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Review article

CLIMATE CHANGE AND AGRICULTURE-IMPACTS AND STRATEGIES

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ABSTRACT
Climate change is recognized as a major threat to the survival of species and integrity of ecosystems worldwide (Hulmi, 2005). Climate change has been recognized globally as the most impending and pressing critical issue affecting mankind survival in the 21st century. It is the most severe problem that we are facing today, more serious even than the threat of terrorism' (King, 2004). The global atmospheric concentration of green house gases (GHG) viz., carbon dioxide (CO2), methane (CH4) and nitrous oxide (NO2) has increased tremendously as a result of human activities from pre-industrial era. Increasing concentration of these gases is expected to have great effect on global climate change and thereby affect on agriculture (Cannon 1998). On the basis of the increase of these greenhouse gases, climatic models predict a 1.4^{o}C to 5.8^{o}C average increase in global warming from 1990 to 2100, probably leading to a more rapid increase in temperature at the surface of terrestrial zones and more extreme local variations (Karl and Trenbeth, 2003). IPCC predicted that global mean temperature would rise between 0.9-3.5 ^{o}C by the year 2010 (IPCC, 2007). The IPCC suggested that if temperatures rise by about 2 ^{o}C over the next 100 years, negative effects of global warming would begin to extend to most regions of the world; it is believed likely that approximately 20-30 percent of plant and animal species will be at an increased risk of extinction. Climate change will show mostly a negative influence on organisms and over all biodiversity (Franco *et al*., 2006). Global agriculture will be under significant pressure to meet the demands of rising populations using finite, often degraded, soil and water resources that are predicted to be further stressed by the impact of climate change. The ongoing buildup of greenhouse gases in the atmosphere is prompting shifts in climate across the globe that will affect agro-ecological and growing conditions. In addition, agriculture and land use change are prominent sources of global greenhouse gas emissions. The application of fertilizers, rearing of livestock, and related land clearing influences both levels of greenhouse gases in the atmosphere and the potential for carbon storage and sequestration. Therefore, whilst ongoing climatic changes are affecting agricultural production, the sector itself also presents opportunities for emissions reductions (Mark et al., 2008).

KEY WORDS: Climate, Agriculture, Mitigation, impacts.

INTRODUCTION

Some environmental problems by their very nature are global in scope. Perhaps the two most immediate environmental threats that we face as a global community are climatic changes due to the artificial introduction of large amounts of Green House Gases into the atmosphere and abnormally high incidences of ultraviolet radiation on the surface of earth due to the destruction of ozone layer. Warming of the climate system is unequivocal, as is now evident from observations of air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC 4th AR, 2007). Global agriculture will be under significant pressure to meet the demands of rising populations using finite, often degraded, soil and water resources that are predicted to be further stressed by the impact of climate change. The ongoing buildup of greenhouse gases in the atmosphere is prompting shifts in climate across the globe that will affect agro-ecological and growing conditions. In addition, agriculture and land use change are prominent sources of global greenhouse gas emissions. The application of fertilizers, rearing of livestock, and related land clearing influences both levels of greenhouse gases in the atmosphere and the potential for carbon storage and sequestration. Therefore, whilst ongoing climatic changes are affecting agricultural production, the sector itself also presents opportunities for emissions reductions.

Climate change has been recognized globally as the most impending and pressing critical issue affecting mankind survival in the 21st century. Climate change is a change in the statistical distribution of weather over periods of time that range from decades to millions of years. It can be a change in the average weather or a change in the distribution of weather events over time (IPCC 2007). It is the most severe problem that we are facing today: more serious even than the threat of terrorism' (King, 2004). The global atmospheric concentration of green house gases (GHG) viz., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) has increased tremendously as a result of human activities from pre-industrial era. Increasing concentration of these gases is expected to have great effect on global climate change and thereby affect on agriculture (Cannon 1998).There will undoubtedly be shifts in agro-ecological conditions that will warrant changes in processes and practices — and adjustments is widely accepted truths — in order to meet daily food requirements. In addition, climate change could become a significant constraint on economic development in developing countries that rely on agriculture for a substantial share of gross domestic production and employment. Two central ideas for dealing with climate change will become clear, namely, mitigation and adaptation. Mitigation — or a decline in the release of stored carbon and other greenhouse gases — must take place. There are opportunities for mitigation in the agricultural sector to help reduce the impact of climate change, and there is significant room for promoting pro-poor mitigation methods. In addition, as a change in climate has already begun, adaptation — or the modification of agricultural practices and production — will be imperative to continue meeting the growing food demands of modern society. Both mitigation and adaptation will require the attention of governments and policy makers in order to coordinate and lead initiatives. It is apparent that a system of regulation to ensure the economic value of carbon sequestration will be an important policy development in the agricultural sector.

Causes of climate change

- Fossil fuel burning
- Rapid industralization
- Deforestration
- Agricultural activities
- Modernisation (home appliances)
- Space explosion
- Wetland destruction
- Landuse change

Power plants emit large quantities of CO_2 produced from the burning of fuel (coal) for the purpose of electricity generation. Coal produces around 1.7 times as much CO_2 per unit of energy when flamed as does natural gas and 1.25 times as much as oil. Heavy industrialization in cities has contributed to air pollution through dust and black carbon originating from them which can absorb short wave radiations and heat the air. Likewise deforestation causes 25% of all carbon release entering the atmosphere by the cutting and burning of about 34 million acres of trees/year.

