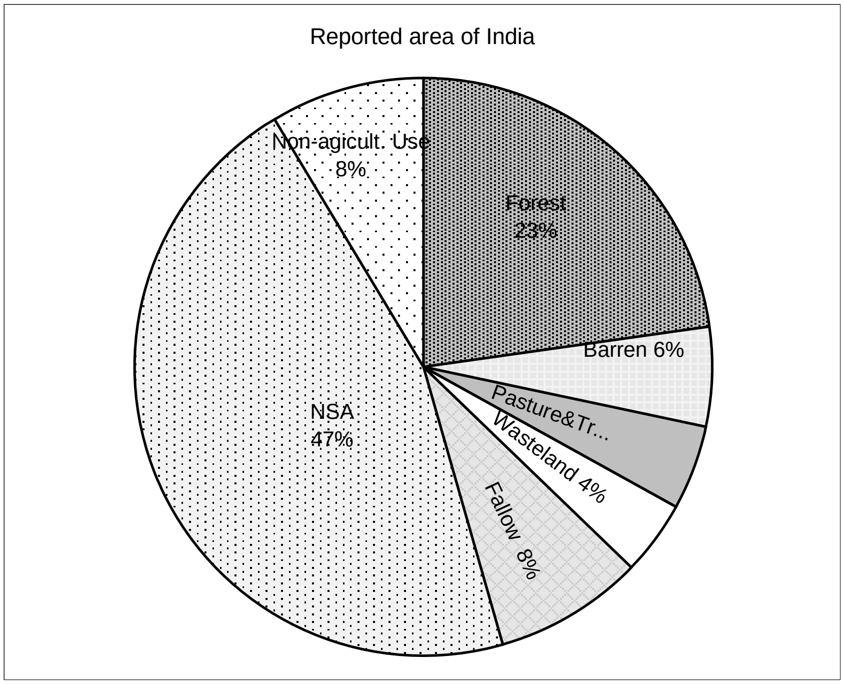
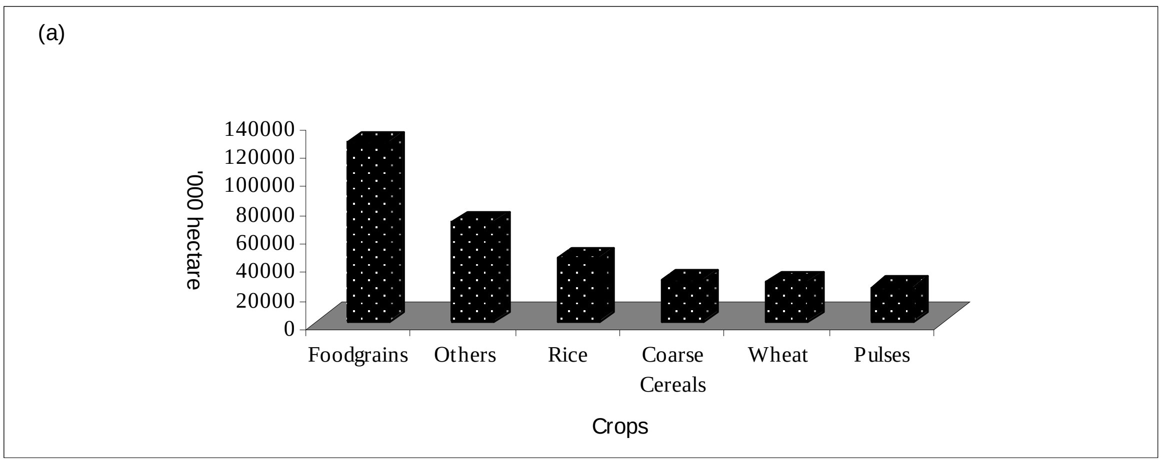


Figure 3.6: Diagram showing the degree of land utilization considering Reported area to be sum of all land use.
The figures are averages for the tree years 2005, 2006 and 2007.
Source: Based on Data from Ministry of Agriculture (GOI), ASG.

Over time with the expansion of irrigation more and more land has been brought under multiple cropping (Table 3.1 A). Over time the NSA has remained nearly stable at 140 million hectares with two visible dips encountered in 1987 and 2002, which are two of the most severe drought years. In this circumstance utilization of the limited land becomes the key way of increasing production. The way to increase cultivated area is to use the limited land more intensively by growing more number of crops in a year. Multiple cropped area has expanded in the 1970s and the 1980s, but the expansion slowed down in the 1990s and nearly stabilized in early 2000s. The expansion accelerated between 2003 and 2005.

The GCA is influenced by the availability of land (which itself depends the size of geographical area, level of non-agricultural activities, population) and the cropping intensity. Figure 3.8 however indicates that large sized states also lead in cropped area. Uttar Pradesh, Madhya Pradesh, Maharashtra and Rajasthan have relatively large reported area and large GCA but Tamilnadu has one of the smallest GCA. Land use is also described by the area allocation among different crops. Due to the increase in cropping intensity the GCA has expanded from 171 to 195 million hectares between 1975 and 2008. There has been a diversification of the area away from foodgrains whose share came down from 75% to 63% (Table 3.3A). However the share of rice has remained constant at 23% but while wheat gained share 12% to 14% together these two major cereals accounted for a little more than 60 million hectares. The decline in foodgrain area has been caused by the fall in area under coarse cereals from 25% to 14% and also under pulses from 14 to 11%. In terms of area occupied rice is the most dominant crop (43914 Thousand hectare), followed by coarse cereals (28481.5 Thousand hectares), wheat (28038.6 Thousand hectare) and pulses (23633.0 Thousand hectare) in Figure 3.8.



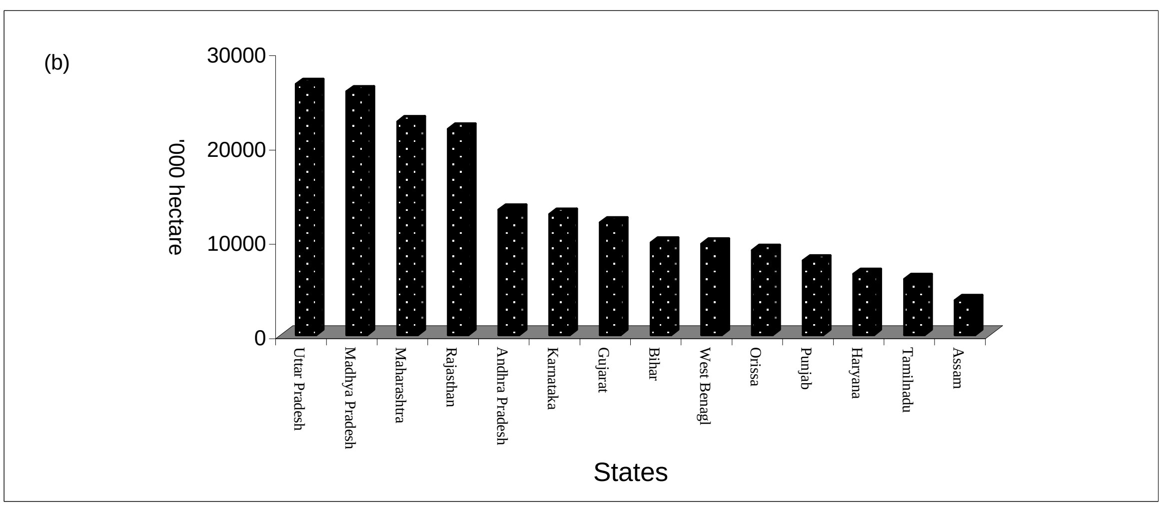


Figure 3.7: Gross Cropped Area (a) under major crops and (b) in major states (average of 2005-06-07)
Source: Based on Data from Ministry of Agriculture (GOI), ASG.

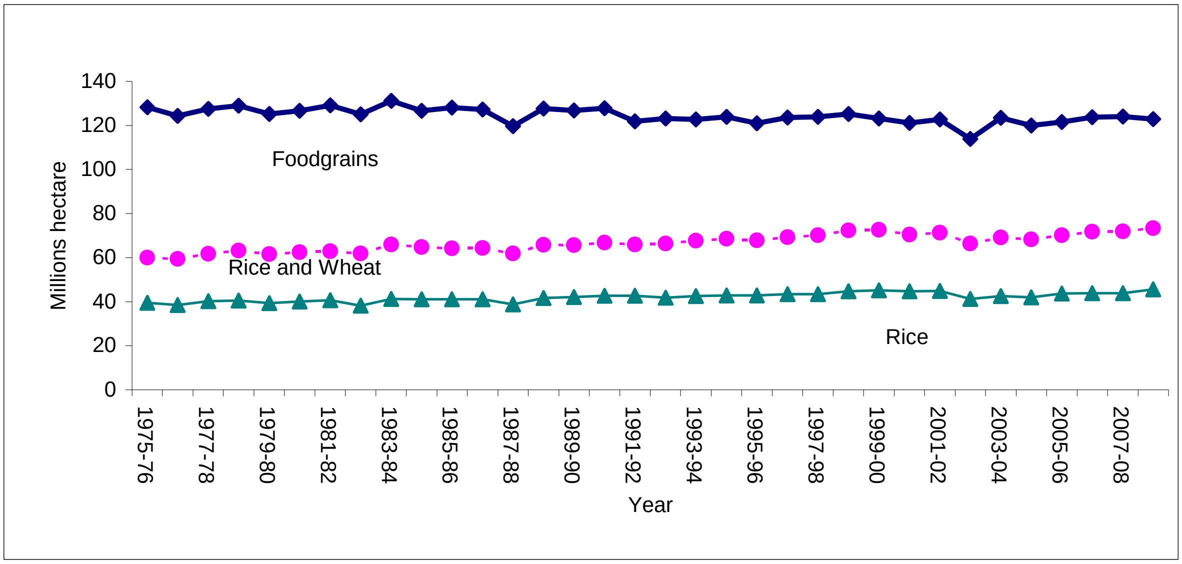
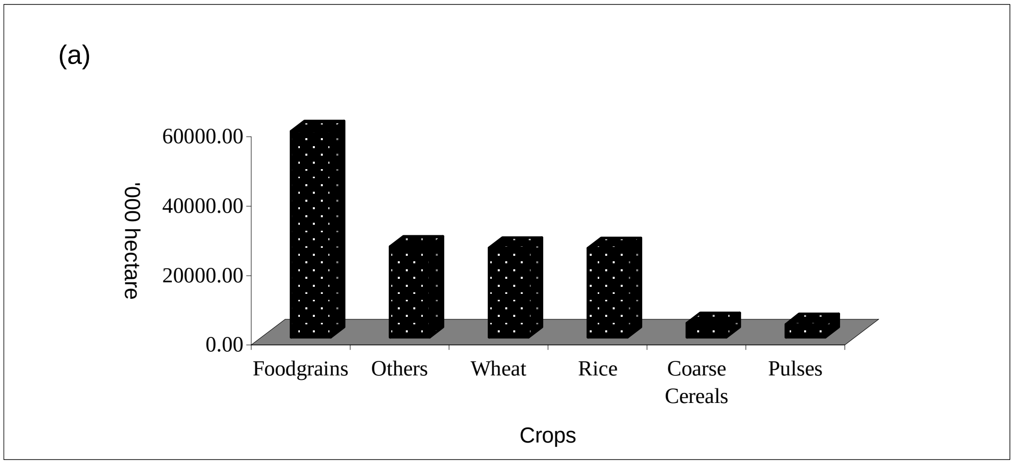


Figure 3.8: Gross Cropped Area in India under major foodgrain crops (average of 2005-06-07)
Source: Based on Data from Ministry of Agriculture (GOI), ASG.

3.5.2. Irrigation

Rainfall is the main source of water but is not adequate for a progressive agriculture when multi-cropping is the objective. Irrigation is the way to provide water that is stored by human design either in preceding times or other regions through a temporal or spatial transfer of water. Higher quality irrigation entails that water supply is more assured and controllable according to what human beings plan. Irrigation is based on surface water or ground water or other non-conventional means. Canals and tanks are the two main surface water sources of which canals are more assured sources involving diversion from rivers and manmade reservoirs. Groundwater comes via tube wells and other wells like the dug wells of which tube-wells are more assured. Foodgrains take up more of the irrigated area than non-food grain crops (denoted as others in Figure 3.10 (a)). Uttar Pradesh has the largest area under irrigation.



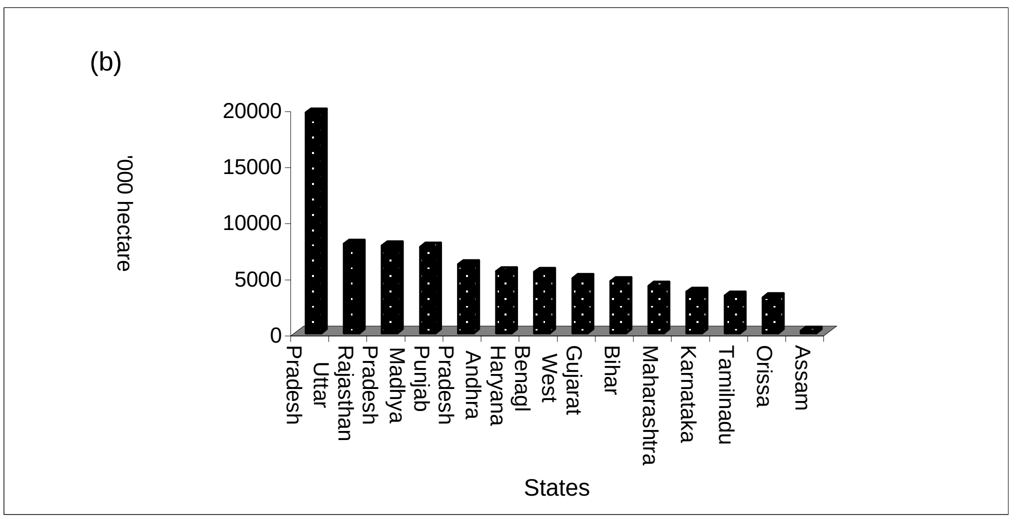


Figure 3.9: Gross irrigate area (average of 2005,2006 and 2007) across (a) major crops (b) Major states in India. Source: Based on Data from Ministry of Agriculture (GOI), ASG.

Irrigation is a way to provide year round water supply to crops even in the absence of monsoon showers. Since some of irrigation sources depend on rainfall recharge and dry up in the absence of rainfall, the presence of perennial irrigation helps land use throughout the year. If a hectare of irrigated land (net irrigated area or NIA) can be used to grow multiple crops in the year, the gross irrigated area (GIA) would exceed one hectare. Figure 3.10 shows that the GIA in India has been more than the NIA over the entire sample period and the gap between the two indicative of the perenniality of the irrigation facilities in the country and thereby the efficacy of irrigation has widened. However this may be attributed mostly to the proliferation of wells. While the GIA increased from 43 million hectares to 88 million hectares between 1975-2008, canal irrigation had a modest increase from 14 to 16 million hectares and area irrigated by wells went up from 14 to 38 million hectares as seen in Table 3.2A. Tank irrigation declined. Figure 3.12 Surface water irrigation that was more dominant as a source of irrigation in India stagnated and then declined but in the 1980s was over-taken by ground water irrigated area.

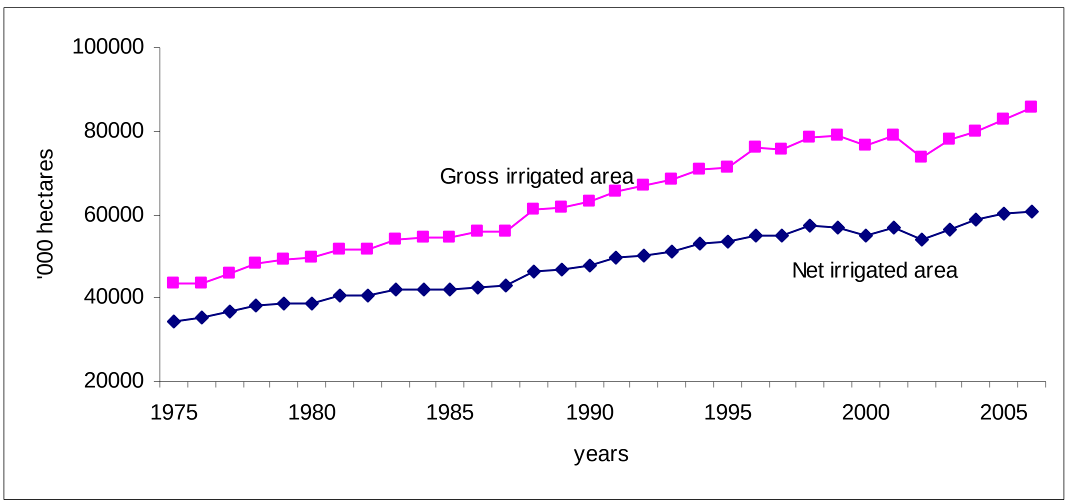


Figure 3.10: Gross and Net irrigated area in India ('000 hectares), Source: Based on Data from Ministry of Agriculture (GOI), ASG.

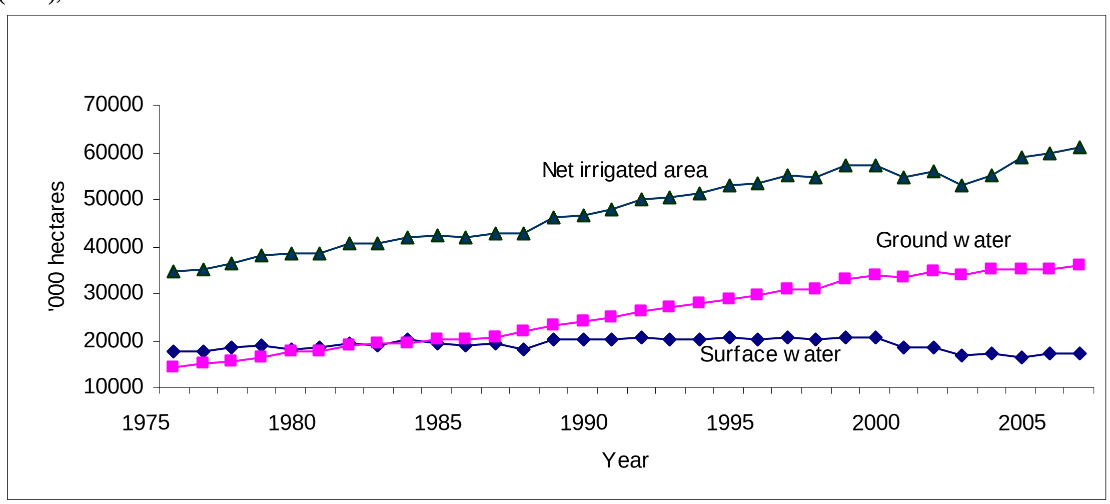


Figure 3.11: Irrigated area in India under surface Water and Ground water sources. Surface water sources include Tanks and Canals and Groundwater sources include Tubewells and other wells. Source: Based on Data from Ministry of Agriculture (GOI), ASG.

3.5.3. Foodgrain Production

Agriculture is the most dominant sector in India for two reasons. Firstly it is still the largest provider of employment accounting for over 50% of the country's workforce. Secondly, it is the source of the most essential need for human life namely food. Over time as the population grows there is a pressure for food production to keep pace. Any temporal shock on agriculture not only affects the incomes of the large number of people engaged in cultivation but the resultant effect on food production can bring considerable hardship in different rungs of society. Food insecurity can prove extremely difficult for the urban middle class and industrial workforce and can be politically difficult to manage. Price rise of foodgrains due to shortage not only affects the citizens of the country, but in a globalized world, can affect global prices and people of other nations as well.

Food grain production (provided in Table Appendix 3.4A) increased by 1.9 times from 121 to 234 million tones between 1975 and 2008 under the force of technological development. After witnessing a period of stagnation in the early part of 2000s due to environmental reasons a quantum leap was encountered in 2007 and 2008 pulling the production figure to 234 million tones. There are a few notable features in this development. The production remains highly vulnerable to rainfall variations. Drought conditions in 2009 SWM season led to a 6% fall in production. This is however less severe than in 2002 when the fall was by 17%. In 2010-11 the La-Nina driven weather at the global scale can disrupt crop output and trigger speculation on food prices and cause food inflation world wide. Excess or untimely rainfall in certain rice producing areas and deficits in others, it is feared has caused damages that will affect kharif crop production.

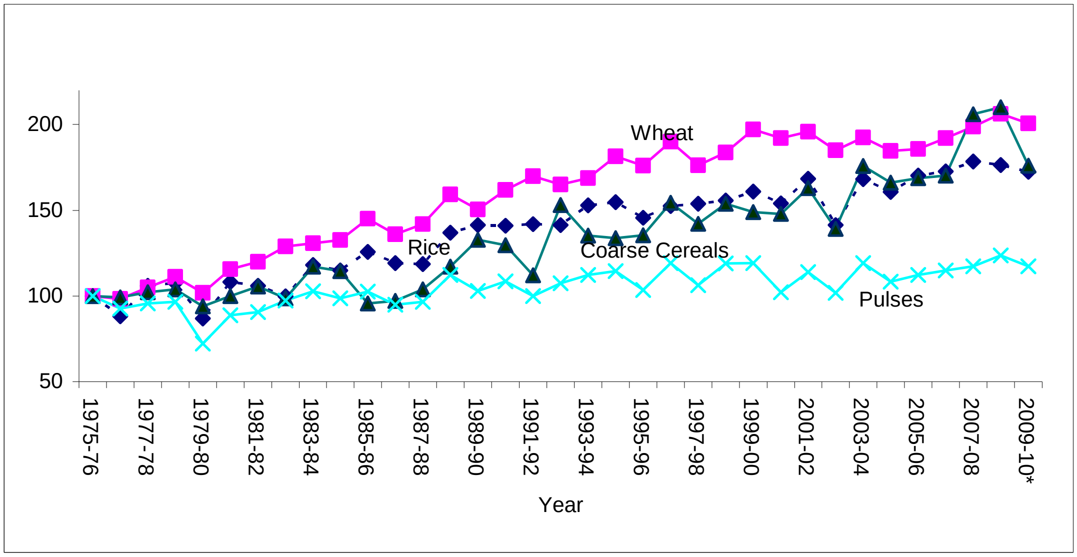


Figure 3.12: Index number of yield rate of Foodgrains (1975-76=100), Source: Based on Data from Ministry of Agriculture (GOI

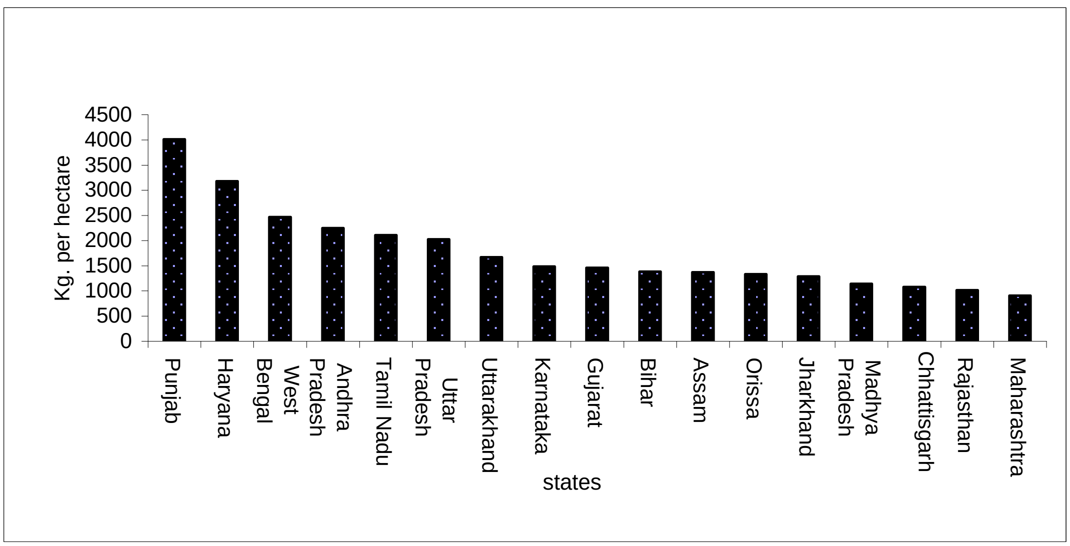


Figure 3.13: Yield rate of Foodgrains state-wise (average of 2005-06,2006-07 and 2007-08) Source: Based on Data from Ministry of Agriculture (GOI

Finally even among the foodgrains there is remarkable disparity of growth performance as seen in trends of indices of crop yield rates Figure 3.12. Wheat has presented the best performance, while coarse cereals, initially lagging has out-performed rice in recent times but pulses known for many attractive attributes have been the slowest moving among the crops. Figure 3.13 graphically shows the disparity in foodgrain yield rates among the Indian states that still persist. Data in Tables 3.5A and amply makes it clear that the growth came from increased use of external inputs. During the period 1975 to 2007 foodgrain productions increased by 27.9%, irrigated area by 23.2% and fertilizer nutrient use by 62.7%. Productivity of the inputs or Total factor productivity also contributed to the performance but its growth slowed down over time (Kumar & Kumar 2010) spatial difference have been wide with coefficient of variation of foodgrain yield bring 47% those of input intensities being 54% for irrigation, 49% for fertilizer and 91% for electricity. Intensities of input use and strongly corrected with yield. Comparison between the two most recent years for which data is reported by agricultural census shows an increasing tendency for mechanization in respect of most common implements (Figure 4).

Table 3.4: Foodgrain Yield and intensity of use of major inputs in Indian Agriculture

States	Yield 00Kg per hectare.	Irrigation Gross intensity	Fertilizer (NPK) Kg/Hectare	Electricity KWH/hectare (Agriculture)
Andhra Pradesh	22.45	46.178	193.863	864.28
Assam	13.69	4.261	53.655	3.94
Bihar	13.86	47.860	121.790	66.67
Gujarat	14.62	39.805	120.867	690.09
Haryana	31.77	85.038	179.477	800.34
Karnataka	14.84	28.740	117.788	602.44
Madhya Pradesh	11.43	30.210	60.755	203.62
Maharashtra	9.08	18.573	96.679	370.87
Orissa	13.36	35.344	46.449	13.81
Punjab	40.14	97.610	215.098	812.50
Rajasthan	10.15	36.466	42.860	234.10
Tamil Nadu	21.10	56.289	186.595	1314.27
Uttar Pradesh	20.25	73.502	85.938	174.04
West Bengal	24.71	56.466	137.606	76.89
Coefficient of Variation	47.34	54.34	48.94	90.74
Correlation with Yield	1.00	0.87	0.80	0.49

Note: Inputs intensities are for all crops together. Source: Based on Agricultural Input survey data.

Table3.5 : Number of Machines used per ‘00 hectare 2001					
STATE	Sprayer	Pumpset	Electric Pumpset	Tiller	Tractor
Andhra Pradesh	17.18	26.06	21.90	2.22	26.75
Assam	0.54	8.02	0.36	7.73	0.75
Gujrat	1.21	12.50	7.53	0.45	6.10
Haryana	5.21	18.31	10.51	3.80	12.44
Karnataka	0.54	9.98	8.69	1.10	4.76
Madhya Pradesh	0.60	11.06	8.21	0.35	4.32
Maharashtra	8.13	19.34	16.60	0.46	2.20
Orissa	0.31	2.70	0.56	1.27	6.83
Punjab	2.01	20.46	11.91	1.40	8.82
Rajasthan	0.83	11.90	4.81	0.46	9.30
Tamil nadu	27.53	78.78	58.90	10.30	47.75
Uttar pradesh	0.35	26.39	3.36	1.12	4.64
West bengal	2.63	14.10	2.16	7.41	6.28
All india	3.75	17.24	9.72	1.72	8.15
Note: The machines are operated by electricity or diesel and obtained on dividing by the gross cropped area. Source: Based on Agricultural Input survey data.					

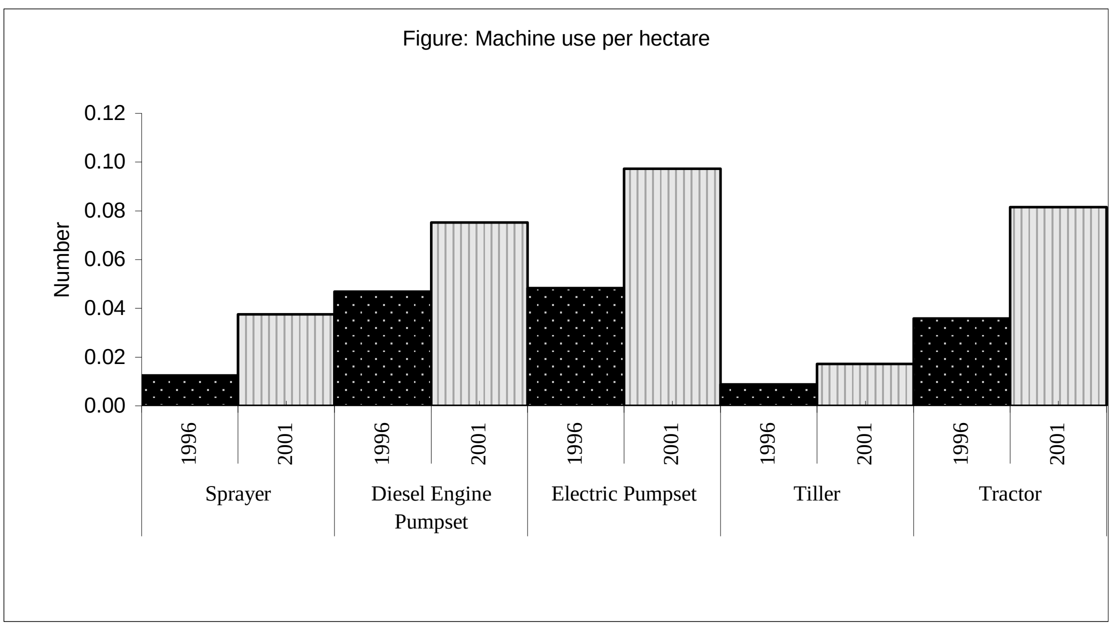


Figure 3.15: Mechanisation in Indian agriculture, Source: Based on Agricultural Input survey data.

Appendix 3.

3.1 The Indian climatic events and IMD's analysis results

3.1.1 Drought

Drought is a situation when a deficit rainfall in an area persists for an extended period. Causing intense scarcity of water, a drought is known to affect the highest number of people among all natural disasters. It is assessed by various ways but most commonly by taking account of the rainfall departure from normal and the extent of area affected. At the regional level a drought is identified when the rainfall from SWM falls short of its long period average (LPA) by say 75% and at the national level a year is considered as a drought year if the areas affected constitute 20-40% of the country and rainfall deficiency in SWM at the country level is at least 10%. Droughts are categorized as mild, moderate and severe. Mean rainfall is the comparison base varies across regions. Since the use of the 'percentage of rainfall departure' method has its limitations, other measures like 'aridity anomaly index' (AI) based on evapo-transpiration potentials in met-stations and the 'standardized precipitation index' (SPI) are becoming popular. The chronically drought prone districts or districts with high probability of drought occurrences typically are in north-western India and decline as one moves towards the east. Trends analysis of district-wise SPI series conducted by IMD showed decreasing trends for drought in some districts but increased trends in others as mostly in central and south of India.

3.1.2. Tropical cyclone

Tropical cyclone is the most devastating of the climate related disasters affecting coastal habitats especially severely. They are large synoptic scale disturbances originating in the warm oceans that develop massive vortices causing swirling winds, intense clouds and torrential rainfall drawing energy from the ocean. Atmospheric and oceanic parameters control the formation of a TC which however dissipates when it enters the land (landfall) or colder seas. Destruction is also caused by associated storm surges implying abnormal rise in sea level when the cyclone moves from ocean to land. Bay of Bengal is the source of 75% of all TCs world wide. Between 1900-2009 the IMD has reported an average of 1387 annual cyclonic disturbances of which 78% were on the Bay of Bengal, 14% on the Arabian Sea and 8% on land. Land disturbances however rarely intensify into TCs. Also over 51% of the depressions occurred in the SWM season (June-September), 35% in the post monsoon season (October-December), 11% in pre-monsoon period (March-May) and only 1.6% in the months of January and February. Long term trend analysis over the period 1891-2008 revealed that frequency of TC over northern Indian Ocean (NIO) , Bay of Bengal (BOB) and Arabian Sea (AS) significantly decreased though there was increasing trend for TC over (BOB) in May and November the principal cyclone months. Since 1961 by when the monitoring improved, signs of decreasing trend of TC formation especially in the SWM months continued but interestingly, there appeared an increasing tendency for annual frequency of severe cyclonic storms (SCS) on NIO and increasing trends were shown by cyclonic storms (CS) and SCS to intensify. Eastern coastal areas in Tamilnadu, Orissa and West Bengal remained vulnerable to TC, along with territories belonging to Sri Lanka, Bangladesh and Myanmar. In the western coast Kerala, Karnataka and Goa were rarely affected by Gujarat in the west was vulnerable. There was no visible trend in the frequency of TCs dissipating before making a landfall.

3.1.3. Floods

Floods are known to cause enormous damage to properties and human life. Inadequate capacity within the banks of the rivers to contain the high flows brought down from the upper catchments subsequent to heavy rainfall. Excessive rainfall in coastal areas, ice-jams or landslides blocking courses of streams, flash floods and glacial lake outburst are other possible reasons but excessive precipitation is mostly the root cause of flood. Floods in India are mostly confined to the Indo-Gangetic plains. Inadequate capacity of rivers to carry surplus water and drain into rivers and streams quickly lead to floods and failure manmade construction of dams and reservoir add to the problem. India has a national flood policy since 1954 and a Rashtrya Barh Ayog (RBA) for estimating damages as also forecasting protocols.

3.1.4. Monsoon vagaries

Monsoon, the dominant feature of Indian climate is marked by erratic behaviour. The variability of monsoon behaviour is usually illustrated by its dates of onset and withdrawal together determining its duration and by its intensity measured by the quantum of rainfall. IMD has examined rainfall data over the period 1941 to 2000 subdivided into two 30 years sub-periods. While the onset has been found to be marginally late compared to a long period normal date, the magnitudes of late onset dwindled in the second period compared to the first. The variability measured by the standard deviation of the date of onset decreased over time and was higher about 11/2 weeks towards the low rainfall areas of the northeast and west and only 1 week over the high rainfall areas of the east. Similarly, withdrawal of SWM was also observed to be later than existing normal by about 11/2 weeks and the withdrawal data has become less variable with time. The late onset and late withdrawal together indicate a shift of the SWM but the duration has become shorter in the second sub-period. The quantum of rainfall has no consistent trend spatially and temporally.

3.1.5. Change in Climate

Analysis of data for the period 1901-2009 to examine if any perceptible changes have been observed with respect to salient climate parameters in India have been reported by IMD. The major findings are as follows:

1. The annual mean temperature for the country as a whole has risen by 0.56^{o}C with significant trends in most part of the country exceptions being Rajasthan, Gujarat and Bihar where the trends were negative.
2. The temperature rise was primarily on account of the similar movement in maximum temperatures. The minimum temperature is rising steadily since 1990 onwards.

3. Maximum rise was observed in post monsoon and winter temperatures followed by pre-monsoon and monsoon season.
4. All India annual monsoon rainfall did not show any significant trend and individual subdivisions showed significant variations.
5. Winter season rainfall is decreasing in almost all sub-divisions with a few exceptions.
6. There has been no significant trend in the number of breaks and active days during SWM.
7. The frequency of extreme rainfall and its contribution to the total rainfall have shown significant and increasing trends
8. Increasing frequency, persistence and spatial coverage of Heat and cold waves are noted.

Appendix table 3.

Table3.1A: Land use ('000 hectare) in India

Year	Reported Area	Fallow Land	Net sown Area	Gross cropped area	Multiple cropped	Forest	Non agricul. Use	Barren	Pastures & Trees	Culturable waste
1970-71	303753	19875	140267	165791	25524	63917	15868	28161	17628	17500
1980-81	304159	24748	140002	172630	32628	67473	19596	19962	15567	16744
1992-93	304855	23559	142509	185487	42978	68067	21771	19382	14877	14589
1996-97	304621	23515	142931	189502	46571	69103	22554	17964	14535	14021
1997-98	304661	24355	141950	190020	48070	69245	23120	17458	14551	13932
1998-99	305006	23693	142753	191649	48896	69215	23348	17524	14575	13899
1999-00	305016	25342	141063	188396	47333	69164	23598	17536	14570	13742
2000-01	305180	25071	141364	185340	43976	69529	23889	17590	14107	13630
2001-02	305118	25905	140733	188286	47553	69406	24049	17524	13982	13520
2002-03	305344	33742	132465	175580	43115	69572	24263	17802	13893	13607
2003-04	305556	25810	140757	190077	49320	69654	24651	17576	13867	13240
2004-05	305578	25168	141167	191545	50378	69646	24890	17578	13856	13271
2005-06	305432	24639	141490	193049	51559	69673	25105	17464	13845	13216
2006-07	305636	25972	139946	193228	53282	69708	25537	17423	13790	13261
2007-08	305685	25148	140861	195835	54974	69626	25923	17295	13699	13121

Source: Based on Data from Ministry of Agriculture (GOI), ASG.

Table3.2A: Irrigation sources for Indian agriculture (Units: Thousand hectare)									
Year	Net irrigated area	Gross irrigated area	Surface Water		Ground Water		Percentage Share	
			Canal	Tank	Well	Others	Surface Water	Ground Water
1975	34593	43363	13791	3972	14444	2386	51.35	41.75
1976	35149	43552	13861	3901	15087	2300	50.53	42.92
1977	36546	46080	14576	3904	15584	2482	50.57	42.64
1978	38059	48307	15149	3937	16429	2544	50.15	43.17
1979	38524	49214	14774	3481	17864	2405	47.39	46.37
1980	38720	49775	15292	3182	17695	2551	47.71	45.70
1981	40503	51412	15946	3376	18737	2444	47.71	46.26
1982	40691	51830	16185	2936	19347	2223	46.99	47.55
1983	41949	53824	16764	3533	19392	2260	48.38	46.23
1984	42145	54529	16275	3021	20394	2455	45.78	48.39
1985	41865	54283	16180	2765	20418	2502	45.25	48.77
1986	42569	55759	16495	2677	20822	2575	45.04	48.91
1987	42892	56036	15746	2523	21796	2827	42.59	50.82
1988	46148	61125	17102	2996	23214	2936	43.46	50.19
1989	46702	61852	17124	2941	23886	2751	42.96	51.15
1990	48023	63204	17453	2944	24694	2932	42.47	51.42
1991	49867	65680	17301	3329	26037	3200	41.37	52.21
1992	50293	66760	16986	3179	26920	3211	40.09	53.52
1993	51340	68255	17111	3152	27762	3427	39.38	53.96
1994	53001	70646	17280	3276	28912	3533	38.78	54.55
1995	53402	71352	17120	3118	29697	3467	37.90	55.61
1996	55112	76025	17352	3343	30825	3623	37.53	55.90
1997	55173	75423	17092	3100	30880	3491	37.01	56.60
1998	57411	78373	17708	2939	33158	3272	36.17	58.09
1999	57109	78794	17995	2706	33632	2905	36.17	58.76
2000	55076	76574	15988	2524	33277	2892	33.85	60.86
2001	56672	78732	16335	2291	34501	2725	33.35	61.77
2002	53778	73545	14863	1868	33840	2578	31.48	63.67
2003	56618	77998	15146	1943	35265	2752	31.01	63.99
2004	58867	79997	14659	1725	34897	7546	27.85	59.32
2005	60196	82625	15284	2080	35067	7447	29.00	58.56
2006	60857	85783	15351	2044	35909	7554	28.58	59.00
2007	63099	87920	16690	1968	38370	6072	29.57	60.81
2008	63196	88419	16596	1979	38576	6045	29.39	61.04
Source: Based on Data from Ministry of Agriculture (GOI), ASG.								

