Impact of Global Climate Change on Agriculture and Food Production

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Introduction

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (IPCC, 2001). In addition to natural variability, it is influenced by human activities in many ways. The global climate has fluctuated considerably since the last delectation period, and major changes in climate have occurred approximately at the same time all over the world. Since the 1980s, scientists have been predicting serious consequences of climate change (Ford, 1982). It is predicted that over 100 million people will be at risk of hunger by 2080 with 80% of them being in Africa (Carter, 2007).

Climate change can result from a variety of natural causes such as increased solar output, sunspot activity, Milankovitch episodes and Volcanicity, or from human activities such as deforestation, overgrazing and burning of fossil fuels which cause an increase in atmospheric Carbon-dioxide, or from both the natural and human activities (Nkemdirim, 2003). It is the developed world who afflicts most of the climate change, but unfortunately, it is the developing world which suffers the most, though its contribution remains small. Average global temperatures are projected to rise between 1.4 and 5.8 °C by 2100. By 2030, the increase will be rather lower than this, between 0.5 and 1 °C. The rise will be greater in temperate latitudes. Global carbon dioxide concentrations in the atmosphere are expected to rise from the present figure of 370 ppm (parts per million) to 540-970 ppm by 2100. Over the period 1990 to 2100, it is projected that the average global air temperature will increase by 1.4 to 5.8 °C, and global mean sea level will rise by somewhere between 9 cm and 88 cm (World Meteorological Organisation (WMO), 2001).

Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded that: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (IPCC, 2001). This human impact will continue to change atmospheric composition throughout the twenty first century. The WMO, United Nations Environment Programme (UNEP) and IPCC assessments have shown that the observed increases in atmospheric greenhouse gasses (GHGs) may cause global warming, a rise in sea-level and changes in the normal pattern of hydro-meteorological parameters.

Trends in Agricultural Productions

The annual growth rate of world demand for cereals has declined from 2.5 percent a year in the 1970s to 1.9 percent a year in the 1980s and to only 1 percent a year in the 1990s. The decline is a result of slower population growth and shifts in human diets and animal feeds. However, in the 1990s, it was accentuated by a number of temporary factors, including serious recessions in the transition countries and some East and Southeast Asian countries (Alexandratos, 1995).

The annual food production growth rate in the developing countries declined from an average growth of 4.2 percent during the period 1991-1995 to 3.5 percent during the period 1996-2000 (WMO, 2001). The demand for cereals is expected to rise to 1.4 percent per year by 2015 and come down thereafter to 1.2 percent. The net production of developing countries is not expected to keep pace with this growing demand. On the contrary, the net cereal deficits of these countries, which amounted to 103 million tonnes or 9 percent of consumption in 1997-99, could rise to 265 million tonnes (14 percent of consumption) by 2030 (United States Department of Agriculture (USDA), 2006).

The three main important alternatives to increase crop production are: (i) expanding the cropped area, (ii) increasing the frequency with which it is cropped (often through irrigation), and (iii) boosting yields. In the coming 30 years, developing countries will need an extra 120 million ha for crops. This is only half the rate of increase observed between 1961-63 and 1997-99 (Food and Agriculture Organisation (FAO), 2002).

In the Near-East and North Africa, 87 percent of suitable land was already being farmed in 1997-99, while in South Asia the figure is no less than 94 percent. In these regions, intensification through improved management and technologies will be the main source of production growth. In many places, land degradation threatens the productivity of the existing farmland and pasture (FAO, 2002).

Irrigation is crucial to the world's food supplies. In 1997-99, irrigated land made up only about one-fifth of the total arable area in developing countries, but produced two-fifths of all crops and close to three-fifths of cereal production. The developing countries as a whole are likely to expand their irrigated area from 202 million ha in 1997-99 to 242 million ha by 2030. Most of this expansion will occur in land-scarce areas where irrigation is already crucial (USDA, 2006).