Annual green house gas emission trends

Climate change is the result of an increase in the concentration of greenhouse gases (GHG) like carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Rising GHG emissions are associated with economic activity, particularly as related to energy, industry, transport and patterns of land use. One million metric tons (MMt) of methane (CH_4) emissions equals 21 million metric tons of carbon dioxide (CO_2) emissions, similarly 1 MMt N_2O = 320 MMt CO_2. This indicates that the global warming potential of methane and nitrous oxide is higher than that for carbon dioxide, because these exist longer in the atmosphere. Yet, due to their significantly smaller concentrations, the actual radioactive forcing of CH_4 and N_2O is one-third and one-tenth of CO_2, respectively.

Share of global green house gas (GHG) emission by sector

Agriculture, including land use change and forestry or LUCF, accounts for nearly one-third of global GHG emissions (WRI, 2008). Further analysis of Figure-1 indicates that agriculture alone contributed 13 percent of total global GHG emission.

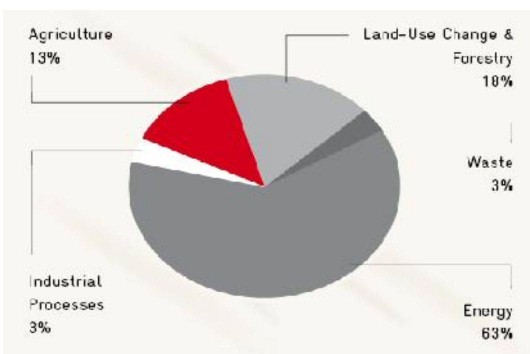


Fig-1

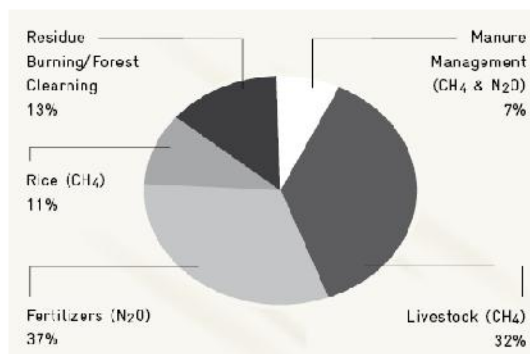


Fig-2

Emissions from this sector are primarily CH_4 and N_2O, making the agricultural sector the largest producer of non-CO_2 emissions. Agriculture also generates very large CO_2 fluxes (both to and from the atmosphere via photosynthesis and respiration), these are nearly balanced on existing agricultural lands. Emissions from agriculture come from four principal sub sectors: Agricultural soils, livestock and manure management, rice cultivation, and the burning of agricultural residues and savanna for land clearing. Share of pollutants derived from each of these sectors is shown in Fig-2.

Agricultural soils (N_2O) and the enteric fermentation and manure management (CH_4) associated with livestock production account for the largest of these shares. Emissions from agriculture are expected to rise due to increased demand for agricultural production, improved nutrition, and the changing dietary preferences of growing populations that favor larger shares of meat and dairy products (e.g. Delgado *et al.,* 1999). This will also lead to increased pressure on forest resources due to agricultural expansion. Figure 3 presents the projected growth in emissions from each source for the years 1990 to 2020. Global agricultural emissions were found to increase by 14 percent from 1990 to 2005, and a 38 percent rise is expected for the entire period 1990 to 2020.

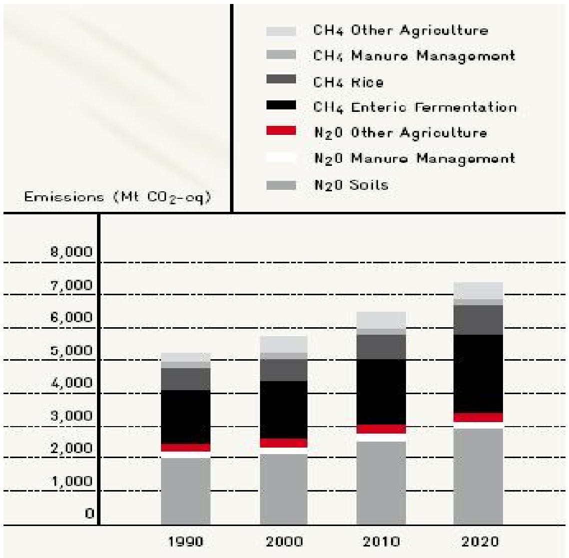


Fig-3: Projected agricultural emission by developed Subsector, 1990-2020 (USEPA,2006)