Table3.3A: Share in Gross cropped Area (GCA) of agricultural crops in India.							
Year	GCA ('000's)	Percentage Share					
		Foodgrains	Rice	Wheat	Coarse cereals	Pulses	Others
1975	171296	74.83	23.05	11.94	25.57	14.27	25.17
1976	167334	74.32	23.01	12.50	25.06	13.73	25.68
1977	172232	74.04	23.39	12.46	24.55	13.64	25.96
1978	174802	73.80	23.16	12.95	24.16	13.54	26.20
1979	169589	73.83	23.24	13.07	24.39	13.13	26.17
1980	172630	73.38	23.26	12.91	24.20	13.01	26.62
1981	176750	73.06	23.03	12.53	24.02	13.49	26.94
1982	172748	72.42	22.15	13.64	23.40	13.22	27.58
1983	179560	73.05	22.97	13.74	23.23	13.11	26.95
1984	176330	71.84	23.34	13.36	22.24	12.90	28.16
1985	178464	71.73	23.05	12.89	22.12	13.68	28.27
1986	176405	72.11	23.34	13.11	22.53	13.13	27.89
1987	170738	70.10	22.73	13.51	21.41	12.46	29.90
1988	182277	70.04	22.89	13.23	21.22	12.70	29.96
1989	182269	69.55	23.14	12.89	20.68	12.84	30.45
1990	185742	68.83	22.98	13.01	19.55	13.28	31.17
1991	182242	66.87	23.40	12.76	18.34	12.37	33.13
1992	185700	66.32	22.50	13.24	18.54	12.04	33.68
1993	186580	65.79	22.80	13.48	17.59	11.93	34.21
1994	188053	65.86	22.76	13.67	17.11	12.25	34.14
1995	187471	64.55	22.85	13.34	16.47	11.88	35.45
1996	189502	65.21	22.92	13.66	16.79	11.85	34.79
1997	190020	65.18	22.87	14.05	16.22	12.04	34.82
1998	191688	65.30	23.37	14.36	15.31	12.26	34.70
1999	188428	65.33	23.97	14.59	15.57	11.21	34.67
2000	185373	65.30	24.12	13.88	16.32	10.98	34.70
2001	189708	64.72	23.67	13.88	15.56	11.60	35.28
2002	175618	64.83	23.45	14.35	15.37	11.67	35.17
2003	190200	64.91	22.39	13.99	16.19	12.33	35.09
2004	190422	63.02	22.01	13.85	15.25	11.95	36.98
2005	192796	63.07	22.65	13.73	15.06	11.61	36.93
2006	193723	63.86	22.61	14.45	14.82	11.97	36.14
2007	195156	63.57	22.50	14.37	14.59	12.11	36.43
2008	195104	62.96	23.34	14.22	14.07	11.32	37.04
Source: Based on Data from Ministry of Agriculture (GOI), ASG.							

TableA3.4 :Production and Yield of Foodgrains in India										
	Foodgrains		Coarse cereals		Pulses		Rice		Wheat	
year	Production	Yield	Production	Yield	Production	Yield	Production	Yield	Production	Yield
1975	121.03	944	30.41	694	13.04	533	48.74	1235	28.84	1410
1976	111.17	894	28.88	689	11.36	494	41.92	1089	29.01	1387
1977	126.41	991	30.02	710	11.97	510	52.67	1308	31.75	1480
1978	131.90	1022	30.44	721	12.18	515	53.77	1328	35.51	1568
1979	109.70	876	26.97	652	8.57	385	42.33	1074	31.83	1436
1980	129.59	1023	29.02	695	10.63	473	53.63	1336	36.31	1630
1981	133.30	1032	31.09	733	11.51	483	53.25	1308	37.45	1691
1982	129.52	1035	27.75	685	11.86	519	47.12	1231	42.79	1816
1983	152.37	1162	33.90	813	12.89	548	60.10	1457	45.48	1843
1984	145.54	1149	31.17	795	11.96	526	58.34	1417	44.07	1870
1985	150.44	1175	26.20	664	13.36	547	63.83	1552	47.05	2046
1986	143.42	1128	26.83	675	11.71	506	60.56	1471	44.32	1916
1987	140.35	1173	26.36	721	10.96	515	56.86	1465	46.17	2002
1988	169.92	1331	31.47	814	13.85	598	70.49	1689	54.11	2244
1989	171.04	1349	34.76	922	12.86	549	73.57	1745	49.85	2121
1990	176.39	1380	32.70	900	14.26	578	74.29	1740	55.14	2281
1991	168.38	1382	25.99	778	12.02	533	74.68	1751	55.69	2394
1992	179.48	1457	36.59	1063	12.82	573	72.86	1744	57.21	2327
1993	184.26	1501	30.82	939	13.30	598	80.30	1888	59.84	2380
1994	191.50	1546	29.88	929	14.04	610	81.81	1911	65.77	2559
1995	180.42	1491	29.03	940	12.31	552	76.98	1797	62.10	2483
1996	199.44	1614	34.10	1072	14.24	635	81.74	1882	69.35	2679
1997	192.26	1552	30.40	986	12.98	567	82.53	1900	66.35	2485
1998	203.61	1627	31.34	1068	14.91	634	86.08	1921	71.29	2590
1999	209.80	1704	30.33	1034	13.42	635	89.68	1986	76.37	2778
2000	196.81	1626	31.08	1027	11.08	544	84.98	7877	69.68	2708
2001	212.85	1734	33.38	1131	13.37	607	93.34	2079	72.77	2762
2002	174.77	1535	26.07	966	11.13	543	71.82	1744	65.76	2610
2003	213.19	1727	37.60	1221	14.91	635	88.53	2077	72.16	2713
2004	198.36	1652	33.47	1153	13.13	577	83.13	1984	68.64	2602
2005	208.60	1715	34.07	1172	13.39	598	91.79	2102	69.35	2619
2006	217.28	1756	33.92	1182	14.20	612	93.36	2131	75.81	2708
2007	230.78	1860	40.75	1431	14.76	625	96.69	2202	78.57	2802
2008	234.47	1909	40.04	1459	14.57	659	99.18	2178	80.68	2907
2009	218.20	1798	33.77	1222	14.60	637	89.13	7459	80.71	2879
Source: Based on Data from Ministry of Agriculture (GOI), ASG.										

Table 3.5A:Foodgrain production and Input use in Indian agriculture					
year	Production (mill. Tonnes)	Irrigation ('000hectare)	Electricity(Ag.)	fertilizer ('000 tonnes)	Farm size
1975	121.0	43363.0	8721.0	2893.7	
1985	150.4	54283.0	23422.0	8737.0	1.69
1995	180.4	71352.0	85732.0	13876.2	1.41
2005	208.6	82625.0	90292.0	20340.3	1.23
2006	217.3	85783.0	99023.0	21652.2	
2007	230.8	87920.0	104182.0	22570.1	
%increase					
1975-85	24.3	25.2	168.6	201.9	
1985-95	19.9	31.4	266.0	58.8	-16.568
1995-2007	27.9	23.2	21.5	62.7	-12.766
Source: Compiled by various sources.					

Table3.6A: Flood affected area and flood damages in India (1953-2004)					
Sl. No.	Item	Unit	Average	Maximum Damage	Damage During
1	2	3	4	5	6
1	Area Affected	Million Hectares	7.63	17.5	8.47
		Years		1978	
2	Population Affected	Million nos	32.92	70.45	34.19
		Year		1978	
3	Human Live Lost	No.	1597	11316	1650
		Year		1977	
4	Cattle Lost	000 nos.	94	618	67
		Years		1979	
5	Cropped Area Affected	Million Hectares	3.56	10.15	2.92
		Year		1988	

Table 3.7A: Descriptive measures of Rainfall in Monsoon months for India (1975 to 2008)					
	JUN	JUL	AUG	SEP	JUNSEP
Mean	154.05	257.06	241.44	157.17	809.73
Std. Dev.	25.78	45.28	34.40	38.49	89.15
Skewness	0.12	-1.01	-0.09	0.54	-0.07
Kurtosis	2.43	5.50	2.25	2.45	2.65
Jarque-Bera	0.54	14.61	0.84	2.08	0.20
Probability	0.76	0.00	0.66	0.35	0.90
%Distribution	17.49	33.02	29.77	19.72	100.00
Note: Rainfall is in millimeters, Normal rainfall is 3 year average of long term normal (2006-07, 2007-08, 2008-09) Source: IMD, Indiastat.com					

Table 3.8A: Correlation Coefficients (Spearman) among the monsoon season months					
	Jun	Jul	Aug	Sep	Junesp
Jun	1.00	0.26	-0.04	-0.13	0.35
Jul	0.26	1.00	0.13	0.38	0.80
Aug	-0.04	0.13	1.00	0.21	0.53
Sep	-0.13	0.38	0.21	1.00	0.67
Junsep	0.35	0.80	0.53	0.67	1.00
Source: IMD, Indiastat.com					

Table 3.9A: Movement of Standard deviation of Seasonal Rainfall in states								
States	1975-85		1985-1995		1995-2005		2005-2010	
	June-Sept	Oct-Dec	June-Sept	Oct-Dec	June-Sept	Oct-Dec	June-Sept	Oct-Dec
Andhra Pradesh	160.89	54.35	152.92	99.79	118.03	84.64	198.97	92.82
Assam	32.15	21.67	70.15	17.40	57.37	18.67	111.36	19.26
Bihar	164.71	69.18	187.08	53.70	183.31	55.49	290.29	44.20
Gujarat	213.07	47.40	244.70	30.25	220.88	38.36	262.05	18.79
Hrayana	150.76	25.55	249.32	28.14	138.55	51.41	182.09	26.46
Karnataka	161.97	59.61	150.97	87.59	172.46	43.18	284.53	73.27
Maharashtra	176.34	37.65	164.40	64.36	121.50	84.69	256.94	42.62
Madhya Pradesh	147.25	28.57	177.86	29.40	112.90	55.62	269.19	27.75
Orissa	119.79	60.76	201.09	127.51	188.06	132.38	382.55	129.06
Punjab	137.96	35.02	286.02	25.84	165.97	45.05	132.05	17.35
Rajasthan	143.21	17.46	117.67	15.55	108.91	28.93	125.90	12.25
Tamil Nadu	83.71	118.07	63.78	147.58	90.25	181.67	84.06	200.56
Uttar Pradesh	192.95	47.08	126.69	46.62	130.45	40.90	240.58	23.91
West Bengal	266.43	50.31	161.50	78.81	191.49	112.53	387.66	137.86
Source: IMD, Indiastat.com								

Chapter 4:

How Climate change can matter for Indian Agriculture

In this chapter we explore how climate changes can possibly impinge on Indian agriculture. Four broad channels are considered although there are overlaps and intricate causality effects tying the categories together. The implications relate to (1) monsoon circulation in India, (2) water availability at the regional level, (3) effect of high temperature on crop biological processes and (4) possible consequences and evidences of extreme weather events. At the outset we stress that the discussion is only based on current level of knowledge and emerging evidences. The literature review is supplemented by some in-house data analyses.

India is bestowed with a monsoonal climate in which the south west monsoon plays a supreme role. Much of India's agricultural activities are in line with monsoon pattern, the kharif season being the most important cropping season accounting for 54% of India's acreage. The performance of India's agriculture, despite all the advancement of technology is till today intensely influenced by the rainfall performance. Climate change can therefore prove critical for agriculture in India if it impinges on the monsoon pattern.
In section 4.2 we have examined the literature in a search for the implications that global warming can have on Indian monsoon and thereby on agricultural production supplemented with our own analysis in sections 4.3.

Secondly, it is anticipated that global warming can change the availability of soil water which is already a scarce resource that is gaining increasing significance in India. Water stocked and recharged in the surface and sub-surface domains of the earth are important for agriculture even in regions that are not directly dependent on monsoon rainfall because of irrigation facilities. Even the rabi crop that is sown in the post-monsoon season is affected by the moisture remains in the soil from the departed monsoon. The implications in India context are discussed in Section 4.4. Finally, higher temperature can directly impact on crop growth by interfering with the phonological processes of plants. Biological processes of plants are suited to certain optimal temperatures, deviations from which can hurt the normal maturation and productivity. The theoretical underpinnings of hypotheses and empirical evidences are reviewed in Section 4.5. We also address the possibilities that the climate change impacts on the coastal areas and the intensities of extreme events may not be favourable for agriculture in section 4.6.

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4.2. Global warming and the Monsoon

Monsoon, associated with the seasonal reversion of the direction of wind is the dominant feature of Indian climate. Its deep relation with the agriculture of the country has been intensely felt through centuries of history. About 75 to 90% of the total rainfall over India occurs during summer monsoon season that witnesses the inflow of moisture laden winds of the south-west monsoon (SWM) from the seas. There is also some rain in the winter season as in parts of northern India associated with western disturbances and in peninsular southern India with north-east monsoon.

Agricultural production is related to monsoonal changes not only via the availability of water but also the shortage of hydroelectric power, regional droughts and floods and receding ground water. Projections of the possible behaviour of the monsoon winds will be important to prepare the country for the effects of climate change. Moreover, since historically monsoon vagaries are an integral part of Indian climate. The revealed responses of farmers to the uncertainty surrounding the date of onset and early withdrawal of monsoon, dry spells and excessive or deficient rainfall could be a clue to the possible adaptation mechanism that can come autonomously.

The Asian monsoon circulation is an important component of the global circulations that shape the climate of the earth. The monsoon is considered as a manifestation of the seasonal migration of the planetary scale equatorial trough or the tropical convergence zone (TCZ). The Asian summer monsoon is one of the most robust components of the global circulation system and makes the largest contribution to the annual cycle of atmospheric heating and to the inter-annual variability of tropospheric circulation. The land to sea temperature gradient during the monsoon months is regarded as the main driving force behind the monsoon circulation over the Indian sub-continent, creating pressure differences and drawing moisture from the ocean to the land that heats up relatively faster. The monsoon season that starts in early June and ends in late September begins at the southeast tip of India and moves northwestward from Kerala towards the rest of India and Pakistan but the progression is not necessarily uniform.

Simulating Asian monsoon circulation is one of the critical tests that global climate models today face. Although these models simulate large scale climatological features in response to global forcings reasonably well, they have difficulty capturing the finer and subtle regional scale atmospheric processes. Simulation of seasonal rainfall and its spatial and temporal variability over the Indian sub-continent has been limited by technical difficulties that hinder the capture of regional complexities like varying topography. In general, regional characteristics like land-sea thermal contrast, orographic features, vegetation cover and inland water basins play an important role in the establishment of summer monsoon over the sub-continent. The thermal structure of the adjoining oceans- the Arabian Sea, the Bay of Bengal and Indian Ocean also have a modulating influence on the monsoon. Significant spatial, inter-annual and intra-seasonal variabilities are observed in India and these are manifested in recurrent droughts and floods often contemporaneously in various parts of the country. The simulation would also ideally take account of other flows like the upper westerly jet during winter and the tropical easterly jet during the monsoon and the seasonal reversal of the surface winds from south easterlies to south-westerlies.

Modeling of the Indian climate is further complicated by the presence of influences other than the monsoon, some of which run counter to the global warming implications. Aerosols and the observed presence of the atmospheric brown cloud (ABC) are an added climatic effect dimming and cooling the earth. Expectedly, the cooling effect of ABC (by reducing temperature gradient) can result in a weakened monsoon (Aufhammer et al, 2006). Extensive ABCs of black carbon and other aerosols are observed to cloak the

Indian sub-continent and the northern Indian Ocean and are noted in many parts of the world.

Due to these clouds manifesting air pollution resulting from burning fossil fuel and biomass, solar radiation in the lower atmosphere is scattered back to the space. In effect they reduce radiation at the earth surface and partially offset surface warming caused by greenhouse gases. Research has indicated their negative implications not only on radiation and temperature but also on rainfall by weakening the temperature gradient. During 1930-2000 the observed cumulative increase in annual mean surface temperature in India was 0.44 ^{O}C less than in regions without ABC and it was smaller in the day when the cooling effect of ABCs is strongest. Since the 19th century increased snow fall in the Himalayas has been linked with weaker monsoon over India due to suppression of temperature gradient. At the same time the presence of ENSO in the tropical Pacific has a profound effect on this relation. Besides, feed back effects of moisture-laden clouds can be both positive due to back radiation from long wave surface warming at night and negative because of the increased reflectance by such clouds allowing less insolation.

The developmental routes taken by human beings as usual add to the uncertainty and the individual forcings of the greenhouse gases and their trajectories as well as of aerosols are also important. Recent experiences of the 2000s decade have demonstrated instances of vagaries of the SWM that could arguably be associated with climate change. Trends of delayed monsoon in certain regions are associated with climate change though there is no firm evidence. There are also sign of abating winter monsoon, greater monsoon rains and intense and shorter spells of monsoon all of which can be arguably associated with climate change.

Recently intense interest has been focused on the projection of monsoon changes associated with anthropogenic emissions. These models have difficulty in capturing some of the subtle atmospheric processes and the complexity of the topography. Using the A-O GCMs developed by the Japanese Centre for Climate Research and the National institute for Environmental Studies that make separate treatments for individual primary greenhouse gases, account for ozone and aerosol effects simulations under the IPCC's four marker emission scenarios (SRES), a study on Asian monsoon found the likelihood of greater increase of winter temperature compared to the monsoon season and an associated increase in monsoon rainfall. No significant change in inter-year variability of precipitation was projected but the model predicted increasing probability of extreme rainfall events and enhanced variability of the date of onset of summer monsoon. Even while there is considerable scope for exploring the effects of global warming on Indian monsoon, preliminary results clearly suggest that monsoon delays could be more common in future along with the increased possibility of drought and excess rainfall. More spatial differences of the incidences of these events can be expected along with reduced rainfall and higher temperature in the winter.

Simulations for future monsoon pattern based on general circulation models made by scientists at the Purdue University (Science Daily, 2009) foresee that climate change can influence the dynamics of the monsoon, cause less rain, delay the start of the monsoon season and elongate the breaks between rainy periods. The models project a delay of 5-15 days by the end of the 21st century and overall weakening of the summer monsoon over South Asia. This is despite the rationale that a temperature increase can strengthen the large scale circulation. This model finds a weakening of the convective circulation and suggests that global warming can in fact change where and when the rain will be delivered. Thus more rain over Indian Ocean, Bangladesh and Myanmar is likely and less over India, Nepal and Pakistan. The probability of intense rainfall also increases. The authors however caution that the detailed simulations only highlight the complexity of the subject and the need for better understanding of the process.

The broad expectations on monsoon effect of climate change as projected by the models are summarized in the Table 4.1 and suggest that both temperatures and precipitations are likely to increase in future along with more erratic monsoon. The trend analysis done with data from recent decades in Chapter3 shows that temperature has increased widely but there is no firm indication that precipitation has increased over time. Pathak, 1999 examined the trends in rice and wheat seasons in Indo-Gangetic plains (IGP) and found

found that the trends in temperatures were not so clear (Table 4.2) though a decreasing trend of solar radiation was detected. This is in contrast with a general evidence of declining minimum temperature all over the world (Kukla and Karl, 1993) as cited by the authors.

Table 4.1 Summary of projections on India's temperature and precipitation	
Temperature	Precipitation
IPCC projected a 0.5-1.2^{O} C rise by 2020 and 0.88^{O} - 3.16^{O}C by 2050 (South Asia). Mean annual surface temperature in North India will increase by 3^{O} C or more depending on anthropogenic forcings in this century.	An Increase of about 7-10% in area averaged mean annual precipitation in the subcontinent by 2080. Alternate projections include reduced precipitation and intensification of extremely hot conditions, decrease in convective precipitation.
Peak warming more in winter than in monsoon season	Appreciable spatial pattern. A30% increase in precipitation in monsoon season in north-west by 2050. The western semi-arid margins of India could receive higher than normal rainfall.
Peak warming will be more in north India than in peninsular India	A 5-25% decline in area averaged winter precipitation compared to 10-15% rise in summer precipitation in monsoon season(ref)
	The year-to year variability of monsoon rainfall is not likely to change. No appreciable shifts in rainfall maxima during July-August.
	Enhanced variability in the date of onset of summer monsoon over central India. Frequent delays in the starting of monsoon season are a common finding.
	Increase in the probability of extreme rainfall events.
Source: compiled from various sources.	

Table 4.2: Number of sites showing increases and decreases in Weather parameters over time in Rice and Wheat seasons of IGP						
Direction of change over time	Radiation	Minimum temperature	Maximum temperature	Radiation	Minimum temperature	Maximum temperature
	Rice			Wheat		
Decrease	4	1	0	3	2	3
Increase	0	1	0	0	0	0
Note: Total numbers of sites are 9. Only statistically significant figures are reported. Trends are based on linear regression. Source Adapted from Pathak et al (2005)						

4.3. Farmer’s responses to Monsoon delay

Crop production depends on both the allocation of land among the feasible crops and on the crop yield rates. Planting decisions are taken voluntarily by farmers who take account of profitability and crop specific agronomic concerns. Although prices are important forcing factors for acreages, the significance of farmers’ anticipation of rainfall as shaped by a continuous monitoring of the emerging reality cannot be minimized. Coping with monsoon vagaries to minimize losses is a strategy that Indian farmers have developed in the course of centuries. Unlike planting that is largely an autonomous decision of farmers, crop yield rates could be beyond control. Nevertheless, farmers are careful to ascertain in a limited way that that enough water is available for the sown crops before making investments on other costly inputs. As in the case of acreage, farmers can to an extent watch and monitor the situation and take measures in a phased way that would reduce the losses even after the crop is sown and a minimum investment is already made. Thus a change in the pattern or intensity of monsoon would influence farmers’ decisions on the input use, and thereby on crop yields and incomes.

Monsoon arrives in different parts of India at different points of time in June so that a delayed onset will be reflected in the shortfall in June rainfall relative to its normal. Thus a shortfall of 20% over the normal can be equivalent to a delay of 6 days assuming that rainfall is expected to be uniformly distributed within the month (20% of monthly normal divided by per day normal rainfall i.e., 0.2/ (1/30))). Figure 4.1 plots the frequency of delayed monsoon specified in this way for the major Indian states. Atleast in 5 states monsoon has been delayed in over 40% of the sample period. In table 3. We found that although the SWH rainfall is negatively skewed, rainfall rainfall in june shows a positive skew so that probability of shortfall is high. Given this indeterminacy about the arrival of monsoon and farmers’ possible responses, acreages contribute to the uncertainty surrounding production prospects. Not surprisingly, every year the farmers, the government and the administrative machinery in India keenly watch the arrival and the unfolding of the SWM in June and July.

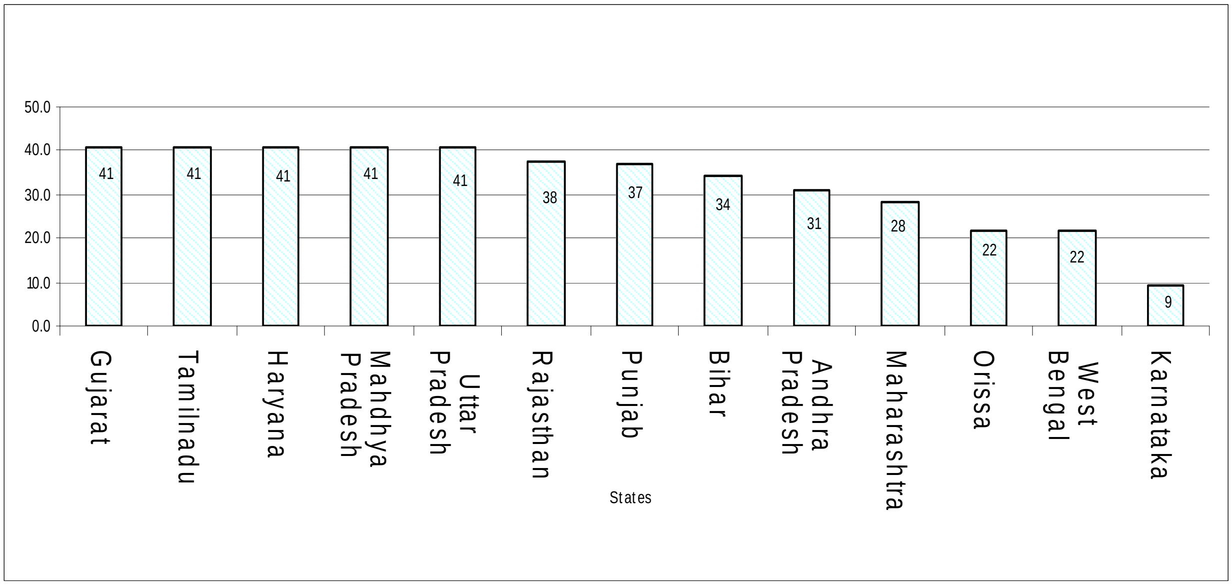


Figure 4.1: Cases (%) of delayed monsoon in 1975-09. Monsoon is assumed to be delayed if June rainfall is less than 20% of the sample average. Source: Computed.

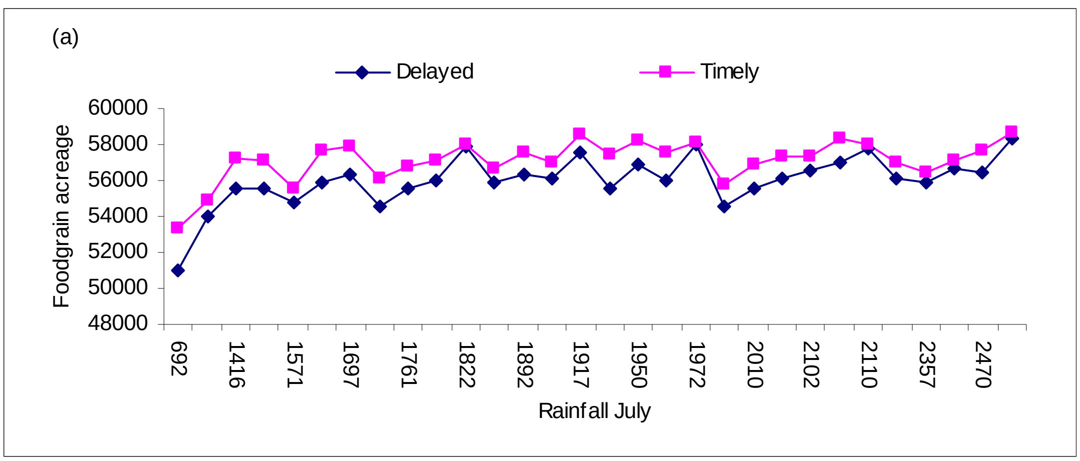
Given that different alternative crops generally vie for limited land in the main kharif season, farmers' responses would incorporate a choice among varied strategies, such as waiting for the monsoon, sowing an alternative crop and deferred decision to sow or not to sow. The decision would depend on agronomic needs of the crops, the nature of rotations, economic considerations and above all on the farmers' perceptions and preferences. Rainfall is crucial weather variable determining crop acreages in the kharif season where the crops are adapted to warmer weather. Empirical evidences using temperature data also found that the effect of temperature on rice acreage is not significant although higher temperatures can hurt rice yields (Auffhamer et al, 2006). Climate change is likely to make the onset (and the quantum of June rainfall) uncertain and increase the rainfall received in the month of July (that generally receives a bulk of the monsoon rain). To the extent that July rainfall increases (assuming climate change is associated with higher precipitation), the effect can actually be beneficial to some crops and even possibly make up for the damage done by the delay. Thus the impact of climate change on food security in the monsoonal country is largely uncertain.

Studies on acreage responses taking account of monsoon delays are rare to come by. We estimated a model under the conventional Nerlovian framework looking for ways to specify sowing season rainfall. The dependent variable is cropped area and the model is estimated for seven major food grain crops raised in the kharif season of which three crops Jowar, Bajra and Maize are Coarse cereals, three crops Moong, Urad and Arhar are Pulses and the seventh and possibly the most important crop in the country is Rice. Thirteen major states are considered and acreage responses of the crops dominantly grown in these states are estimated. As there are tremendous heterogeneities among the state in terms of agro-climatic conditions, crop varieties and cropping practices, time-series data based single equation method for each crop-state was preferred to a panel data analysis from pooling the states that would require that the states share certain common parameters. The equations are corrected for other effects like relative prices, irrigation availability and input price. Data reported by the Ministry of Agriculture (website) and IMD (website) are used.

We considered two models one with rainfall levels in the months June and July constituting a monthly rainfall model (MRM) and a delayed rainfall model (DRM) where the responses to the June and July rainfall levels are made sensitive to the timeliness of the monsoon by using a dummy interaction variable. A comparison of the root mean square measures of suggested the superiority of the DRM.

Preliminary analysis of the results (the study is under completion and so the results are only initial, awaiting further checking) suggest that the marginal effects of rainfall are not always positive except in the case of Rice. For coarse cereals and pulses more rainfall in June or July generally discourages planting. In the specific case of July rainfall, a larger response in the delayed monsoon case would indicate an effort to make up for the loss of acreage due to the June shortfall. In Rice there are two cases in which the coefficient is larger and the difference is also statistically significant. In some of the major producing states like West Bengal Uttar Pradesh and Tamil Nadu, contrary to expectations, the power of July rainfall to increase acreage falls short when monsoon is delayed compared to when it is timely suggesting that the farmers shift their land to other crops or choose to leave it fallow.

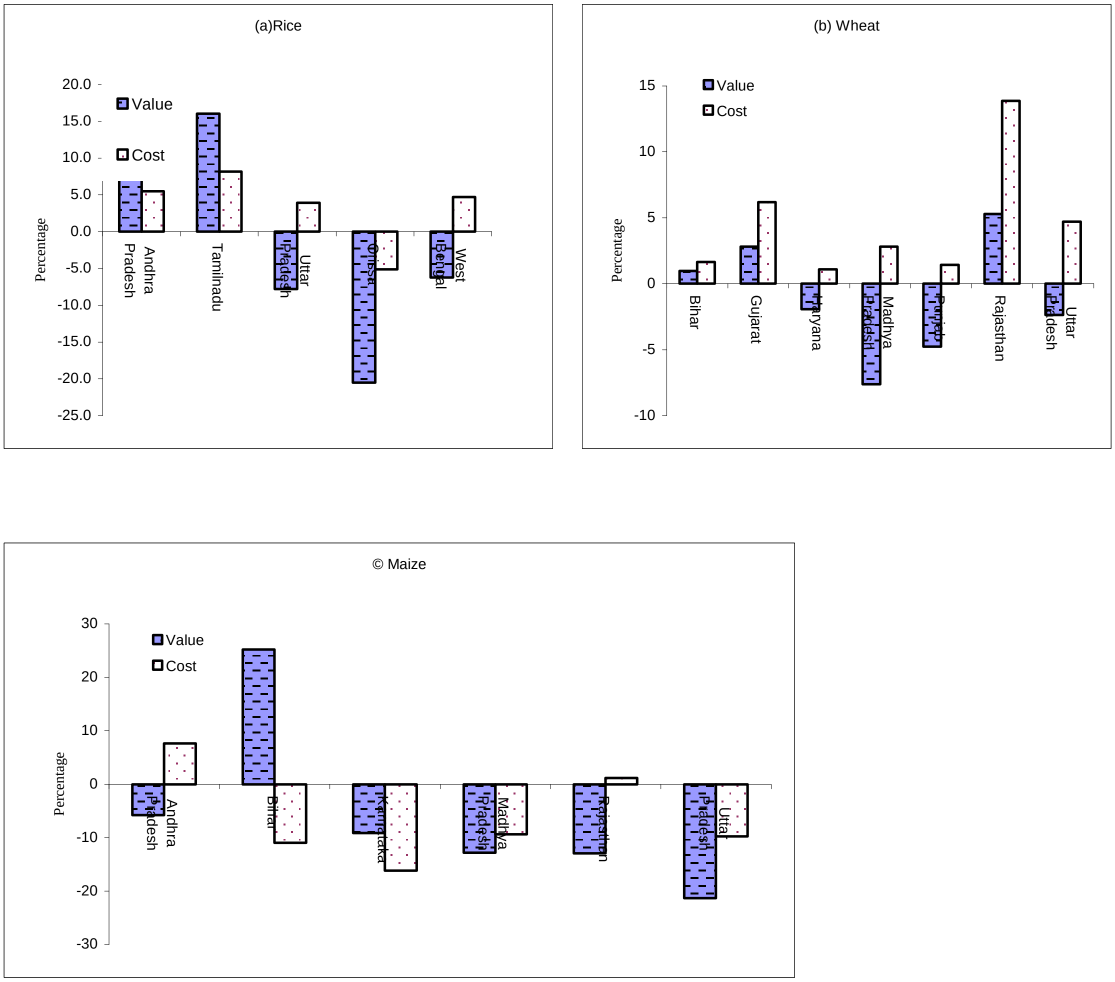
Given that regressions estimates are contrasting among the states, we attempt to get a comprehensive picture by aggregating acreages for all foodgrains over all the states combined under two sets of assumptions (a) the delayed rainfall case assuming June rainfall is one percentage point below the threshold of 20% shortfall or 6 days delay and (b) a timely rainfall case when June rainfall is normal. The July rainfall and all other variables are allowed to take their actual values. Since a positive influence of July precipitation is a conjecture, the simulated values of acreages are plotted against a domain of July rainfall in Figures 4.2. The plots suggest a weak response to July rainfall for foodgrains production and the two curves do not cross, but only meet at few points. Despite the opportunity of making up lost acreages due to delayed rainfall, simulations suggest that foodgrain production is less under delayed rainfall than under the default scenario of timely rainfall. Thus even if July rainfall increases with climate change, it does not assure acreage gains for foodgrains whereas the timing of the monsoon appears to be crucial factor.



Figures 4.2: Estimated acreages under broad crop group kharif Food grains as sum of Coarse cereals, Pulses and Rice aggregated over the states under two alternative Monsoon scenarios. Acreages are in '000hectares. July rainfall is the weighted average of the states under the individual crop groups using net cropped area as weights and is measured in millimeters. Source: Computed.

Monsoon effects on crop yields and farm incomes have been of greater attention. That monsoon failure can have harsh and adverse effects of famers' conditions and crop production and also invoke various coping strategies are documented in the vast literature on risk literature. In recent times monsoon has failed severely twice once in 2002-03 and the other in 2009-10 demonstrating how despite all the technological progress Indian's agricultural performance is still linked with that of the monsoon. It may be noted that farmers too are cautious about their decisions and stay in tune with the observed rainfall behaviour and may also respond to forecasts if available. When the rainfall is less than expected, the farmers may choose to spend less on fertilizers, seeds and other inputs and use less of labour than they would have done if rainfall was normal. This will help in cost saving. However, containing economic losses can hardly overcome physical yield losses. We take a look at the farmers' responses and the outcomes of the drought in 2002 kharif season as reflected by the cost of cultivation data provided by the Ministry of Agriculture.

In the year 2002 the SWM failed miserably and brought only 81% of the long period average of the normal rainfall. The month of July saw a 49% shortfall of rainfall. We have compared farmers' investments and crop performance in that year with normal circumstances in respect of three major crops in specific growing states. Since 2001 and 2003 were fairly normal years in respect of SWM performance, we have used the average of the two years that were proceeding and subsequent to the drought year in question as the reference normal case. We expect to find reduction in respect of all attributes relating to input use, cost, yield and value of product as part of farmer's coping mechanism and the outcome of rainfall failure.



Figures 4.3: Changes (%) in value of output and cost of cultivation per hectare in Drought year 2002 relative to the average of two normal year values 2001 and 2003. Source: Based on Cost of cultivation of Principle crops, Government of India. Source: Computed based on Cost of Cultivation data (MOA)

Rice is a kharif crop directly impacted by the performance of monsoon but wheat which is a rabi crop and maize which is partly so, the soil moisture content determined by the monsoon is a serious influence. Wheat too underperformed in 2002. In Table 4.3 the use of inputs fertilizer has failed to respond o the drought in most cases except in the case of maize. The same can be said about seeds and labour in physical quantities to a lesser extent. Crop yield rate have fallen, rice in Andhra Pradesh and maize in Bihar being exceptions that could beat the drought to an extent. Figures 4.3 show that in cases where the value of output fell, the cost too followed the same direction suggesting farmer's adaptation to protect income. The percentage by which cost decreased was generally

Table 4.3: Crop performance and input use in a drought year								
	Fertilizer(Kg)		Labour (Hrs)		Seed (Kg)		Yield(Kg)	
	Normal	Drought	Normal	Drought	Normal	Drought	Normal	Drought
Rice								
Andhra Pradesh	180.39	189.50	975.90	1019.10	80.53	80.34	50.20	49.70
Tamilnadu	200.07	183.12	926.38	881.99	0.00	0.00	44.91	45.67
Uttar Pradesh	116.78	120.86	838.46	874.13	0.00	0.00	35.53	30.91
Orissa	90.36	90.10	1113.54	1058.19	90.90	92.03	31.85	25.52
West Bengal	102.88	115.89	1209.04	1250.35	72.72	70.83	36.05	35.59
Maize								
Andhra Pradesh	147.38	169.62	630.17	583.61	21.70	20.76	28.95	26.77
Bihar	118.22	106.31	811.18	758.24	21.18	20.31	28.32	31.91
Karnataka	132.89	92.63	674.33	495.18	17.56	16.88	20.46	17.57
Madhya Pradesh	30.54	24.39	456.75	428.65	22.10	22.10	10.15	7.49
Rajasthan	62.52	56.50	661.77	594.75	30.50	30.43	16.34	11.19
Uttar Pradesh	51.66	53.64	788.04	647.07	20.61	21.19	15.56	8.19
Wheat								
Bihar	123.935	130.24	495.72	485.68	118.28	121.33	22.71	22.53
Gujarat	142.175	159.18	608.53	685.94	153.515	149.20	30.99	29.2
Haryana	194.115	198.08	305.175	311.12	120.745	121.40	40.77	39.61
Madhya Pradesh	83.775	97.12	349.41	392.65	115.115	116.31	20.66	18.35
Punjab	224.575	222.12	217.11	216.57	103.685	104.63	42.86	40.66
Rajasthan	108.445	116.1	591.36	619.14	152.59	147.54	34.07	33.05
Uttar Pradesh	145.35	153.16	459.01	444.65	141.095	145.77	32.54	30.7
Note: Drought year=2002, Normal=average of 2001 and 2003. Source: Based on Cost of Cultuvation data od Government of India. Source: Computed.								

lower than that of the output. Indeed in four such states the cost of producing wheat actually increased indicating over investment. Only in Tamilnadu for rice and Bihar for maize did the output increase more than the cost. These findings possibly indicate the inadequacy of the autonomous mechanism under existing conditions.

4.4. Water Resources in India and Climate change

Climate change can affect water availability in three major ways. They are (a) by affecting monsoon circulation and changing the incidences and timings of rainfall (b) the snow melt and increase in the proportion of precipitation received via rainfall changes the run-offs in rivers at any point of time (c) the higher temperature intensifies evapo-transpiration and groundwater stock. Moreover, extreme events like droughts and floods that can actually be caused by (a) and (b) and the cyclones and sea ingression can affect coastal areas.

The growth of population and the economy in India is exerting increasing pressure on the demand for water for various uses intensifying the competition faced by irrigation. A growing number of river basins in the country are depleting. Besides the contribution of the current rainfall, water sequestered naturally or artificially in surface and sub-surface reservoirs contribute to India's water resources creating challenges for the public budget, the environment, cross-state and cross-section iniquities. Both abundance and shortage of water has caused disruptions to human life and agriculture. Evening out inter-annual and inter-seasonal differences has become a crucial challenge in the water policy.

Some of the programmes undertaken by The National commission for Integrated Water resources development to cope with the water situation include (1) command area development, water logging and drainage, (2) crop diversification and (3) irrigation water management, water distribution system and conjunctive use of surface and groundwater. Since 1950 direct public investments of Rs. 88000 crores have been made for providing irrigation infrastructure to Indian agriculture. Deceleration of irrigation potential formation and in public investment on this have been pointed as binding restraint of agricultural growth in the last decades.