FAO studies suggest a total irrigation potential of some 402 million ha in developing countries, of which, only half is currently used. However, availability water resources will be a major factor constraining expansion of cropping area in South Asia, which will be using 41 percent of its renewable freshwater resources by 2030, and in the Near East and North Africa, which will be using 58 percent. These regions will need to achieve greater efficiency in usage of water.

In the past four decades, rising yields accounted for about 70 percent of the increase in crop production in the developing countries. Wheat yields grew at an average rate of 3.8 percent a year between 1961 and 1989, but at only 2 percent a year between 1989 and 1999. For rice, the respective rates fell by more than half, from 2.3 percent to 1.1 percent. Overall, it is estimated that some 80 percent of future increases in crop production in developing countries will have to come from intensification: higher yields, increased multiple cropping and shorter fallow periods (FAO, 2002).

Impacts of Climate Change on Agriculture

Climate change will have very diverse impacts on agriculture. The climate is also expected to change with an increase in the frequency and severity of extreme events such as cyclones, floods, hailstorms and droughts. These calamities will substantially reduce the crop yield and local food supplies. In areas where water level is low, especially in the tropics, the rise in temperature will increase evapo-transpiration and lower soil moisture levels. Some cultivated areas will become unsuitable for cropping and some tropical grassland may become increasingly arid. Temperature rise will make it more habitual for agricultural pests to multiply and also increase their ability to survive during the winter and attack spring crops. Global climate disturbances create widespread harvest deficiencies and subsequent devastating famine in countries which are unable not in a position to purchase food. (Gribbin and Kelly, 1989).

The change in climate affects cultivation in many ways, but with the current trend, it imposes a greater threat to the security of food. World scientists in the field of meteorology, climatology and agriculture warn the impact of a changing climate in the productivity of staple food crops cultivated throughout the world. Unfortunately, majority of the food consumed by the world is produced in tropical countries which are more vulnerable to climate change. Precipitation during the 20th century has, on average, increased over continents outside the tropics, but decreased in the desert regions of Africa and South America. Warm episodes of the El Niño Southern Oscillation (ENSO) phenomenon have been more frequent, persistent, and intense since the mid 1970s, compared with the previous 100 years (IPCC, 2001).

The impacts of climate change on agriculture are caused mainly by: (i) regional temperature rises in northern latitudes and in the centre of some continents; (ii) increased heat stress on crops, (iii) increased vapor-transpiration rates caused by higher temperatures, (iv) concentration of rainfall into a smaller number of rainy events with increases in the number of days with heavy rain, (v) changes in seasonal distribution of rainfall, (vi) a rise in sea level, (vii) frequent and severe extreme changes of climate causing food production and supply disruption. Some important impacts of climate change on agriculture and food production are explained in the following sections:

(i) Impacts due to temperature increase

An increase in the temperature in the north temperate regions could affect agriculture by altering the range of crops grown and by increasing productivity. An increase in temperature will move the northern boundaries for crops further north, altering the range of crops available to farmers. A 1 °C increase in temperature may move the northern agricultural boundary 150-200 km further north. A study on the extent of US Corn Belt assumed that it would be moved 175 km per 1 °C in a north-eastern direction as the climate is drier and warmer. In Europe, the northern limit of maize production would move 300 km north for each 1 °C rise in temperature. As a consequence, grain maize may be a viable crop through out the British Isles and much of Scandinavia by the middle of the next century (Jonathan and Duncan, 1996).

In South Asian countries, there are also significant potential losses in many regional staples, including millet, maize and rice. These losses are going to be really crushing on the poor farmers who are in the margin of survival. The nations of southern Africa - Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe - could lose about 30 percent of their main crop of corn, also known as maize. Agricultural losses also could be significant in the South Asia region encompassing India, Pakistan, Nepal and Sri Lanka, with a drop-off of at least 5 percent in many regional staples, including millet, maize and rice (FAO, 2002).