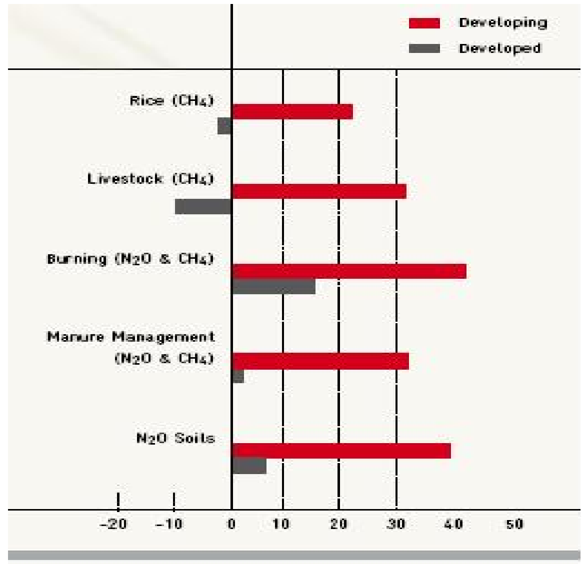


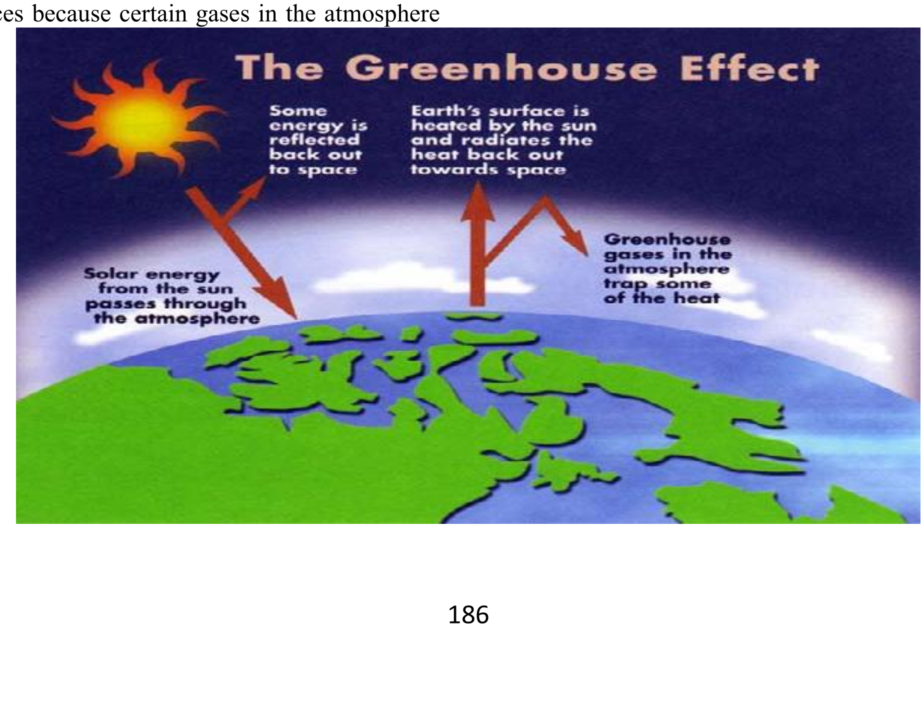
Fig:4 Percentage change in sector emissions in & developing countries, 1990-2020(USEPA, 2006)

Figure 4 illustrates the share of expected emissions growth likely to come from developing countries for each sector. Agricultural emissions in developing countries are expected to increase by 58 percent in 2020. Meanwhile, emissions from the burning of agricultural residues and savanna and N_2O from soils are projected to grow by over 40 percent from 1990 levels. From a mitigation perspective, one of the largest challenges lies in aligning increasing demands for food, shifts in dietary tastes, and demand for agricultural commodities for non-food uses with sustainable, low-emitting development paths.

Significant carbon release, however, results from the conversion of forested land, which is accounted for under the LUCF category. Certain GHG emissions arising from agricultural activity are accounted for in other sectors, such as those relating to (upstream) manufacture of equipment, fertilizers, and pesticides, plus on-farm use of fuels and the transportation of agricultural products.

Green house effect

The green house effect is the rise in temperature that the earth experiences because certain gases in the atmosphere (water vapour CO_2, N_2O and Methane e.g) trap energy from the sun. Without these gases, heat would escape back into space and earth's average temperature would be about 60^o F colder. Because of how they warm our world, these gases are referred to as green house gases. The earth's atmosphere is all around us. It is the air that we breathe. Green house gases in the atmosphere behave much like the glass panes in a green house. Sunlight enters the earth's atmosphere, passing through the blanket of green house gases. As it reaches the Earth's surface, land, water and biosphere absorb the sunlight's energy. Once absorbed, this energy is sent back into the atmosphere. Some of the energy passes back into space, but much of it remains trapped into the atmosphere by the green house gases, causing our world to heat up. The green house effect is important. Without the green house effect, the Earth would not be warm enough for humans to live. But if green house effect becomes stronger, it could make the earth warmer than usual. Even a little extra warming may cause problems for humans, plants and animals.