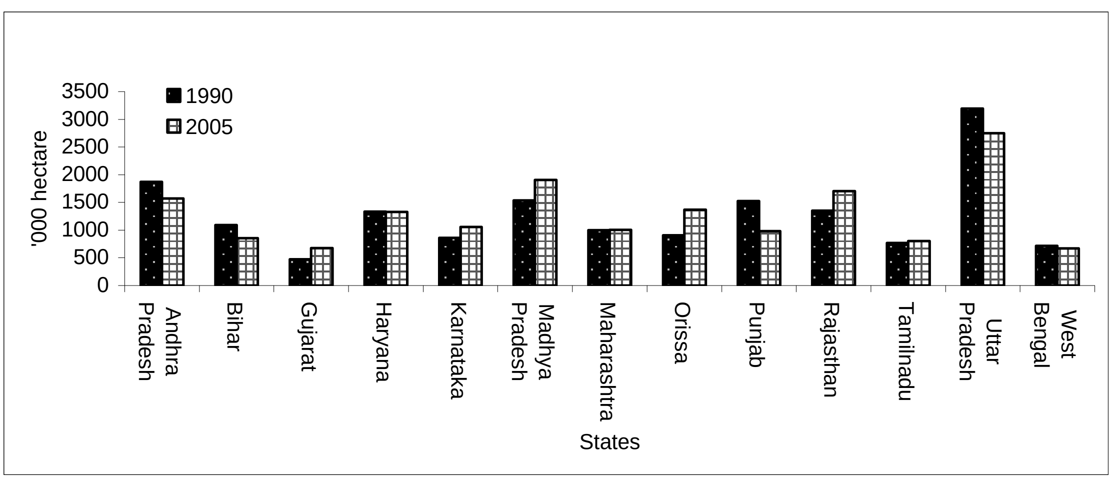


Figure4.4: State-wise increase in Canal irrigated area in India, Source: Based on Government of India.

Ground water today account for over 60% of the irrigated area, double the share of surface water. Canal irrigation is a principal source of surface water that is determined primarily by public initiative. Several instances of improper use has been reported partly motivated by wrong policies. Sharda canal command in Joshi and Jha (1992) has seen over use of water combined with under use of ground water due to low water rates and leading to distorted crop choice, land degradation falling productivity and incomes and even abandonment of land (Joshi and Jha, 1992). Rising water table and deterioration of groundwater quality are reported in Haryana (Sharma et al, 1997). Irrigated area under canals has come down between 1990 and 2005 and many states (such as Uttar Pradesh, Andhra Pradesh, and Punjab) have undergone stagnation or decline in canal irrigated acreage. Water-logging, rise of water table and salinisation of groundwater are common problems arising from inadequate drainage. In many cases public expenditure on draining water tends to exceed that on supplying water for crops. Reduced public investment and fiscal incentives have shifted farmers towards ground water based on private initiative. Wells are groundwater sources of which tubewells, like canals can be perennial in supply while other wells are charged by rainfall. Subsidies on electricity are a major reason behind this shift and the development has been responsible for a growing number of 'dark' zones in terms of the depth of water table. Thus water management already remains as a severe challenge in India and climate change can only add to it.

While the moisture gain due to precipitation adds to river flows and other water-bodies and also percolates to recharge groundwater, this is countered by evaporation from the soil and transpiration by which plants lose water to the atmosphere together constituting the evapo-transpiration process of water loss. Annual precipitation generates 4000 Km^3 of water in India and the potential evapo-transpiration constitutes 1775 mm varying from 1239 to 2052 in Andhra Pradesh. North India will be affected mostly by the changing snowfall and ice melt in Himalayas while increased evapo-transpiration is a threat for peninsular India.

4.4.1. The river basins

Rivers are the principal means of water transfer in India over space and time and their total catchments estimated to be 252 million hectares in India. There are 20 river basins as delineated by the Ministry of Water resources including major and other basins. A majority of the rivers that flow over the northern part of the sub-continent are of Himalayan origin, are largely perennial and supporting multiple crops in the year. The Indo-Gangetic Plain (IGP) is the largest and agriculturally most important region in the country drained by the Indus, Ganga and their tributaries including the Brahmaputra. Rivers arising from mountains and hills other than the Himalayas are watered by rainfall and may dry up after the monsoon season. The rivers in peninsular India are also strained by limited and seasonal water recharge.

Precipitation in India has a dominant component of snowfall in the mountains. It is clear from the geography of the basin (see Appendix 4.3) that the melting of Himalayan glaciers due to global warming will have profound effect on the water flow in the system. Increased share of rainfall in the precipitation rather than the slow melting of ice would enhance the discharge in the short term and could cause floods even though the flow will abate later in the seasonal cycle. Thus climate change may speed the hydrology, make the water flows more variable in the basin and contribute to floods and water scarcity in the same year. The effects will be spatially unequal with regions lying towards the mouth being affected more. A most notable feature is the inter-national dimension of the implications. Many of rivers originate in Tibet and some of them flow into Pakistan. The variations of flow in the river basins would have joint and differentiated implication for a number of countries like India, Pakistan, Nepal, Bangladesh and China sharing the rivers or their tributaries and may add to the general portfolio of international diplomacy and disputes. The entire plain drained by Ganga-Yamuna-Brahmaputra-Indus has a strategic place in the achievement of food security in the country as also in Bangladesh and Pakistan accounting for over 73% of area under rice in India and nearly 89% under wheat (Table 4.4). That these rivers are strategically managed for the distribution of water for agriculture against industrial and domestic uses[1] are an important component in managing water in IGP.

Table 4.4: Foodgrain cultivation in Indo-Gangetic Plains			
	State	Area (%all India)	Production (% all India)
Rice	West Bengal, Punjab, Haryana, Orissa, Uttar Pradesh Bihar, Madhya Pradesh, Assam	73.46	68.78
Wheat	Punjab,Haryana,Bihar,Rajasthan,Uttar Pradesh,Madhya Pradesh, West Bengal, Assam.	88.62	93.06
Source: Computed.			

4.4.2. Tanks

Tanks are traditional methods of water storage and is still common in peninsular south where the terrain is hard. Rivers, where present, are seasonal in their flows. The tanks have existed historically under community based maintenance system. Tanks in turn depend on rainfall for recharge and are considered less reliable than canals and tubewells. Nevertheless they are important for lack of alternatives or the failure of other means. Tanks are sometimes the only source of irrigation for farmers.

4.4.3. Projections

It is intuitively clear that water resource availability will be impacted by the projected climate change implications that foresee changes in precipitation, their intensity and frequency. When in surplus, these changes can lead to enhanced runoff and floods and deficits can lead to droughts especially when the adaptation mechanism on the engineering front is not developed. Simulation of hydrological conditions that will prevail under given weather conditions can be used for assessing water resources. Hydrological responses are complex processes governed by factors like terrain, land use, soil properties

[1] . The Yamuna river joined by rivers Tons and Giri in the Himalayas descend to the IGP and by the time it reaches the Tajewala-Hathikund barrages the water is diverted to canals to supply irrigation in surrounding districts. The recharge in the area is mostly from effluents.

and moisture content. Understanding these processes will be necessary for continuous simulation of moisture conditions.

World Development Report has predicted that the IGP is likely to witness increased water availability from snow melt up to 2030 but reductions thereafter along with part of the basin receiving less rain than in the past. The diminution of natural storage in the aquifers in the form of ice and snow would need to be replaced by artificial storage in reservoirs (Vadivelu, 2009). Annual water resources are under pressure worldwide and especially so where the adaptation capacity is poor on account of shortage of finance and technology. Hydrological processes are complex and governed by various factors like terrain, land use, soil moisture.

A SWAT model (Soil and Water Assessment Tool) is used by Gossain et al, (2006) to determine spatio-temporal water availability in 12 Indian ricer basins under control baseline scenario and GHG climate scenario. The river basins are delineted into sub-basins using digital elevation model (DEM) related to topography. Weather data generated by Hadley Centre for climate prediction. U.K. is used. The results suggest that increased rainfall does not always assure improved surface run-off (Cauvery basin shows decline in runoff when rainfall increases by 27% while run-off improves in Narmada basin despite a fall in rainfall). Evaporation has a serious part. In Krishna basin the study predicts an increase in the number of drought weeks in 16 of the 21 sub-basins, a 30-50% decrease in water yield and also evapo-transpiration. In Mahanadi on the other hand increased precipitation, evapo-transpiration and water yield is indicated in all sub-basins with the ominous possibility of worsening severity of flood in the worst flood affected sub-basin. The study identifies the hot-spots for attention among the sub-basins. There is a general overall reduction in the quantity of runoff under GHG scenario with water crisis being marked in Gujarat and Rajasthan and imminent flood problems in Godavari and Brahhmani and Mahanadi.

A rigorous analysis of global warming effects on glaciers using ten GCMs have pointed to the possibility of a 75% shrink of Alpine glaciers by the turn of the century, a 12 cm rise in global sea level by 2100 due to melting of ice sheets in the Arctic regions of Alaska, Russia, Canada, Norway and Antarctica. A relatively less pronounced 10% reduction of Himalayan glaciers is projected three years after a claim, later withdrawn subsequent to a controversy, by a IPCC report that the Himalayan glaciers would disappear by 2035 (Hindustan Times, 11th January 2011). A study by Mall et al (2006) also provides an alert on the possibility of increased evaporation. When evaporation leads to increased moisture uptake the possibility of intense precipitation is more but when no moisture is available in the soil the soil temperature raises affecting ground water storage and causing droughts. The study also draws attention to the fact that rainfall is not well distributed over the year and across regions and rivers are not at their high stage even through the monsoon season. Given the concentration of rainfall in a few months and moreover in spells of few days or hours, harnessing the river run-off will be a challenge.

4.4.4 Water management

The discussion highlights the need for emphasis on water management. In this connection the emphasis will require to be on equitable spatial distribution of water and conservation of water. Technology on water storage, canals, flood control will need attention. River linkage is a possibility that can be explored at a limited level. Inter-linkage of the Ken and Betwa rivers in Madhya Pradesh is currently in consideration[2]. Farming practices should also respond to the changing scenario. Agronomic measures such as countours, mulching, bunding, and mixed cropping, mechanistical means (terracing, strip, conservation) and community actions that take an integrated approach at farming and water distribution can be useful. Cropping pattern has been distorted in India by the policy of MSP and water/electricity charges. This needs to be corrected by promoting optimum crop choices aligned with the comparative advantage of regions reflecting resource availability. Rice is one of the most water intensive crops that have been encouraged by policy even in regions starved of water, leading to extraction and

[2] The state government ha proposed this project involving a transfer of Ken water to a reservoir from where it can be diverted to the Betwa River. The project has faced environmental resistance for the possible damage to the state's ecology especially in view of the facts that the Betwa region houses an important tiger reserve (Panna) and the intervention will cause land submergence with possible implications for biodiversity.

inequitable distribution of ground water. Pulses and coarse cereals on the other hand make little demand for water and possess other positive qualities too. Irrigation processes may expand to accommodate innovative technologies and improve water use efficiency. Methods like border irrigation (controlled surface flooding), basin irrigation, sprinklers, drip irrigation and rainwater harvesting by recycling run-off, local water structures, pond positioning adjunct to canal system and groundwater management may be mentioned.

4.5. Global warming effect on Crop yields

Each crop has its own optimum of maximum and minimum temperature conditions for its growth and development. Some plants grow better in cooler temperature like wheat while others prefer warmer temperatures. Thus, what is favorable temperature for one crop may be unsuitable for another. Generally, temperature increases, because of the positive influence on physical and chemical reactions, have favourable effects on plant growth but only in a specific range beyond which plants have to struggle for survival. At the same time the air temperature also affects water demand by increasing the loss of moisture by transpiration and evaporation as a result of which the plant wilts.

4.5.1. Models and Methods

Models of climate and crop growth have been linked together to project future changes in crop yields and food supply across the globe. Economic and hydrological models also supplement the process depending on the objectives. Two families of models have been used widely for predicting crop yields namely, Decision support System for Agro-technology transfer (DSSAT) and Erosion productivity Impact Calculator (EPIC). A review made of these projections by Long et al (2006) cast doubt on any conjecture that rising CO_2 will fully offset losses due to climate change(see Chapter2,2.2.2). The IPCC projects that total crop yield when averaged across the globe may rise but the optimism dims when one considers that this net gain will result from generally lower yields in the tropics.

In the regression models used by various scholars for explaining crop yields, temperature, rainfall and other meteorological variables and their derivatives are used as explanatory variables. Diurnal patterns of biological processes demand the recognition of the influences of minimum and maximum temperatures. The minimum daily temperature, usually nighttime temperature affect yield by speeding up respiration. The length of the growing period and period of sunshine are also important for the crop. A common analytical measure used in the studies on yield effects of climate is Growing-degree days (GDD) which helps to place the pants in their course to maturity (see appendix 4.4).

4.5.1(a). Prospects for Rabi crop yields

Wheat is a major rabi crop dominantly grown across the northern stretch of India where the winter temperature is low enough to suit its biological tolerance. Some insignificant amount is also raised in southern parts of the country. One of the prime beneficiaries of technological advances, wheat yield is sensitive to various biotic and abiotic stresses like weather. Winter crops are especially vulnerable to high temperature during reproductive stages. Some of the other major rabi crops in India are barley, mustard and chick-pea or chana that can potentially face the same predicament.

Much of the wheat crop is grown with irrigation so that unlike kharif crops, shortage of precipitation is not the major limiting factor. On the other hand, temperature can be a crucial influence on growth. Changes in seasonal temperature affect grain yield mainly through phonological processes. Low temperatures and frosts, common in some of the very cold wheat growing regions, are harmful for the chemical life processes of plants but upward modulation of the temperature can be particularly harmful since the optimal temperature of this crop is relatively low.

Temperature plays a key role in determining the sowing time. Timely sowing of the crop, by providing adequate time for the reproductive phase and consequent grain formation is necessary for high productivity. The optimal sowing dates in northwest India for winter crops are relatively early compared to the eastern parts of the country. Delayed sowing can hurt yield by reducing the duration of the reproductive phase and minimizing the exposure period to the high temperature in March. Such exposure at the grain formation stage can lead to forced maturity and low productivity. This makes timely sowing of wheat plant of utmost importance. The a temperature rise can have a implications for the calendar for wheat planting operations as well as for rotations since the sowing has to be rescheduled with the harvest of the preceding crop which is often rice.

In the absence of any carbon fertilization effect, crop simulation studies had found that wheat yields could decrease by 28-68% but the higher temperatures and reduced radiation will offset the possible effect of carbon fertilization. The use of dynamic crop growth models like WHTGROWS, INFOCROP and CERES indictated that in north India a 2^{o} C rise in mean temperature reduced potential grain yields of rice and wheat by 15-17% (Aggarwal and Sinha, 1993, Hundul and Kaur, 2007). Using the WTGROWS model a study by Kalra et al, 2008 on rabi crops in north India found that an increase in temperature by 1-3^{o} C is likely to advance the optimal sowing dates for wheat by 5-8 days per degree rise in temperature but this advancement is less in relatively cool regions. A positive correlation with GDD observed could reflect the effect a longer period of growth. A decline in grain yield with rising temperature was noted in all cases. For wheat, the decrease was the maximum in Haryana (4.3 q/hectare) followed by Rajasthan (2.5 q/hectare) but modest for Punjab and Uttar Pradesh (0.6 q/hectare). The model indicates the need for advancing the date of sowing by 6 days per degree rise in temperature. Yield reduction due to shifting of sowing ‘window’ seemed to be less in Punjab and Haryana compared to eastern UP and Rajasthan. For mustard the shifting will have extremely deleterious and a 20 day delay may reduce the yield to half. Experimental field data on Karnataka found that dates of sowing play a major role in the accumulation of GDD and PTU from sowing to maturity. The early sown wheat also showed better performance with respect to yield when compared to others but the GDD and PTU requirements seem to vary by genotypes. A negative correlation with minimum temperature as theory would predict is noted in Iran (Esfandiary at al, 2009)

Table 4.5: Summary indications about the Temperature responses and implication for Crop yield.				
Study	Crop	Site of study	optimal sowing	Response
Kalra et al 2008	Wheat, mustard, barley and chickpea	Punjab, Haryana, Rajasthan and Uttar Pradesh	Advance by 5-8 days per degree rise in temperature	Decrease in grain yield –maximum in Haryana (4.3 q/hectare).
(Prabhakar et al, 2007)	Wheat	Karnataka	Early sown wheat showed better performance than late sown.	
Esfandiary at al, 2009	Wheat	Iran		Negative correlation between Yield and minimum temperature. Meteorological variable s account for 83% of yield variation.
Aufhammer et al, 2006	Rice	9 major rice growing states in India		negative effects of minimum temperature in October-November period on production
Welch et al, 2010	Irrigated rice	Farms in six Asian countries		T_{min} has a large negative impact on yield, positive effect of T_{max}
Jalota (2007)	Varieties of Bt. Cotton	Punjab	Every 1^{O} C increase in temperature reduces the duration of the vegetative phase by 3.2days	Decreasing radiation and increasing temperature jointly reduce yield.
Pathak (2005)	Wheat	IGP		At places yield was stabilized by effects of radiation and decreasing temperature or Maximum temperature.
Pathak (2005)	Rice	IGP		Decreased both due to reduced radiation and temperature increase.
Our regressions (2011)	Rice	Temperature zones India		Negative but insignificant
Our regressions (2011)	Wheat	Temperature zones India		Negative insignificant except for minimum post-monsoon season temperature

4.5. 1(b) Evidences on Rice, summer crops

Interest has also surrounded rice which has been associated more with water availability than heat and for which the effect of temperature rise on yield may be shrouded by opposing impacts of heat and radiation. This is complicated also by the varying incidences of the effects at various phases of crop growth, the relative impacts of diurnal temperature cycle and the relative movement of the maximum and minimum temperatures.

The effects of maximum and minimum temperatures on phonological development and physiological processes differ. Extremely high levels of daytime temperature T_{max} during the growth stages has been known to hurt yield mostly through spikelet sterility caused by reduced pollen production in reproductive phase while reduced photosynthesis caused by chloroplast damage in the vegetative phase and increased energy consumption caused by higher respiration demand at ripening are also factors. But evidences have emerged that in locations where spikelet sterility is rare and temperature T_{max} rarely rises to the extreme levels, yield may be more sensitive to nighttime temperature $T_{min..}$ The mechanism behind the effect of T_{min} possibly needs greater understanding but increased respiration losses, reduced grain-filling duration and endosperm cell size during the ripening phase are offered as possible explanations. The T_{min} is rising faster than T_{max} in some important rice growing countries like India and China and is also projected to continue doing so (Christensen, 2007). Trends estimated in Chapter 3 affirm this feature in the monsoon season.

Rice harvests in India and other parts of Asia are noted to be positively correlated with rainfall and also with solar radiation in the late season. The ABC (section 4.2) can also affect the temperature records, radiation and monsoon strength. The cloudiness caused by the ABC impacts on insolation as well as back radiation of long waves causing nighttime temperatures to rise. Thus together the two processes of ABC and global warming would impact on rice through the drying and dimming effect of the ABC and the warming effect of the greenhouse gases. A few studies examining the impact of ABCs on agriculture estimated that the dimming effect of ABC has reduced rice yield by 6-17% (United Nations Environmental Programme and Centre for Clouds Chemistry and Climate, 2002) but they have been criticized for not representing actual field conditions and for omitting the effect of inoptimal input use by farmers.

The interaction of the ABC and the global warming in influencing rice yields is a source of complication in modeling. In particular, cloudiness would affect both the nighttime temperature and the day time radiation. A Philippines based study projected yield of irrigated rice decreased by 10% for every 1^{O} C increase in T_{min} averaged over the growing session. A reanalysis of the data concluded that is effect would be smaller because of the negative correlation between temperature and radiation which was an omitted variable in the regression. The effect of high night temperature on rice yield was not fully understood.

Table 4.6: Regression coefficients on Climate variables for Rice		
Variable	Production function	Area demand function
Rainfall March-May	-0.027	0.011*
Rainfall Jun-Sep	0.317**	0.074**
Temp Jun-Sep	0.013	-0.0
Max. Temp. Oct-Nov	0.662	0.135
Min. Temp. Oct-Nov	-0.865**	-0.059
Solar radiation Oct-Nov	-0.048	0.005
Solar radiation Dec	0.085	0.151
Source: Reproduced from Auffhammer et al, 2006		

A multivariate regression method (Aufhammer et al, 2006) on historical data from India found positive effects of rainfall in June-September and negative effects of minimum temperature in October-November period on production. Only rainfall was found to be significant for rice area determination. Although the opposing coefficients of rainfall and temperature make the ABC effects of drying and cooling rather ambiguous, simulations suggested that reduction of both global warming and ABC conjunctively would have complementary and favourable effect.

Analyzing a panel dataset of farms intensively managed by International Rice Research Institute and its partners in countries, Welch et al, 2010 found that warming has ambiguous impacts on rice yield. T_{min} has a large negative impact but contrary to expectations a positive effect of T_{max} was noted. The findings on T_{max} is explained by the fact that in the studied sites temperatures have rarely reached the threshold temperature causing chloroplast damage, spikelet sterility and higher respiration led energy demand. The most important methodological finding is that it is necessary to analyze the impacts of T_{max} and T_{min} jointly to avoid bias.

Simulations using climate effect on global yields of six most widely grown crops (Lobell et al, 2007) showed that the global losses due to warming trend since 1981 were substantial. The foregone production levels were estimated to be 19mt/year for wheat, 12mt /year for maize and 8 mt/year for barley. Precipitation trends had only minor effects on yield. The CropSys model for the warm season crop cotton (Jalota, 2007) brought out the effects of the temperature on yield clearly. Each phenol-phase of the crop has its own demand for heat. With every 1^{O} C increase in temperature from 30-36^{O}C the duration of the vegetative phase was 3.2 days shorter. Simulation also showed that with the decrease in duration between sowing and flowering by 14 days, flowering to boll formation by 9 days, boll formation to maturity by 21 days and sowing to maturity by 45 days cotton seed yield was reduced by 236, 140, 116 and 75 Kg/hectare per day delay respectively. Despite the shrinkage of the period of growth, overall evaporative demand increased due to the vapour gradient enhancement and crop water productivity also declined. Simulations of potential yield using CERES-RICE and GENERIC-CERES models assuming other inputs are not limiting (Pathak at al, 2005) showed that yields of both rice and wheat decreased as one moved to lower IGP (28% for rice and 34% for wheat). Rice yield data showed extensive incidences of negative trends but wheat yield appeared to be more stable countered by radiation effects. In Tamilnadu during kharif season rice yields are anticipated to reduce by 10-15% by 2020 due to temperature and precipitation changes (Geethalakshmi and Dheebakaran, 2008) and the magnitude of decline will further aggravate to 30-35% by 2050. Adverse effects on rainfed crops like pulses and coarse cereals are also expected. Decreases in yields have been reported for chiclpea and pigeon pea (Mandal, 1998), sorghum (Chatterjee, 1998), pearl millet (Ramakrishna et al, 2000). The effect can be pronounced for short duration vegetable cropssuch as tomato, garlic and onion.

The quality of product can also be affected by climate change. For example sugarcane undergoes a crucial period of sucrose formation that determines the juice content. A dry spell in June-July 2008 affected the quality of cane that became available in the crushing season. This however went with a production level far in excess of what was planned for because the abundant rainfall later in the year, sugarcane being a crop with a long gestation period on field.

4.6. Yield temperature correlation in Indian case

Figures 4.5 show the plots of wheat yield in the most important producing state Punjab against the minimum and maximum temperatures recorded at the north-west zone. Since the yield of a crop is affected by technology and may have a time trend, the data has been corrected against the three year moving averages. Wheat is sown between October and December and harvest continues between February and March. The minimum temperature in the post monsoon season October to December (Fig 4.5(a)) shows a negative slope though no relation is evident with respect to the maximum temperature for January and February. The slope appears to be positive, possibly indicating the negative impact of frosts in that season. March again shows a negative slope. Similar plots also presented for rice using monsoon season rainfall as the covariate show negative relations for both minimum and maximum temperatures. Regressions however find the coefficients insignificant except in the case of wheat yield and minimum temperature of the post monsoon season.

In India out of the 28 million hectares under wheat, 9 million hectares in north-eastern plains, the central zone and the peninsular zone is prone to terminal heat stress. Most of the wheat grown in eastern regions of India and about 20-25% of area in Punjab, Haryana and Rajasthan constitutes late sown wheat which is especially vulnerable to temperature rise in the late season. The experience of 2004 has also highlighted how an inordinately hot winter could hurt wheat production[3]. Wheat yield declined by 2004-05 by 4% compared to the previous year.

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[3] According to the NASA's Goddard Institute for Space Studies the 2004 meteorological year was a hot one. Average global surface temperatures in both December 2003 and February 2004 were 0.66 degrees Celsius above the long-term average (1951-1980). Overall, 2004 temperatures were 0.48 degrees Celsius above the climatological average. The high temperatures of 2004 make it the fourth hottest year since the late 1800s, the time that most scientists recognize as the start of accurate meteorological record keeping.

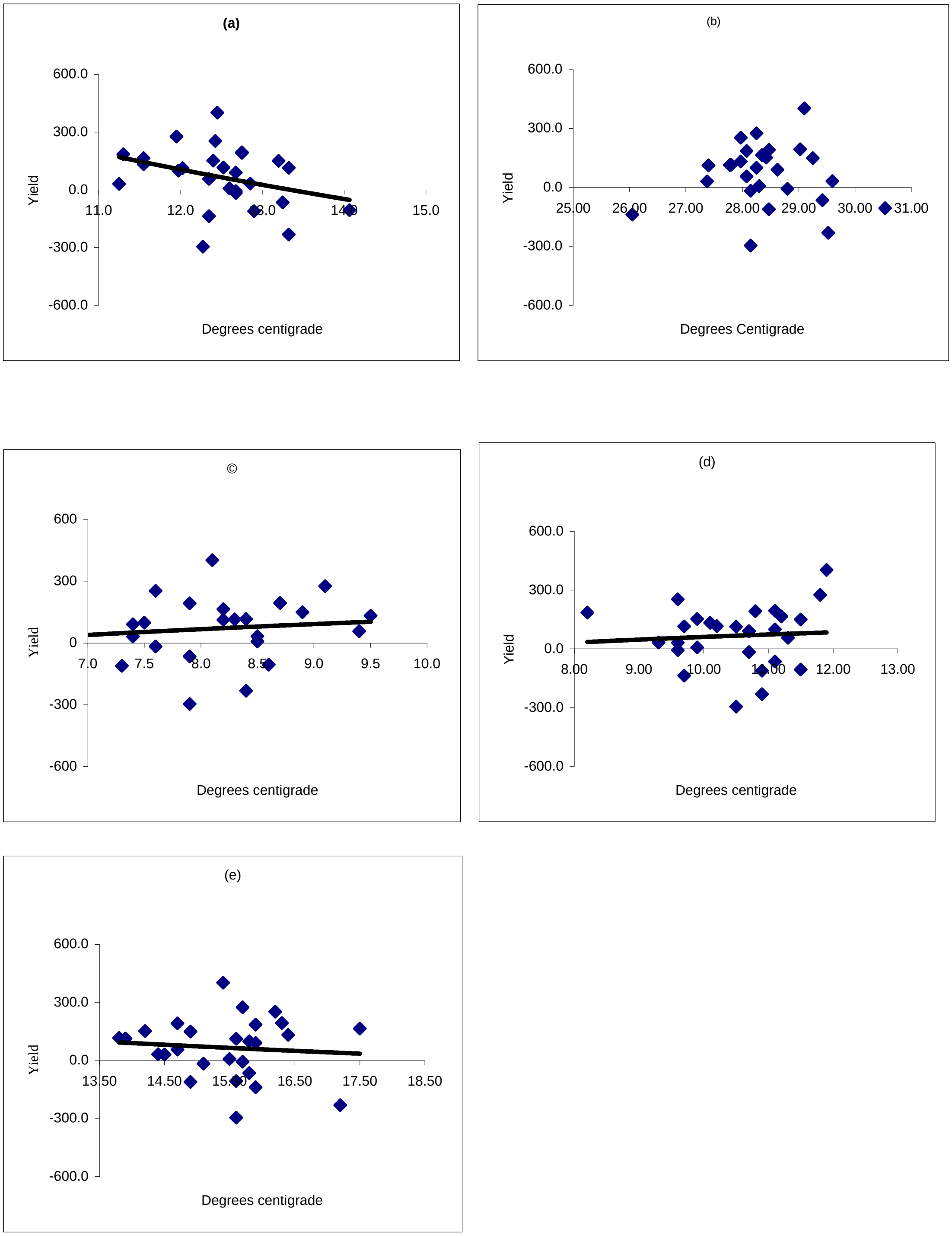


Figure4.5: Temperature yield curve (1975-2003) for Wheat in Punjab. Yield is detrended by taking deviations from 3yr moving averages. Temperature is for the North-west zone. (a) Minimum of Post monsoon season (Oct-dec)-Yield = 1078.47 – 8.10*Temp, (b) Maximum of Post monsoon season (Oct-dec)- Yield = 325.88 - 0.91*Temp, (c) Minimum of January- Yield = -158.13
(-1.80) (-0.25)
28.02*Temp, (d) Minimum of February- Yield= -110.07 + 16.82*Temp and (e) Minimum of March Yield = 308.12 – 15.65*Temp
(0.47) (0.72) (-0.45)

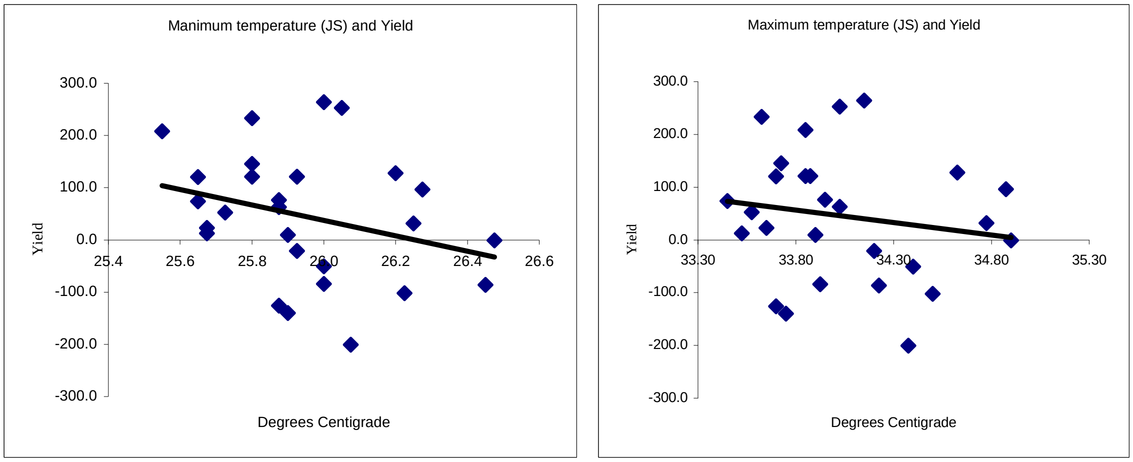


Figure: Temperature yield curve (1975-2003) for Rice Yield is detrended by taking deviations from 3yr moving averages. Temperature is for East Coast. (a) Minimum of monsoon season (Jun-Sep)- Yield = 3577.97 13.85*Temp + 0.04*rainfall (b) Maximum of monsoon season (Jun-sep) Yield = 1324.54 – 4.08*Temp + 0.08*rainfall
(-1.35) (0.32) (-0.68) (0.55)

Rising temperatures in March and April has been a continuous source of concern in recent times. In India research under taken by the Indian Council of Agricultural research (ICAR) finds there is 3-4% decline in grain yield with every 1^{O} C rise in temperature at the grain filling stage. However no major reversals of wheat production has been observed from the growth trend since wheat production grew impressively in the 2000s. While the government has also taken measures for adaptation such as promoting heat tolerant varieties (DBW14, DBW16, Raj3765), moisture conservation technologies and zero-till farming, irrigation at critical stages and timely sowing, and how far such policy reponses are responsible for the status quo would merit questioning.

4.6. Extreme climatic events and Coastal agriculture

Climate change is associated with greater frequency of intense rainfall or periods of droughts, devastating floods and with the greater ferocity of cyclones. In Chapter 3 we have discusses how the Indian Diaspora is characterized by various climatic conditions. Droughts are a common occurrence and about 92 districts of the 640 districts in the country are declared as drought prone and special programmes are undertaken in these areas to address this weakness. Similarly we found that between the years area affected by floods was 25 million hectare and the frequency of cyclones, even severe cyclones was high.

Table 4.7: Vulneberability of Indian agriculture weather events									
	Drought Prone Area		Flood Prone area		Number of Cyclone (1900-2009)			Coastal	
States	Districts	Net sown area (mill. hectare)	No. of villages	Net sown area (mill. hectare)	Origin	Cyclone	Severe	Districts	Area affected (hectare)
Andhra Pradesh	4	47.1	21	1.39	BOB	41	27	8	34.9
Bihar	7	11.1	-	4.26	BOB	-	-	-	-
Gujarat	12	73.3	30	1.39	AS	5	11	12	45.7
Harayana	4	8.8	98	2.35		-	-	-	-
Karnataka	14	70.2	-	0.02	AS	-	-	3	3.5
Madhya Pradesh	11	41.12	-	0.26		-	-	-	-
Maharashtra	8	72.6	-	0.23	AS	-	-	4	9.0
Orissa	2	4.7	29	1.4	BOB	19	20	8	8.3
Rajasthan	13	87.9	-	3.26		-	-	-	-
Tamilnadu	8	16.8	4	0.45	BOB	24	26	12	19.2
Uttar Pradesh	6	17.1	4511	7.336				-	-
West Bengal	3	11.6	-	2.65	BOB	19	20	3	10.2
Source: Water and related statistics and various sources.									

In recent times there have been signs of extreme events occurring in unexpected manners such as untimely rainfall, floods and cloud bursts in unconventional regions, heat and cold waves etc. While the connection between these events and climate change cannot be confirmed at this stage, the linkage deserves an attention and cannot be ruled out. In 2010 the rice crop was affected by untimely rains in various regions. Pre-harvest heavy showers are not uncommon in Punjab and Haryana but the shift of the monsoon trough brought unusually heavy rains in July damaging the crop. The same year incessant rain in Andhra Pradesh compromised a ready rice harvest seriously. Recurrent onslaught of heavy rains and floods have been a threat to agriculture at the regional level. ‘Khaimuk’, ‘Nisha’, ‘Laila’ and ‘Jal’ are some of the killer cyclones that have visited the state of Andhra Pradesh and played havoc on rice production in recent times. In 2010 kharif season when a good harvest was all but ready, cyclone Jal late in the season may have damaged foodgrain production to the tune of 6 lakh tones due to rain and floods. On the positive side the untimely rains have filled up water bodies and raised groundwater levels including in rainshadow districts like Anantapur, but the short run effect has been devastating. Besides the event has had a toll on human lives and damaged infrastructure all of which come as a shock to the agriculture. In 2010 the inordinately high March temperature in many places especially in the northern and eastern states and the lack of western disturbances have been attributed to climate change although yhe meteorologists were cautious about the unexpectedly early instance of heat wave.

Some of the recent experiences may be listed as follows.

Table 4.8: Climatic Events			
Year	Place	Event	Remarks
2008	Bihar	Flood	One of the worst in 50 years
1996	Andhra Pradesh	Cyclone	Devastating
2006	South India	Tsunami	Coastal areas seriously affected, no relation to climate change known.
2002, 2009	All India	Drought	Rainfall was short of the normal by 23% at the all India level.
2010	Punjab, Haryana	Rains in the early kharif season	This was accompanied by weak monsoon in eastern India
2010	Andhra Pradesh	Rains in November	An unexpected disturbance at the harvest stage after a good monsoon
2010	Himachal	Floods in August	unusual
2010	Leh, Ladakh	Cloudburst in August	Cloudburst causing a huge damage to life and property in the Ladakh region.

Appendix 4.

4.1. Monsoon

Temperatures in north-central-west India soars in summer, the hottest regions being observed in the western margins of India. An elongated zone of low pressure called the monsoon trough is created over the Indian region with its axis located at 22^{o} N in the east to 27^{O}N in the west. The difference observed between the seasonal land surface temperatures over north-west where the heat low dominates and over the east Arabian Sea where the monsoon winds becomes considerable. The low pressure systems forming over the Bay of Bengal move along the monsoon trough, accompanied by moist convective clouds causing intense spells of rain over the land regions of central India. The quantum of monsoon rainfall is largely determined by the intensity and frequency of the 'synoptic scale' systems in a particular year.

4.2. Method of Model estimation

The simple OLS method of estimation is adopted unless serial correlation is indicated by a BG-LM test in which case the autocorrelation is corrected for. The equations were subjected to tests for multicollinearity, stability, unit root tests on errors. The fit of the model and the significance and signs of the estimates are used as criteria for selection of the best possible specification among possible alternative specifications. The specifications of the explanatory variables are described as follows. Wholesale prices prevailing in major markets, irrigated area under different sources as well as unirrigated area are used for specifying the price and irrigation variables.

4.3 The Indo-Gagetic Plains

The IGP is located within the subtropical to warm temperate climates characterized by cool and dry winters and warm wet summers. Rivers Ganga, Indus and Yamuna drain about 129 million hectare of area in India. Numerous streams and tributaries fall into the three rivers in their courses from the mountains to the seas and add to their flows. The Ganga and the Yamuna originate in the Indian territory at Gongotri and Yamunotri glaciers and bring down waters from the melting of snows in the Himalayas. The two rivers meet in Allahabad and flow down towards the east to fall in to the Bay of Bengal. Several tributaries add their share of water to the Ganga-Yamuna basis coming from both north and south of the main basin and some of these arise in other mountain ranges like the Vindhya and in Nepal. Another major river that drains into the Ganga before its confluence is the Brahmaputra. The Brahmaputra originates in the Mansarovar Lake in Tibet and runs most of its course eastward outside the Indian territory before it encounters a U-turn at Arunachal Pradesh and enters India and further into Bangladesh. The Indus has five tributaries the Satluj, Chenab, Jhelum and Beas all of which originate in the Himalayas. The Indus and the Satluj also have their sources in Tibet. The Indus and its tributaries mostly fall into the Bay of Bengal in Pakistan.

4.4. Growing degree days

As developmental events in plant life depend on the accumulation of specific quantities of heat, in normal circumstances, plants grow in a cumulative stepwise manner strongly influenced by the ambient temperature. Growing degrees is a term defined as the number of temperature degrees above a certain threshold base temperature which varies among crop species. The base temperature is that temperature below which plant growth is zero.

$$\mathbf{GDD = [(T_{max} - T_{min})/2] - T_{base}}$$

GDDs are cumulated by adding each GDD contribution as the season progresses. If a GDD is negative a value of zero may be attributed. Other variables likely to affect yield via phonological processes relate to radiation and precipitation and various appropriate transformations of the temperatures.