Desertification could accelerate around the Sahara. There are likely to be severe water shortages in many parts of the continent. Many important grain crops, such as field corn, wheat and oats tend to have lower yields when summer temperatures increase, because the plant developmental cycle is speeded up and the duration of the grain-filling period is reduced (Mitchell et al. 1993). It is estimated, for example, that the production of winter wheat will decrease by 55% in India and 15% in China by the year 2100. This will in turn have a serious impact on Japan, which depends heavily on other countries for its food supply.

In India 70% of the total population is dependent on agriculture. In the past 50 years, agricultural production has been increased mainly due to adoption of high-yielding varieties (HYVs) and other technological developments. But in the recent decades, production has been frequently affected by extreme weather events such as droughts and cyclones. Sinha and Swaminathan (1991) showed that an increase of 2°C in temperature could decrease the rice yield by about 0.75 t/ha in high-yielding areas, and 0.5°C increase in winter temperature would reduce wheat yield by 0.45 t/ha. Another study showed that for every one degree rise in temperature, the decline in rice yield would be about 6%. (Science Daily, 2007).

In Japan, the impact of global warming is already seen in the production of rice, the country's staple food, and wheat. While rice harvests are expected to increase in the Hokkaido and Tohoku regions, wheat production is likely to decrease in all regions. It is also possible that global warming will trigger frequent natural disasters, including accelerated activity of weeds and harmful insects, allowing harmful insects from the tropical and subtropical zones to spread to the temperate zone and damage harvests.

It has been estimated that by 2030, grain production in China might decrease by up to 10 per cent because of the changes in temperature. The output of the three major crops in China (rice, wheat and maize), are expected to see reductions. The output of maize crop may be affected by higher temperatures combined with the resulting increase in evaporation and poor irrigation due to less rainfall by shortening the growing period and thus by reducing overall yields.

Tropical regions in the developing world are particularly vulnerable to potential damage due to climate changes because the poor soil that cover large areas of these regions has already made much of the land unusable for agriculture. The rate of evaporation depends on temperature, but is also affected by the humidity of the atmosphere. Higher temperatures will increase evaporation and thereby cause more rapid depletion of soil water. For example, a 2 °C increase in temperature could increase vapor-transpiration by as much as 20%.

Soil moisture is the principal factor affecting crop productivity over large areas of the world, particularly in warmer climates. The amount of water in the soil available to plants depends on the balance between supply and loss of water. Water can be lost from the soil as it drains over the surface, by direct evaporation from the soil and through the transpiration of the plants.

Higher temperatures usually accelerate the development of a plant, through its life cycle more rapidly. In many crop species, there is a particular development stage during which the yield component of the crop is produced. In grain crops, this is the period between the initiation of the grain and its maturation. More rapid grain maturation results in loss of time for the grain to grow and hence reduced yield.

Although higher temperature accelerates expansion of the leaf canopy early in the season, later increased temperature accelerates maturation and reduces yields. Some plants, such as barley and oats which are planted in the autumn, require a cool period for a vernalisation processes. If the winter temperature increases, the vernalisation period may be insufficient, causing low flower bud initiation and hence reduced yield.

In many parts of the world, agricultural productivity is limited by low temperature. This may restrict the variety of crops and limit the rate of crop growth. Low temperatures can severely damage crop. As winter temperatures are likely to rise more than those in the summer, crops that are limited by frost occurrence, such as citrus fruits and grapevines can be grown.

(ii) Impacts due to Extreme Weather Events

Extreme events are the principal cause of the year-to-year variability in agricultural output. The impact caused by an increase in the frequency of extreme events such as droughts, floods, storms, cyclones or typhoons, El Niño and heat waves may be more important than average changes in climate. If the average temperature rises, the frequency of extreme temperature events will increase at any given location. This heat stress could reduce crop production, particularly in hot years. In Northern India, where wheat is grown at a low tolerance limit, yield could decrease by 10% for a temperature rise of 0.5°C (Sinha and Swaminathan (1991).