Ozone depletion: Ozone layer in the stratosphere of earth plays an important role as an umbrella to protect the habitat of earth from the effects of dangerous ultra-violet radiation from sun. It plays a beneficial role absorbing most of the biologically damaging ultra-violet (UV) sunlight radiation called UV-B (290-320nm wavelength). The absorption of UV radiation by OZONE creates a source of heat and thus plays a key role in the temperature structure of the Earth's atmosphere. Without the filtering action of ozone layer, more sun's UV-B radiation would penetrate the atmosphere and would reach the earth's surface in greater amounts and causing the following unwanted effects:

- Harm to plants, animals and humans
- Heat genetic material and photosynthetic chemicals, which can lead to mutation, genetic defects and cancer development
- Affecting human immune system and leading to skin cancer, skin burns, skin aging
- Lowering sea productivity thus adversely affecting the marine flora and fauna
- Contributing towards greenhouse effect
- Various effects on vegetation
- Increase in eye diseases

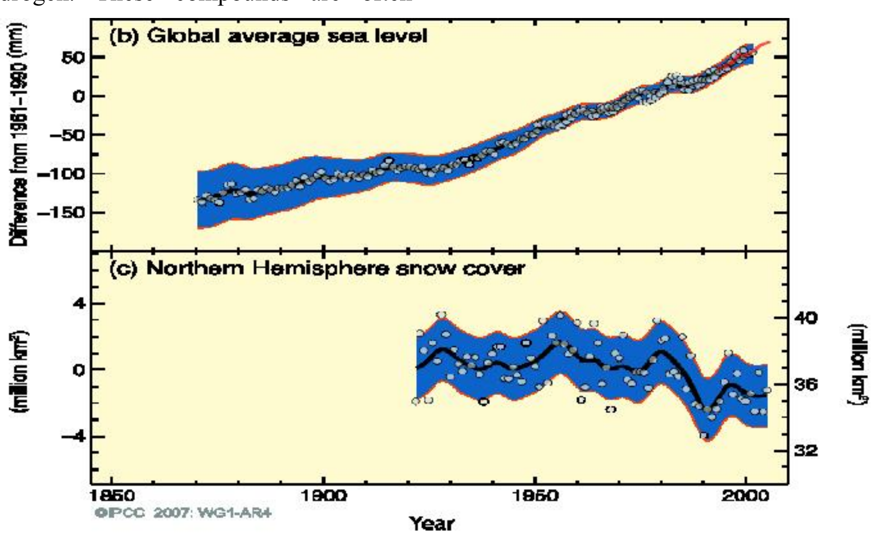
Humans have been injecting enormous quantities of ozone depleting substances into the atmosphere especially a class of chemicals known as cholorofluorocarbons (CFC's) that found important uses as solvents, aerosols, fire extinguishers, air conditioners and refrigerants. The ozone-depleting compounds contain various combinations of the chemical elements like chlorine, Flourine, Bromine, Carbon and Hydrogen. These compounds are often described by the general term "Halocarbons". Compounds that contain only Carbon, Chlorine and Flourine are called Chloroflourocarbons (CFC's). e.g. (CFCl3 or CFC-11, CF2Cl2 or CFC-12, C2F3Cl3 or CFC-113. Halons contain carbon, bromine, flourine and chlorine. In addition oxides of nitrogen released from the exhausts of large fleet supersonic air-crafts have also been held responsible for increasing the rate of ozone depletion. Other human produced substances that can attack stratospheric ozone are hydrochloroflourocarbons with 2-5% ozone depleting potential of CFC's and therefore often used as substitutes for CFC's.

How to prevent ozone depletion?

- Remove CFC's selectively from our atmosphere
- Using airplanes to spray alkalenes, ethane or propane in the ozone hole
- Drastically reduce the use and production of ozone depleting chemicals and substitute them with more environmental friendly compounds
- Industries to develop more ozone friendly substitutes to the above compounds
- Stringent measures to be put forward to restrict the use of CFC's and halons

Environmental factors influenced by climate

The atmosphere temperature rise is not a new phenomenon and it has started million of years ago. Scientists were analyzing the fossilized remains of leaves of trees about 55 millions years ago and they reached a conclusion that planet was undergoing a period of warming. They believe rise in global temperatures caused by a tripling of CO_2 levels during the palaeocene age.Through a series of observation and modeling studies, the IPCC has shown that GHGs have resulted in warming of the climate by 0.74°C between 1906 and 2005 (IPCC, 2007).



Maximum area covered by seasonally frozen ground has decreased by about 7% in Northern hemisphere since 1900

This has in turn resulted in increased average temperature of global ocean, sea level rise and decline in glacial and snow cover. Mild winter temperature and warmer spring, bud burst is advanced and the onset of growth occurs earlier. Due to warm temperature in March buds open earlier and are more susceptible to frost damage. Increase in winter temperatures will result in advancement of the growing season .Rise of diurnal air temperature in the interior of green house promotes a significant reduction in the production of pollen grains. High temperature shortens stigmatic receptivity and or ovule abortion and effective pollination period. Climate change is expected to affect irrigation water demand due to increase in temperature and changes in available soil moisture which is due to amount and distribution of precipitation. Net irrigation requirements globally could increase or decrease by as much as 30% by the 2020 depending upon region (Doll 2002). In southern Spain, it has been projected that climate change may reduce available water up to 34% which increases irrigation requirement (Rodriguez Diaz., *et al* 2007).