Table4.1A: Districtwise drought prone and Coastal area in India
Drought Prone
Andhra Pradesh: Anantpur, Chittoor,Cuddapah, Hyderabad. **Bihar**: Munger,Nawadah,Rohtas,Bhojpur,Aurangabad,Gaya,Palamau. **Gujarat**:Ahmedabad,Amreli,Banashantha,Bhavnagar,Bharuch,Jamnagar,Kheda,Kachchh,Mahesana,Panchmahals,Rajkot,Surendranagar. **Harayana**: Bhiwani,Gurgaon,Mahendragarh,Rohtak. **Karnataka**:Bengalore,Belguam,Bellary,Bajapur,Chikmagalur,Chitradurga,Dharwad,Gulbarga,Hasan,Kolar,Mandya,Mysore,Raichur,Tumkur. **Madhya Pradesh**: Betul,Datia,Dewas,Dhar,Jhabua,Khandwa,Kahargone,shahdol,Shajanpur,Sidhi,Ujjain. **Maharashtra**: Ahmednagar,Aurangabad,Beed,Nasik,Oomandabad,Pune,Sangli,Satara,Solapur. **Orissa**: Phulbani,Kalahandi. **Rajasthan**: Ajmer,Banswara,Barmer,Bikaner,Churu,Dungarpur,Jaisalmar,Jalore,Jhunjhunun,Jodhpur,Nagpur,Pali,Udaipur. **Tamilnadu**: Coimbatore,Dharmapuri,Madurai,Ramanathpuram,Salem,Tiruchirapalli,Tirunelveli,Kanyakumari. **Uttar Pradesh**: Allahabad,BandhaMamirpur,Jalaun,Mirzapur,Vanarasi. **West Bengal**: Bankura,Midnapur,Puruliya.
Coastal
Andhra Pradesh: Guntur, Khamam,Krishna, East Godavari,West Godavari, Vishakhapatnam, Srikakulam and Vizianagaram. **Gujarat**: Kutch, Jamnagar, Porbandar, Junagadh, Amreli, Bhavnagar, Ahmedabad, Anand, Bharuch, Surat, Navsari,Valsad. **Karnataka**: Dakshina Kannada, Uttar Kannad, Udupi. **Maharashtra**: Ratnagiri, Thane, Raigadh, Sidhudhar. **Orissa**: Balasore, Bhadrak, Ganjam, Jagatasinghpur, Kendrapara, Khurda, Nayagarh, Puri. **Tamilnadu**: Tiruvallur, Chenani, Kanchipuram, Villuppuram, Cuddalore, Nagapattinam, Thanjavur, Pudukottai, Thoothukodi, Tirunalveli, Kanyakumari and Ramanathapuram **West Bengal:** North 24 Praganas, East 24 Praganas and Purba midanapur.

Chapter 5:
Low carbon Agriculture

Climate change is a subject that is profoundly cross-cutting. Even though large bodies of literatures are present in various scientific disciplines that directly or indirectly impinge on greenhouse gas mitigation, communication becomes an essential component to make all this insights useful. Assemblage of all the information linking different possible cropping practices to emissions and removals of greenhouse gases is a precondition for designing comprehensive policies on mitigation. Further, the awareness gained could be instrumental in measurement and inventory building as required by UNFCCC. India with a large agriculture and experiences with diverse cropping systems can contribute to international knowledge. Encouragement of research on the mitigation potentials of agriculture and interpretation of the outputs in a multidisciplinary perspective would strengthen the process.

This chapter is an outcome of a review of literature on varied biological and chemical sciences and seeks to present the case of soil as a possible source and sink for carbon emission keeping in perspective the imperatives of India. The processes that go on in soil that is converted to cropland are studied by scientists and the factors that affect soil carbon sequestration (Sections 5.2 to 5.4) and the implications of conventional farm practices (Section 5.5) are reviewed. It is germane to admit at this juncture that results are more often unresolved and arguable than not and the chapter addresses this difficulty by marking certain areas open for further research. Section 5.2 and 5

5.2. Agriculture as a Carbon Sink

Sinks exist because greenhouse gases take part in reactions that transform them to more benign forms. While sinks and sources are two important and contrasting concepts in literature it is useful to note that the distinction between the two is not too sharp. Sinks are generally also potential sources of emission as best demonstrated by the fossil fuel.

Basically natural sinks that have safely stored carbon deep under the earth, human beings are responsible for changing fossil fuels to sources of emission. When burnt they constitute net addition to the carbon cycle because the carbon released would have been removed millions of years ago in the carboniferous age. The process is quite irreversible given the prolonged periods of time and the exacting conditions of heat and pressure that create fossil fuels. Trees too are potential sources and conservation of forests and careful disposal of wood become essential to keep the carbon drawn during their life cycles from reverting to the atmosphere. Soils supporting the native vegetation too receive and store the carbon passed on by the trees so that trees along with the forest soils serve as an enormous reservoir for carbon that is kept away from the atmosphere. Forestry has been instrumental in offsetting carbon emission in other activities to maintain the carbon balance but the potential of forests to serve as sinks is limited because land has alternative uses like agriculture and urban development.

Clearing of forests for food production is held responsible for large amounts of carbon loss from global soils and most if not all of the present release from forests and soils occurs in the tropics (Detwiler, 1985). Estimates of carbon content has been placed at 1576 Pg in global soils and only 506 Pg in tropical soils (Eswaran et al, 1993) varying with the type of soil and vegetation. That land use change and in particular the replacement of natural ecosystems (forests) by agro-eco-systems (cropland, fallows, pastures etc.) could result in the release of carbon dioxide to the atmosphere of magnitudes comparable to fossil fuel burning was suggested back in the 1970s (Bolin, 1977, Woodwell and Houghton, 1977). The loss is both account of the loss of vegetation that stores carbon and the soil to which it is transferred. Different studies have estimated rates of release due to deforestation and the range is wide. For example, carbon release in peta grams per year is estimated at 2.5-20 by Woodwell and Houghton (1977) from both soil and vegetation. Corresponding estimates from vegetation and soil respectively are given at 0.8 and 0.3 by Bolin (1977) and 1.5-13 and 0.3-5 (Woodwell et al, 1978, Hampicke (1979). Detwiler(1985) estimated that in 1980 annual release from soil due to tropical land use changes constitute 0.11-0.26 gega tones of carbon equivalent to 2-5% of the release from fossil fuel while clearing of vegetation contributes 0.9-1.2 gega tones.

Similar estimates for tropical soils are given at 1.5 (Wong, 1978), 1.0 (Woodwell, 1978) for vegetation and 0.25-2.5 (Woodwell et al, 1978) and 0.4 (Hampicke, 1979) for soil.

The emissions from soils due to the clearing of forests are a small though significant contributor to carbon release compared to the destruction of vegetation incurred. Burning and decay of vegetations and increased oxidation of organic matter are said to be the two components of carbon loss on account of forest clearing but there are evidences where after the burn, carbon content of the soil even exceeded that before the clearing (Lal and Cummings, 1979). Also numerous instances have shown that clearing has affected only the top layers of soil which is in active exchange with the atmosphere. While a depth of 1 m is usually considered for measuring carbon change, carbon content is not vary different at greater depths between soils in virgin forests, pastures and tilled or untilled croplands. The depths affected by the clearing is shown to be between 10-60 cm and mostly up to 25 cm in numerous studies covering land under continuous forest cover, varied crop cultivation, palm plantation and fallows. Even after forest clearing though surface layers lost carbon, deeper layers can even contain more carbon than undisturbed soil (Kowal and Tinker, 1959). Between 35-80% of the carbon contained in the first meter of soil is also concentrated in the top 40cm. Moreover it is likely that the carbon loss measures are overestimates due to various natural factors like soil compaction that are beyond control and affect measurement.

While the loss of vegetation (trees) can be a serious alarm, the potential of soils to persist as sink even after the clearing can be a conclusion from the aforesaid discussions. Regardless of the skepticisms surrounding the ability of soil to serve as a sink subsequent to clearing, there is a feeling that the specific use of the land is of considerably more significance than the clearing itself. The sources of carbon loss subsequent to clearing are erosion, removal of topsoil by mechanical clearing and increased decomposition of organic matter. Detwiler (1977) points out that it is the last source that deserves the most attention as it is unlikely that all the organic matter removed from site will be converted to carbon dioxide in a short time. Conversion of soil organic matter due to respiration and decomposition induced oxidation are certain to return carbon dioxide to the atmospheric pool. The bias arising both because the rate of soil loss is unknown and because the fate of the soil eroded by wind or water or removed carelessly by bulldozers is not fully known needs to be recognition when making measurements. Nevertheless the significances of all the three sources call for appreciation in the strategy towards climate change. Detwiler used spline regressions to assess the equilibriums in carbon content under alternative land use cases and traces the dynamics in carbon recovery after clearing of forests and find that crop lands have lesser potential than pastures or forest fallows. Crop lands are found to attain carbon storage of 60% of the amount found in forest soils and this equilibrium is reached after 5 years of cultivation. In pastures the carbon is lost immediately on clearing and this loss of 20% carbon remains independent of the pasture's age. Land abandonment leads to a 73% loss of carbon initially but slow recovery brings carbon content back to its original level but only over a very long period of 35 years. The loss in carbon is fast in the case of crop cultivation with a 18% loss in the first two years of conversion but in fallow land the loss during the same period is 27%. Although with fallowing organic matter increases in soil under secondary forest over a long time horizon, in real life the length of fallow periods is decreasing in tropics providing less time for soil to recover (Meyers, 1984).

Agriculture is an essential activity of human beings and has a large dimension. Given that crops grown for human consumption are also vegetations with photosynthesis and respiration based life processes, there is a serious need for developing management practices that provide the maximum benefit for the atmospheric greenhouse gas pool while the sector also meets the specified needs of the human community. So long as agriculture continues to demand land for crop cultivation, the theoretical potential for carbon sequestration will remain only notional as reversion will be an impractical option. While the ultimate capacity of agricultural soil is considerably less than forest soil it is worthwhile to explore ways to maximize cropland soils to absorb and retain carbon removed from atmosphere. The role of agriculture as a sink and a source of carbon probably requires greater attention than it presently gets independent of forest linked comparisons and calls for more research, measurement and communication among the disciplines.

Trees and plants absorb carbon dioxide from the atmosphere for photosynthesis generating organic biomasses that eventually get transferred to the soil as roots, litters, leaf falls, decayed parts and dead plants. This incorporation is followed by a proliferation of soil biota that supplements the soil organic content. Thus vegetation as green plants by their own survival process forms a passage for carbon dioxide to the soil which stores the carbon as different compounds for various periods of time. While whether agricultural soil can act as sink for atmospheric carbon dioxide (Lemon, 1976, Loomis, 1979) has been contested, (Delwiter,1985) there is a consensus that improved practices leading to greater return of crop residues to the soil and management of the decomposition and soil removal can reduce loss of soil organic matter.

Crops unlike trees in wild forests are selected by human design but agricultural soil like forest soil (though to a lesser degree) is enriched with carbon drawing from crop biomass of the plants raised. Like the varied trees in the forest each crop has a different implication for carbon sequestration and even the cropping system that embodies the assortment and time schedule of crop choice can have its own implication. The agricultural soil too becomes a zone of biotic activity as the micro-organisms metabolize the incorporated carbohydrates to generate energy for their body functions. Their respiration involves a reaction with oxygen to produce carbon dioxide but where oxygen is not present a special class of organisms that cannot tolerate oxygen respires to produce methane, carbon dioxide and energy. Methane like carbon dioxide is another greenhouse gas that is produced mostly in wetland soils that support anaerobic conditions. Methane can however react with oxygen where available to produce carbon dioxide, water and energy in the respiration process of yet another class of organisms. Apart from respiration the biomass also decays under chemical decomposition releasing carbon dioxide. Soil can be instrumental for carbon sequestration to the extent that by human intervention can maintain photosynthetic removals in excess of the returns through respiration and decomposition. This creates a case for exploring appropriate management practices and technologies to enhance the power of agriculture to serve as a sink and to reduce its role as a source.

5.3. Carbon sequestration, Soil health nexus and research advances

Carbon sequestration has gained increasing importance in context of agricultural development in India. In the last few decades, the pressure to produce more food and the impact of the agrarian technology led to intensive application of external inputs. Raising cropping intensity and greater use of chemical fertilizer on any unit of sown area increasingly became means to generate higher productivity of land. The shortsightedness of the strategy became evident over time. Continuous and intense mining of nutrients from soil for crop growth had impoverished the soil making it difficult to maintain even the attained productivity level. Both the monetary cost in terms of fertilizer imports and the social cost of pollution made the gains questionable. Emphasis in the agricultural policy shifted to sustainable development and efficiency of using all the scarce resources of production.

Sustainable agriculture involves careful conservation of soil health or quality, for which a key indicator is the soil organic carbon content. Carbon sequestration in this context is the means by which carbon is fixed in the soil by the conscious strategies in farming. It involves the reduction of carbon loss through soil respiration, erosion and land degradation. Indian soils (the top 30 cm) contain 9Pg of carbon as against the world's 1500 Pg and fierce efforts are needed to maintain the balance in favour of the soil. Promoting soil carbon sequestration in agriculture would mean development of practices that lead to accumulation of organic matter in soil. Preferably the resulting organic materials should be stable and resistant to natural forces as far as possible. The presence of carbon itself imparts stability to the soil further reducing carbon loss so that the benefit of carbon sequestration is self-propelling. Scientists have classified the organic matter as labile (easily decomposible), intermediate or recalcitrant (stable). The soil's microbial biomass and the plant residues that are cycled rapidly are easily-decomposed whereas the in the pool in which carbon is more tightly held by physical encapsulation or chemical complexing within soil aggregates carbon may reside for thousands of years. Humus is the soil organic matter that has reached a point of stability where under unchanged conditions it will not break down further. Soil organic carbon (SOC) is the carbon content in soil and its quantity is directly related to the soil organic matter in soil (SOM).

The measurement of soil carbon is made possible today by technological advances although there is a need for conciliation among alternative methods, the Walkley-Black being the most popular. Technology to measure emissions at specific sites has also developed with ways of cross checking. Alkali absorption method is used to measure soil respiration. Mathematical models simulate the behaviours of soil. Nitogen and carbon are two related components of soil and the ratios are important for the stability and fertility of soil. Soil potential to hold carbon and nitrogen varies with geography. For example nitrogen and carbon holding capacity is observed to be low in warm deserts and peak in subtropical wet forests. The processes are however incompletely understood and are complex with non-linear effect. Soil carbon sequestration became an area of prolific research driven by the growing interest in sustainable development. Given the double benefit of carbon sequestration both for agricultural progress and for climate change such research certainly needs to encouraged.

5.4. Factors influencing Carbon exchanges in agricultural Soil

Economic considerations rather than natural selections decide the crop choice and human induced elements too enter the carbon cycle when fertilizer, pesticide and herbicide used for producing crops. The biomass generated by the plants recharge the carbon content in soil. Crops have relatively shorter life cycles which require periodical land preparation and multiple harvesting leading to exposure and raise frequent disposal issues exposing and destabilizing the soil and its carbon pool more often. We will see in this section that a number of natural factors like temperature, moisture and soil texture affect the rate of emission. Figure 5.1 gives a view of the input and the output sides of the carbon flows that lead to soil carbon sequestration in agriculture. On the output side, part of the carbon is removed by harvest that might enter the carbon cycle at a later point in another way through animals who consume the crop outputs.

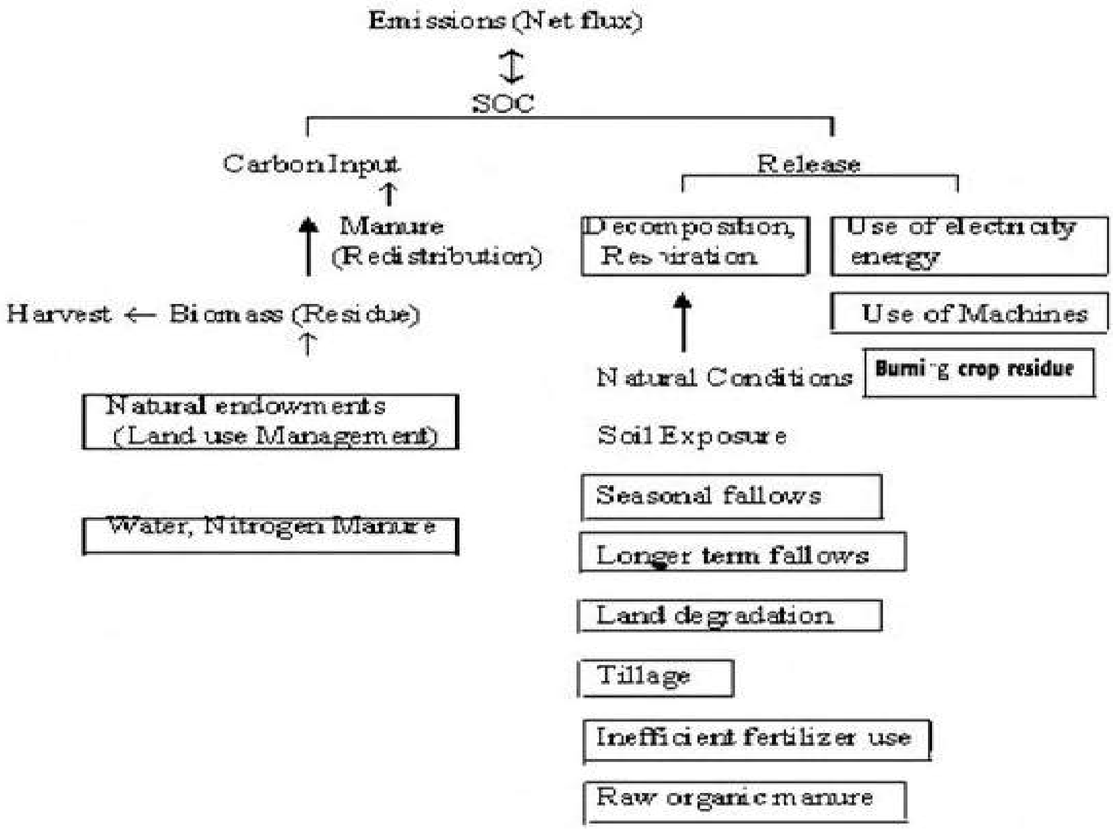


Figure 5.1: Carbon Exchange with agricultural soil.

5.4.1. Soil texture and acidity

Soil aggregation is associated with the arrangement of soil pores, the flexibility of movement of water and air in soil, biological activities and the growth of plant roots. A good structure is associated with aggregation, low density and high porosity but the definition is not always straight forward. Aggregation that tends to fall apart when struck by raindrops is not stable and is amenable to emission. The stability of the soil aggregate is its ability to resist disruption when outside force (mainly water) is applied. In general aggregates with large pore spaces between them and smaller ones within them are more stable and improves when the soil contains more organic matter.

Organic matter in various stages of decomposibility influences the emission potential of soil. Certain constituents are relatively labile while others are recalcitrant. There are other parts that have reached stable forms and may be resistant to decomposition for many years to come. Soil biota, chiefly earthworm has an important role in soil aggregation and stability. Low pH levels of soil suppress microbial activities, lower the respiration rates and reduce decomposition and hence lead to lower carbon dioxide evolution. However acidity may stand in in the way of biomass production and inhibit the generation of soil carbon. Similarly, progressive decrease in carbon dioxide evolution is observed as salinity of soil increases (Rastogi and Pathak, 2002). The stability declines rapidly when crops are planted on tilled soil and is higher on sod (grass-covered surface soil held together by matted roots) and land cropped with cover crops.

5.4.2. Temperature

Temperature is noted as the single most important variable for predicting soil carbon dioxide flux (Raich, 1995) but beyond an optimal level, increasing temperature can depress soil respiration. This optimal temperature also varies with soil conditions and activities of the plant system and increases in emission with rising temperature are marked even at very high temperatures above 50^0 C (Bunt and Rovira, 1955). The non-linear relation between temperature and chemical reactions such as the decomposition rate is usually described by a power (Arrhenius) function. Carbon dioxide peaks observed in mid-July reflect the synchronization of high plant growth with temperature induced increasing root activity and decomposition rates. The temperature-emission relation is associated with an important feed back effect. A rise in mean annual temperature of 5^o C would potentially increase carbon dioxide emission by a factor of 2-4 (Chapman and Thurlow,1996) and estimates suggest that a 1^oC rise in temperature could lead to a 10% (3%) loss of SOC in the regions of the world with mean annual temperatures over 50^O C (30^o C).

5.4.3. Moisture

The sensitivity of emission to moisture largely depends on temperature (Bajracharya,2000,). Decomposition decreases as the soil dries but saturated conditions too inhibit decomposition by reducing diffusion of oxygen. Observed emission rates from wetland soils are generally lower than those in nonwetlands (Raich, 1995). However, a moisture constrained state can also mean limitated opportunities of improving biomass production and hence lead to less crop residues for carbon formation. Hence desert soils have low potential and irrigation of dry soils is useful input to carbon sequestration.

5.4.4. Soil nutrients

Addition of soil nutrients can affect the accumulation of SOC and rate of emission in different ways. Soil fertilization leads to greater biomass production and in turn increases carbon input in soil through greater residue generation and improved SOM content. A part of the SOM may of course decompose and stimulate emission but the intensity of this depends on the tillage practices. Amendment given as animal manures is directly effective in building up carbon stocks in soil. They are rich in carbon and have high proportions of materials recalcitrant to decomposition because the labile compounds get selectively removed in the digestion process of the animals. Rustogi et al (2002) on the contrary cite studies that indicate that organic manures, especially soluble compounds and sewage sludge applied for supplying nutrients to crops contribute significantly to emission of carbon dioxide. Paustian (1997) points out however that the carbon gain by manure application may not reflect atmospheric removal but simply a redistribution via animals through feeding and bedding functions but nevertheless, the resulting plant growth would add new litter and subsequntly SOM to soil.

Although nitrogen is a major constituent of the atmosphere, it had been the limiting factor for plant growth until human beings learned to make the nitrogen usable (nitrate) for plants with the invention of the Haber-Bosch (HB) process. The HB process has not escaped criticisms for relying on fossil fuels and being energy intensive. Addition of nitrogen (via urea, ammonia etc.) is thought to be a positive influence for soil carbon accumulation indirectly because of its stimulating effect on plant growth and biomass and also indirectly by repressing the respiratory activity of soil organisms in the more acidic ambience. Besides, nitrogen is also required for the formation of stable humus for which the Carbon-Nitrogen proportion is important. But such arguments are not untouched by scepticisms expressed by other soil scientists. It is argued that the increased biomass resulting from fertilization can stimulate biological acitivity in soil and generate excessive respiration and the processes are not fully understood till date. The net balance between carbon uptake and release is important in this context. Theory is not altogether clear about the expected impact on carbon sequestration.

5.5. Cropping practices and carbon emission

We have seen that biomass generation of plants lies at the root of both carbon accumulation in soil and emission from soil. Exposure to high temperature, precipitation and winds accelerates decomposition rates and promotes emission especially when the soil texture is amenable to destabilization. Thus cropping practice need to take increasing account of aspects like soil exposure, crop choice, soil disturbance and soil amendment that are consistent with scientifically tested evidences. In this section we will discuss a few common practices in agriculture and their intended purpose in the light of their linkage with carbon sequestration.

5.5.1. Fallowing

Leaving the land uncultivated for short periods will enhance exposure as well as erosion. Fallowing is a primitive method of restoring fertility in soil and is more common in tropical regions where cropping cycle is alternated with land fallowing. A typical system is shifting cultivation in which long periods of fallowing (over 20 years) are alternated with short crop periods (1-2 years). A fallow land is a piece land that is not seeded for a season or more. Sometimes this land is ploughed long before it is seeded which increases the exposure even more. Fallowing not only represents under-utilization of land. The exposure accelerates the loss of any carbon that is stored in the soil and the lack of vegetation effects a break from carbon sequestration from photosynthesis in the short term.

Fallowing of land, coming as a break from continual coverage under a certain crop, was believed to reduce weeds, pests and diseases to which such crops were especially vulnerable to and can conserve moisture and nutrients by pausing the uptake. In developing nations where farmers are poor, shortage of resources is a key reason for leaving land fallow. Shortage of water is another important reason. Well-off farmers also tend to refrain from cultivating land when they find more lucrative options for investing their time and available resources.

In section 5.2 we found that fallowing can actually be a way to sequester carbon that can return to its hypothetical capacity level i.e., when the soil is under native vegetation, given that enough time is allowed. However, fallowing over a long time horizons (say 35 years) can be a costly process when other eco-system services from agriculture need to be weighed against carbon sequestration. With land being under pressure for food production especially in tropical countries the fallow periods can only be for short periods as dictated by water and resource constraints. Even the traditional system of shifting cultivation appears to be giving way to continuous cultivation. In normal agro-systems fallows range over few months (seasonal) to few years where the land is essentially amenable to cultivation. Fallowing over short periods provides little returns in terms of carbon removal. Table 5.1A shows that continuous cropping has been accountable for 20% carbon loss in one year compared to 43% loss under fallow. This creates a case for exploring alternatives to fallowing in agricultural land. Table 5.1 finds a positive effect of including fallow in the cropping cycle for 20 years in contrast to soil carbon loss under different rice-wheat based cropping cycles in India.

Table 5.1: Organic status of soil in the Indo-gangetic plain under rice-wheat cropping system for 20 years						
Location	Soil	Cropping system	Initial Soil Carbon (gram per kg.)	Soil organic carbon after 20 years (gram per kg.)		
				Control	NPK	NPK+FYM
Pantnagar	Mollisol	Rice-Wheat	14.8	5	9.5	15.1
Pantnagar	Mollisol	Rice-wheat-cowpea	14.8	6	9.0	14.4
Faizabad	Inceptisol	Rice-Wheat	3.7	1.9	4.0	5.0
Barrackpore	Inceptisol	Rice-Wheat-Jute	7.1	4.2	4.5	5.2
Karnal	Alkali soil	Fallow- Rice-Wheat	2.3	3	3.2	3.5
Source: Compiled by Singh, 2010						

5.5.2. Rotation

Fallowing as a method of soil fertility restoration is a slow process. In general fallow lands end up hosting unplanned vegetations consisting of shoots of the harvested crops, unwanted weeds and shrubs and even trees. However, the practice of rotation is found to be preferable to fallowing for maintaining soil quality. Like fallowing rotation too avoids the harmful effects of raising the same crop in succession. Rotation, a practice of growing a series of dissimilar crops in the same area in sequential seasons can have many distinct advantages from the agronomic point of view since appropriate crops can be chosen for the purpose. Changing the crops and resultantly also the precise crop calendar help to check diseases, pests and weeds specific to the crops and the season. Annual crops like maize (corn) and rice can be grown in a continuous sequence while wheat is an annual that grows only in winter in India (summer in cold countries). All crops cannot be grown in a continuum depending on their temperature and moisture demands and their commercial value. Continuous cropping of the same variety depletes soil of certain nutrients they particularly need while rotation with other crops avoids the overuse of the same nutrients even while full use of the land resource is accomplished. A question however arises about the choice of crops in the rotation.

5.5.3. Cover crops

Fallow periods are typically bridged by growing cover crops as rotation. Cover crops and green manuring were the primary ways in which nitrogen was traditionally supplied to crops. Cover crops are grown to manage soil fertility and for many of the advantages discussed for rotation. They help to prevent soil erosion by slowing down the velocity of rainfall and wind before reaching the soil.The exposure of lower layers os soil is diminished and nutrient leaching is reduced. They help to check drainage problem in soil and form a physical barrier between rainfall and soil surface so that rain trickles down and water is conserved. They cool the soil and prevent evaporation, effectively combat weeds by competing with them and cutting off of sunlight from weeds. Conservation of nutrients and water and prevention of pests are the agronomic values of cover crops and rotation.

5.5.4. Does crop choice influence carbon sequestration

Agronomists have shown that use of different cropping systems is one means of conserving organic matter in soil regardless of its use for producing food. Biomass generation, their easy decomposition and the soil micro-organisms they support have a say on carbon sequestration. Crops vary with respect to the biomass generated at various levels. Annual and cereals crops like corn, rice and wheat generate more surface biomass than legumes and evidences suggest that cereals or annual crops could be relatively benificial (Table 5.3). On the other hand, grasses have dense and deep root structures that lead to ample biomass generation under the soil surface. These residues decompose slowly increasing the carbon longevity in soil. The roots promote soil micro and macro aggregate formation and stability of the soil where SOC is protected. Legumes can fix nitrogen in the soil which in turn helps in biomass generation, reduce chemical use and help in humus formation. Each crop type has its distinct implications (Table 5.2).

Table 5.2: Carbon sequestration potential via different crops		
Crop	Carbon gain	Carbon loss
Cereals	More surface biomass	Carbon depletion, nutrient loss, soil diturbance, chemical use
Beans/legumes, Root crops	More nutrient for biomass generation, less dependence on chemical	Less biomass
Grass	High and deep root bio-mass, soil stability	Low in surface biomass and residue
Fallow	Slow carbon restoration, may take 35 years	No significant biomass generation

Large scale conversion of grassland to mono-cropping under cereals have been held responsible for soil carbon losses. On the other hand cereal crops too have sequestering potential and prudent management like reduced tillage and nutrient management may make up the loss. Paustian (1997) suggests that soil carbon levels tend to be lower under maize-soyabean rotations compared to continuous maize. Experiments in the US found continuous maize and continuous surghum maintaining higher carbon levels than rotations (Havlin,1990)) and between cropping systems involving Switchgrass and Corn-Soyabean rotation for 25 years, swtchgrass showed more carbon accumulation even in exposed sub-soil conditions (Al-Kaisi, 2008). However experiments in US also showed that in a comparison among three sequences Continuous Corn (CC), Corn-Oats rotation (CO) and Corn-Oats-Meadow (COM) a higher rate of decline was seen under continuous corn. West and Marland's (2002) measurements incorporating emissions from input use under conventional tillage find carbon sequestration to be higher for soyabean than corn and wheat under unirrigated cultivation but with irrigation wheat performs better. Emission also varies with the seaon and time of day for the same crop. Buyanovski (1986) Thus inter-crop dimension of carbon sequestration is not conclusive, the responses being related to specifities of practices and site conditions. More research is needed on this aspect. It is considered preferable to adjust the rotations to allow a varied cropping cycle. Plants with deep roots alternated with shallow rooted plants including the annual crops improve soil structure and quality and reduce emission. Rotating forages with annual crops helps carbon accumulation in soil because of the high carbon allocation above and below ground, low transpiration and formation of stable soil aggregates

(Nilsson, 1986). Bhattacharya et al (2007) provided an account of SOC gain ranging from -26 to 395% between 1980 and 2005 in different soils and crop systems of the IGP.

Table 5.3: Evidences on crop choice and soil carbon		
	Area	Results
Paustian eta al 1997	North America	C level lower for maize-soya bean rotation compared to continuous maize.
Zeilke and Christenson 1986		High correlation of C change with residue returned and with frequenncy of maize in rotation
Havlin 1990	Kansas	Contuous maize/sorghum maintain more C than rotation including soyabean
Johmston 1973, Nelsson 1986	Europe	C gain more with annual crops and ley (temporary pastures) than only annual crops

5.5.5. Land use options

It is desirable to promote intense and continual coverage and avoid short term land fallowing in order to minimize exposure. Even degraded land needs to be reclaimed and managed using appropriate strategy. Rotations with suitable crops can help to avoid fallows and such crops could chose with care. While rotation among dissimilar crops is encouraged, comparisons of potentials of carbon sequestration among crops do not yield any firm message. In US rotating corn with soyabean has been found to be a viable option especially since soyabean also offsets emission as a feedstock for biofuel. Grasses also prove beneficial for soil conservation over long periods and help animal farming. Pulses are a good option in India and can help to ameliorate protein security of population.

5.5.6. Fertilizer use modulation

Modulating fertilizer use as an instrument for mitigation deserves special attention in view of the supreme importance of fertilizer for food production. Research results about the direction of effect of increasing fertilizer use on carbon sequestration are not convincing. Field and laboratory based research failed to give consistent results. A summary of the research results is given (Table 5.4).

Table 5.4: Fertilizer use and soil carbon changes		
Kwalenko 1978	Region-crop	Fertilized soil showed low emission
Wilson 2001	US corn-soyabean	No significant relation
Al-Kaisi et al 2008	U.S. maize-soyabean	Site specific effect
Khanet al2007	US-continuous corn	Long term use fertilizer use lead to soil carbon depletion
Mulvaney et al 2009	US, rice-wheat	Long term use fertilizer use lead to soil carbon and nitrogen depletion

Field and laboratory based research on the effect of nitrogen fertilization on soil microbial biomass and on carbon dioxide emission has not given consistent results. Findings ranged from negative impact on emission (Kowalenko et al,1978) to lack of significant relation (Wilson (2001). AL-Kaisi et al (2008)'s field studies on four sites in the US for a maize-soyabean cycle found that different N-fertilization rates had no consistent and significant effect on emission rates which were more site specific. Cumultaive emission in soyabean production was also not affected by N-application in the prior corn crop. A laboratory incubation study controlling for root activity however showed that emsission was reduced with increasing nitrogen use. On the whole the results on nitrogen effect are inconclusive and at best they do not indicate a positive effect on emission. On the other hand, log term studies based on Morrow plots which are the oldest experimental research soils in U.S. found depletion of carbon as well as nitrogen after about four decades of chemical fertilizer use (Khan, et al., 2007, Mulvaney et al., 2009). In view of the confirmed and unconfirmed results the strategy for mitigation would be to use chemical fertilizer in doses and in ways that would bring out the maximum grain yield. The kind of fertilizer used and the mode of application also matters.

5.5.7. Zero-tillage and Reduced Tillage

In modern agriculture sowing of crops take place in well prepared beds where soil is made aerated, porous, free from weeds and separated as furrows by the use of different mechanical intervention. Though these intrusions are meant to improve crop productivity, they also disturb the soil and have profound consequences that may not be immediately or patently visible. Some of the changes effected by tillage are

(i) Soil aggregates are broken undermining the stability of the soil so that the soil becomes more susceptible to degradation and erosion.

(ii) The underlying layers of soil are exposed to natural elements like air because of ploughing and soil reversion, soil particles upto great depths (up to 40-60 cm) are affected by higher temperature and precipitation and decomposition and oxidation of organic materials are accelerated.

(iii) Greater exposure also leads to evaporation and moisture loss making irrigation more important.

(iv) Soil organisms including earthworms are killed while ploughing affecting biodiversity adversely as well as reducing soil biological activities.

(v) Soil carbon in the sediments will be removed by erosion and the plant residues that are the source of SOC are dislodged.

(vi) Soil carbon loss though the process undermines soil quality making it less fertile and unstable as carbon also acts as a glue to hold the soil together.

(vii) Further the use of machines for tillage leads to greater use of energy and adds to the cost of cultivation.

All these changes transpire over the years and adversely affect soil productivity. Cost of productio increases, there is greater pressure for nutrient replenishment and water extraction in turn triggering greater use of synthetic fertilizers and digging of wells.. Some plots become degraded and uncultivable. Farming gradually becomes unprofitable and farmers may abandon land and move to other occupations.

No till or zero tillage farming is an emergent agricultural technique pioneered by a scientist and philosopher Masanobu Fukuoka. It provides a way of growing crops year to year without disturbing the soil by tillage. Intuitive understanding suggests that avoiding tillage would help water conservation by reducing evaporation, would reduce soil erosion and improve biodiversity in soil all of which help to alleviate soil productivity. In addition it offers a powerful way to conserve soil carbon content and also reduce carbon dioxide and othere greenhousehas emissions. The crop residues left intact on the soil help water from natural precipitaion and irrigation better infiltrate the soil so that roots can grow deeper to absorb the water. The residues limit evaporation and prevent soil compaction. The top layers of the soil that is disturbed by conventional tillage can become more stable and less vulnerable if tillage is eliminated. No-till cultivation curtails the need for energised machines and saves labour use and aside from agriculture, this method also preserves any underlying artifacts in the soil that may enrich heritage.

While no-tillage is a well-defined and possibly difficult to implement option, conservation agriculture is a method involving reduced tillage and a group of practices directed towards sustainable agriculture that minimizes the loss of valuable soil resources. These practices involve different tillage implements such as the chisel plough and deep rip or no plough while conventional pluoghing generally makes use of the advanced plough known as the Mouldboard. No-tillage is a type of conservation agriculture and reduced tillage (RT) another. West and Marland distinguished three practices No-tillage (NT), Reduced tillage (RT) and Conventional tillage (CT) as tillage practices that leave more than 30%, 15-30% and less than 15% of the residue cover intact respectively. Conservation agriculture however combines a variety of other measures with zero or reduced tillage such as rotations, use of surface mulch, organic nutrients and bio-pesticides. Drip irrigation is also a possible accomaniment since it creates less soil mixing and disturbance and maintains greater residue coverage.

However no tillage or even low tillage farming is not an easy method nor is it suitable for all kinds of soils. Critics point out that the crop stubbles left on the fields are liable to create emission whereas ploughing could incorporate them in the soil. One of the purposes of tillage is to remove weeds. No tillage can not only proliferate the growth of weeds but also change the composition of weeds to unmanageable forms. As a result this method of farming may be expected to be associated with greater use of chemical weedicides. Special arrangements are necessitated where the soil has drainage problem as also to contain diseases adapted to the cool and moist environment. While all this may make this method costly there is significant potential for cost saving due to reduced use of machinery, labour and irrigation and the possibility of growing an additional intervening crop due to the greater availability of moisture. The method could actually prove more profitable than conventional farming. Even the crop yield rates can increase due to moisture conservation and enrichment of soil carbon but generally the initial effect of the transition is expected to be yield depressing but over a longer period the effect will be favourable. The effect on profit would also depend on relative impacts on yield and cost. A review of literature on the subject is provided below.

Research has recently been focused on comparisions of RT and CT, facilitated by the increasing popularity of the NT or RT methods in various parts of the world and development of measurement techniques. Coverage under conservation agriculture in the Midewest region of the US doubled between 1992 and 2002 and covered about 22% of all cropped land in 2002 (AL-Kaisi2005). In nearly all experiments NT was found to have a favourabl effect manifested as increase in soil carbon or reduction in emissions.

Potentials of NT to maintain higher carbon levels compared to CT in sub-humid and himid tropics is demonstrated by experiments which found Carbon content to be doubled in NT in top 10cm relative to CT in land under maize (Juo and Lal, 1979) and organic matter loss from 4 year maize cultivation to be less than 10% in NT but 19-23% in CT (Agboola, 1981). Reduced erosion and soil temperature and surface mulches are important attributes for NT in tropics (Lal,1986). Similar evidences emerged from other parts of the world (a comprehensive review is provided by Paustian,1997). However the studies often explored effects of a package of practices rather than just low tillage and sometimes had coverage beyond agriculture. For example long term European field experiment data on tillage (including manure, straw and sewage sludge applications and afforestation of surplus arable land and increased rotation with forages) found mitigation potential to be 165-210 Tg C/year (Smith, 1997). This estimate however indicates the upper limit and derives from sources like offsets from biofuel and afforestation too. Sequestration potential of 2Tg C/year was based on calculations from data on Canadian agriculture (Dumanski et al (1998) (involving summer fallow reduction, rotation and intensive use of fertilizers). US data found assessments of of carbon stock changes to be an additional 5-6Tg C/years for RT and NT (Doningen et al 1994) and 2-5Tc C/year only at the surface (Lee et al, 1993).A potential of 3.3 Pg C was reported for the former Soviet Union (Lolchugina and Vinson,1996).

While NT and RT are largely found to reduce emissions, variability and complexitiy in the patterns cannot be overlooked. In CT increase in flux and soil respiration are observed to increase soon after tillage but the effect was shortlived (Rustogi, 2002). Evidences suggest that carbon sequestration may be a long drawn process through tillage changes. Although SOC changes in response to management practices could be relatively rapid. It took 10 years to obtain stable management effects (Monreal and Janzen, 1993) in Numerous field studies showed increases in macroaggregate stability with RT andNT (Paustian, 1997). Since tillage affects a limited part of the soil horizon, the effect will vary with soil depth. In an Iowa University experiment on Corn-Soyabean rotation for alternative 3-year long practices of No till (NT), Strip till (ST), deep rip (DR), Chisel pough (CP) and Moulboard plough (MP) with identical fertilizer (Al-Kaisi, Yin, 2005) significant soil depth-tillage interaction effects on SOC changes were noted (See appendix Table 5.1A). The interaction effects were higher for NT and ST and lowest in MP which represents the most intense disturbance (Table 5.3). The Carbon effect was 32% greater with NT and ST than CP on 0-5cm soil horizon and 36-41% at greater depth of 5-10 cm but stabilized thereafter. Reducing tillage intensity in Corn-Soyabean rotation could enhance carbon gain at the 1-15 cm soil depth. The experiment was also conducted with and without surface residues and since the differences were not significant among the practices when surface residue is removed manually, the gain in SOC in NT and ST over the others could not be attributed to the aboveground crop residue but to the disturbances involved. Crop residue effect on carbon dioxide emission varied temporally but the total emission was lowest for NT with residue (300.4 Kg/hectare) compared to NT without residue (396.4 Kg/hectare), ST (377.6 Kg/hectare), DR (402.2 Kg/hectare), CP (415.8 Kg/hectare) and MP (511.3 Kg/hectare). The lower emission from NT with residue than MP was attributed to lowering of soil temperature, lower decomposition of crop residue placed on the soil surface and not incorporated. Since tillage operations facilitate emission from soil pores, barrier created by the residue between soil and atmosphere could be another factor explaining this effect.