Tropical cyclones have severe adverse effects on agriculture and food security, water resources, and on other key social and economic sectors. In China, more than 400,000 hectares of crop lands were affected by typhoon *Winnie* in 1997. In recent years, major storms and floods have struck Bangladesh, Cambodia, the Caribbean, Central America, China, India, Southern Africa, Venezuela and Vietnam. As of April 2001, some 60 million people in 36 countries were confronting food shortages of varying degrees (WMO, 2001).

El Niño is warm water current that periodically flows along the coast of Ecuador and Peru. It has climatic effects through the Pacific region and in many of other parts of the world. El Niño is generally associated with worldwide disturbances in the patterns of precipitation and temperature, as well as with patterns of tropical storms and hurricane activity. Since 1983, rice production in India has been greatly affected by year-to-year climate variability, especially El Niño/Southern Oscillation events. During a warm El Niño, the arrival of the monsoon rains is delayed, prolonging the hungry season and disrupting the planting of the main crop in December-January (Stanford University, 2007).

The climate changes can increase the stress on plants, especially at the edges of their distribution. One cause of stress is drought. A decline in soil moisture could cause desiccation of food plants, early leaf loss and the death of seedlings. On the other hand, water-stressed plants are likely to be warmer because they are less cooled by transpiration.

Drought is a natural hazard originating from a deficiency of precipitation that creates water shortages for agricultural activities. In 2001, much of Western Asia, Central Asia and the Middle East suffered the third year of a continuing drought that severely reduced crop yields in these regions. The extremely low level of precipitation destroyed almost all the rain-fed crops. In the Islamic Republic of Iran, successive droughts from 1999 to 2001 threatened more than 6.4 million acres of irrigated farms, 9.88 million acres of rain-fed fields and 2.7 million acres of orchards. Agricultural damage across the country was estimated at more than US $ 2.6 billion (WMO, 2001).

(iii) Impacts due to Sea-level Rise

Mean sea level is projected to rise by 15 to 20 cm by 2030, and by 50 cm by 2100. This would cause flooding, seawater intrusions and storm surges which could lead to loss of low-lying areas. The over extraction of groundwater due to global warming may exacerbate the saline intrusion problem in some areas. It will damage vegetable growth and aquaculture in low-lying areas. This impact will be most serious in coastal zones, especially heavily-populated deltas used for agriculture, which are of the kind found in Bangladesh, China, Egypt, India and mainland Southeast Asia. In India alone, losses by 2030 could range from 1,000 to 2,000 km², destroying perhaps 70,000 to 150,000 livelihoods (FAO, 2002).

Salinisation occurs in irrigated areas, usually with inadequate drainage which causes salts to concentrate in the upper soil layers where plants root. It is a problem mainly in the arid and semi-arid zones, where 10 to 50 percent of the irrigated area may be affected. Salinisation can cause yield decreases of 10 to 25 percent for many crops and may prevent cropping altogether when it is severe. It is estimated that 3 percent of the world's agricultural land is affected. In East Asia, however, the proportion is 6 percent and in South Asia 8 percent. For the arid and semi-arid tropics as a whole, 12 percent of agricultural land may be affected (FAO, 2002).

Sea level rise induced by global warming could lead to loss of land through flooding and saltwater intrusion, and damage to mangrove swamps and spawning grounds. Sea levels are rising at about half a centimetre per annum, and are likely to continue at this rate for several decades, even if there is rapid implementation of international agreements to limit climate change. Thus, sea levels could be 15-20 cm higher by 2030 and 50 cm by 2100 (IPCC, 2001b), increasing the flood risk in large parts of South and East Asia and placing populations and agriculture at risk (Gommes et al., 1998). Three valuable production systems will be most affected: vegetable production that tends to be irrigated and heavily concentrated around urban areas threatened by saltwater intrusions; aquaculture systems sited in areas at or below sea level; and coastal fisheries dependent on spawning grounds in mangrove swamps and other coastal wetlands threatened by sea level rise, although some adjustment might take place through sediment deposition and the accumulation of organic matter.