Future climate projections

1. Plants will be directly stimulated by enhanced concentrations of CO_2 leading:

i. to larger and more vigorous plants

ii. to higher yields of total dry matter (roots, shoots, leaves)

iii. Stomatal opening decreases in response to increased CO_2 concentration resulting in increased resistance to water loss from leaves.

2. Higher temperature will lead to:

i. yields reduction of determinate crops, i.e. cereals (shorter growing season)

ii. yield increase in indeterminate crops, i.e. forage crops (longer growing season)

3. Lower rainfall in summer season will lead to water shortage that may be harmful especially for crops like wheat, sunflower, and soybean.
4. Demand of water for irrigation will rise increasing the competition between agriculture and urban as well as industrial users of water. Water tables will fall making the practice of irrigation more expensive. Peak irrigation demands will rise due to more severe heat waves. Risk of soils salinisation will be increased for higher evaporation.
5. Higher air temperatures speed up the natural decomposition of soil organic matter increasing the rates of other soil processes resulting in the loss of soil fertility. Elevated temperatures are found to accelerate the cycling of C, N, P, K, and S in the soil-plant-atmosphere system leading to enhancement of CO_2 and N_2O greenhouse gas emissions. High temperature also increases the process of nitrogen fixation due to greater root development.
6. Like-wise changes in rainfall increase the vulnerability to wind erosion suppressing both root growth and decomposition of organic matter (lower summer precipitations). Higher frequency of high intensity precipitation events increases soil erosion favouring run-off.
7. Depending on the specific interaction between pests/diseases/weeds, and crops and climate, there may be an increase, a decrease or no change in their effects on agricultural crops. e.g. Maize Streak Virus and Cassava Mosaic Virus in areas where rainfall decreases, and sorghum Headsmut (a fungal disease) in areas where rainfall decreases.
8. Higher temperature may be more favourable for the proliferation of insect pests (longer growing seasons, higher possibility to survive during winter time). Enhanced CO_2 may affect insect pests through amount and quality of the host biomass (higher consumption rate of insect herbivores due to reduced leaf N) .Recent occurrence of stormy rain in kashmir conditions have increased bacterial gummosis of stone fruits. Altered wind patterns may change the spread of both wind-borne pests and of bacteria and fungi. Increased frequency of floods may increase outbreaks of epizootic diseases (i.e. African Horse Sickness).
9. The differential effects of CO_2 and climate changes on crops and weeds will alter the weed-crop competitive interactions. Higher CO_2 concentration will stimulate photosynthesis in C_3 species and increase water use efficiency in both C_3 and C_4 species. Changes in temperature, precipitation, and wind and air humidity may affect the effectiveness of herbicides.

PROSPECTED AGRO-ECOSYSTEM RESPONSE TO CLIMATE CHANGE

The response of agricultural production will be extremely variegated and very crop and site dependent. Crop productivity is projected to increase slightly at mid- to high altitudes for local mean temperature increases of up to 1-3°C depending on the crop, and then decrease beyond that in some regions. At lower latitudes, especially seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1- 2°C), which would increase the risk of hunger.Increases in the frequency of droughts and floods are projected to affect local crop production negatively, especially in subsistence sectors at low altitude. Following climate change, crops are likely to shift their cultivation area to meet their specific optimum climate conditions.

a. Cereals and seed crops

The cultivation area will shift toward higher latitudes or altitudes**.** Drier conditions may lead to lower yields**.**Warmer temperatures will shorten the length of growing season and reduce yields**.** Such an effect will be partially counteracted by the increase in CO_2 concentration, which also will lead to increased symbiotic nitrogen fixation in pulses.

b. Root and tuber crops

Due to their large below ground sinks for carbon are expected to show large response to rising CO_2. Warming may reduce the growing season in some species (potato) and increase water requirements with consequences for yields. Other species (sugar beet) will benefit from both warming and the increase in CO_2 concentrations.

c. Pasture

Yield is strictly dependent on the projected rainfall pattern. Primary production may increase in temperate regions but decrease in semiarid and tropical regions. Species distribution and litter composition will change (high CO_2 levels may favor C_3 plants over C_4; the opposite is expected under associated temperature increases). Yields will differently affected by weeds, pests, nutrient, and competition for resources.

PROSPECTED IMPACT ON LIVESTOCK SYSTEMS

Climate change may influence livestock systems through different pathways:

i. Changes in availability and prices of grains for feeding (cereals, pulses and other feed grains)

ii. Changes in productivity of pastures and forage crops

iii. Change in distribution of livestock diseases

iv. Changes in animal health, growth, and reproduction (direct effects of weather and extreme events)

Climate change may also affect the turn-over and losses of nutrients from animal manure, both in houses, storages and in the field influencing the availability of manure in organic farms.