Tillage incurs not just soil disturbance induced emissions but the use of energised implements is also a source of emission. Moreover, as is envisaged NT and RT also tend to alter the use of inputs which themselves incur emission costs in their life cycles. West and Marland (2002) considered the use of inputs seeds, major fertilizers, herbicides and insecticides, energy use for irrigation from on-site and off-site sources and use of machines for input application when arriving at emission potentials for US for three crops Corn, Soyabean and Wheat. Agronomic input use data was taken from USDA and emission rates and soil sequestration from US Department of energy to work out average C emissions at 168, 146 and 137 kg C/year for CT, RT and NT respectively under no irrigation (See appendix Table 5.2A). They present alternate corresponding estimates of 52.8, 41.0 and 29.0 Kg C/year provided by Kern and Johnson (K&J, 1993) that they find comparable to their own estimates of emission due to machinery use at 69.0, 42.2 and 23.3. kg C/year. Their estimates unlike K&J take account of emissions associated with the manufacturing, transportation and apllication of inputs. With carbon sequestration due to NT being reported as 337 Kg C/ hectare year, the net carbon flux in CT and NT are found to be 168 and -199.6 Kg C/hectare for unirrigated and 325 and -74 Kg C/hectare for irrigated land. The data reported also reveal certain associated changes in input use due to the conversion. In most cases across crops and on the average input use has declined except for herbicide use (greater weed growth) and greater use of Nitrogen in Corn and Soyabean. W&M study however considers only emission of carbon dioxide while NT may intensify emission of methane and nitrous oxide via surface stocks and input use. Duxbery (1993) considers the addition of Nitrogen as amendment with W&M data and finds that a change to NT alters the fluxes of the two GHGs and effectively adds 67 lb per acre of carbon equivalent.

5.5.8. Management options

The above discussion indicates certain broad options for management even as the inconclusiveness of many of the results are highlighted (Table 5.5). Reason suggests that leaving fallow land would cause soil exposure to temperature, water and wind and reduce biomass generation. Over many years there will be replenishment through the growth of unplanned weeds but in the normal cropping cycle fallowing is not advisable for carbon sequestration.. Rotation does appear preferable but require conscious planning of crops. While crops vary in their ability to generate biomass at different levels, experimental research does not yield any firm direction for a preferred crop rotation as each type of plant has its strengths and weaknesses and the implications depend on the site conditions, the associated farm practices and the season of cultivation. On the whole literature suggests a choice of varied rotation involving crops with high surface biomass, those with deep and dense roots and also legumes that fix nitrogen. Advantages other than sequestering potential such as nutrition for human or animal and market value can lace the choice. However more studies need to be required in this matter.

Use of fertilizer can have beneficial effects on carbon sequestration but there are both theoretical basis and empirical evidences to believe otherwise. With this lack of resolution a policy for optimal use of nitrogen could be the best path keeping in view the objective of food production. Tillage is a source of soil disturbance that leads to emissions as sown by numerous studies but reduction of tillage can compromise on crop yield in the short run. This is an area that requires research priority. Thus management options like cover copping with rotation and optimum use of fertilizer agree with the objective of land utilization for increased production and options like optimum fertilizer use and conservation farming conform with the standards of sustainable agriculture.

Table 5.5 Summary of Implications of conventional and emerging farm practices for Carbon sequestration				
Practice	Emission	Accumulation	Positive effects	Negative effect
Fallow	Increase (exposure)	Reduce (lack of biomass)	Agronomic advantages	Land under-utilizatiom
Rotation	Decrease (less exposure)	Increase (biomass above and below ground, nutrient fixation)	Agronomic and economic benefts	Choice of crops difficult, increased cost, water shortage may not be profitable.
Low tillage	Decrease (less exposure)	Increase (weeds, nutrient, water lead to biomass)	Agronomic advantages, economic gain due to low cost	Reduce short run yield, increase use of herbicides
Fertilizer	Uncertain (can increase)	Increase (nutrient for biomass and humus formation)	High yield	High cost, pollution
Water management	Excess moisture can increase emission	Increase through more biomass	High yield	Can cause environmental degradation if not properly managed

5.5.9. Waste management and Methane capture

Crop cultivation generates considerable amounts of wastes and residues whose disposal becomes a burden. Health damages due to pollution caused by burning rice straw in Punjab is estimated at Rs 70 millions (Kumar and Kumar, 2009). The climate change concern adds another dimension to this existing problem because greenhouse gases are generated when these wastes undergo decomposition. Although with appropriate disposal strategies, these wastes are mostly biodegradable and also recyclable with considerable use value, rotting and burning cause trace gas emission along with the emission of all the three major GHGs.

Burning of residues is a common practice in India because there is very little use for these materials at the given time and place of generation (Sahai et. Al, 2010). Most common rotations like the rice-wheat rotation in north India leave very little time interval for effective disposal of residues like stems and roots since any delay in wheat planting can have adverse effects on production as discussed in chapter 4. Part of the waste management challenge can be overcome by the practice of low tillage if possible as this method entails the incorporation of the residues back into the soil. Since agricultural wastes can have alternative uses as fuel, fodder and packaging materials, development of commercial opportunities within easy proximity can help to reduce emissions in an economic way. Composting facilities and biogas plants if available within easy reach can help to convert these wastes into valuable fuel. Contributing to farm electrification this method of waste disposal has always had its appeal in India where rural electrification is a challenge by itself but due to various limitations related to resource scarcity, the progress has been tardy. Not surprisingly, composting and biogas production are appropriate subjects for investment under the CDM and have significant prospect in the carbon market. The methane generated from rice production, although a threatening greenhouse gas, also has valuable potential to serve as a fuel. Openness to technologies for capturing the methane for useful purposes such as farm operations and lighting arising in other sectors as in industry could be an option and the opportunities provided by the carbon market need to be fully exploited.

5.5.10. Biofuel

Like carbon sequestration, the use of the cultivated crop as biofuel is an added way in which agriculture can help mitigation. Plants convert atmospheric carbon dioxide into carbohydrates that they store in their tissues. Some of the chamical pathways in plants synthesize fats composed of triglycerides from the photosynthetics carbohydrates and this is stored as vegetable oils in seeds to serve as an energy source for germinating embryos. Human beings have made use of this storage of carbohydrates and vegetable oils for producing oils to serve various purposes including human consumption. Combustion of these oils would mean return of carbon dixide that was only recently withdrawn photsynthetically from the atmosphere as compared to burning fossil fuels that implies a net injection to the system of carbon that was withdrawn millions of years ago. The energy of biofuels originates from the energy in sunlight. Therefore, if human beings were to replace petroleum and diesel by fuel derived from oils originated from plants, the carbon cycle would be completed in the short term. However, this solution has its costs. Vegetable oils and carbohydrates have alternative uses, most crucially as food for human beings. The gain from a biofuel scheme would depend on not only how far the harvest would be in excess of the need to fulfill alernative uses already in practice. Producing crops as feedstocks of biofuels also imposes demands for inputs some of them being also fossil fuel based. Thus the costs involved need to be weighed against the benefits of shifting to biofuels.

Biofuels are fuels derived from living materials and include bioethanol, biomethane, and biodiesel. Bioethanol is produced through the fermentation of a carbohydrate like glucose from crops like sugarcane, corn or wheat to produce ethanol (along with carbon dioxide and energy) which can further be combusted to generate carbon dioxide, water and chemical energy. A comparison of the inputs in the photsynthesis and the output in the combustion makes it clear that the whole process converts electromagnetic energy in sunlight to chemical energy that can be used tto propel a vehicle without making any net additions of greenhouse gases. Biomethane or biogas is produced by a similar system of conversions involving the production of methane by the anerobic fermentation of carbohydrates in a process called ‘methane capturing’ and further the combustion of methane too produce carbon dioxide and chamical energy for propulsion. Unlike natural gas that too consists mostly of methane and is mined as a fossil fuel from under the earth, the emission constitutes carbon dioxide that has been recently removed. Biodiesel is produced through a complex series of chemical reactions involving the fats or vegetable oils stored in the seeds. The esters of the fatty acids have properties similar to those of petro-diesel and the combustion of biodiesel returns carbon dioxide recently removed by photosynthesis. Soyabean, mustrad seed, rape seed and and a large number of other possible feedstocks are known to have potential. The conversion process also generates glycerol that is used in industry for various reasons.

In theory the chemical energy that is produced by burning biofuel propels a vehicle without causing any net production of greenhouse gases. In practice, however the neutrality indicated by this assumption is not above question because of the inefficiencies that arise at various stages of the process. During the production of the biomass, i.e, cultivation of the crop, inputs including fertilizer and machine power are used that may generate net emission unless conducted in appropriate ways. Since land necessary for production is limted with several alternative uses, the emphasis is on generating higher yields from land for food production. In turn, this promotes higher uses of external farm inputs. Much depends on the technology involved in production including the varietal development of crops and management practices as discussed in order to obtain higher yields without causing disproportionate emissions. Since biofuel production potentially displaces usages for human consumption the net gain may not be significant unless technology is available to drastically expand production which is not likely or if feedstocks are developed from crops that are unfit for human consumption.The processing of biofuel also adds complexity to the assessment. Plant biomass has low energy density in comparison to fossil fuels, so that volumes involved for biofuel feedstocks are large. Transport costs for such large volumes over long distances becomes uneconomic so that processing facilities need to be loacted near the sites of production. Even with average distances being short, emissions during transportation constitute 2-4% of the total emissions caused by bioethanol production. Processing would involve drying the biomass that too calls for emissions as well as loss of soil nutrients if waste biomass is used for the purpose.

In the case of India. India the option of using biofuels is not easy. India has a deficit in the production of edible oil and so the use of oiseeds for the purpose is nearly ruled out at this stage. Food security is also of great significance in the country and a strategy of shifting to biofuel can prove disastrous if farmers are encourage to shift land from food production. Indeed, the merit of diversion of area from food to fuel is debated across the world.

Cultivation of biofuel is an emerging way in which agriculture is employed to effect mitigation worldwide. Several countries have devoted extensive areas of agricultural land for raising corn, wheat, sugarcane, soyabean and mustard in order to produce biological ethanol, ethane and diesel for fuelling transportation needs. USA and Brazil are leading countries to produce bioethanol from corn and sugarcane and biodiesel from soyabean. India’s progress is still limited and laced with caution. In the case of biodiesel, the national shortage of edible oil restrains the use of oilseeds for the purpose and although maize and sugarcane are recognized as possible feedstocks the option needs to be weighed against food security constraints as all these crops vie for limited land. It is mandatory to blend biofuel with petrol. A preference for feedstocks that have no alternative and valuable use and that can be grown on degraded or forest soils is natural. Jatropha is such a forest agro-product that is identified as a potential feedstock for biofuel in India and for the additional benefit of generating rural employment for the poor. Global auto companies like the General Motor are collaborating with scientific organizations in India for the commercial use of jatropha integrated with a holistic clean fuel venture involving hybrid and electric vehicles, fuel cell and alternative fuels like CNG and LPG.

5.5.11. Tradeoffs

The strategy for management of agriculture towards a low carbon path would need to take account of complexities of the subject, the paucity of knowledge about many of the agronomic processes, the difficulty of measurement and above all the contradictions and tradeoffs implicit in the options. The subject is growing and possibly near its inception. Many of the strategies have different channels of action resulting in dissimilar outcomes. The most patent is the effect of nutrition supplementation that on the other hand helps soil carbon formation, mitigating atmospheric concentration and on the other, it contributes to substrate generation in soil that in turn creates the environment for emission. The effect of temperature, moisture and soil pH level are neither linear nor unidirectional. The impact of any one strategy can be favourable for the emission of one gas but inhibitive for another. Above all the effect on crop productivity needs to be assessed especially in the case of low tillage.

5.5.12. Carbon offset

Emission trading is an institution with a comparatively recent origin. It started with a conceptualization process and demonstrations made between 1967 and 1970 wby computer simulation studies at the National Air Pollution Control Administration (predecessor of the US Environmental Protection Agency). With an inception in the US's Clean Air Act 1977 and the successful achievements in Acid Rain Programme in 1990 the market based cap and trade mechanism for controlling emission has had a short life span as yet but nevertheless shown sufficient promise in its relatively short period of evolution. The Kyto Protocol of 1997 has provided a further impetus to this innovative yet nascent market. First under the KP the developed countries have made commitments to reduce their emssions generally with respect to the 1990 level and on the average by 5.2%. Secondly the KP has provided for certain flexible mechanism for attaining the commitments. While the cap and trade option is implemented and operates at various levels of development in many developed countries, the developing countries have no specific obligations for mitigation under the KP. Nevertheless given the success of the market there are efforts at building up voluntary markets. Howver, the developing also participate in the world carbon market through the Clean Development Mechanism (CDM). Given the current tendencies there are possibilities that subsequent to 2012 the carbon market will have expand and there will be greater participation of developing countries. India is an active participant in the CDM as of now and the potential for participation can increasing coming times. Agriculture may be explored as a possible sink and the development programmes need to be designed in ways so that not only does agriculture follow the low carbon path itself, but the farmers especially the poorer farmers gain economically from participation in the mitigation drive even while state of the art technology and resources flow in from developed countries for the progress of agriculture.

5.6. Potentials in India

In chapter 3 we discussed the progress of intensification of agricultural land in India.This is al illustrated in Figure 5.1. Cropping intensity that is a prime determinant of the extent of seasonal fallows is influenced by the availability of irrigation and also financial resources along with options of non-agricultural economic activities. Today only 38% of the net sown area is under multiple cropping wile 62% are only single-cropped. Although over time the multiple cropped area grew by 115% between 1970-71 and 2007-08, there is a long way to go before the gap is bridged. Figures A5.1 in appendix give the positions in major states. While a generally declining trend is shown by the proportion of sown area under single cropping, signs of stabilization are evident in Madhya Pradesh and Punajb and in Tamilnadu, underutilization has grown.

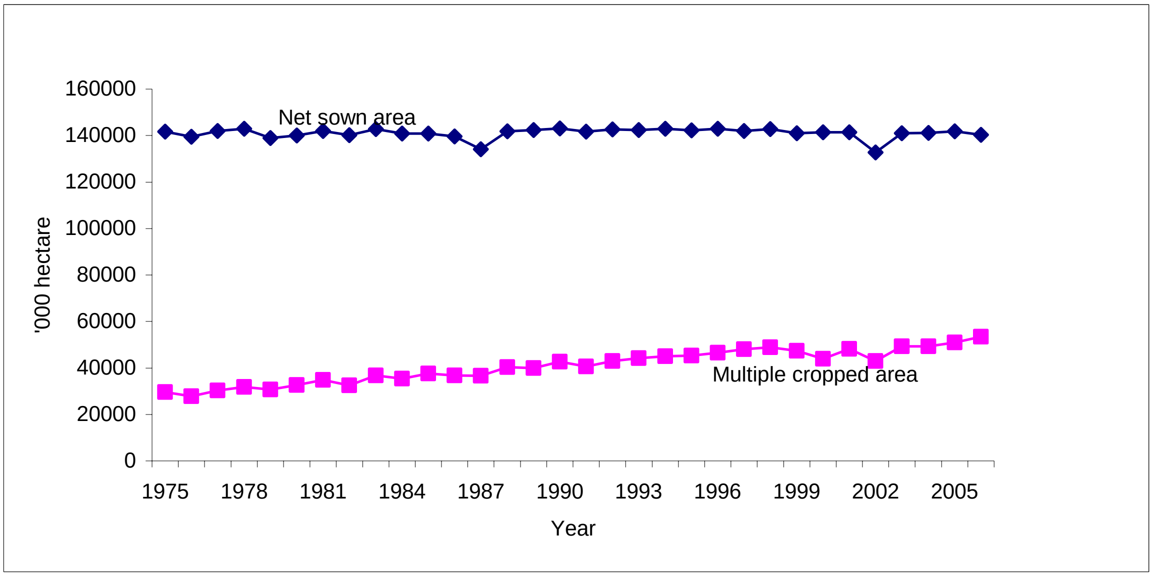


Figure 5.2: Net Sown Area and Multiple Crop Area in India, Source: Ministry of Agriculture (GOI), ASG.

Considering land that is left fallow for a year or more reflecting more of resource scarcity it is seen that of the total land that is potentially available for planting (cultivated and fallow), 15% is constrained to lie fallow. Since this land is also a potential victim for carbon emission in the duration of time concerned, judicious management is required for covering such land. Additionally, degraded land ravaged by wind and water erosion needs to be reclaimed. However economic viability may come in the way of reclaiming or re-greening unsown land with planned vegetation. Thus investment on efficient water conservation and irrigation schemes will be necessary as much as new ways of financing such endeavours. As covering the soils would be compatible with the long standing agricultural objectives of the country even though past un-fulfilment highlights the additionality, the carbon market can prove to be important.

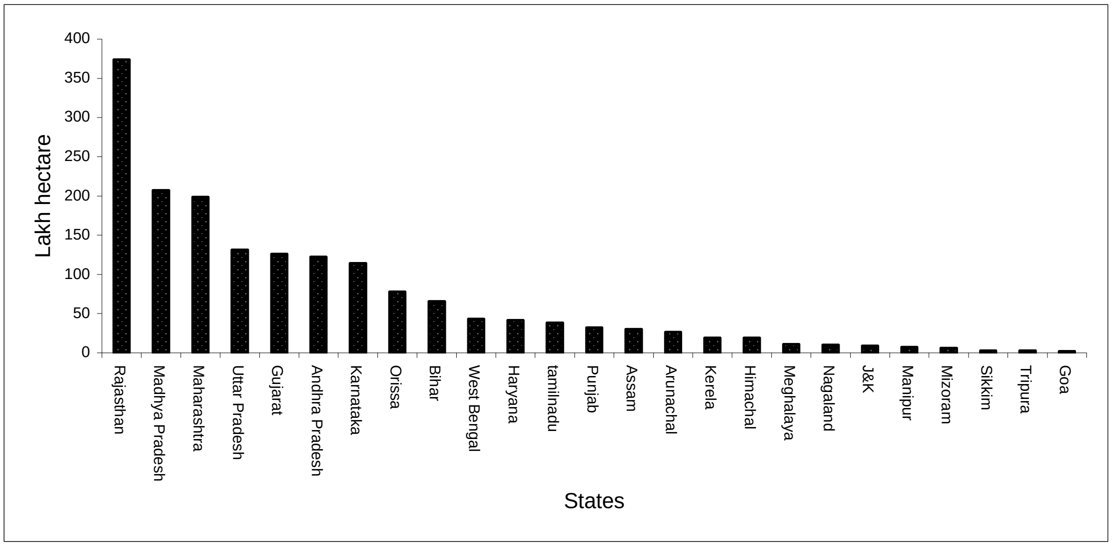


Figure5.3: State-wise degraded area in India, Source: Water and related statistics, 2004.

Figures in 5.2A traces the decreasing trends of the yield fertilizer rations for three different food crops in the major states where the crops are grown. Each unit of fertilizer has yielded less output per hectare in successive years and even though much effort has been made in recent times to raise the ratio at best they have stabilized at a level below 20 in the case of rice and wheat for all the states. Only in maize positive signs have also emerged and there have been considerable diversity of performance. With the advancements made in technology there are options of promoting site specific and precision driven input use that is based on monitoring plant biological nutrient needs for timely and measured application and innovative ways of incorporating fertilizers in soil.

That the phenomenal growth in foodgrain production discussed in Chapter3 was driven by intense use of inputs is shown in Figure 5.4 where the indices of foodgrain production compared with those of use of inputs in agriculture show remarkable imbalance. While irrigated area grew faster than production by a small margin the gap between production and fertilizer use was large and widened overtime. This shows that production growth has been coming with increasing additions to fertilizer a costly input. The unyielding response of production to increasing fertilizer use is a malaise of Indian agriculture that has been engaging policy makers and agronomists striving for agricultural growth. Figures 5.2A in the state level for a few major crops reflect a wide-spectrum stagnation of fertilizer use efficiency with maize being a possible silver lining. This is an area that needs for research and toying with technology.

Table5.6: Mitigation potential of state Agricultures

States	Fallow	States	Single-cropped	States	Yield/Fert	States	Machine cost/value prod
Tamilnadu	0.33	Tamilnadu	0.85	Rajasthan	23.20	Uttar Prad.	0.29
Bihar	0.30	Karnataka	0.76	West Bengal	21.27	Madhya Prad.	0.22
Andhra Prad.	0.28	Gujarat	0.75	Punjab	19.52	Bihar	0.20
Rajasthan	0.19	Andhra Prad.	0.74	Orissa	19.47	Punjab	0.18
Karnataka	0.15	Maharashtra	0.70	Haryana	18.89	Rajasthan	0.17
Maharashtra	0.13	Rajasthan	0.70	Uttar Prad.	17.19	Haryana	0.16
Orissa	0.12	Madhya Prad.	0.65	Madhya Prad.	16.84	Andhra Prad.	0.14
Uttar Prad.	0.11	Assam	0.61	Karnataka	16.58	Karnataka	0.13
Madhya Prad.	0.09	Bihar	0.57	Andhra Prad.	16.02	Tamilnadu	0.13
Gujarat	0.07	Uttar Prad.	0.48	Bihar	15.35	Assam	0.08
Assam	0.06	Orissa	0.40	Tamilnadu	10.49	Gujarat	0.07
West Bengal	0.06	Haryana	0.20	Gujarat	10.31	West Bengal	0.03
Haryana	0.03	West Bengal	0.16			Orissa	0.03
Punjab	0.01	Punjab	0.12				

Notes: Fallow as proportion of total cultivable (fallow + net sown area), Single cropped as proportion` of net sown area., Fertilizer use efficiency is ratio of fertilizer use per hectare to yield as weighted average of rice, wheat and maize, Machine cost as proportion of value of product as weighted average of rice, wheat, maize. ,Source: Ministry of Agriculture (GOI)

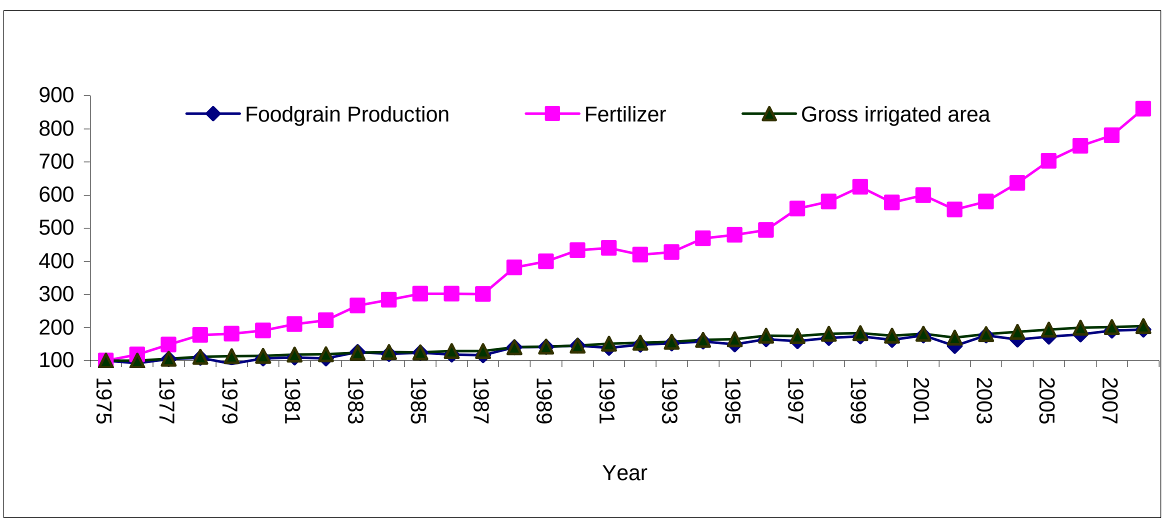
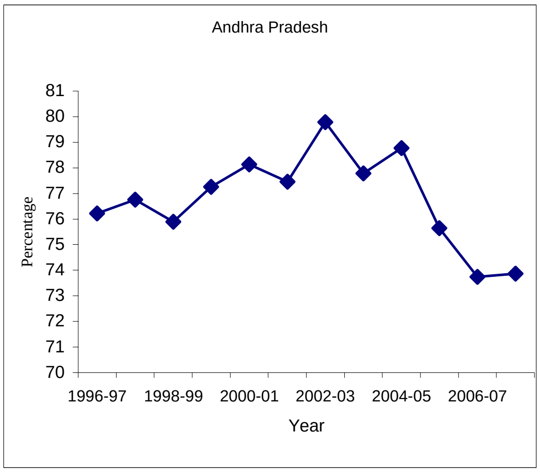


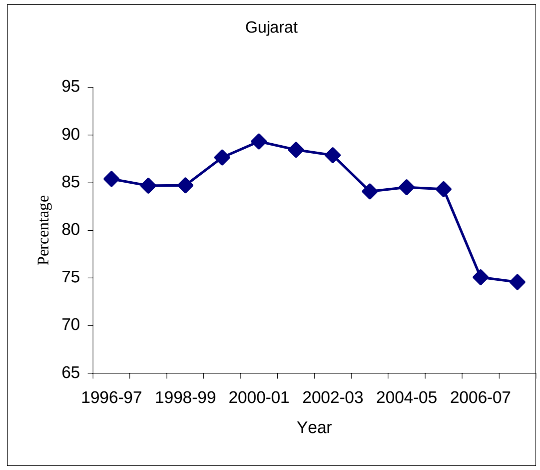
Figure 5.4: Foodgrain production and agricultural input use as indices (1975-76=100), Source: Ministry of Agriculture (GOI),ASG

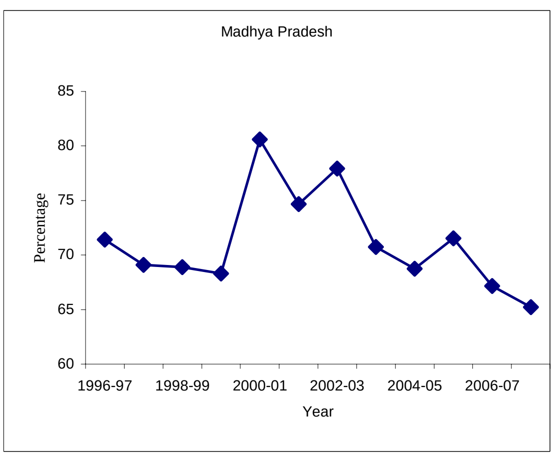
Mechanical intervention in agriculture helps to expedite agricultural operations reducing the use of labour that involves a wage bargain, labour discontent and supply uncertainty and mmanagerial complications. On the other side, in a land scarce and labour abundant rural economy in India where poverty is widespread mechanization has always generated misgivings about employment implications and urban migration. The context of greenhouse gas emissions raises two further issues namely that of soil interference created by the intrusion and the onsite and offsite emissions created by the use for fossil fuel both for operating the machines and for manufacturing the machines. Given the structure of Indian agriculture and the small size of farms, minimization of mechanization could possibly be an acceptable option although the implications of not tilling the soil especially with heavy implements merit careful deliberation. In chapter 3 we saw that there is an increasing tendency of using machines like tractors, sprayers and tiller in agriculture and electricity used per hectare has risen over the years. The ratio of the value of product in agriculture to the cost of using machines has been rising reflecting either inefficiency as in the case of fertilizer use or increasing substitution of labour by machines or perhaps both.

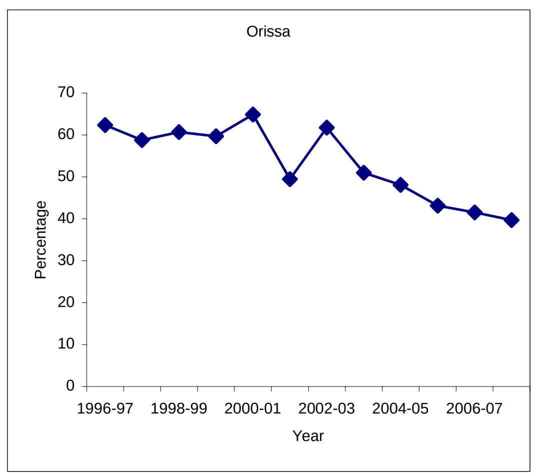
Appendix 5.

5.1. Figures and Charts









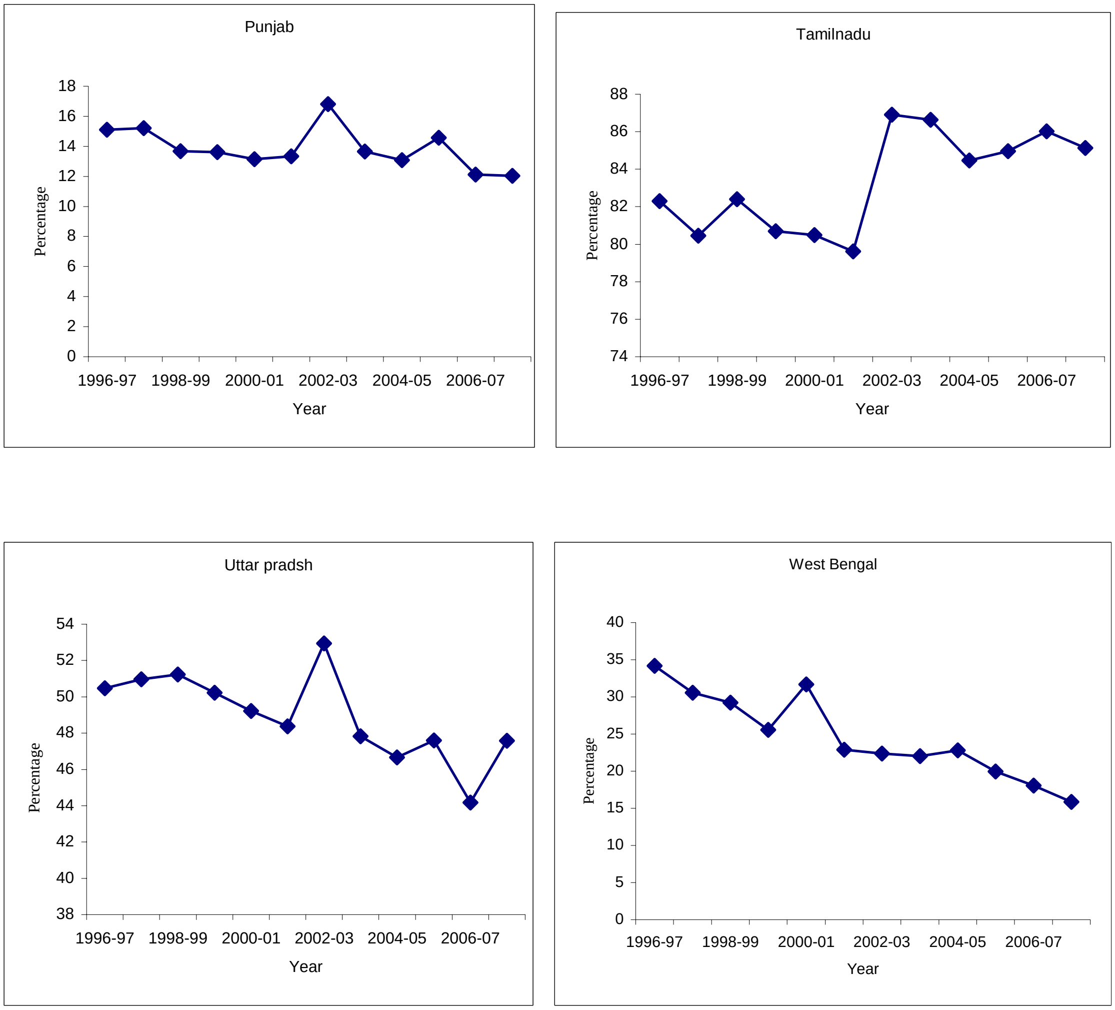
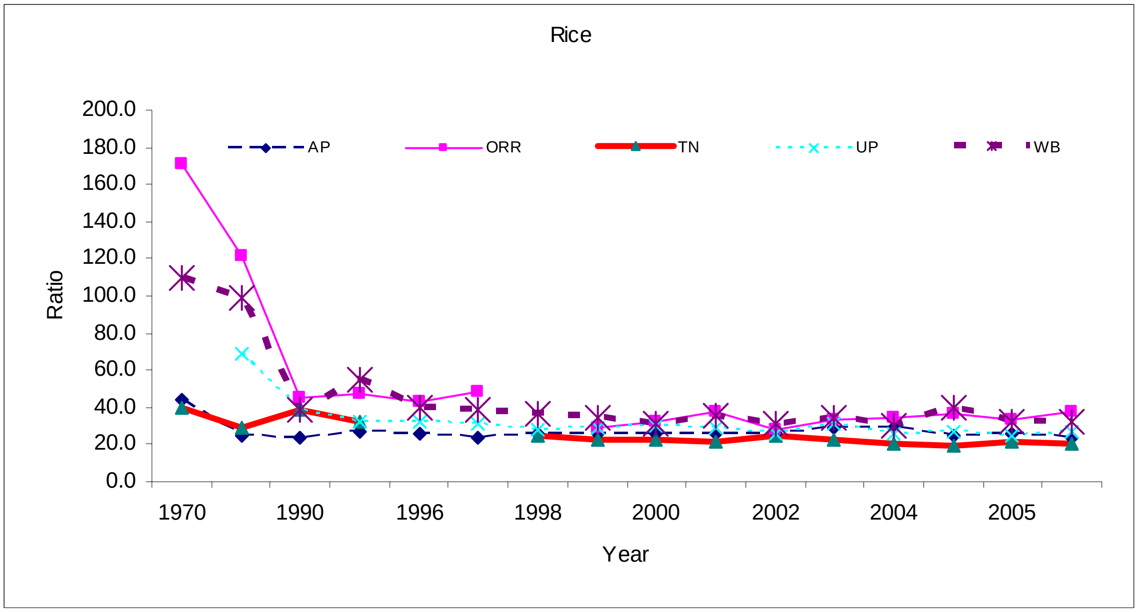
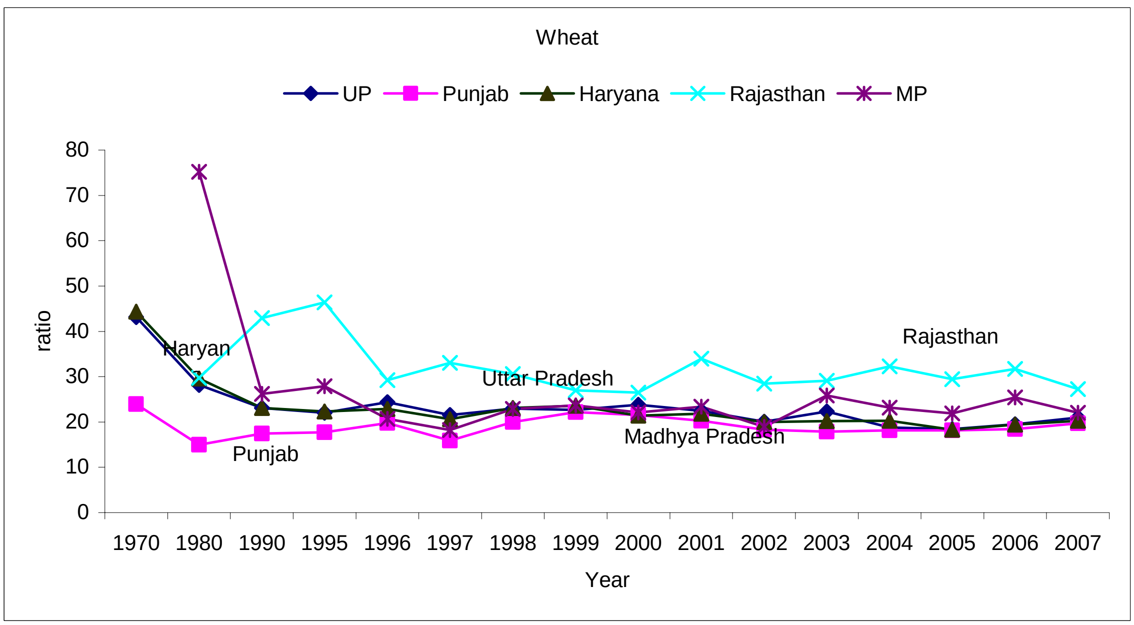


Figure 5.1A: Percentage share of single cropped land in the Net sown area in different states. Source: MOA (GOI).


Rice
Ratio
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
AP
ORR
TN
UP
WB
1970
1990
1996
1998
2000
2002
2004
2005
Year


Wheat
UP
Punjab
Haryana
Rajasthan
MP
ratio
80
70
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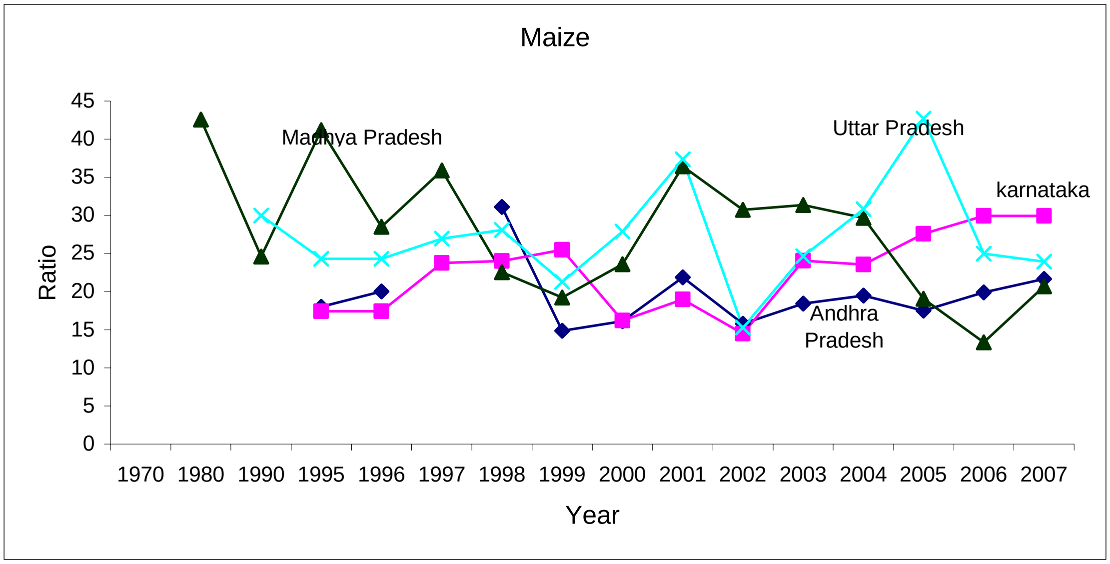

Figure 5.2A: Yield to Fertilizer ratios in different states. Fertilizer use is as reported for the crop from the cost of cultivation of principal crops by Government of India. Source: MOA (GOI).