The loss of cropland could be substantial. India, for example, has more than 6500 km² of low-lying coastal land, much of which is cultivated.

Asthana (1993) estimated that a 1 metre sea level rise in India would result in the loss of some 5500 km². Rises of this magnitude are not foreseen before 2100 according to the IPCC's latest estimates. Losses by 2030 could be from 1000 to 2000 km². Assuming an average farm size of 1.5 ha, this could represent the loss of some 70,000 to 150,000 livelihoods. In the case of Bangladesh, a similar rate of sea level rise by 2030 could result in the loss of 0.8-2.9 million tonnes of rice per annum, offsetting yield gains arising from changes in temperature, precipitation and atmospheric CO_2 concentration. In Bangladesh and Egypt, rising sea levels is threatened crop production and livelihoods in large areas of low-lying land.

(iv) Impacts due to Increase in Carbon di-oxide (CO_2) Level

The rise in atmospheric concentrations of carbon dioxide not only drives global warming but is also essential for adequate growth of plants. It stimulates photosynthesis (the so-called CO2 fertiliser effect) and improves water use efficiency (Bazzaz and Sombroek, 1996). Up to 2030, this effect could compensate for much or all of the yield reduction coming from temperature and rainfall changes. Recent studies in the United States suggest that the benefits from CO2-induced gains in water use efficiency could continue until 2095 (Rosenberg et al., 2001).

The higher carbon dioxide (CO_2) levels in the atmosphere, which resulted from human activities, may increase the growth and yields of crops mainly through their effects on the crop's photosynthetic process. Higher temperatures also exacerbate stress on water resources that are essential for crop growth and warm and wet conditions also tend to affect the prevalence of pests, diseases and weeds. Further, the high frequency of natural disasters like floods and droughts associated with climate change can make the situation even worse.

An increase in the concentration of atmospheric CO_2 will stimulate the growth of most crops. The nutrients are added to optimise plant growth, and under these conditions the maximum increase in performance will be achieved as a result of CO_2 fertilisation. An increase in CO_2 concentration by 10 ppm results in 1% increase in crop growth. At the same time, other environmental factors also alter crop performance from year to year. But, its significance is yet to be studied in detail.

There are many experiments conducted to investigate the eventual impact of CO_2 enrichment. The response elicited by different crop species falls in a wide spectrum. Some crop species could increase production by as much as 3% for every 10 ppm increase in CO_2 concentration. In some species the greatest stimulation of growth takes place at a concentration of between 500-600 ppm CO_2, with less significant response above this concentration (Jonathan and Duncan, 1996).

The net growth of a plant is the difference between the amount of carbon fixed by photosynthesis and the amount lost through respiration. Therefore, higher temperatures can increase growth if it stimulated photosynthesis more than respiration. The impact of temperature on net carbon flux will depend on the temperature conditions where the crop is grown. In cooler climates, higher temperatures will increase growth by stimulating photosynthesis, but in warmer regions growth will be reduced by higher respiration rates. Carbon dioxide causes plant stomata to narrow, so water losses are reduced and the efficiency of water use improves. Increasing atmospheric concentrations of carbon dioxide will also stimulate photosynthesis and have a fertilising effect on many crops.

The enriched CO_2 is likely to have detrimental effects on agriculture. The amount of plant growth per unit nitrogen tends to increase in enriched CO_2 as a consequence of the increased efficiency of photosynthetic carboxylation. The nitrogen content of leaves may also fall as carbohydrate accumulates in leaves as a result of increased photosynthesis by CO_2 enrichment. This will directly affect crop growth where additional fertiliser is not available.

Benefits of Global Warming

Global warming may also be beneficial for agriculture. These gains may, however, have to be set against the loss of some fertile land due to flooding, particularly on coastal plains. The areas suitable for cropping will expand, the length of the growing period will increase, the costs of over wintering livestock will fall, crop yields will improve and forests may grow faster.