Impact of climate change in Jammu and Kashmir

The state of Jammu and kashmir is up against major climatic challenges such as erratic weather behaviour, unexpected flash floods, absence of regeneration of major forest species, depletion and degradation of high level pasteurs, rapid recession of glaciers and snowline. Recently Srinagar has been placed in the category of 100 most quickly growing cities in the world which definitely is going to have its impact on the climate (G.K report). Rainfall and snowfall patterns have changed substantially. Valley used to record maximum snowfall in the second fortnight of December or during January but of late snowfall has been witnessed during late February or first fortnight of March. Both air and soil temperature are on plus side during these periods resulting in melting of snow and unexpected flash floods even during March and April .Water which is required for irrigation is not available at right time resulting in drought, failure of paddy and horticultural crops. Snow tsunami during 2005 resulted in huge loss of human life. Climate models used by the Intergovernmental Panel on Climate Change predict that the number of extreme events such as cloudbursts will increase with rising global temperature as was experienced in the Himalayan town of Leh in Ladakh on 6th of August,2010 resulting in flash floods and mudslides washing away houses that were not built to withstand such rainfall. Climate change impacts are also adversely affecting the horticulture sector in the state which is considered to be the backbone of state's economy

Fig-A

Fig-B

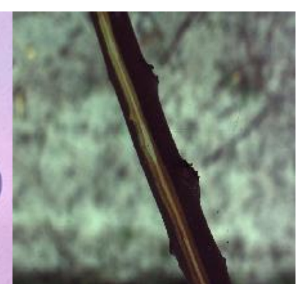
Fig-A: The picture shows blooming of flowers amidst snowfall in Srinagar in February 2007. Early blooming of fruit blossoms and flowers due to warmer temperatures during February and March in Kashmir has been damaging fruit produce as sudden late snows in February and March devastate blossoms.

LOW TEMPERATURE DAMAGE

Damage to Peach on bloom

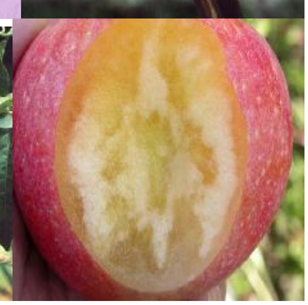
Damage to young Apple fruits

Mild winter damage to Cambium



Damage to young Apple fruits

Damage to young Peach fruit



water core in Apples

Extreme events

Climate change may be responsible for some trends in natural disasters such as extreme weather. Climate change is in indeed responsible for the increased frequency of pronounced heat waves, heavy rainfall events and other erratic and destructive weather events. Recently Thailand floods were due to heavy monsoon rains that drenched Southeast Asia**.** Villagers in India's North Eastern State of Meghalaya are also concerned that rising sea level will submerge neighboring low-lying Bangladesh resulting in an influx of refugees into Meghalaya. If server climate changes occur, Bangladesh will lose land along the coast line. Flooding, coastal erosion, droughts, salt water intrusion into soils, unusual high levels of tropical storm, cyclones, huge loads of rain are among the effects seen in various parts of the world during the past years which have been attributed to global temperature rise.

Canada, Alaska and Russia are experiencing initial melting of permafrost due to temperature rise. This may disrupt ecosystems and by increasing bacterial activity in the soil lead to these areas becoming carbon sources instead of carbon sinks. As the temperature of oceans increases, they become less able to absorb excess CO_2 due to ocean acidification. Climate change is projected to result in rising sea level due to thermal expansion and melting of glaciers and ice sheets. The loss of glaciers not only directly cause landslides, flash floods and glacial lake overflow but also increases annual variation in water flows in rivers. Having effects on ecosystems by melting sea ice, warming reduces the ocean's ability to absorb CO_2. Forest fires due to decreased rainfall and increased risk of drought releases more stored carbon into the atmosphere than the carbon cycle can naturally re-absorb, as well as reducing the overall forest area on the planet.

Vulnerable areas- a focuss on developing countries

Developing countries will bear the brunt of climate change impacts. Smallholder and subsistence agriculture are particularly vulnerable, but to understand the impact of climate change on them it is necessary to:

i. Recognize the complexity and high location-specificity of their production systems

ii. Take into account non-climate stressors on rural livelihoods.

iii. Consider the multiple-dimensions impact of climate change on rural farming systems and livelihoods.

The possible vulnerable areas include:

i. Significant loss of biodiversity through species extinctions in many areas of tropical Latin America.

ii. Reduction of tropical forest due to replacement by savannah (eastern Amazonas, central and South Mexico), increased susceptibility to fire occurrences, Land-use change (deforestation, agriculture expansion, financing large scale project such as dams, roads, etc…).

iii. Desertification and salinisation of agricultural lands are very likely to take place due to increased evaporation rates.

iv. Changes in precipitation patterns are projected to affect water availability for human consumption, agriculture and energy generation.

Vulnerable areas: Asia and Africa

A northward shift of agricultural zones is likely to take place. Rice, maize and wheat production will decline due to the increased water stress, arising from increasing temperature and reduction of rainy days. Yield of rice is expected to decrease by 10% for every 1°C increase in growing season minimum temperature. Aridity in Central and West Asia may reduce growth of grasslands and increases bareness of the ground surface. Agricultural irrigation demand in arid and semi-arid regions of Asia is estimated to increase by at least 10% for an increase in temperature of 1°C (IPCC, 2007).