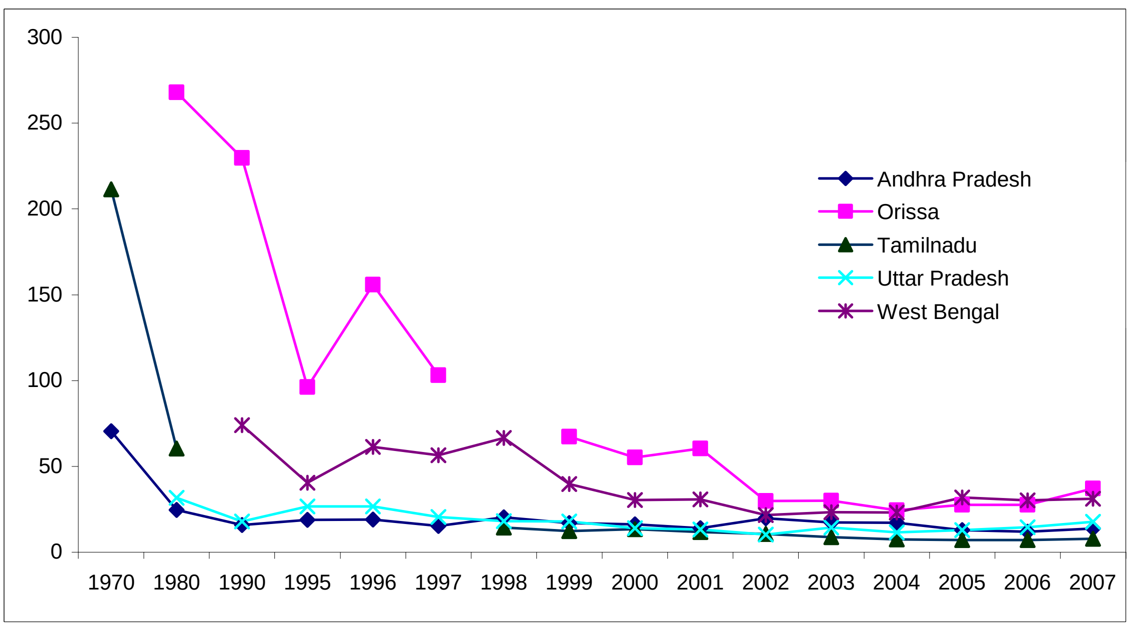

Figure 5.3A: Value of main product to machine labour cost ratio for rice. Source: MOA (GOI).

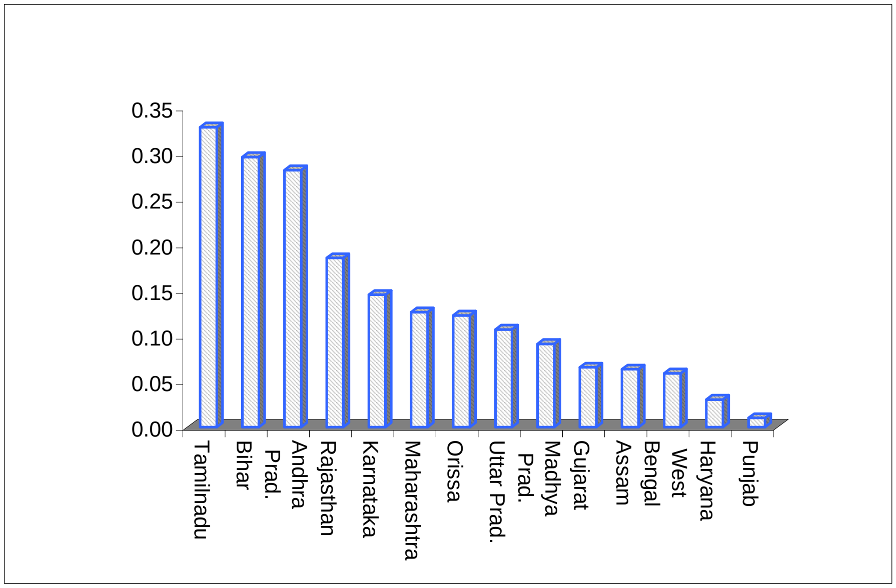

Figure 5.4A: Proportion of Fallow land in cultivable land. Cultivable land is specified as sum of fallow land or Net sown area. Source: MOA (GOI).

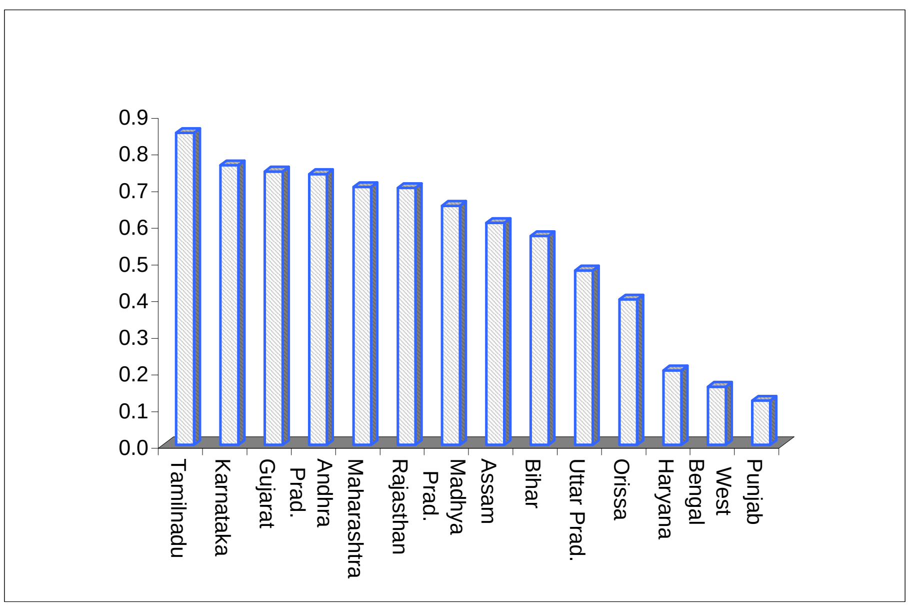

Figure 5.5A: Proportion of Single cropped area in Net sown area. Source: MOA (GOI).

5.2. Tables

Table 5.1A: Tillage effect (Soil depth X tillage)on Soil organic carbon and on from Surface residue (Mg/hectare)							
	Soil Organic Carbon at different soil depths				Carbon input from above ground residue		
Tillage	1-5cm	5-10cm	10-15cm	0-15cm	Corn	Soyabean	Total
No tillage	17.0*	16.9	18.6	52.6	5.5	2.8	8.2
Strip-tillage	16.9	17.6	18.5	53.0	5.0	2.4	7.5
Deep rip	12.3	13.0	19.4	44.7	5.9	2.8	8.7
Chisel plough	12.9	12.5	18.3	43.6	5.7	2.6	8.3
Moulboard plough	11.4	14.2	14.3	39.9	5.9	2.9	8.8
Note: * not significant Source: Al kaisi and Yin 2005.							

Table 5.2A: Input use and Emissions under Conventional Tillage and No tillage systems								
	Corn		Soyabean		Wheat		Average	
	CT	NT	CT	NT	CT	NT	CT	NT
Input use								
Irrigation water	0.32	0.25	0.38	0.3	0.2	0.16	0.30	0.24
Fertilizer (N)	107.6	150.2	12.3	29.1	70.6	58.3	63.50	79.20
Herbicide	2.71	3.63	1.12	1.5	0.22	0.4	1.35	1.84
Insecticide	0.99	0.68	0.64	0.39	0.48	0.33	0.70	0.47
Emissions								
Machines	72.02	23.26	67.45	23.26	67.45	23.26	68.97	23.26
Input use								
Total emission-Irrigated	395.62	359.660	307.350	229.060	273.650	199.260	325.54	262.66
Total emission-Unirrigated	227.58	225.460	107.750	71.460	168.550	115.260	167.96	137.39
C-Sequestration	0	-337	0	-337	0	-337	0.00	-337.00
Net C flux								
Irrigated	395.62	22.66	307.35	-107.94	273.65	-137.74	325.54	-74.34
Unirrigted	227.58	-111.54	107.75	-265.54	168.55	-221.74	167.96	-199.61
Note: CT and NT are conventional tillage involving moulboard pough and no tillage. Inputs use is in Kg per hectare for fertilizer, herbicide and insecticide and Ha-m per ha for irrigation. Emission in Kg C per hectare. Source; Marland and West (2002)								

Table 5.3A. Changes in the carbon content of forest, Cropped and Fallow soils					
Study	Reference	Years since Clearing	Depth (cm)	% C	%Change in C
Falesi et al. 1980	'Virgin forest'	-	0-50	0.54	
	Crops	1		0.49	-81%
Lal and Kang 1982	'Secondary forest'	1.5	0-15	2	-13%
	Crops	2		1.6	-30%
	Crops	3.5		1.15	-50%
	Crops	7		1.45	-37%
Sanchez et al. 1982	Humid Secondary forest'	17	0-15	1.24	
	Crops	1		0.9	-27%
	Crops	8		0.9	-27%
Glubczynski 1983	Moist Forest		0-25	1.39	
	Crops	3-5		1.06	-24%
	Crops	50		1.39	0%
Glubczynski 1983	Dry Forest		0-25	3.46	
	Crops	60		1.71	-51%
Falesi et al. 1980	Humid Tropical forest		0-50	0.54	
	Pasture	4-7		0.65	20%
Hecht 1982	Humid Tropical forest		0-30	1.26	-29%
	Pasture	1		0.9	-5%
	Pasture	2		1.2	-44%
	Pasture	10		0.7	
Glubczynski 1983	Maure uptropical forest		0-50	2.86	
	Pasture	10		0.95	-67%
	Pasture	50		1.75	-39%
	Wet forest		0-50	2.33	
	Pasture	50		2.3	-1%
Falesi et al. 1980	'Virgin forest'		0-15	0.54	
	Forest fallow	5-10		0.52	-4%
	Forest fallow	15-20		0.44	-19%
Aweto 1981	Moist tropical forest'		0-30	2.7	
	Forest fallow	1		1.54	-43%
	Forest fallow	3		1.45	-46%
	Forest fallow	7		2.06	-24%
	Forest fallow	10		2.67	-1%
Raich 1983	Wet forest		0-50	2.82	
	Forest fallow	17		2.5	-11%
Glubczynski 1983	Wet forest		0-50	2.33	
	Forest fallow	20-25		1.62	-30%
	Forest fallow	38-47		2.17	-17%
	Forest fallow	5	0-25	1.39	
	'Mature subtropical			0.79	-3%
	dry forest		0-25	3.46	
	Forest fallow	35		4.29	24%
Werner 1984	'Mature tropical wet		0-10	4.65	
	forest'	16		3.88	-17%
	Forest fallow	31		4.26	-8%
Source: Detwiler, 1986.					

Chapter 6:

Emissions of Methane and Nitrous oxide from Agriculture

Given that large sections of the Indian population are rice eaters and rice constitutes over 40% of India's food production, the disturbing concern surrounding the emission of greenhouse gases (GHG) on account of rice cultivation comes as a severe challenge as also a confounding research question for India. Although carbon dioxide is the major GHG at the centre of international discourses, given that methane concentration in the atmosphere is growing a 3% per annum rate as compared to growth rates of 0.4% and 0.22% respectively (Battle et al, 1996) of carbon dioxide and nitrous oxide, methane too calls for serious attention. Nitrous oxide is known for its destructive effect on stratospheric ozone apart from its global warming effect. Increasing methane concentration in the atmosphere can have unpredictable consequences on the very chemistry of the atmosphere (Neue, 1993).

Both methane and nitrous oxide emissions have been associated with food production. The importance of rice in the Indian diet creates a strong case for understanding the process working behind methane emission and to explore ways of mitigating the emission. Given that fertilizer was at the heart of India's breakthrough in food production that served to support millions of human lives and that the policy surrounding fertilizer supply has gained a critical place in India's political economy, the emission of nitrous oxide also merits serious attention in the context of Indian agriculture. India's share in global methane emission at 8.6% is more than her share in the other GHG emissions and nitrous oxide and methane are the major components with agriculture respectively accounting for 82% and 58% of the nation's emissions (World Resource Institute, 2009). These statistics highlight the significance of agriculture in the GHG emissions that taken place in India.

6.2. Rice as a Source of methane

Wetland fields are identified as a major source of atmospheric methane. Methane is produced by fermentation taking place in anaerobic flooded soils and both methane and nitrous oxides are generated dominantly by biogenic (bacterial) processes taking place in the crop lands. More than 90% of world's rice is produced in Asia which creates enough grounds for Asian countries to deliberate seriously over the issue of climate change in that context. Asia is also home to 63% of the world's hungry people so that the issue of food security and climate change that might in turn feed back into agricultural production call for a fine balance. India has in the recent past been pre-occupied with uplifting her agricultural performance especially in the background of high growth rates achieved in the other sectors in the economy. In fact agricultural growth itself has been closely linked with the reduction of poverty and rural poverty has been seen as a key factor in aggregate poverty (World Bank, 2008). The Eleventh Five year Plan visualized that the 'agriculture sector has to contribute a growth rate of above 4.1%'. With food prices in recent times increasing food production rising has become indispensable for meeting the Millennium Development Goal (MDG) of reducing hunger. Setting and chasing elevated targets every year is a common strategy in agricultural planning in India. The National Food Security Mission (NFSM) and the Rashtrya Krishi Vikas Yojana (RKVY) focus attention on regions lagging in productivity while providing supplementary funds to states and finally, even India's National Action Plan on Climate Change (NAPCC) of 2008 emphasizes that 'Maintaining a high growth rate is essential for increasing living standards of the vast majority of our people and reducing their vulnerability to the impacts of climate change'.

The average per capita consumption of rice in India is about 73 Kg per annum as compared to 49 Kg of the other major cereal wheat. Rice makes up 55% of the average Indian's foodgrain intake, 58 % of public procurements of grains and of late it has also emerged as a leading export item. It is highly demanding in water though considerable portion of India's rice is raised in rainfed and naturally wet regions. Rice is also known to demand high doses of nitrogen, synthetic fertilizers urea and ammonium compounds being common supplements though rice has a natural mechanism of biological fixation (Ghosh, 2004). Table 6.1 gives an indication that the importance of rice in Indian economy has grown in many respects in the last three decades.

Table 6.1: Importance of Rice in India

Different measures of importance	1980s	1990s	2000
Production in relation to all food grains (%)	41	42	43
Area in relation to Gross cropped area (%)	23	23	24
Consumption in relation to all cereals (%)	45	52	53
Irrigation in relation to total irrigated area (%)	33	31	32
Fertilizer (N) in relation to total use (%)	32.4	36.1	32.7
Export in relation to all rice production (%)	1.24	0.71	3.50
Procurement in relation to rice production (%)	10.0	17.0	22.0
Irrigation in relation to Rice area (%)	40.8	45.6	55.0
Fertilizer intensity of Rice (Kg/hectare)	40. 6	56. 8	68.5

Note: Figures for the three decades 1980s, 1990s and 2000s relate to 1980-81, 1990-91 and 2000-01 respectively except for the following. For consumption the corresponding figures relate to 1983-83, 1993-94 and 1999-2000, for fertilizer they are 1986-87, 1991-92 and 2000-01 and for Export the years are ratios for trienniums ending with 1982-83, 1992-93 and2002-03.
Source: Compiled by various sources.

In most parts of monsoonal Asia rice is grown as a transplanted crop where fields are flooded before planting and percolation of water is reduced by the process of 'puddling'. India has four rice ecosystems[i] . They are (i) Rice Irrigated lowlands (RIRL), (ii) Rice Rain fed (RRFL) lowlands, (iii) Rice Rain fed uplands (RRFU) and (iv) Rice Deepwater land (RDWL). In the lowland ecosystems rice seedlings are transplanted in puddled conditions and the fields are kept either in continuous submergence as in the east or south of India or in intermittent submergence as in north India. Upland rice is directly seeded on seed-beds and the fields are never flooded. Deepwater ecosystems tend to occur in low lying high rainfall areas and the sowing strategies depend on the onset of the monsoon.

Except the 'upland', other rice ecosystems can be categorized as 'wetlands' whose soils are naturally or artificially saturated during part or all of the year. Wetlands are described

[i] This is consistent with UNFCCC guidelines for classification.

as ‘transitional’ between terrestrial and aquatic status (Neue, 1993) with gradual boundaries. While in irrigated lowlands, flooding and drainage can be humanly controlled, in deepwater areas drainage is often naturally insufficient and soil submergence in rainy season is unavoidable. Wetland soils have free water at the surface during the rice growing season, partly due to natural reasons but humans also intervene for retaining water by land leveling and building of dykes. The water content reduces the diffusion of atmospheric oxygen into the soil bringing down the ‘Redox Potential’ of soil sharply. The Redox Potential (RP) is a quantitative index of ‘oxidation and reduction tendencies’ measured in volts.

Methane is produced as a terminal step of anaerobic breakdown of organic matter by ‘methanogenic’ bacteria that can metabolize only in the absence of oxygen and at a RP below a certain critical level. Since paddy soil is generally transient between saturated and unsaturated states, the RP too varies widely. The organic materials or ‘substrates’ that are acted upon by the enzymes in the soil system are affected by the activities of the root system which has a deep synergic relation with the microbial population that compete for nutrition under evolutionary pressures. The GHGs methane and nitrous oxide are produced at two different stages of the RP and expectedly their production is highly uneven within the growth cycle and emission varies by the stage of vegetation, season, time of day and plant zone in the soil system. The complexity of the subject and the brevity of the history of human interest on the subject place research outcomes more at an initial than at a definitive stage.

6.2.1Methane emission from Wet soils

Methane emission takes place mostly through diffusion of dissolved methane and ebullition of gas bubbles**.** But absence of oxygen is a precondition for formation and transmission.The flood water-soil interface generally contains oxygen and root zone or the ‘rhyzosphere’ is also oxygen-fed by the respiratory system of rice. Emission of the methane generated is thus essentially limited by its oxidation while within the soil. Up to 60% of the methane produced during the growing season may be oxidized before reaching the atmosphere (Hlzapfel-Pschorn et al, 1985). Frequent human induced soil disturbances via practices like transplanting contribute to the release of a large amount of the methane generated. A number of other components of the soil system expedite or delay emissions.

The factors behind methods methane emission have been studied by scholars under settings. Diurnal and seasonal patterns of emission with multiple in-season peaks, responses to temperature changes, fertilization and organic amendments were observations reported from a study conducted in Italy (Schultz et al 1989). The importance of soil organic carbon (SOC) as a major factor was also identified in California based case studies (Ciceron et al, 1992) where fertilized fields emitted more than unfertilized ones, SOC is identified as a key factor affecting emissions of both methane and carbon dioxide. The use of chemical nitrogen influenced the timing rather than the quantum of release. A study based in China found that slope and water management practices are determining factors but no effect of urea was noted (Cai et. al, 2000). As empirical knowledge grew, complex relations among nitrogen uptake, biomass and methane emission attracted much attention While the initial hypothesis was one of a linearly increasing effect of biomass on emission, that several other factors also count gradually gained recognition. Indeed evidences of negative correlation of emission with grain yields and an absence of correlation with the above ground biomass in intensively managed rice fields were considered perplexing (Corton et al, 2000). Emission was observed to be 1.5 to 4 folds higher in the wet season than in the dry season. Although nitrogen application stimulated emission via growth, even with no nitrogen materials from earlier crops decayed to generate methane.

A study conducted at the International Rice Research Organization or IRRI in Philippines (Denier et al., 1992) indicated that a lower plant performance as measured by a Harvest Index[ii] (HI) led to excess carbon formation that got partly transferred below ground and eventually provided the substrate for methane formation. While the low HI

[ii] The mass ratio of grain yield and total above ground dry matter.

was causal to methane generation, greater solar radiation was shown to be responsible for a lower HI in the wet season. The study concluded that optimizing grain yield (minimizing the gap between actual and potential yields) brought about by the judicious use of fertilizers, phyto-sanitary controls and varietal improvements can abate emission. Alkaline or clayey soils, composted organic amendments, intermittent or midseason drying of land, sulphate content in fertilizer and various methane inhibiting chemicals can low down if not prevent emissions (Li et al, 2002, Pathak, Li and Wassman, 2005, Neue, 1993) .

6.3. Emission of nitrous oxide

Nitrogeneous fertilizers, known for their yield enhancing influences on agriculture are chiefly associated with the emission of nitrous oxide[iii]. Emission occurs due to incomplete uptake of nitrogenous amendment. Two major known sources are nitrification and de-nitrification. These processes are chains of reactions that involve interactions among nitrogeneous compounds and living organisms and nitrous oxide is only an intermediate product in the two chains. Since nitrous oxide is not a final outcome and it further breaks down or adds up to form different nitrogenous products, the two processes provide not only sources but also sinks for the GHG. Like methanogenesis they are complex processes modulated by various factors. De-nitrification, by far the more common source of nitrous oxide, takes place in anaerobic conditions and is affected by the moisture and the consequent oxygen content of soil. Emission of nitrous oxide is found to increase with soil water content (Henault et al, 1998) but at field capacity, nitrous oxide gets eventually reduced to nitrogen in the de-nitrification process (Goodroad and Keeney, 1985). The relation with moisture is thus highly non-linear. Certain chemical and microbial processes are also known to be sources of emissions.

[iii] The Atmospheric Lifetime Experiments (ALE) and the subsequent Global Atmospheric Gases Experiment (GAGE) conducted in the helped to bring attention the growing concentration of nitrous oxide in the atmosphere. The experiments also exposed that concentration was more in the northern hemisphere and that tropical land disturbances and fertilizer use rather than the burning of fossil fuel that were primarily responsible for the phenomenon.

Table 6.2: Determining factors on Methane and Nitrous oxide production and emission		
Factors	Methane	Nitrous oxide
Temperature	Production increases	Production Increases
Soil texture	Emission declines as clay content increases	Fine soils promote production
SOC	Production increases	Production increases
Soil pH	Alkaline soil conducive to production	Alkaline soil favours production but severe acidity may increase emission; process is not fully understood
Water (irrigation/precip.)	Production increases but emission inhibited	Production increases up to a point but could mitigate beyond a point
Grain yield	Production increases but optimum grain yield will reduce emission	Production increases if use of fertilizers is more relative to output.
Alternate wetting and drying practice	Emission reduces	Production increases (evidence)
Fertilizer use	Production increases but sensitive to the type of fertilizer. Green manure increases emission, Composting can control emission from organic amendment	Production increases but sensitive to the type, FYM more effective for production
Source: Compiled by various sources.		

Volatilization of applied nitrogen and their re-deposition is another source and emissions from leached out and run-off fertilizers that land up in other places like rivers and sewage make the site of emission both dispersed and intractable. Intermittent drying of soils increases emission (Smith and Patrick, 1983). Soil texture affects the emission rate by changing the air-water composition in soil and temperature is an important positive effect[iv]. Plant residues, green manures and farmyard manures are reported to increase de-nitrification but beyond a certain point losses may be reduced due to immobilization of nitrogen. Thus the form in which nitrogen is applied, the type of soil and the crop involved make a difference.

Early methodologies for measuring emissions banked on data collected from studies that related nitrogen use and agricultural practices for various crops and fertilizers. Inhibitors

[iv] As global temperature increases more nitrous oxide may be released.

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of nitrification of fertilized fields are nitrapyrin and acetylene reduce emission from urea applied fields. Emission is noted to be more on organic soils (histosols) than others. Since emission is both direct and indirect and much remains unknown till date, measurement of nitrous oxide emission is an important challenge. Little information as yet is available on how important is denitrification relative to nitrification, how much fertilizers gets leached out, how much is naturally fixed or is trapped in water and even what is the precise nitrogen content of animal waste. Empirical estimates of the benefits of organic fertilizers, biofertilizers and fertilizer use efficiency yet elude the scientists.

6.4. Measuring Emission rates

Measuring emission rates of GHG is gaining increasing importance. However, measurement of an average figure for emission remains daunting. Initial measurements relied on simplistic assumptions and approximations but over time investigations exposed the dangerous inaccuracies of making suppositions. Some of the estimates of global methane emission gave large ranges such as 18-280 Tg/year i.e., 10-70% of the anthropogenic emissions (Khalil and Rasmussen, 1991) and 20-100 Tg per year (IPCC, 1992). In the case of India divergences among various estimates (Table 6.2) based on different assumptions have been quite remarkable.

The relation between biomass (as a proxy for availability of substrates for methane production) and emission was treated as the clue to measurement (Sinha, 1995, Anastasi, 1992) in the initial regression based exercises. A more differentiated approach (Cao et al, 1995) followed from greater recognition of the complexity surrounding the process and subsequent models took account of decomposition rates of SOC and the RP of the soil was taken as an input. Models became suited to the varied conditions of tropical regions and low lying rice fields as different soil-climatic factors were brought under consideration. Today several empirical models are either available for application or are at a development stage such as the MERES (Methane emission in Rice ecosystems), CENTURY, INFOCROP, DAYCENT and MEM. A review of literature finds the De-

Nitrification De-Composition (DNDC) model[v] to be by far most widely used currently. Developed by C. Li. of the Chinese Academy of Science and his colleagues it originally focused on carbon dioxide and nitrous oxide emissions and subsequently became popular for studying rice systems. Li et al (2003) studied the effect of water management in China's rice paddies on the decline in atmospheric methane. Despite its significance, estimates as yet are far from reliable in the case of nitrous oxide (Cai, et. al., 2003). The IPCC provides certain coefficients for aiding calculation but they are partly presumptuous and researchers often show preference to using other methods or coefficients based on literature or on their own field experiments (Bhatia et. al, 2004).

6.5. Assessing the challenge of Mitigation

Being a crop of great economic and political significance in India there is little space for compromising the production of rice. On the other hand, it is futile or even counterproductive to underestimate the cost of GHG emissions that may be obligated by its cultivation. How severe is the challenge of GHG emission mitigation in India's rice economy? While the enormity of size of the rice economy in India may give rise to apprehensions, a critical view may be taken in the light of research findings available so far.

6.5.1 Wetlands: Rice is not the main offender

An argument may be made that methane emission is a quality of wetland ecosystems regardless of human use. Such ecosystems naturally tend to become factories of anaerobic fermentation where methane is generated. Indeed the oxygen free ambience creates several nice properties too. The flooded conditions preserve soil carbon and nutrients reducing chemical use and weed growth and support biological fixation of

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[v] The DNDC is a generic model of carbon and nitrogen cycles simulating on daily and sub-daily basis using a number of sub-models. The model has been validated against observations taken in different countries. Necessary modifications are incorporated to capture specific cases (Li, 2004) and to make it workable for India, calibration, sensitivity tests and up-scaling using geographic Information System (GIS) database were required. Eventually most studies estimated the GWP[v] of emission in the Indian case.

nitrogen. A soil layer known as 'plow pan' typically develops, which prevents detrimental water percolation, nutrient leaching and water pollution. Like rainforests wetlands too prevent soil erosion and help carbon sequestration. They are reservoirs of biodiversity. While all these features benefit rice cultivation as much as they are recognized as ecosystem services, rice is often grown there because wetlands already exist and rice thrives in these conditions and not vice versa (Neue, 1993).

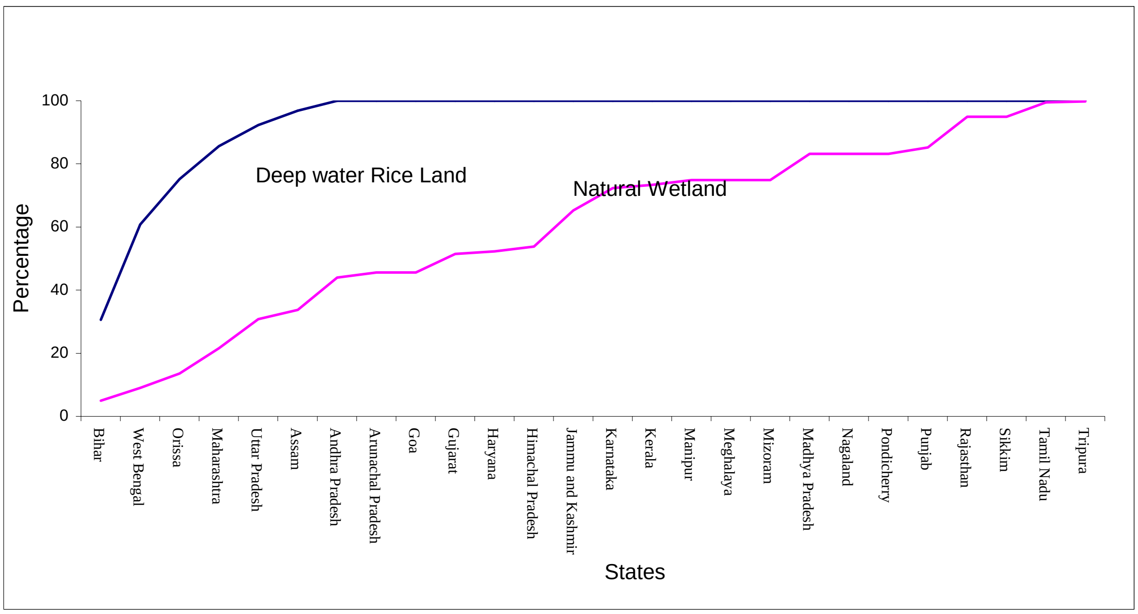

Figure 6.1: Cumulative state shares in Deepwater Rice lands and Natural Wetlands. The States are sorted by their shares in wet lands.

The value of natural wetland for many of the reasons cited in the case of rice lands was well recognized in the Earth Summit of 1992 and demonstrated in the Ramsar Convention to prevent degradation of natural wetlands. At the same time the role of wetlands as a potential source of methane is not unknown. They account for an estimated 170 Tg emission[vi] out of the 200 Tg per year global non-anthropogenic emissions because they provide habitat for organisms that survive without oxygen and can decompose organic materials. Recognized as the largest natural source of methane

[vi] Emission from wetlands is highly variable spatially and temporally and the quantification of the extent of wetlands and emission is far from complete.

emission wetlands in northern latitude wetlands are associated historically[vii] with today's non-significant methane concentration in this earth's atmosphere. The net contribution of wetlands to GHG emissions would depend on the balance of carbon sequestration and methane emission over the years.

That rice fields present similar conundrums is hard to refute. While the role of geography rather than choice in adoption of deepwater rice farming may have some grounds. the plots of cumulative shares of states in deepwater ricelands (RDWL) and Natural wetlands (NWL) in Figure 6.1 demonstrate that while natural wetlands are fairly well distributed across the country, deepwater rice-lands are concentrated in a few states only, implying that culturing practices and the advantages of puddling land are responsible for the practices apart from geography. The states West Bengal, Bihar and Orissa account for 75% of total deepwater rice-lands in India but only 13.6% of natural Wetland.

How influential is deepwater ecosystem in determining methane emission from rice cultivation can also be questioned given the multitude of emission causing factors. Table6.1A in the appendix clearly shows that deepwater rice holds only a little over 5 % of rice lands in the country mostly in Bihar, Maharashtra and West Bengal and land voluntarily flooded by irrigation accounts for more than a half especially in states Andhra Pradesh, Punjab and Tamilnadu.

6.5.2 Understanding Complexities

The relations underlying emissions as understood now are complex, non-linear and suggestive of critical thresholds and reversals. Upland rice is not associated with methane production. Emission is low in RRFL because of drought periods during the growing season and poor growth rates of the plant. In RIRL emission is high but is controllable by human management while in RDWL methane production is high but its emission is slowed down by the reduced mobility of methane in water and the possibility of oxidation

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[vii] A sudden increase in methane on the earth ecosystems may have occurred due to a climate change (Dansgaaed-Oeschger events) about 40,000 years ago.

in soil. In practice the emission rate even in this case is accentuated by human culture. In the case of nitrous oxide research is focused on comparing fertilized and unfertilized soils. However, measurement is no simple task in this case as the location of the source is highly diffused though the advent of sophisticated equipment has aroused expectations on precision.

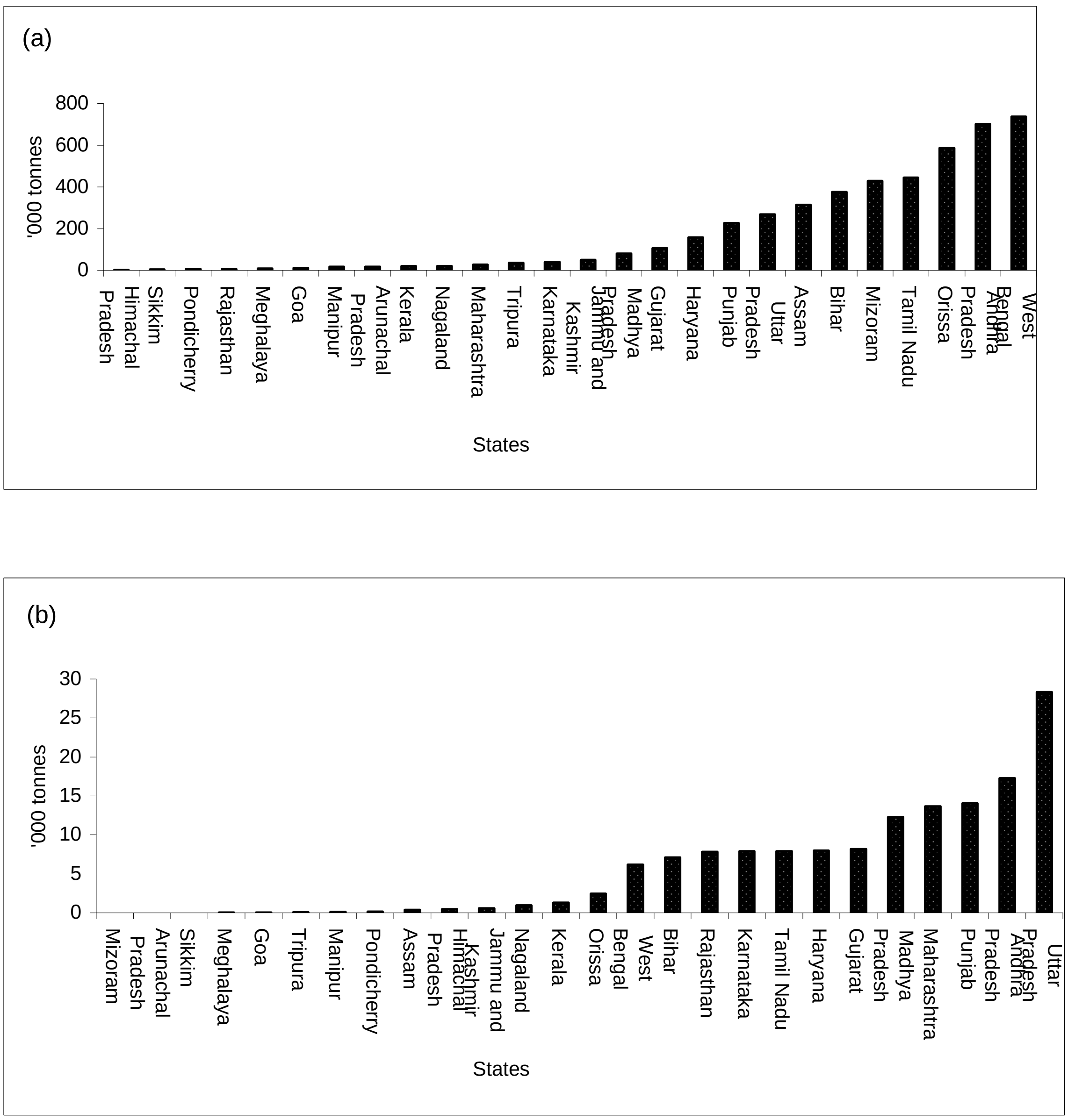


Figure 6.2: Total Emission of (a) Methane from ricefields and (b) Nitrous Oxide. Source: Based on Bhatia (2004)

6.5.3 Measurement Issues

Measurement of both the gases is complicated by the simultaneous dynamics of a large number of explanatory factors which makes estimates sensitive to the location and timing of field experiment or to assumptions about coefficients. Knowledge of local topography including the depth of soil and presence of ditches and depressions becomes important and detailed mapping would greatly improve precision. For nitrogen the problem of run-offs needs to be resolved probably by developing run off estimates for different sites or by eliminating the run off. Mathematical models which are becoming popular also rely on field experiments for validation and calibration. The coefficients provided by the IPCC Guidelines are said to be at best approximates and take little account of finer attributes of the location.

Normally for measurement closed chambers or enclosed sheets are used but variations in the equipment used can make a difference in field measurement (Pathak, 1999, Babu et al, 2005). A study in China making use of Atmospheric Turbulent and Diffusion Model (ATDL) produced estimates of emission that were comparable to the conventional method for the month of June when emission is thought to be most significant but for September the estimates were higher (Liu et al, 2000). There is a need to understand the processes and factors leading to emission, to extend coverage and develop alternate methods to help in cross checking estimates.

Emission figures for India went through significant revisions. The United States Environment Protection Agency (USEPA) in the early 1990s produced estimates of methane emission based on extrapolation of measurements made in Europe and USA. The annual estimate of 37.8 Tg per year was considerably downscaled later once actual measurements were carried out in India. The initial measurements relying on the simple relation with biomass gave estimates such as 1.22 Tg per year (Sinha, 1995) and 3 Tg/year (Parashar, 1991). A national campaign for measurement across rice growing states assigned a methane budget of 4Tg/year for Indian paddy fields. Detailed experiments carried out by the Indian Agricultural Research Institute (IARI, New Delhi) and Central Rice Research Institute (CRRI, Cuttack) under different rice management practices contributed to better quantification and access to mitigation options.

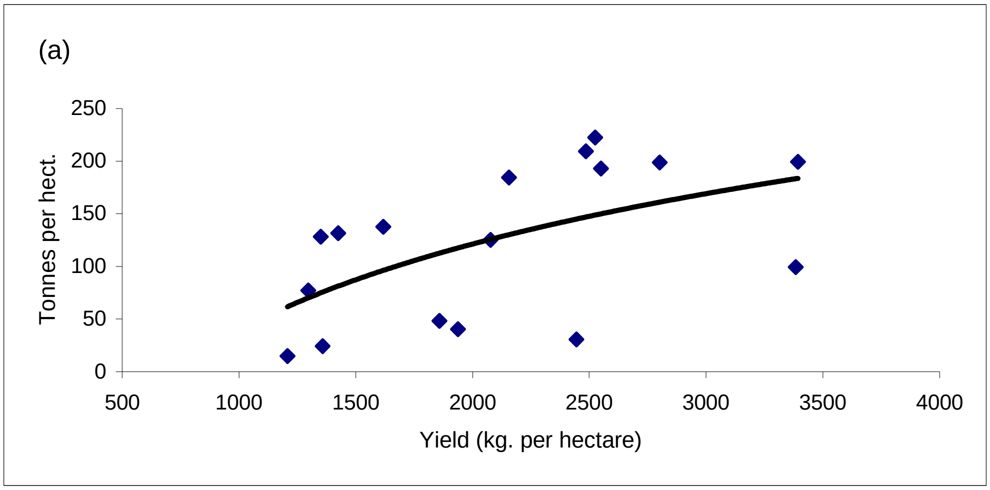
Using IPCC coefficients an IARI study arrived at emission estimates which we denote as BIE (Bhatia at. al., 2004) at 2.9 Tg/year for methane and at 0.08 Tg/year for nitrous oxide. Bhatia et al also reported parallel estimates, to be denoted as BE, using coefficients that are based on specific experiments carried out at various rice growing regions across the country under different moisture regimes for methane. For nitrous oxide the methodology accounted not only for fertilizer application but also other sources like crop residues, animal manure incorporation in soil as also indirect sources like leached out nitrates and volatilized ammonia as collected from the literature. The authors compared these estimates with the BIE estimates that gave higher figures at 4.1 Tg per year and 0.14 Tg per year for the two gases respectively. The emissions from Indian soils were found to be accounting for only 0.23% and 0.1% of global warming for world carbon dioxide emissions. Another study yielded an annual methane budget of 4.09 with a standard error of 1.19 Tg per year and a trend of at least 3.6 Tg per year over the period 1979- 2006 (Gupta,2009).

In Table 6.3 estimates made for methane emissions in India shows a large overall variability. The variability was much higher across rival estimates in the 1990s which marked the beginning of systematic measurement. Estimates reported during the 2000s varied less and the average estimate also came down from 12.5 to 3.5 Tg per year. The Ministry of environment and Forests, government of India in its assessment of 2007 reported an emission of 69.87 million tones of carbon dioxide equivalent per year from rice cultivation that comes to 3.27Tg per year of methane constituting 21% of GHG emissions from Indian agriculture.