Africa is probably the most vulnerable continent to climate change and climate variability. Climate change will cause some countries to become at risk of water stress exacerbating current water availability problems and is likely to reduce the length of growing season as well as force large regions of marginal agriculture out of production. Thus, agricultural production and food security (including access to food) are likely to be severely compromised.

Hotspots for vulnerability in Africa are: semiarid mixed rain-fed crop-livestock systems in the Sahel, arid and semiarid grazing systems in East Africa and mixed crop-livestock and highland perennial crop systems in the Great Lakes Region.

How to cope with climate change?

Two central ideas for dealing with climate change become clear, namely, mitigation and adaptation.

Mitigation is a response strategy to global climate change, and can be defined as measures that reduce the amount of emissions (abatement) or enhance the absorption capacity of greenhouse gases (sequestration). The total global potential for mitigation depends on many factors, including emissions levels, availability of technology, enforcement, and incentives. In many situations, the efficiency of agriculture can be improved at a low cost. However, when low cost incentives are unavailable, policy development is important.

Mitigation potential and options in agriculture:

The technical potential for GHG mitigation in developing country agriculture by 2030 indicates significant opportunities for emissions reductions, together with an enhanced income earning potential for farmers, and associated benefits from lower natural resource degradation. Developing countries are estimated to account for three fourths of global technical potential, with Asia accounting for 40 percent, Africa 18 percent, and Latin America and the Caribbean 15 percent (Smith *et al.*, 2007). The economic potential for mitigation in agriculture depends on the price of carbon and on policy, institutional, and transaction cost constraints. It is estimated that the economic potential is about 36 percent of technical potential at carbon prices of up to $25 per t CO2-eq, 44 percent at prices of up to $50/t CO2-eq, and 58 percent at prices of up to $100/t CO2-eq (Smith *et al.*, 2007).

Based on USEPA (2006) results, rice cultivation mitigation strategies have the highest economic potential for emissions reductions in developing countries. However, Smith *et al.* (2007) have found that soil carbon sequestration offers the highest economic potential, and with best prospects in developing countries.

Adaptation

Formally defined, adaptation to climate change is an adjustment made to a human, ecological or physical system in response to a perceived vulnerability (Adger *et al.*, 2007). Adaptation responses can be categorized by the level of ownership of the adaptation measure or strategy. Individual level or *autonomous adaptations* are considered to be those that take place in reaction to climatic stimuli (after manifestation of initial impact), that is, as a matter of course and without the directed intervention of any public agency (Smit and Pilifosova, 2001). Autonomous adaptations are widely interpreted to be initiatives by private actors rather than by governments, usually triggered by market or welfare changes induced by actual or anticipated climate change (Leary, 1999). *Policy-driven or planned adaptation* is often interpreted as being the result of a deliberate policy decision on the part of a public agency, based on an awareness that conditions are about to change or have changed, and that action is required to minimize losses or benefit from opportunities (Pittock and Jones, 2000). Thus, autonomous and policy-driven adaptation largely correspond to private and public adaptation, respectively (Smit and Pilifosova, 2001).

Main adaptive strategies

Economic and agronomic adaptation strategies will be important to limit losses and exploit possible positive effects. The economic strategies are intended to render the agricultural costs of climate change small by comparison with the overall expansion of agricultural products. The agronomic strategies intend to offset either partially or completely the loss of productivity caused by climate change. Agronomic strategies can be either short term adjustments or long term adjustments.

Short Term Strategies: Short-term adjustments may be considered as the first defence tools against climate change and aims to optimise production with minor system changes through:

- *The management of cropping systems*
- *The conservation of soil moisture*

The management of cropping systems considers changes in crop varieties e.g varieties with different thermal requirements, varieties given less variable yields etc, introduction of greater diversity of cultivars, changes in agronomic practices (sowing/planting dates) and changes in fertiliser and pesticide use etc.

The conservation of soil moisture considers the introduction of moisture conserving tillage methods (minimum tillage, conservation tillage, stubble mulching, etc.) and the management of irrigation (amount and efficiency) etc.

Long Term Strategies: Long-term adaptation may overcome adversity caused by climate change through major structural system changes like:

- *Changes in land allocation* to optimise or stabilise production (e.g. substituting crops with high inter-annual variability in production (wheat) with crops with lower productivity but more stable yields (pasture)
- *Development of "designer-cultivars"* to adapt to climate change stresses (heat, water, pest and disease, etc.) much more rapidly than it possibly today.
- *Crop substitution* to conserve of soil moisture. (e.g. sorghum is more tolerant of hot and dry conditions than maize).
- *Microclimate modification* to improve water use efficiency in agriculture (e.g. windbreaks, inter-cropping, multi-cropping techniques).
- *Changes in nutrient management* to reflect the modified growth and yield of crops, and also changes in the turn-over of nutrients in soils, including losses.
- *Changes in farming systems* to maintain farms viable and competitive (e.g. conversion of specialised farms in mixed farms less sensitive to change in the environment).

Main implications for related sectors

i. Forestry may be affected by drier and warmer conditions in the Mediterranean region that could lead to more favourable conditions for agro-forestry
ii. Water resources may be interested by warmer and drier conditions during summer that will enhance the demand for freshwater, especially for agriculture and human consumption
iii. Insurance my be affected by an altered frequency of extreme weather events (e.g. storms, hails or floods) that will lead to lower or higher damage costs
iv. Other sectors that will contribute to rural income (e.g. ecotourism, nature management, culture) may be affected directly or indirectly by climate change.

Main unknowns:

i. The impact of climate change on secondary factors of agricultural production like soil, weeds, pests and diseases
ii. The impact of increased surface receipts of UV-B radiation on future agricultural performance and agricultural response to climate change.
iii. The response of the quality of agricultural products to atmospheric CO_2 concentration increases, climate change and exposure to atmospheric pollutants
iv. The impact of changes in mean climate and climate variability on mean yield and yield variability
v. The impact of increasing isolated and extreme events (e.g. hail, strong winds, flooding and extreme high temperatures) on agricultural production
vi. The response of crop production and farming systems in sensitive or vulnerable regions (e.g. Asian and African countries on the Mediterranean shore)

CONCLUSION

Agriculture impacts climate change significantly through livestock production and the conversion of forest to land cover that has low carbon sink or sequestration potential. Nitrous oxide emissions from crop production and methane from rice production are also significant. Mitigation options that are the most technically and economically feasible include better rice, crop- and pasture land management. Although there are viable mitigation technologies in the agricultural sector, particularly in developing countries, some key constraints need to be overcome. First, rules of access — which still do not credit developing countries for reducing emissions by avoiding deforestation or improving soil carbon sequestration — must be changed. Second, operational rules, with their high transaction costs for developing countries and small farmers and foresters in particular, must be streamlined. Climate change is also likely to have a significant negative impact on agricultural production, prompting output reductions that will greatly affect parts of the developing world. Adaptation, including crop choice and timing, has the ability to partially compensate for production declines in all regions. While a number of models have predicted this development, there is still a range of specific regional effects to be considered. Furthermore, insufficient attention has been given to multiple stressors, like extreme weather events, pests, and diseases. In addition, to date, only a limited number of studies have focused on the climate change and carbon fertilization effects related to crops of importance to the rural poor, such as root crops and millet. As a result of changes in production, food security will be affected by climate change. Indeed, climate change alone is expected to increase the number of food insecure by an additional 5 to 170 million people by 2080, especially in Africa. Nevertheless, socio-economic policy, especially trade liberalization, can compensate for some of the negative impact here. Even the most aggressive mitigation efforts that can reasonably be anticipated cannot be expected to make a significant difference in the short-term. This means that adaptation is an imperative. Yet, in the face of this imperative, many developing countries are lacking in sufficient adaptive capacity. As a result, there is a large role for national governments, NGOs, and international institutions to play in building the necessary adaptive capacity and risk management structures.

In order to facilitate these roles, global scale assessments should be conducted to help identify intra-regional variations in the effects of climate change. These studies would clarify the range of outcomes possible under plausible climate and adaptation scenarios, which would then assist in the targeting of high priority areas. Once areas of prioritization have been identified, evaluation criteria should be applied, that not only consider net economic benefits, but also environmental and social appropriateness. In addition, adaptation measures should maximize the complementarities between existing rural and sustainable development objectives. Finally, climate change adaptation and mitigation have to proceed simultaneously. Since adaptation becomes costlier and less effective as the magnitude of climate changes increases, mitigation of climate change remains essential. The greater the level of mitigation that can be achieved at affordable costs, the smaller the burden placed on adaptation. Policies focused on mitigating GHG emissions, if carefully designed, can help generate a new development strategy; one that encourages the creation of new value in pro-poor investments by increasing the profitability of environmentally sustainable practices. To achieve this goal, it will be necessary to streamline the measurement and enforcement of offsets, financial flows, and carbon credits for investors. It will also be important to enhance global financial facilities and to reform their governance, namely to simplify rules and to increase the funding flows for mitigation in developing countries. There has been a tendency to treat adaptation to climate change as a stand-alone activity, but this should be integrated into development projects, plans, policies, and strategies. Meanwhile, development policy issues must be addressed in association with the climate change community. A combined perspective is required to ensure the formulation and implementation of integrated approaches and processes that recognize how persistent poverty and environmental needs exacerbate the adverse consequences of climate change. Climate change will alter the set of appropriate investments and policies over time, both in type and in spatial location. Effective adaptation therefore requires a judicious selection of measures within a policy context and a strategic development framework, but must also explicitly counter the impact of climate change, particularly with respect to the poor. At the end some important recommendations are put forward to mitigate the impacts of climate change:

i. Encourage flexible land use.
ii. Encourage more prudent use of water
iii. Improve the efficiency in food production and exploring new biological fuels and ways to store more carbon in trees and soil
iv. Assemble, preserve and characterise plant and animal genes and research on alternative crops and animals
v. Encourage research on adaptation, developing new farming systems and developing alternative foods
vi. Enhance national systems that disseminate information on agricultural research and technology, and encourages information exchange among farmers
vii. Promote the development of agricultural weather information systems including the use of long-term weather forecasts
viii. Integrate environmental, agricultural and cultural policies to preserve the heritage of rural environments.

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