6.5.4. State Performances in Emission

State comparison can be made only based on limited reporting of measurements albeit the imperfect methodologies. A comparison between the BE and the BIE is enough to mark the impact of the choice of method. While Andhra Pradesh and West Bengal figure at the top in methane emission by both methods, state level estimates vary. For example BIE ranks the two eastern states Orissa and Bihar at 375 and 586 respectively at the top while BE finds the emissions lower at 187and 177 respectively. Another study using the DNDC model (Pathak et al, 2005) found both the north-western region and the eastern region among high emitters. A more recent study conducted by Gupta et al, (2009) identified the states West Bengal, Bihar, Madhya Pradesh and Uttar Pradesh as hot-spots accounting for 53.9% of total emission.

The plots in Figures 6.2(a) and 6.2(b) of the state-wise BIE emission estimates that are based on the IPCC's coefficients indicate that West Bengal, Andhra Pradesh, Orissa and Uttar Pradesh, the prominent rice growers, are the top methane emitters by this measure. States like Punjab, Uttar Pradesh and Gujarat also figure despite the dominantly upland status. While this could be an account of other factors including high summer temperature, more conspicuously, in Nitrous oxide emission, the more agriculturally progressive states Uttar Pradesh, Andhra Pradesh and Punjab are found to stand out. Intriguingly, a positive relation between agricultural performance and emission also emerges when state level rice yield per hectare is plotted against the emissions per hectare (barring the North-eastern states Arunachal Pradesh, Mizoram, Nagaland, Manipur, Meghalaya and Sikkim), in Figures 6.3(a) and 6.3(b). While the correlation is weak in the case methane emission, the possibility that higher yield states could be higher emitters calls for some policy attention and perhaps much more research on such relations at more micro levels.



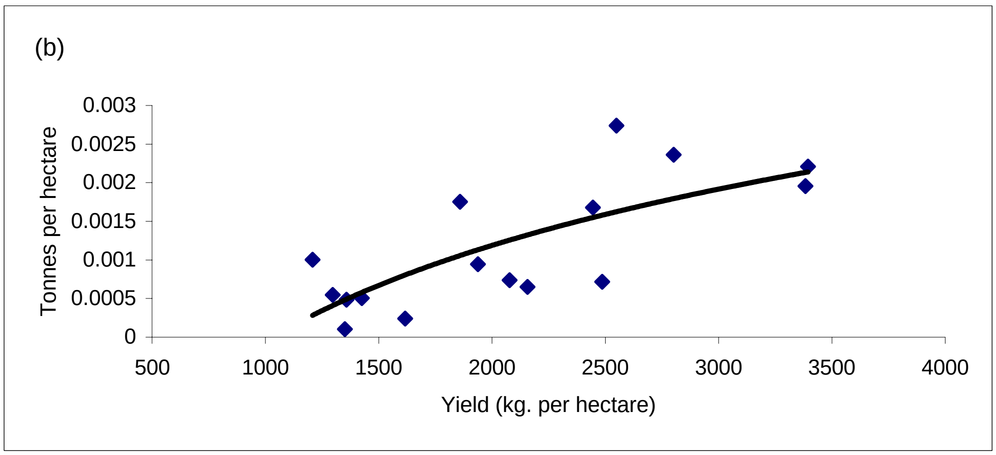
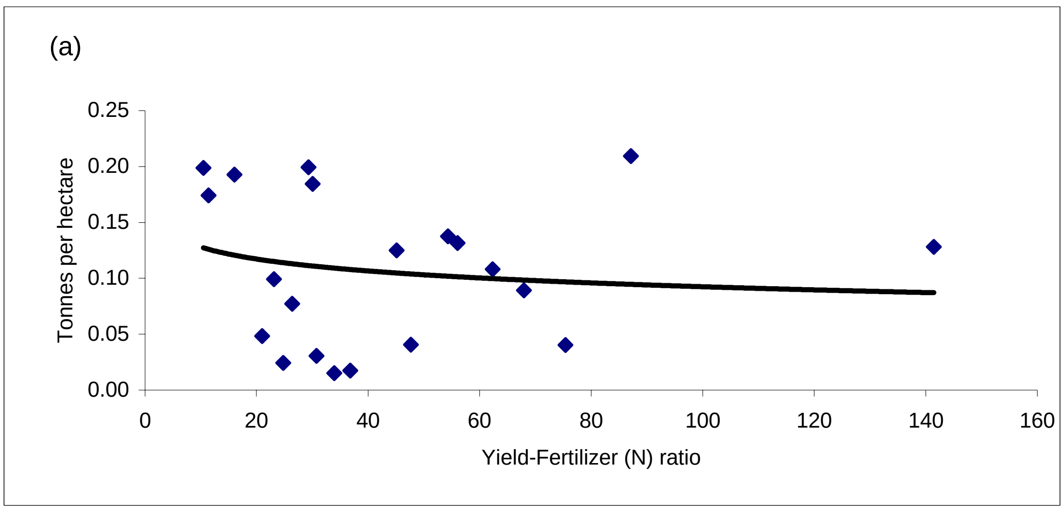


Figure 6.3: (a) Per hectare Methane emission and crop yield in Rice area (Correl=0.52)
(b): Per hectare Nitrous oxide emission and crop yield in Rice area (Correl=0.75).
Note: Emission from rice is calculated by applying the proportion of Nitrogen used by Rice (Agricultural Input survey 1996 data) on Total Nitrogen emission data sources from Bhatia (2004)
Sources: Estimates based on IPCC coefficients (Bhatia, 2004) for emission and Input survey for fertilizer use.

Table 6.3. Comparison of alternate annual Methane emission estimates from rice fields in India.		
Reference	Estimate Tg per year	Methodology used
Ahuja (1990)	37.5	Extrapolated from studies in USA and Europe to the rice growing regions in India
Neue et al. (1990)	14.5	Assuming a Methane -NPP (net primary productivity) ratio of 4.5%
Mitra (1991)	3	Extrapolated from a certain field measurements in India
Matthews et al. (1991)	21.7	Based on area under rice, crop calendar and daily methane emission rate
Taylor et al. (1991)	18.4	Assuming a Methane -NPP ratio of 5%
Khalil and Shearer (1993)	15.3	Extrapolated from a few direct flux measurements
Sinha (1995)	1.2	Based on relationship between biomass production and methane emission in rice
Parashar et al. (1996)	4	Extrapolated from several measurements all over India
Cao et al. (1996)	14.4	Using the Methane Emission Model (MEM)
Sass and Fischer (1997)	4.2	Extrapolated from measured data from selected rice-growing areas in India
ALGAS (1998)	3.6	Extrapolated from large Number of measurements all over India
Matthews et al. (2000c)	2.1	Using the MERES simulation model
Gupta et al. (2002)	5	Using Methane emission coefficients based on water regime and soil organic Carbon
Yan et al. (2003)	5.9	Using the region specific emission factors
IINC (2004)	4.1	Using the IPCC methodology and IPCC default Methane emission coefficients
Bhatia et al. (2004)	2.9	Using the IPCC methodology and measured Methane emission coefficients
Pathak et al (2005)	1.5	Using the validated DNDC model and newly compiled soil, area and weather data base
Min. of Environment and Forests (2007)	3.3	Based on revised IPCC 1996 guidelines and IPCC Good Practice Guidelines 2000
Average of Estimates for 1990s	12.53	
Average of estimates for 2000s	3.54	
Source: Based on compilation of Pathak et al. (2005)		

6.5.5. Choosing fertilizer practices

Scientific research has underlined the role of fertilizers on emissions but a positive relation of emissions of the two GHS with application of nitrogenous fertilizers could be a matter of discomfort given that much of the productivity gains in agriculture come from the use of external amendments. However in research findings from India (Pathak, 2005, Babu, et al, 2005) and abroad (Schultz et al 1989, Ciceron et al, 1992) the role of synthetic fertilizer use has been shown to be weak while variations in the type of fertilizer are shown to modulate emissions[viii]. Experiments also found that efficient use of fertilizer could be more effective than its reduction which comes at the cost of grain yield, making yield gap reduction a potent instrument for mitigation (Denier et al., 1992). Emission of nitrous oxide is also associated with excessive use of fertilizers relative to uptake which again makes efficient use of fertilizers useful. Prevention of leaching and runoff would further add to efficiency. Figures 4 (a) and (b), which plots the emission rate per hectare against the yield rate deflated by fertilizer (nitrogen only) consumed across the states show an inverse relation between efficiency and emission of both gases. Thus in both cases the efficient use of fertilizers present a win-win-win situation where emission is reduced, productivity gain is achieved and non-renewable resource (fossil fuel) is conserved.



[viii] The IARI (Pathak, 2005) showed that grain yield, nitrogen uptake increased with greater use of fertilizers and so did methane and carbon dioxide emissions but after a point all these stabilized. On the other hand up beyond a point an increasing relation was noted with nitrous oxide. Substitution with farmyard manure not only reduced grain yield but increased emission. A study at CRRI (Babu, et al, 2005) used the DNDC model for paddy soils to find an exponential response of methane emission to temperature, a heightened sensitivity to soil pH, a weak reaction to carbon content in soil and to nitrogen application by urea broadcast along with a reduction when fertilizer type was switched to ammonia. Emission decreased when water was drained. A CRRI study conducted in Cuttack, Orissa rice fields over the period 1995-98 found methane fluxes to be higher when organic amendment was used alongside chemical urea than when chemical was used alone, use of azola, compost and sesabania gave similar results, intermittent irrigation reduced emission compared to continuous flooding and the application of nitrification inhibitors effected mitigation (Adhya et al, 2000).

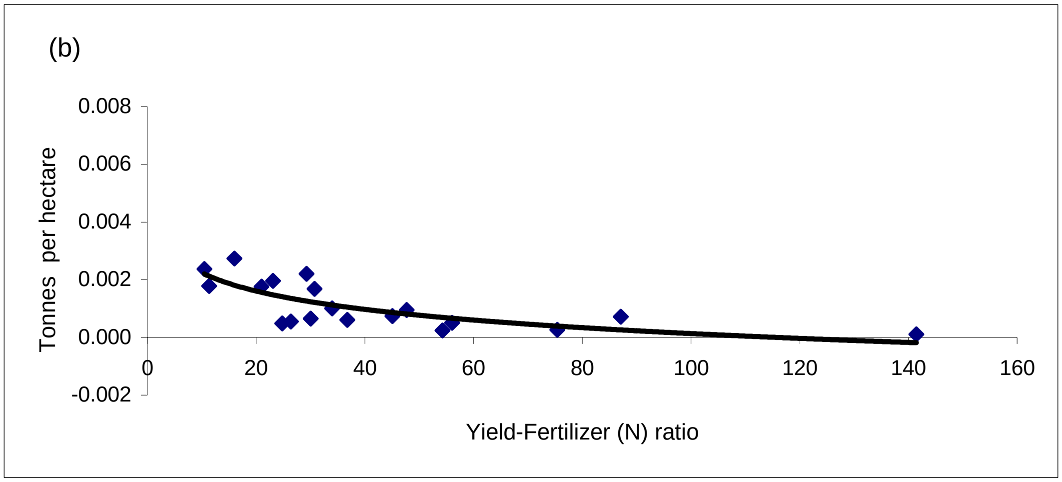


Figure 6.4: (a): Emission and Fertilizer use efficiency across states: Methane (b) Emission and Fertilizer use efficiency across states: Nitrous oxide.
Source: Emission data is taken from Bhatia et. Al. (2004) using IPCC coefficient and fertilizer data for rice is projected using Agricultural census data. For emission data see also notes in Figure 6.3.

Efficiency of fertilizer use can be achieved in various ways. The most commonly used nitrogenous amendment in India is Urea. Ordinary urea is noted for the rapid release of nitrogen that helps crop growth in the short term but not only does it cause degradation of soil quality in the longer term and loss of valuable resource but chances of water pollution is enhanced by the vaporization and leaching of fertilizer. Inevitably part of the lost fertilizer finds its way to the atmosphere as GHG. Further the source becomes more dispersed and less amenable to monitoring and measurement. Trials involving suitable coating of urea are showing promise. In contrast to synthetic fertilizers that are easily assimilated by plants as also lost to nature, fertilizers of organic origin are slow releasing in nutrients but enrich carbon content of the soil besides having other desirable properties. The use of organic fertilizer has been emphasized for sustainable agriculture. As sinks of carbon dioxide and sources of methane and nitrous oxide organic fertilizers do present a contradiction but as with synthetic fertilizers modulation of the types and efficient use can lead to the best solution. Organic fertilizers blend more firmly with soil and also reduce the expanse of the source and emission is more controllable. Composting of animal wastes in a country endowed with a large cattle population serve better in nourishing plants with less emission while easily degradable green manure, especially rice straw should be strongly avoided. In practice this may not be easily accomplished. Given that a majority of the farmers are poor, facilities are meager, weather is not always favourable and regulation and monitoring are difficult, moving from easily sourced green materials to composting could be anything but easy. In this regard the state has a significant role in promoting the use of composted manure and efficient practices of fertilizer use. Arguably organic farming does present some trade-offs and choices have to be made carefully regarding both quality and quantity of amendment.

6.5.6. The practices of soil culturing

Methane is produced in anaerobic conditions of flooded soils but natural restraints like solubility and oxidation limit actual emission to the atmosphere. In rice fields it is human interventions of culturing soil for tillage, weeding and transplantation that expedites the release of the gas. Zero tillage farming could be a way to reduced emissions in synergy with the search for carbon sink although technical capacity is largely lacking in India. Zero tillage is also critiqued for the probable emission inducing effects of organic residues that could have been recycled into the soil by tillage.

In most parts of India transplantation, a labour intensive[ix] procedure is a common practice in rice farming. This enables germination to take place in the appropriate aerobic conditions but seedlings on transplantation grows in puddled fields with advantages like weed-free smbience, conservation of water and preservation of nutrients that the anaerobic condition sustains. Mechanization is also reduced helping mitigation. These advantages can be weighed against adverse consequences like the extremely difficult task imposed on the transplanter, possible destruction of soil quality over time, prevention of seed-soil contact through clod formation, water logging and incongenial conditions for any subsequent crops. Besides, transplanting is a disturbance on the soil and technological move towards direct seeding or other improved methods would help to reduce emission.

[ix] Transplantation could require 250-350 man hours per hectare, involves human drudgery and often unhygienic postures especially for women who are especially engaged in the operation in India.

6.5.7. Water management

Water management has been shown to be an effective way to reduce methane emission around the world. Studies have shown how China reduced emission by moving to mid-season drainage MSD from continuous flooding (CFL). Evidences from India also suggest that methane emission is reduced by the frequency and duration of drainages although nitrous oxide emission may be marginally increased (Pathak, 2005). Taking carbon dioxide also in account the GWP improved from 202 to 152 from CFL to MSD (Bhatia, 2004). The MSD technique may be economically costly in some of RDWL regions, and is a difficult option in rainfed areas where droughts are not unlikely. Irrigated land with continuous flooding accounts for 47% of methane emission (Bhatia, 2004) so that irrigation management could be important strategy for mitigation. Implementing at least one drainage in the growing period in all irrigated areas will help to reduce methane emission by 18% without hurting yield (Nelson et al, 2009). There is considerable scope of focusing on areas outside deepwater ranges and experimenting on the effect of water management changes on yield rates.

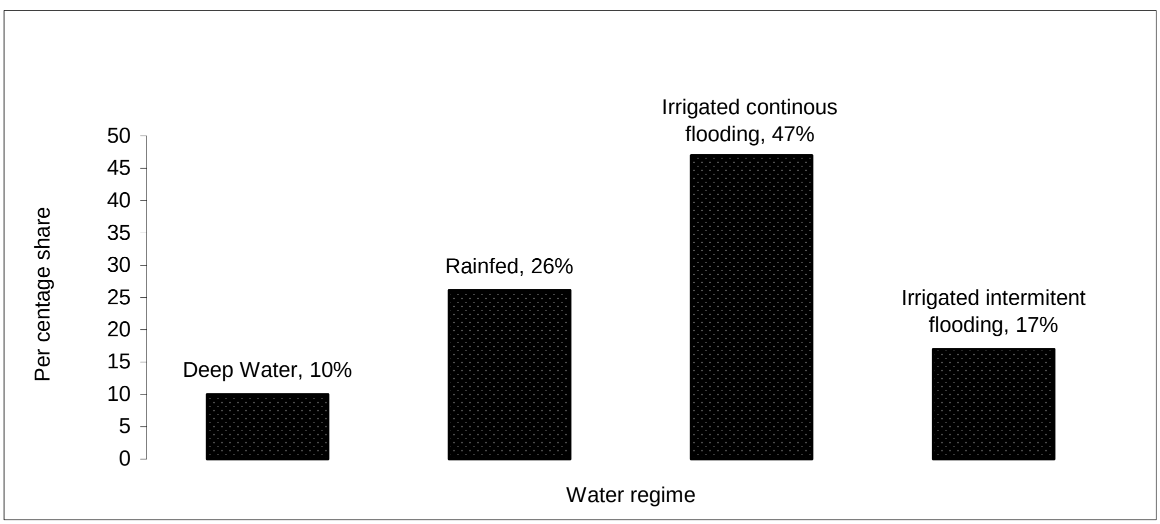


Figure 6.5: Contribution of different water regimes to Methane emission in India. Source: Bhatia, 2004

Table 6.4. Annual GHG emissions from Indian rice fields under continuous flooding and midseason drainage practices.(TG/Year)				
Parameter	Continuous Flooding (CFL)	Midseason drainage (MSD)	Emission Ratio (CFL/MSD)	
	Average of Maximum and Minimum		Maximum	Minimum
Methane emission	1.085	0.125	9.167	8.231
Nitrous oxide emission	0.045	0.055	0.833	0.800
Carbon dioxide emission	41.06	32.73	3.659	0.434
GWP	201.88	151.765	2.974	0.618
Source: Based on data provided by Pathak, et. al.(2005)				

6.6. Do we change crop compositions?

One of the largest challenges for mitigation lies in 'aligning increasing demands for foods, shifts in dietary tastes with sustainable and low emitting development paths' (Rosegrant et al, 2008). In the current context does this could suggest diversification of agriculture from rice? While crop diversification finds a place in India's agricultural policy for many reasons other than global warming, the meaningfulness of the strategy in this context is questionable. When the crop in question is rice, food security is a caution to heed. Secondly crops are not easily substitutable and in the special geography of wet areas such a strategy would require the identification of upland crops suitable for the soils usually devoted to rice. Third the public policy of repeatedly increasing the minimum support prices for farmers' economic protection is an important variable affecting land use allocation relentlessly in favour of cereals rice and wheat. Evidences that the dietary habits of Indians are changing away from cereals could herald a future less dependent on rice cultivation due to market forces. Yet this could lead to more problems than solutions.

In reality food habits are known to be deeply related to the culture and ecology of a region as also external interjections including public policy (Baviskar, 2010). The green revolution in India and the government's public distribution of subsidized grains have moved traditional local tastes for coarse cereals towards rice and wheat and current socio-economic changes are radically amending even these acquired food habits of the people led by the middle classes of the country. That the changes often portend environmental ills through greater processing, preservation and packaging with practically no net gain in nutrition has raised widespread concern. A food habit in favour of animal products that is becoming clear now and matches existing habits in many western countries could impose more serious challenges of managing animal wastes in a country where farmers have little awareness and resources to do that effectively. Globally, enteric fermentation in the digestive processes of livestocks is the largest source from agriculture and even in India its share is over 60% in agriculture induced emissions. Thus a shift in consumption from food to animal products could not really deliver from methane emission problems rather add to it. Rotating and to an extent substituting rice with upland leguminous pulses appears as a more attractive option than extensive animal farming since pulses reduce the use of external fertilizers and also potentially replace protein intake from animal based food. However the currently poor productivity of pulses stands in the way.

6.7. Research and technology

Investment on research and contributions of the scientists of different disciplines can provide potential directions for solving the emission problem. First new varieties that intervene in the carbon cycle to reduce emission can be developed. The process of nitrogen uptake and the formation of soil substrates need to be better understood. Rice itself calls for more research (Nguyen, 2003). The properties of the root system and the surrounding zone (the rhizosphere) encompassing the microbial community and the rhizodeposits should be studied in context of the global warming[x]. There is a need for understanding the processes that drive the root system in conjunction of soil agro-geo-chemical system in order to develop suitable cultivars, devise appropriate cropping and irrigation techniques and formulate new synthetic or organic fertilizers. Biotechnology can potentially but arguably improve the traits that could ultimately reduce emission.

[x] The release of organic compounds from plant roots or rhizodeposits and their subsequent assimilation by the soil organisms are the key processes behind carbon fluxes and other GHG emissions from soil.

Cultivation practices are already receiving extensive scientific attention and alternatives to the conventional farming methods like the System of rice Intensification or SRI[xi] (Uphoff et. Al, 2006) Finally, the shift towards new varieties, irrigation and fertilizer practices and the modification of conventional cultivation techniques would mean fundamental shocks on the cultural traditions acquired over long periods of time and the wider social implications need sensitive treatment too.

6.8. Methane Capture

Technologies to capture GHGs from wastes electricity and natural oil and gas extraction are receiving world wide consideration both for efficiency and for mitigation. In agricultural waste disposal, biogas plants have been a more visible endeavour. For carbon sequestration, biological, physical and chemical processes are used to capture carbon dioxide in its pure form or as other byproducts in petro-refining as 'flue' gases. Attempts to capture methane are on from waste electricity, water treatment plants, landfills and organic waste disposal especially rotting garbage of food products. Organic wastes can be anaerobically fermented in sealed tanks to generate biogas that can in turn be blended with conventional fuels for transportation. The task is yet challenging and in many cases waste gases that cannot be economically exploited are flared instead of putting them to gainful uses. The carbon offset policy and the clean development mechanism may be exploited to encourage development of technology for methane capturing in the near future.

[xi] The SRI method involves the following :(a)rice field soils should be kept moist rather than continuously saturated, minimizing anaerobic conditions, as this improves root growth and supports the growth and diversity of aerobic soil organisms; (b) rice plants should be planted singly and spaced optimally widely to keep all leaves photosynthetically active; and (c) rice seedlings should be transplanted when young, less than 15 days old to avoid trauma to roots and to minimize transplant shock.

6.9. Conclusion

India is the second largest producer of rice in the world. Research efforts need to be directed at rice cultivation as a source of food security as well as GHG emission. By joining the emerging research scene on the subject the Indian scientific community not only helps mitigation at home but also contributes towards the understanding of the complex processes and factors that underlie emission from rice fields. While estimates based on measures and technology yet available place India's emissions at reasonably low levels, synchronization with the trajectories of knowledge and the demand curve for food will require more than complacency in this regard. The visible evidences of the emission-productivity nexus by current measurement also call for greater willingness to identify points of weakness and address them. On the whole research outcomes do provide a number of solutions, the key elements in this being a search for efficiency in resource use especially in high external input based practices and a need for physical and social scientists to work collaboratively for feasible answers.

Appendix Table 6.

Table 6.1A: Rice ecosystems and distribution of Natural Wetlands in India							
	% Share of Ecosystem in state Rice area					% Share of states	
States	RDWL	RIRL	RRFL	RUPL	RWL	RDWL	NWL
Andhra Pradesh	1.99	98.01	0	0	100	3.15	10.30
Arunachal Pradesh	0	33.33	66.67	0	33.33	0.00	1.58
Assam	4.08	21.63	65.31	8.98	25.71	4.50	2.84
Bihar	14.19	40.89	33.69	11.23	55.08	30.18	4.99
Goa	0	10	90	0	10	0.00	0.06
Gujarat	0	64.52	35.48	0	64.52	0.00	5.88
Haryana	0	100	0	0	100	0.00	0.76
Himachal Pradesh	0	62.5	0	37.5	62.5	0.00	1.54
Jammu and Kashmir	0	92.59	0	7.41	92.59	0.00	11.43
Karnataka	0	66.92	3.08	30	66.92	0.00	7.14
Kerala	0	54	16	30	54	0.00	0.96
Maharashtra	20.92	27.45	0	51.63	48.37	14.41	8.01
Manipur	0	47.06	52.94	0	47.06	0.00	1.49
Meghalaya	0	45.45	54.55	0	45.45	0.00	0.06
Mizoram	0	14.29	85.71	0	14.29	0.00	0.00
Madhya Pradesh	0	24.36	75.64	0	24.36	0.00	8.26
Nagaland	0	46.15	53.85	0	46.15	0.00	0.03
Orissa	3.37	36.18	44.94	15.51	39.55	6.76	4.57
Pondicherry	0	100	0	0	100	0.00	0.00
Punjab	0	98.68	1.32	0	98.68	0.00	2.02
Rajasthan	0	31.25	68.75	0	31.25	0.00	9.69
Sikkim	0	100	0	0	100	0.00	0.06
Tamil Nadu	0	88.41	11.59	0	88.41	0.00	4.54
Tripura	0	19.23	80.77	0	19.23	0.00	0.28
Uttar Pradesh	4.24	62.06	24.49	9.21	66.3	10.36	9.24
West Bengal	11.79	26.52	46.45	15.25	38.3	30.63	4.04
All India	5.25 (2.22)	50.67 (21.41)	34.2 (14.45)	9.94 (4.20)	55.93 (23.63)		
RDWL=Deepwater Lowland, RIRL=Irrigated lowland, RRFL=Unirrigated rainfed Lowland, RUPL=Upland, RWL= Wetland= RDWL+RIRL, NWL= Natural Wetland.. Figures in parenthesis are land area in million hectares. Total Riceland=42.25 million hectares. Source: Computed from Pathak et. Al.(2005) and Prasad at. Al (2002).							

Chapter 7:
Towards a Climate sensitive Agricultural Policy

In a dynamic world economy, the share of fast growing developing countries in current global emissions and their accountability in global warming are fast becoming a serious issue in global negotiations. The Montreal protocol has beautifully demonstrated that global environmental threats can be tackled through international cooperation. In India the objective of poverty alleviation is an important component of the economic policy. That climate change effects can prove to be particularly adverse for the large sections of the country's poor engaged in climate sensitive sectors like agriculture needs hardly a mention. Thus India's own stake in the common menace would demand that the country actively cooperates in the international initiatives in mitigation as well as adaptation. In turn this requires that the country revisits her development policy in light of the emerging concerns.

Mitigation by curbing the burning of fossil fuel has a limited potential in India given the growth imperatives of the nation and the lack of adequate alternatives at the current state of technology and economics. Agriculture is also a major source of emission of greenhouse gases but more significantly, it is important to recognize that improved farm management practices can sequester carbon into the soils and vegetations offsetting also some of the emissions made in the course of other economic activities. Agriculture is therefore a potent tool for addressing mitigation objectives. Whether an agricultural policy consistent with mitigation of greenhouse gases would imply compromising on the food security of the people and the income of farmers is a critical question to be resolved.

The vulnerability of agriculture as a possible victim of climate change is far easier to perceive. Higher temperature, changes in rainfall patterns including the increased uncertainty surrounding monsoon, the altered hydrology of rivers and its impact on water availability, incidences of extreme events such as severe storms and the salinization and submergence of coastal lands are implications of climate change that together undermine productivity, increase the costs and change the nature of agriculture. To cope with such changes powerful and motivated defense mechanism are required. There will also be likelihood of advantages being derived from climate change the effect of elevated carbon dioxide in the atmosphere being one.

Any mitigation cost borne by the sector will be offset to an extent by the benefit generated to the sector due to reduction of the potential adverse impact of emission but since such benefits are shared with a large number of other entities operating in other sectors and even other countries mismatches between cost and benefit are normal. Mitigation is a site specific and easy to track procedure but its effect on the contrary is dispersed and ill-defined in coverage and intensity. In contrast adaptation is a response, the benefit of which is far more focal and predictable. Besides, the mitigation costs imposed can be unmanageable in a poor country and in a sector characterized by poverty and lack of organization and the cost should be shared by all the entities that benefit from its effects. However, Mitigation is seldom regarded as a better option than adaptation (Perrings, 2003) can also be costly. Exploration of innovative financing methods and global financial collaborations assume importance in this context to share the costs across countries and sectors and ensure that the wrongdoers pay for their actions and the victims get compensated are supported. All this requires an improved understanding of the climate change process and its interactions with agriculture, subjects that are highly inter-disciplinary in character and formative in stage.

This report brought together the insights gained from studies conducted in different fields taking a balanced perspective in order to summarise the lessons gained on challenges and imperative lying ahead for Indian agriculture. A review of the existing literatures supplemented by the author’s own data analysis is the broad method for arriving at certain conclusions and indications for policy direction.

7.2. **Climate change manifestations**

Climate change refers to a change in the statistical distribution of weather over reasonably long periods of time. Some of the visible effects of global warming due to anthropogenic forcings would be the following. (1) Temperature rise: Global surface is anticipated to warm by somewhere between 1.1-6.4^{o} C over the 21st century relative to 1980-1999, (2) Changing precipitation: Global precipitation is likely to increase on the whole but the incidence of rainfall will vary across regions, (3) Extreme events: Floods and droughts will be simultaneous and frequent occurrences in various places and water availability will be affected, (4) Sea level: Sea level will rise by 0.2m to 0.5 m between 2000 to 2100 but the rise could be up to 1.2 m higher than 2000 (island countries and coastal areas will be the worst victims), (5) Storm: Storms with greater intensity of fury could become more frequent, (6) Forest Fires: Hotter and drier weather becomes a trigger for forest fires that in turn lead to greater emission and feed back into the global warming process, (7) Feedback effects of climate change: Climate change can be self-propelling because of certain circularities and non-linearities. Global climate models are used for projecting future climate under alternative socio-economic scenarios. The IPCC has in the TAR and AR4 been using a number of emission scenarios (SRES)- whose nomencalture A1,B1,A2 etc. were confused. In the 5th Assesment Report currently under preparation the IPCC is planting to use new climate scenarios called ‘Representative Concentration Pathways’ (RCP). There will be 4 RCPs or stories for future climate

7.3. Climate change and global agriculture

The effects of climate change on the agricultural sector could be very complex, diverse and dynamic. Plants thrive in specific soil climatic conditions and any variation of the conditions may disturb the situation and even make certain plants unsuitable for the place that has been its usual habitat. The biological process of crop maturation is significantly linked to the ambient temperature and the moisture availability that will be affected by climate change. The climate change effect on agriculture and food security need not however always be adverse. Increased number of snow-free days in cold arctic regions, greater amount of rainfall in drier areas and the effect of increased carbon dioxide in the atmosphere can be beneficial to agriculture, helping to bring more area under cultivation and improving crop yields. Thus IPCC's projections find the climate change may benefit certain temperate regions but tropical areas may feel the brunt. Africa is likely to be the worst affected. Models of climate and agriculture have been used to project future for agriculture and food security. In developing countries the GDP from agriculture is expected to fall by 9-21%. Modelling exercises done by IFPRI suggests that while the world cereal production can come down by0.6-0.9% , that in South Asia will probably fall by 18-21%, wheat being hardest hit. In China vegetation zones will move in equation with climate change and more of natural vegetation will change to arable land. Though area suitable for rice and wheat will increase yield rates of crops may not be benefited due to greater evaporation. While the climate changes, human being will also hardly be mute spectators of the transition and under any hypothesis of rationality, human beings and human systems will adjust to the changes that are either becoming visible or anticipated in order to reduce the adverse effects. Autonomous adaptation, regardless of international or national interventions will be constituted of a wide range of measures such as changing the cropping pattern, selection of appropriate seeds, adjustment in crop calendars and the use of inputs that will reduce the severity of the impact.

The impact of climate change may range from beneficial to adverse but much would depend on the capacities of the affected countries to make use of the advantage and to overcome the calamity. Though the losses due to climate change afflict focused groups the outside world will not be insulated from the adverse effects. In a globalized world to the extent that climate change hurt crop yields, the food security effect can spill over from one country to other countries and the inflicted hardship of food price rise is likely to be the cruelest for the poorest countries. As agriculture becomes unprofitable, conditions become naturally unhabitable and land gets submerged, the tendency of out-migration will grow affecting other regions. Since climate change presents a classic case of the public goods where there is little or no exclusion from the benefits of mitigation and also of adaptation, the case for global sharing of resources will be strong. India has to examine the culpability and vulnerability of her own agriculture, the external benefits of domestic mitigation and the costs involved.

7.4. Expected effects

The Food and Agricultural organization (FAO) has divided the anticipate impacts of climate change on agriculture into two groups as follows:

Bio-physical impacts:

(i) Physiological effects on crops, pasture, forests and livestock (both quantitative and qualitative)
(ii) Changes in land, soil and water resources (both quantitative and qualitative)
(iii) Increased weed and pest challenges,
(iv) Shifts in spatial and temporal distribution of impacts
(v) Sea level rise and changes in ocean acidity
(vi) Sea temperature rise causing fish to inhabit different ranges

Socio-economic impacts:

(i) Decline in yield and production
(ii) Reduced marginal GDP from agriculture
(iii) Fluctuations in world market and domestic market prices of agro-products and inflationary impacts
(iv) Changes in geographical distribution of trading regimes,
(v) Increased number of people at risk of hunger ad mal-nutrition
(vi) Migration and civil unrest.

7.5. Climate change implications for India's Agriculture

India's experiences in recent decades indicated positive trends in both minimum and maximum temperatures in most regions although the contribution of global warming to the development can not be confirmed but no specific trends in rainfall were visible. The frequency of cyclones has not increased but the storms of greater severity have become common. Unexpected droughts and untimely precipitations are increasingly observed in recent times though relating the events with climate change may not be easy. Model based projections indicate that temperature in South Asia will increase by about 0.5-1.2^{O}C by 2020 and by 0.88-3.16 ^{O}C by 2050 and though average precipitation is likely to increase, (there are contrary projections as well) enhanced variability and longer droughts will accompanied. The incidences of rainfall will be uneven and unexpected and the onset of monsoon can become more variable with climate change. Himalayan glaciers will retreat albeit at a more easy pace than some others in the world but the effection the river basins will season the availability of water.

The climate change effect on monsoon circulation will be a serious consideration for the future of India's agriculture. The vagaries of monsoon is a well recognized problem for India's agriculture creating unpredictable changes in crop patterns, yield and farm incomes. Climate change intensifies the uncertainty and adds a new dimension to the challenge. Climate models suggest that although climate change may strengthen monsoon circulation, the spatial distribution will be affected and rainfall may become more uncertain. The onset of monsoon will be more variable. Analysis shows that farmer's adjustment of acreages in response to delayed monsoon can bring down foodgrain acreage on the whole and the positive effect of any increase in July rainfall can be weak. Also a drought year reflecting monsoon failure is accompanied by farmers' reducing their input expenses to an extent but the responses are not sufficient to prevent financial losses and probably reinforce the negative yield effects. Secondly the global warming through its effect on rainfall, the melting of Himalayan snows and greater evaporation will affect the water cycle in the country possibly speeding up and shortening the duration of river run-offs and portending more frequent and more intense floods and droughts. In northern

India where rivers are fed by snows, unless well planned water management systems are adopted to spatially and temporally redistribute water, the impact can be hard for many of the food crops grown in the Indo-Gangetic plains.The Himalayan region housing the upstream courses of the races will also be seriously affected. In peninsular India, already stressed by water shortage, the challenge can be great with evaporation worsening the soil moisture scene.

Finally the rising temperature is also expected to affect the crop yields by interfering with the biological processes. In particular wheat and other winter crops are shown to be adversely affected by the temperature rise in winter in northern India. Theory suggests that rice yield can also be affected negatively by the rise in minimum (night) temperature and this is empirically demonstrated by some of studies. The optimal sowing date of wheat will require to be altered. Numerous empirical studies have demonstrated the negative relation between temperature and crop yield. By analyzing data we also show a negative relation between rice and wheat yields and temperature though the effects are not generally statistically significant.

7.6. Climate change: Need for Action

Agriculture is a dominant and vital sector in India, where it is the mainstay of the nation's food security. It also provides livelihood to large sections of people. The implications of global warming for Indian agriculture can turn out to be a serious threat to the country. Many model projections have indicated that the effect of climate change on food production can be adverse in South Asia. The menace of climate change for the economy at large needs to be weighed with the potential role that agriculture can play in combating the menace. As agriculture is both a victim of climate change and a source-sink for greenhouse gases policy needs to be address the varied character of the nexus between agriculture and climate change.

7.7. Towards a low emission development path for Agriculture:

Climate change has yet not found a place of prominence in India's agricultural policy in which growth remains a supreme concern. One reason for the under-emphasis of mitigation in agricultural policy could be the comfort generated by low share of agriculture in respect of carbon dioxide emission although agriculture is a major source nitrous oxide. More importantly, the complexity of the process of emission due to crop cultivation, measurement difficulties and the meagerness of human understanding of the processes surrounding emission from arable soils are also factors that have kept agriculture from receiving its due attention. Above all, the importance of not compromising food and livelihood security probably discourages mitigation initiatives. Recently the methane emission due to rice cultivation has become a global apprehension.

India has pursued a vigorous agricultural development policy since independence. While there have been amendments in priorities and minor shifts in approaches, by and large the objectives were to improve crop productivities through fuller utilization of scarce resources and to uphold the profitability of the sector. The initial years of planning were directed to increase food production by means of intensive use of inputs, but with the green revolution giving way to some relief on the food front and to newer problems affecting soil health, the approach shifted to sustainable development in which resource use efficiency becomes paramount although food insecurity remains to be a longer term concern. Also, because the industrialization in the country has not been adequate enough to draw any substantial section of population, agriculture continued to be a main source of employment and its economic performance remains crucial in determining the status of the nation's poor. We examine if and to what are these objectives at inconsistency with mitigation protocol.

7.8. Carbon sequestration through Agriculture

Trees sequester considerable carbon during their life cycle but the potential of forests to serve as sinks is limited because land has alternative uses like agriculture and urban development. Deforestation taking place over the past three centuries was responsible for large emissions in recent centuries. However, crops raised in agriculture are also vegetations that have photosynthesis and respiration based life processes and agricultural soils like forest soils also get enriched with carbon drawn from crop biomass. This soil too becomes a zone of biotic activity and respiration of living elements of the soil and the chemical decomposition of organic materials produce carbon dioxide that may reach the atmosphere again. Thus soil can be instrumental for carbon sequestration to the extent the photosynthetic removals can be maintained in excess of the returns through respiration by human intervention. This creates a case for exploring appropriate management practices and technology to exploit the power of agriculture to serve as a sink mostly by the regulation of waste disposition in soil.

The pressure to produce more food with the help of the agrarian technology the sown area was subjected to intensive application of external input. Greater use of chemical fertilizer along with necessary support from other inputs like water, pesticides and machines was the way to procure higher yields from the cultivated area. Continuous and intense mining of nutrients from soil for crop growth has impoverished the soil of nutrients, most specially carbon making the soil more susceptible to degradation. As a result it has become increasingly difficult to increase crop productivity even if more input is applied. The social cost of pollution caused by fertilizer leaching also made the strategy questionable. Emphasis in the agricultural policy shifted to sustainable development and efficiency of using all the scarce inputs of production. Soil carbon sequestration viewed as a net balance between carbon input and output in soil is a way to achieve a more sustainable agriculture. Intimately linked with both carbon accumulation in soils and carbon dioxide emissions from soils, carbon sequestration promises to yield double benefit both for agricultural development and for combating climate change impact.

7.9. Factors influencing Carbon exchanges in agricultural Soil

Crops have relatively shorter life cycles which raise frequent issues on the disposal of crop residues and the harvests also expose soil and its carbon pool to the elements of nature more often. Some of the elements that have been associated with carbon sequestration either through the input or the output side are as follows. (1) Temperature: Temperature is noted as the single most important variable for predicting soil carbon dioxide flux, (2) Moisture: The sensitivity to moisture largely depends on temperature. Therefore Emission also decreases but as the soil dries biomass production, crop growth and carbon sequestration decrease. (3) Soil composition: Soil aggregates with large pore spaces between them and smaller ones within them are more stable. (4) Soil nutrients: There is considerable disagreement among scientists on the effect of using synthetic nitrogen on carbon sequestration but a large number of evidences do not suggest any adverse effect on carbon emission of increased nitrogen use.

7.10. Nitrous Oxide emission

The agrarian technology based on application of chemical fertilizers has been responsible for much of the nitrous oxide emission in this world. Nitrous oxide has a high global warming potential and also destroys atmospheric ozone. The mode of application and the type of fertilizer used have modulating effects on the emission. Nitrogen added to soil tends to leach out or runoff to other sites also gets volatilized before re-deposition making this form of emission intractable. Controlling the emission of nitrous oxide is a sensitive issue because of the importance of the fertilizer for crop production. An acceptable path would be to improve efficiency of fertilizer use.

7.11. Methane emission

Methane emission in mostly associated with rice cultivation that takes place in submerged conditions and is affected by factors like temperature, texture, moisture and a soil property called the redox potential. Excess use fertilizer in relation to grain yield is associated with production of substrates that support the generation of methane. Methane is hazardous but it can serve as a useful fuel, being the main constituent of natural gas. Like nitrous oxide the emission of methane too is a sensitive and difficult issue in India because of the food security implications.

7.12. Management strategies for a low Emission Agriculture

Exposure to high temperature, precipitation and winds destabilize soil, accelerate decomposition rates and promote emission. While the application of chemical nitrogen may or may not increase emission of carbon dioxide, it is believed to influence methane emission and it is a key source of nitrous oxide emission. Carbon accumulation of soil takes place through the decomposition of biomass generated by plants.

Plants differ in their carbon sequestration properties. Certain crops like cereals generate more surface biomass that incorporate in soil as carbon but these crops may call for more fertilizers and tillage. Legumes have less biomass but have other intrinsic qualities like nitrogen fixation and the products like pulses are rich in protein. Grasses have dense rootmass and stabilize the soil. Fallows cannot replenish soil carbon within reasonable time frame. Given the heterogeneities involved, rotational practices may demand a preference for varied crop types.

Thus management techniques in agriculture that are aligned with mitigation typically will tend to (1) reduce short term agricultural fallows and promote continuous soil coverage, (2) reduce or eliminate soil disturbances and (3) optimize fertilizer use and (4) promote varied and useful crop rotations. Water management as an aid to biomass production is another component. By avoiding drainage problems water management will help to contain emission of methane while lack of moisture compromises biomass generation. Organic farming will help to stabilize the soil but even here the processing of manure is important. Composting before application will reduce emission.

To the extent that the strategies to combat emission and sequester carbon converge with productivity objectives farmers themselves will have the incentive to take them up. However shortage of resources (finance, water) may come in the way. As much of the information on climate change is in the public domain and many of the initiatives would require investment, public initiative is also important. Above all, both climate change and the mitigation actions have impacts that are generally non-excludable across section and international communities just as for most public goods have. Strategies, financial engineering and negotiations would call for strong government participation. Public policy becomes important.

7.12.1 Fertilizer use modulation

There are reasons to believe that nitrogen use can help carbon sequestration by providing more nutrition for plant growth and its support for stable humification of soil. Field and laboratory based research on the effect of nitrogen fertilization on soil microbial biomass and on carbon dioxide emission has not given consistent results. Studies based on Morrow plots which are the oldest experimental research soils on the contrary indicate signs of depletion of not only soil carbon but also nitrogen after about four decades of chemical fertilizer use. In view of the unconvincing results, the use of chemical fertilizer in doses and in ways that would bring out the maximum grain yield would be advisable for mitigation. The kind of fertilizer used and the mode of application also matters.

Nitrogenous fertilization of soil is the key source of emission of nitrous oxide. Besides emission is incurred while manufacturing and transporting fertilizer. In the case of methane many studies have shown a weak relation between emission and use of chemical fertilizers though organic fertilizers are linked more strongly with emissions. However, since the substrates generated by the fertilizer induced biomass production provide nutrition to methanogenic organisms, the relation with fertilizer cannot be ruled out. However, since the biomass generation net of the grains is actually involved in this matter, optimal use of fertilizer has been suggested to mitigate methane emissions in rice fields.

7.12.2. Investment on Water management

On the one hand, excess water is found to promote emission especially in the case of methane emission in rice fields and nitrous oxide leaching. On the other, lack of water is also a hazard as it leads to land fallowing, low yield and biomass generation and wastage of fertilizer applied. Thus availability of water and its efficient use can be extremely important for reducing emission and promoting carbon sequestration. In areas of water scarcity, the strategy must focus on rainwater harvesting, water conservation, restoration of tanks and precision based irrigation technology like dip irrigation. When water supply is abundant, drainage takes a significant role. This can be supplemented with effective weather forecasts to plan irrigation strategies.

7.12.3. Reduced use of machinery

In modern agriculture sowing of crops take place in well prepared beds where soil is made aerated, porous, weed-free and separated as furrows by different mechanical interventions. This is often done with the aid of motorized machines such as tractors. Though these intrusions are meant to improve crop productivity, they also disturb the soil and have profound consequences that may not be immediately or patently visible. Soil aggregates are broken undermining the stability of the soil and exposing the underlying layers of soil to natural elements. Evaporation and moisture loss resulting from the exposure makes irrigation more important. Soil organisms including earthworms are killed while ploughing, affecting biodiversity adversely as well as reducing soil biological activities. Soil carbon in the sediments will be removed by erosion and the plant residues that are the source of SOC are dislodged The use of machines for tillage leads to greater use of energy and adds to cost.. These changes transpire over the years and adversely affect soil productivity. Cost of production increases, there is greater pressure for nutrient replenishment and water extraction.

No till or zero tillage farming is an emergent agricultural technique providing a way of growing crops year to year without disturbing the soil by tillage. Intuitive understanding suggests that avoiding tillage would help water conservation by reducing evaporation, reduce soil erosion and improve biodiversity in soil all of which help to alleviate soil productivity. In addition it offers a powerful way to conserve soil carbon content and also reduce carbon dioxide and other greenhouse gas emissions. The top layers of the soil that is disturbed by conventional tillage can become more stable and less vulnerable. Soil compaction is prevented. Diminished used of energised machinery also reduces emission. Besides the agronomic and environmental benefits, no-till cultivation curtails the need for machine, labour and other associated inputs for land preparation leading to reduction of production cost. The method also preserves any underlying artifacts in the soil that may enrich heritage.

A less well-defined option is conservation agriculture that involves reduced tillage and a group of practices directed towards sustainable agriculture. The conventional tractor drawn Mouldboard plough is replaced by other tillage implements such as the chisel plough and deep rip or no plough. Conservation agriculture however combines a variety of other measures with zero or reduced tillage such as rotations, use of surface mulch, organic nutrients and bio-pesticides and even drip irrigation.

No-tillage farming is not an easy method nor is it suitable for all kinds of soils. It can not only proliferate weed growth raising the demand for chemical herbicides crop yield may be compromised in the short run. There is significant potential for cost saving due to reduced use of machinery, labour and irrigation and the possibility of growing an additional intervening crop due to the greater availability of moisture and the method could actually prove more profitable than conventional farming. The effect on profit would depend on relative impacts on yield and cost.

7.13 Problems of reducing emission through Agriculture in India and a Perspective

India is a tropical country and the geographic conditions specific to the location have a decisive role on the emission potentials especially when a comparison is made with temperate countries. Socio-economic realities add to the constraint. High temperature and intense precipitation in the main growing season is amenable for emissions. Given the extent of semi-arid and unirrigated land, moisture shortage inevitably constrains the choice of crops and even encourages fallowing of land. Demand for fuel competes for animal wastes limiting the scope of organic based farming. Similarly crop residues are in demand as animal feed while well maintained pastures and feed management are rare. Lack of resources and the low profitability of agriculture also discourage cropping. Fallowing of land and resultant erosion often becomes unavoidable given the limitations.

Agriculture is primarily subsistence based and is the largest provider of employment. Farmers are generally poor and lack of resources severely compromises the management options. Food security remains an intense compulsion. Most parts of northern India falls in the Indus-Ganga-Brahmaputra plains, is well watered by the Himalayan rivers and the soil is fertile. These lands are intensively farmed with up to two or even three crops in a year. Continuous cultivation leads to soil exhaustion. Owing to the pressure for generating food for household consumption and the government policy to promote food production, the preferred crops are generally rice and wheat, there is very little option for moving to non-food crops, reducing inputs and toying with new methods. With the prospect of snow-melt diminishing under climate change the water security may come under question too. In contrast, many temperate countries are endowed with low temperature where moisture is not a serious constraint. Crop productivity is high because of fertile soils and intense input use leaving a significant leeway for modulating practices so as not to hurt production seriously. In fact surplus output is frequently observed to be a problem in western agriculture calling for land set-aside programmes.

7.14. Management options for India

While the constraints to mitigation are many and the objectives of agricultural development are beyond compromise, exploration of solution could be promising. The following discussion lays out on the basis of the above review the possible management options for Indian agriculture, the contradictions and conformities between the objectives of greenhouse gas reduction and that of food security and to track India's potentials in the possible paths to a low emission economy. Three of the major routes to a low emission agriculture would be to assure continual soil coverage through a ever-green agriculture, to optimize the use of chemical fertilizers and to reduce the use of energised machines in agriculture.

7.14.1. *Ever-greening Indian agriculture*

Vegetative coverage of land is found to protect land from high temperature, moisture loss and weeds. This would require diminution of fallow periods both in frequency and duration. Increasing cropping intensity of land by growing more than one crop in the year has always been promoted by agricultural policy in the country. In a land scarce country effective utilization of land both my multiple cropping and by attaining higher crop yields are natural objectives. In India's soil climatic conditions it is in principle possible to grow up to three crops in a year since most annual crops remain for three to four months on the field and areas under winter snow cover are scarce in the country. Nevertheless, there are binding constraints, moisture and financial resources being the most limiting ones. The monsoon brings heavy rainfall to most parts of India but is concentrated in a few months of the year. With no rainfall occurring for about seven months in the year and irrigation facilities not being accessible in most cases, cultivation of chosen crops become infeasible. Identification of suitable cover crops that match the resource conditions becomes an important component of providing soil coverage. Mixed cropping is sometimes recommended for the protection of the soil, greater leaf litter generation and nutritional security. Alternately, efficient water use through appropriate temporal redistribution can help in accessing moisture in the dry months of the years. It is preferable that selected crops also present other market or non-market based benefits in terms of soil enrichment, nutrition and use-value. Green manures ploughed back into the soil can add nitrogen free of cost and also help in stabilizing soil. Suitable grasses can prevent erosion and also support animal husbandry. Pulses are a most attractive option to fill in the fallow periods. They are a key source of protein for the people and given a shortage position large imports have to be made.

Today only 38% of the net sown area is under multiple cropping while 62% are only single-cropped. In the southern and the western states the single cropped area constitutes over 70% of net sown area while the proportion is relatively low in Punjab and West Bengal. Although over time the multiple cropped area grew by 115%, there is a long way to go before the gap is bridged. The proportion of single-cropped sown area shows signs of stabilization in Madhya Pradesh and Punajb and in Tamilnadu, land underutilization has grown. Of the total land that is potentially available for planting, 15% is lying fallow for one year or more due to moisture or resource constraints, with the incidence of fallowing being over 30% in Tamilnadu and Bihar both states being highly irrigated. These tendencies mark the limits of present policy capacity and call for new ideas. Additionally, degraded land which is a source of emission needs to be reclaimed. Pulses that could be potential crops for rotation occupy only a little more than 10% of the gross cropped area. However economic viability may come in the way of reclaiming or re-greening unsown land with planned and desirable vegetation. Thus investment on efficient water conservation and irrigation schemes will be necessary as much as new ways of financing such initiatives. As covering the soils would be compatible with the long standing agricultural objectives of the country even though past deficiencies highlight the 'additionality' one looks forward to, the carbon market can prove to be important in bridging the gap.

7.14.2 Towards more efficient in Fertilizer use

Nitrogenous fertilizer use has been strongly associated with India's agricultural progress but efficient use of fertilizer has evaded practitioners leading to high cost benefit ratios.

Over time production growth has hardly kept pace with growth in the use of fertilizer that involves dependence on imports and environmental pollution. Whether fertilizer use accentuates carbon dioxide emission is not firmly confirmed by experiments On the other hand, application of chemical fertilizer is the key source of emission of nitrous oxide. In the case of methane although a positive relation with emission is indicated due to the role of biomass in serving as substrates for bacteria, it is the optimal use of fertilizers to obtain high grain yield that could be the correct approach to control emissions.

Given the importance of drawing higher food production from land as well as the complexities cited in literature a low emission management policy would require not the reduction of fertilizer input but rather the achievement of the highest yield-fertilizer ratio possible. Implicitly this would mean reducing fertilizer loss by leaching or volatilization, greater uptake by plants and more effective assimilation for grain output. Trends of the yield fertilizer ratios of food crops in India suggest that each unit of fertilizer has yielded less output per hectare in successive years and despite all efforts the yield fertilizer ratio at best has stabilized at a level below 20 in the case of rice and wheat for all the states. Only in maize positive signs have also emerged and there have been considerable diversity of performance. Bihar, Tamilnadu and Gujarat are some of the states that lag behind significantly in fertilizer use efficiency. With the advancements made in technology there are options of promoting site specific and precision driven input use that is based on monitoring plant biological nutrient needs for timely and measured application and innovative ways of incorporating fertilizers in soil.

7.14.3. Tillage and Machine use

Reducing machine use would mitigate emission not only by diminishing emissions from use of fossil-fuel driven energised machines and similar processes at the manufacturing stages of machines but by effecting reduced tillage a technique that has shown promise in reducing carbon emission in many parts of the world. India has a labour abundant agricultural sector where farm size is typically very small. Thus use of machinery is limited in agriculture although land is routinely tilled with humand and animal labour of the value of output.

However India being supply constrained in most crops the strategy of reduced tillage may be taken up with caution since the possibility of declining yield cannot be ruled out in the short run. Increasing tendency for mechanization in respect of most common implements and the ratio of the value of output to the cost of machine labour (fuel cost) are indications shown by data. The ratio of machine cost to value of output is low in the three eastern states Assam, West Bengal and Orissa and Gujarat in the west and highest in Uttar Pradesh in Machine cost as variables cost constitutes 3-30%.

7.14.4. Manure management

Organic nutrients are a critical component for sustainable agriculture but poor management of organic manures are associated with contrary effects as in methane emission, indirect nitrous oxide emission and also as some studies suggest, in the emission of carbon dioxide from agriculture. Incorporation of organic manure in soil effectively, green manuring, composting and avoidance of easily decomposable materials like straw have been recommended in various studies. Management of manure use and provision of composting facility would deserve attention. Manure management deserves serious attention not only for its emission reducing and carbon enriching services to agriculture but because manure production itself is a major source of methane emission and needs to be conducted in a judicious and scientific manner.

7.14.5. Water management and Rice cultivation practices

Water level has a weak relation with emission but the combination of moisture and temperature makes a difference. While water content in soil increases emission of methane, carbon dioxide and nitrous oxide, beyond certain levels, it inhibits the causative processes. On the other hand, lack of water is a major cause of land fallowing and low biomass generation that in turn lead to high emission and low sequestration. In India the supply of adequate water and the choice of suitable crops are important concerns for maintaining farming continuity even in seasons that are not associated with monsoon rainfall.

Water management and the economic incentive for optimal water use need to become important in an approach toward mitigation. On the one hand, this calls for serious planning of irrigation and investment on engineering water works to effect inter-temporal storage and temporal and spatial distribution of water. Technology for promoting water efficient irrigation needs to be developed. Weather forecasting also can help farmers to plan their crops rather than wait. Deep rooted plants are adaptable to water-constrained situations and reduced tillage and cover cropping could help in water conservation. Maintenance of tanks and other water bodies and rainwater harvesting to support at least the cover crops would be important especially at the community level.

Methane emission is strongly linked with wetland farming but alternative tillage practices and transplantation could alleviate the emission. Mid season drying and alternated wetting and drying are suggested to reduce methane emission but this has to be weighed against possible effect on other emissions such as nitrous oxide. There is a search for alternative cultivation method for rice that diminishes the need for land puddling and provides for favourable conditions for the labour.

7.14.6. Waste disposal and Methane capture

The disposal of waste is gaining increasing significance. In agriculture the wastes created are generally biodegadable and recyclable and more over they may have considerable potential to act as inputs for further growth. Low tillage is one such way in which the remains of plants after harvest are incorporated to enrich the soil. Some of the residues can be put to practical use for thatching, cattle beds and packing. Field burning of crop residue is a very common way of disposing crop residues, causing emission of green house gases and trace gases. In India 253 Tg of dry residue is generated as of 2010 of which 63 Tg are subjected to field burning emitting 26 Tg of nitrogen and 4.86 Tg carbon dioxide equivalent of GHG (Sahai, et. al. (2010). Health damages due to air pollution caused by burning rice straw in rural Punjab is estimated at Rs 76 millions (Kumar and Kumar, 2010). Burning is resorted to because of the use of combined harvestors in their present form, the generation of large amounts of wastes in farms, the short time interval available for disposal given the rotations in practice and the poor opportunities of commercial use of the wastes at the site. Yet agricultural wastes can prove to be useful for various purposes including the making of biogas and other fuels. While penalization of burning could be a short term way, this has to be backed by creation of opportunities for their useful disposal and development of technology for their quick removal and storage. In the ideal case the waste product or the emission itself can be gainfully and commercially utilized to change a 'bad' to a 'good'. One possibility emphasized is developing technology for the capture of methane from rice fields and its possible use to energies farm operations. In the process not only GHG emission from rice field is reduced but also the use of fossil fuel is diminished. In another innovative instance cited in news paper, oil company Shell is pumping carbon dioxide from a refinery in Netherlands to greenhouses producing fruits and vegetables.

7.14.7. Biofuel cultivation

Cultivation of biofuel is an emerging way in which agriculture is employed to effect mitigation. By replacing petroleum and diesel by fuel derived from plants, the carbon cycle would be completed without a net injection to the system. Although, keeping with the rising prices of petrol, several countries have devoted extensive areas of agricultural land for raising crops to produce biological ethanol, ethane and diesel for fuelling transportation needs, India's progress is still limited and laced with caution. Rapid growth of global biofuel production especially in 2006 and 2007 has been associated with the disturbing phenomenon of food price rice that has been evident world wide. Between 2005 and 2008 price of wheat increased by 143%, corn by 105%, rice by 154%, sugarcane by 118% and edible oils by 197% while the price of crude rose by 71%. The food price rise which will increasingly become related to global fuel price movements is expected to affect the poor people of the world severely and the feasibility of the option is questionable even at the global level. About 3% of world transport fuel is met from biofuels.

Brazil and US are major producers with ethanol being mainly sugarcane based (32%) in Brazil and corn based (43%) in US while in E U rapeseed is a source of biodiesel. While the bifuel considered here are better known as first generation biofuels, there is option of developing second generation fuels from non-food sources such as grass, stalks and wood and third generation fuels still in research stage such as algae and biotechnology.

India has a system of mandatory blending of biofuel with transport fuel but the option raises many grounds for caution. In the case of biodiesel, the national shortage of edible oil restrains the use of oilseeds for the purpose and although maize and sugarcane are recognized as possible feedstocks the option needs to be weighed against food security constraints as all these crops vie for limited land and resources. Products that have no alternative use and that can be grown on degraded or forest soils may receive preference. Also questions arise whether raising the sufficient feedstocks would require fertilizers and machinery that would outweigh the emission reduction.

7.15. Adaptation and climate change effects on Agriculture

Adaptation is defined by IPCC as the adjustment in natural and human systems in response to actual or expected climate stimuli or their effects. An alternate definition refers to adaptation as the adjustment of a system to moderate the impacts of climate changes, either to take advantage of new opportunities or to adjust to the consequences (Adger et al, 2003).This definition recognizes opportunities provided by climate change. An adaptation process seeks to moderate the harm or exploits the benefits of climate change. Comprising a set of actions taken at various possible levels ranging from individual or local to national or global, adaptation potentially insulates agriculture and the people involved from adverse climate change effects. Associated with adaptation are the concepts of vulnerability and the adaptive capacity. Vulnerability is the degree to which a system is susceptible to and unable to cope with adverse effects of climate change and adaptive capacity is the capability of the system to adjust to climate change to moderate potential damage, take advantage of opportunities and to cope with consequences (IPCC, 2007). Thus a policy aimed towards adaptation may also seek to reduce vulnerability and strengthen the adaptive capacity of a system.

Defensive expenditures designed to reduce the cost of climate change include the construction of coastal and estuarine defences and 'managed retreats', strengthening and relocation of infrastructure and civil structures, water impoundment in and use in keeping with changing hydrological regimes, changed land use and public health initiatives. Modeling exercises have shown that large reductions in adverse impact from climate change are possible if adaptation is implemented. Traditionally climate change has largely been synonymous with energy policy linked with sector specific mitigation but the IPCC TAR illustrated increased interest in adaptation. Subsequently certain decisions introduced opportunity for the less developed countries to prepare National Adaptation Programme of Action (NAPA) based on the recognition of the low adaptive capacity of the LDCs.

Adaptations can be autonomous when the individuals themselves undertake them in response to their perceived vulnerability. To the extent that farmers are capable of sensing the imminence of hostile eventualities and also in taking offsetting actions agriculture will be partly protected from climate change even without the active intervention of the State. In this sense autonomous adaptation is closely linked to their risk management process that keeps the farmer prepared for one time sudden changes. Often the first visible sign of the adverse effect is the required trigger for such action. Adaptation usually implies that reduce the expected damage of an event and actions that pool or transfer rise of an event.

Past experience sounds an alarm and activates certain responses. For example the farmer waits for the first monsoon shower and the delay in the rainfall is a message to put off rice sowing. Further, this may be a message to look for finance to install irrigation facility. When rainfall over the growing season matters and is highly uncertain the farmer may sow multiple crops with varying water demands and include drought tolerant varieties in the basket. Uncertainty prompts them not to ‘put all the eggs in the same basket’ leading to crop diversification. The investment on inputs may also be adjusted downwards or upwards as seen optimal under the circumstance. The literature on risk suggests that the objective function of an economic agent functioning under uncertainty may differ from the conventional function. A safety-first approach may replace the standard profit maximization objective. Autonomous responses to climate change may involve individual and local water management protocols, shifts in cropping patterns, selection of appropriate seeds, manuring practices and adjustment of crop calendars. Farmers may be compelled to choose to undertake some adaptation measures only when the event has already occurred, notable ones being borrowing from money lenders, defaulting on institutional loans, cutting down consumption expenditure, migration in search of off-farm jobs.

While such measures may help in reducing losses, they can hardly assure a compromise of food security whether at the national or the household level and are likely to be inadequate in terms of protecting income levels. Both community level and public initiative will be essential for effective protection against climate change.

7.15.1. Community role

Even in normal circumstances informal networks are woven for mutual support and reciprocal exchange to take place when the need arises. (Cox anf Jmenez, 1990). Extensive field work has established that individuals voluntarily organized themselves to gain from trade, to provide mutual protection against risks and create and enforce rules that protect natural resources. The support need not always be mutual or reciprocal and altruism has not been ruled out as a motivation for one-way flows (Ravallion and Dearden, 1988). Evidences of altruistic responses leading to transfers to the poor and more exposed sections are available. Considerable transfers from private sources are evident in combating calamities like floods and cyclones in Bangladesh where people are typically not insured formally. However, the question also arises on whether formal action would crowd out such informal social insurance and safety-nets. Ostrom argues that a synergy of state and society and 'co-production' of services can produce a virtuous cycle and the thesis that the 'rational agents were not likely to cooperate even when such cooperation would be for mutual benefit' contradicts observation of everyday life (Ostrom, 1996). Thus the possibility of community based and collective actions does not minimize the State's obligation as such actions can be effective mostly with public facilitations such as whether forecast, research, extension and technology and law enforcement.

7.15.2. Public role

Conversely, adaptation could desirably be planned and consciously designed by governments or communities. Planned adaptation generally falls in the public domain as opposed to private initiatives seen in autonomous adaptation. Unlike individual farmers the government has better access to information and resources and greater opportunity for global cooperation. This requires conscious efforts to work out possible perils and disasters, their probability of occurrences, to identify the susceptible victims, to design appropriate and efficient strategies in advance and build up a required degree of readiness to implement the strategies in a timely way so as to minimize harm. A basic difference between autonomous and planned adaptation would arise from the information and resource advantages of the public body. For a government, to an extent climate change would not appear as sudden risk but a climatic contingency that has been projected in advance albeit with a known margin of error for which necessary preparations have been taken, while to an unprepared entity it would be a sudden aberration.

Adaptation at the public level undoubtedly will take into account human responses such as adjustments in cropping practices that determine the selected crops, productivity and resource use, the tendency for migration, changing trade partners and political resistance and will depend on the pool of administrative skills to manage the crises. The effects of global warming are a concern both at a regional level and at a global scale so that governance at the regional or national scale may not be enough. Adaptation is a costly process, whether in terms of cost of maintaining the production or income trajectory or in foregoing the benefits. To the extent the adaptation is voluntary and autonomous, often indistinguishably integrated in the overall farm management scheme, the cost is borne by the farmers themselves but a welfare minded government would deem it's a responsibility to design and implement well planned responses and share the cost of overall adaptation to climate change. Climate change effects typically arise at localized scale and even within a country the expressions could be disparate across regions. There is need for preparedness and coordination among the various levels of government, sub-national and national to meet the contingencies with adequate finance.

7.15.2.1. Food management Information and infrastructure

To the extent that climate change will make monsoon more unpredictable, the complexity of implementing a food policy will intensify. There will be a continual need for monitoring the food situation and planning and implementing food based operations such a promoting imports or exports, releasing of stocks and organizing public distributions appropriately will be more challenging. All this requires reinforcing the public system of early estimate of food grain as well as a revamping and updating of the statistical system. Forecasting of weather based on meteorological and remote sensing techniques will assume greater significance. At the same time the system of stocking grains need to improve in order to bridge inter-year and inter-regional disparities and inventory keeping will require string attention. Construction of local level maintenance of an efficient road transport system will be essential as climate change involves profound spatial implications. Buffer stocking and public distribution in terms of shortage will be crucial safetynets. The information system must reflect the current and emerging scenario in terms of production prospects, stocks and prices to enable traders both at the national and the global levels to work efficiently and for farmers to gain in the process.

7.15.2.2. Insurance

With climate change farmers will tend to face an increasingly risky environment. Agricultural insurance is an important instrument under the circumstances but given the limitations faced by such schemes, India's NAIS needs to be redesigned and up to the situation. The weather based insurance will also be important. A well designed insurance scheme will not only be useful for the farmers and the lending institutions that also face the heat of the risky situation, it needs to protect the interests of the insuring company to make the scheme viable. Incorporation of more relevant information such as long term climate forecasts typically based on ENSO and climate change projections can make the schemes more efficient as resulting climate pattern can have intimate causal linkage with crop performance[1]. The catastrophe risk modeling (CRM) approach as a tool to anticipate the likelihood and severity of potential future weather based catastrophic event has been recommended by the US government. Quantifying the impact of events through agricultural-weather-index (AWI) and developing realistic scenarios of future losses under anticipated weather conditions can help insurance firms in deciding and negotiating on reinsurance coverage and communicating with investors and rating agencies. The government also needs to make the insurance more market based and less rigid as is the current NAIS in terms of premium rates and the policy for threshold yield

While reinsurance companies vie for premiums from insurance companies, there has been an increased trend for them to use market instruments like insurance linked securities and growing interest for Catastrophe bonds (CAT) in the west. The risk-linked CAT bond, conceived in the aftermath of Hurricane Andrew by the faculty at Wharton Financial Institution of USA and first experimented in the 1990s by AIG, transfers risk from a sponsor to an investor. Floating such a bond would mean that the principal will be lost to the investor if the trigger conditions are met, the amount then being used by the sponsor

[1] Non-parametric analysis of country level annual yield series on corn, cotton and peanut shows that estimated yield distributions in El Nino, La Nino and natural years are significantly different from one another though such phase dependent differences in mean equality tests are not authenticated. Higher moments of yield subsets indicate that El Nino yield distribution of cotton and corn are more negatively skewed whereas La Nina yields are least skewed. Such distributors could be used to calculate actively fair premium rates for each phase. Expected losses from farmers are generally highest during ElNino years ad lowest in La Nino years but peanut losses are typically higher during neutral years.

to pay the policy holder, while in normal circumstance the bond offers a coupon return. The main advantage of the CAT bond lies in being able to spread the risk over a large body of investors who would choose it as an option because the returns are uncorrelated with the returns from other investments in stocks. The Government of India in its Economic Survey of 2009-10 has implicitly suggested the introduction of the CAT bond in Indian market mentioning that ‘ capital market solutions for catastrophic risk insurance is another area that needs focus… widely used in advanced countries’..

7.15.2.3. Credit and employment support

Credit is an instrument that has always been used tide over good and bad times and the services of credit institutions will become more important in coming times. While the challenge of providing credit in an agriculture steeped in poverty and burdened by risk has been proving insurmountable, the urgency to continue the effort for finding workable solutions cannot be minimized. That climate change can make agricultural credit even riskier needs to be recognized and as in the case of insurance climate projections need to be built into recovery estimates and the financial concerns of the lending institutions deserve attention. A further alternative is the relief expenditures incurred by the government in times of crisis. This can be in the form of outright grant via bank as loan waiver in times of natural calamities. Recent instances of droughts and monsoon failures have already made the issue of coping important (Chand, 2009) and strategies like additional employment generation such as through the public works programme (MNREGA) has been suggested. However the importance of developing irrigation with an eye on water use efficiency, buffer stocking of grain, choice of appropriate crop varieties and timely weather forecasting also remain important. Managing the crisis through trade is considered as a costly proposition. Climate change funds may become essential especially in context of extreme events.

7.15.2.4. Water Supply

The changed hydrology owing to melting snow in the Himalayas and the replacement of snows by rainfall as the source of water in North Indian Rivers and the unpredictable pattern of precipitation can increase the incidences of both floods and droughts, the implications being closely linked with the ecology. While the direct effect of climate change can be felt on surface water flows, ground water that draws recharge from surface water and is impacted by the intensified evaporation will also be affected. Water management and the economic incentive for optimal water use need to become important in an approach toward mitigation. India is the world largest irrigation water user and is facing a major crisis. Much of the problem lies in the limited knowledge available on the nature and magnitude of water scarcity and on the factors that drive water future (Kumar, 2010). Many argue water availability in India may be sufficient provided large scale engineering intervention help to correct demand-supplies mismatches. Investment on large water works is a government function and involves not only used budgetary allocations but also in depth engineering and ecological analysis. Besides water productivity is a measure that is becoming more popular. This depends mostly on farmer’s ability for water management and partly on Micro Irrigation (MI) initiatives of the government. However it is important to recognized that farmer’s ability to carry out efficient agromic practices depends on the reliability and quality of irrigation and despite the vast scope, farmers face constraints to adopt MI such as reliable power supply and lack of incentive that government can only address

Hydrological interdependence of water resume system in the different administrative and political implications of ground water draft on river hydrology also require public involvement. On the one hand, this calls for serious planning of irrigation and investment on engineering water works to effect inter-temporal storage and temporal and spatial distribution of water. Where the river flows through multiple countries, international collaboration at every step is necessary and the upstream-downstream nexus in the river basin will be a useful focus. On the other, technology for promoting water efficient irrigation needs to be developed. Weather forecasting also can help farmers to plan their crops rather than wait. Deep rooted plants are adaptable to water-constrained situations and reduced tillage and cover cropping could help in water conservation. Maintenance of tanks and other water bodies and rainwater harvesting to support at least the cover crops would be important especially at the community level.

This is especially relevant in southern peninsular states Andhra Pradesh, Tamilnadu and Karnataka where the river system is seasonal and the geology restrains modern irrigation works. Historically the topographical unevenness was exploited for impounding rainwater in times of excess rainfall and floods and storage tanks numbering about 120000 were maintained by the zamindars and village community bodies. The weakness of the system and the problem of silting were recognized after the British took up the responsibility of maintenance. With the lack of voluntary, labour compulsion was necessary. However lack of lack of labour, paucity of funds and the decline of the Kudremath system remained drivers of the fall of the tank system. Today the restoration of the tank system demands attention. Such tanks can serve as percolation tanks for ground water recharge amenable for conjunctive irrigation and can be charged both from other surface water sources and from rainfall in the catchments. Management option include the employment of sluices and the practice of social forestry

7.16. Research, Experiment and Documentation

The enormity of the unknown zone in human understanding of the subject can not be over emphasized. That the climate is changing over time had been highly contentious supposition for many years and it is the untiring efforts of amateur and professional climate scientists supported by the research of technologists that finally confirmed the fact as also their dangerous implications for human beings. Agriculture is an essential part of human economic activities but the bio-physical processes that underlie this activity are incompletely understood till now.

Policy to promote research on agriculture’s contribution to emission or the removal of emission based on agro-science expertise is becoming essential. Integrated with supporting research in economic, sociological and financial subjects the investment can be useful in combating global climate change while also having collateral spill-over benefits for agricultural production. Needless to say such studies will require extensive use of designed experiments. These experiments will help effect better measurement and improved understanding of the chemical process in soil. More experimentation at the empirical level will also help to answer critical questions on farming methods like (a) how suitable will low-tillage farming be for Indian agriculture, (b) what are the implications of cropping cycles/rotation of different types for carbon sequestration (c) how fertilizer use efficiency can be improved (d) how water security can be ensured in the presence of climate dynamics and (e) how food security can be assured. Documentation of results will help in choosing cropping practices under various conditions, making inventories and contributing to global science. India plans to publish regular inventories[2].

7.16.1. Technology, implements and methods

Technological modification has immense scope to make agriculture compatible with the climate change objectives. Zero-till farming is a prospective methodological upheaval for agriculture that needs more investigation. Low-tillage that may involve a range of new technologies and require induction of a new technology and specialized implements including less intrusive ploughs and drip irrigation. Improving the efficiency o fertilizer has been an incessant effort and research and innovation. Research has generated not only new types of fertilizers but also new methods of use such as drill based incorporation, fortification and precision application. Specifically the focus needs to be on demand based and targeted fertilizer use when the fertilizer demand of the plant is intensely monitored over the day and the material is delivered at the correct time and at the precise spot of uptake. Implements like the chlorophyll-meter are in use in some areas. Early forecast of weather will be greatly useful in planning water use and fertilizer application.

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[2] "India has become the first "non-Annex I" (i.e. developing) country to publish such updated numbers. I am also happy to announce that we will publish our emissions inventory in a two-year cycle going forward. We will be the first developing country to do so"(Jairam Ramesh, Minister of State for Environment and Forest in Government of India.

New methods of rice cultivation that avoids puddling and laborious transplantation may need to be developed. The potentials of mid-season drainage of water and the system of rice intensification are being explored. Water saving irrigation like drip and sprinkler irrigation will help in adaptation. Construction of roads and scientific grain storage will be useful at the local and national level.

7.16.2. Extension

The changes in farming practices that are desirable can only be implemented on the fields through training, inputs and constant guidance. Water management especially in the case of rice, fertilizer use methods, protocols for the use of organic materials, cover crop and desirable rotations are some of the aspects that the extension system now promoted by the government and implemented in a partnership with private agencies. Extension will be an important component of both mitigation and adaptation

7.16.3. Financial options and the Carbon market

Financial methods of curbing emissions generally include 'command and control' in which there are certain curbs and penalties imposed on acts leading to emission. Carbon tax is also an option and in the case of agriculture government may introduce fiscal measures like subsidies to encourage good management practices treating mitigation as a social good whose benefit is shared by other sectors. Taxing the emission sources and subsidising the sequestering activities would imply fiscal balance. The Kyto Protocol of 1997 has promoted the innovative yet nascent market of carbon offset. India is an active participant in the CDM as of now and the potential for participation can increasing coming times. Given a range of technologies with varying emission in use in India a fiscal mechanism can be used to create India's own CDM fund on lines of EU trading scheme. A recent survey estimated that 65% of companies in Annex I countries are planning to buy credits rather than cut emissions.

The market based process of regulating the environment is gradually gaining ground in the Indian economy and carbon market cannot be left out of the initiative. Agriculture may be explored as a possible sink and the development programmes need to be designed in ways so that not only does agriculture follow the low carbon path itself, but the farmers especially the poorer farmers gain economically from participation in the mitigation drive even while state of the art technology and resources flow in from developed countries for the progress of agriculture.

7.17. Exploiting synergies

Assigning relative emphases on adaptation and mitigation is a task that has proved contentious. Creating and exploiting synergies between adaptation and mitigation is an emerging approach. Though much critiqued (Klein et al, 2005) for its lack of focus it is important to note that the two are convergent in certain issues and are in most cases not contradictory to one another. Water management is one such synergy between mitigation and adaptation that can be linked with agriculture. While excess moisture is generally associated with emission especially of methane, poor water availability leads to less biomass and greater fallowing that in turn slows down carbon sequestration and accelerates emission. The effect of climate change also manifests through water availability generating cases of excess watering or water scarcities. Search for efficient water use methods, rain water harvesting, conservation and larger scale engineering interventions for inter-regional and inter-temporal water distribution are part of both adaptation and mitigation strategies. Similarly greater and economic land utilization is shown to be a way to reduce emissions from soil and yet by increasing incomes, providing better nutrition and effecting ecological benefits for agriculture this is also a route to greater coping strength. Financial options like taxes and subsidies and carbon offsets can address both mitigation and adaptation.

Climate change poses a threat to important development issues such as water supply, food security, health, natural resources and protection against natural disasters. Viewed from this perspective, adaptation against climate change falls in broad ambit of development concerns of a country. In particular, the links between sustainable development and adaptation and sustainable development and mitigation are hard to ignore. Thus water use prudence, economic use of chemical fertilizers, conservation and low-till agriculture, organic farming and multiple cropping find their places in one or more slots in the areas of adaptation, mitigation and sustainable development. Coping with risk has been a subject of long standing interest among development economists and policy makers. With adaptations strategies and risk mitigation having strong overlaps its may make sense to embrace adaptation initiatives within the fold of decision making for risky agriculture. Efficient use of financial and human resources can be made and the complementary roles of climate and development policies can best comes from climate 'mainstreaming', which involves the integration of policies to address climate change into the ongoing sectoral and development planning and decision making.

7.17.1. Accountability

The climate change imperative has deep implications for the deployment of available technology and the development, acquisition and diffusion of technologies for addressing the issues. The IPCC Working Group III in the Fourth assessment report (Edenhofer, 2008, Mitigation of Climate Change, paper presented by Edenhofer Ottomar at ISEE conference) emphasized the importance of technology policies while observing an inverse relation between the level of stabilization GHG at C equivalent in the atmosphere and the efficiency of research and development. Government supports both through direct finance such as taxes and through market creation will be essential. The disadvantage suffered by the developing countries in this regard has drawn major attention. The Kyoto protocol exempted the developing countires from the set targets and the 'measurable, reportable and verifiable' emission reduction commitment (MRV) was explicitly imposed only on the developed countries. The UNFCCC puts the onus on the developed countries to help the developing countries in mitigation efforts.

With the current dynamic situation not ruling out a situation when the future annual emissions from some developing countries will exceed those from the developed world there is also an emerging feeling that the MRV provisions be extended to developing countries as well (Dasgupta, 2010). This will additionally enable more comprehensive information gathering on emissions, mitigation and the efficacy of mitigation measures. An alternative regime would possibly find developing countries like India facing reduction targets and legally permitted penalties for non-compliance. This could also address carbon leakages through relocation of industries. Technology transfer lies at the core of mitigation for climate challenges (Dasgupta and Taneja, 2010). The study finds considerable scope for Indian agriculture to fall in line with global initiatives for emission reduction. Although by and large a Low Emissions Agricultural Management (LEAM) policy appears to be in line with the conventional objectives of increasing crop production and profitability from agriculture, the shift may require a volume of finance that may be unaffordable, undoubtedly a reason for the shortfalls registered till date. The nexus with climate change raises an opportunity of novel methods of financing particularly vide the carbon market.

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