In Europe, there is likely to be a shift in agricultural potential in favour of the northern countries. In Scandinavia, agricultural potential will be increased by 10-20%, but countries such as Italy and Greece will have reduced potential by 5% and 36% respectively. Iceland is a country where temperature is a severe constraint on agriculture. It is estimated that Icelandic agricultural output could more than double by the middle of the next century. (Parry and Carter, 1988). In Australia, an increase in summer rainfall of about 40% is predicted. This would stimulate an increase in yield of over 20% (Parry, 1990).

Conclusion

According to the United Nations Food and Agriculture Organisation, there are twelve regions including much of Asia, sub-Saharan Africa, the Caribbean, and Central and South America which have a large share of the world's malnourished populations. The agricultural sector faces many challenges stemming from growing global populations, land degradation, and loss of cropland to urbanisation. In this century, climate change is one factor that could affect food production and availability in many parts of the world, particularly those most prone to drought and famine. Although food production has been able to keep pace with population growth on the global scale, there are serious regional deficits, and poverty related nutritional deficiencies that affect about a billion people globally.

A substantial number of the world's one billion poor depends on agriculture for their livelihoods.. Unfortunately, agriculture is also the human enterprise most vulnerable to changes in climate. Understanding where these climate threats will be greatest, for what crops and on what time scales, will be central to our efforts at fighting hunger and poverty over the coming decades. Temperature and rainfall are key factors affecting crop yield in the developing countries. The average temperature in most of these areas could rise 1.8°F (1°C), while seasonal precipitation in some places including South Asia, South Africa, Central America and Brazil will fall.

Although relatively inexpensive adaptations, such as planting earlier or later in the season or switching crop varieties, could moderate the effects of climate change, the biggest benefits will likely result from more costly measures, including the development of new crop varieties and expansion of irrigation. These adaptations will require substantial investments by farmers, governments, scientists and development organisations, all of whom face many other demands for their resources.

In addition, urgent investment is needed in agricultural adaptation to specific areas, such as Southern Africa and South Asia. It is important to note that these are only the changes that may result from global warming in the absence of any other factors. In practice, changes in technology are likely to reduce the impact of climate change. These most important technological changes will be improved crop varieties and cropping practices, which will increase yields. The expansion of irrigation combined with dissemination of new crop varieties will reduce the sensitivity of some systems to climate change.

Climate change seems to benefit agriculture in developed countries located in temperate zones, but have an adverse effect on production in many developing countries in tropical and subtropical zones. Hence, climate change could increase the dependency of developing countries on imports and accentuate the existing North-South differences in food security.

Food security of the poor people is threatened by climate change. Even by 2030, there will still be hundreds of millions of such people, who will be either undernourished or on the brink of undernourishment. They will be especially vulnerable to disruption of their incomes or food supply by crop failure or by extreme events such as drought and floods. For example, in the south of Mozambique, maize prices in the spring of 2000 increased rapidly following the floods.

Policymakers must have a long-term outlook. Work must be done further to develop farming technology to cultivate high-temperature and pest-resistant crops. However, more work needs to be done to develop water-conserving agricultural practices. A recent set of models examines cross-sectional evidence from India and Brazil and finds that even though the agricultural sector is sensitive to climate, individual farmers do take local climates into account, and their ability to do so will help mitigate the impacts of global warming.

In developing countries, structural changes in the sectoral composition of the economy, employment and access to food will increasingly be determined by urbanisation and non-agricultural incomes. As a result, food security in some countries will improve and become less vulnerable to climate change. However, as far as the factors such as poverty and the lack of food purchasing power are concerned, the basic food security issue will remain unchanged. Institutional changes are going to be as important as or more important than technological ones. Institutional actions will be needed to raise national preparedness and reduce rural and urban poverty to enable vulnerable low-income groups to purchase all of their basic food requirements.

Agriculture is a local activity in many parts of the developing world. Thus, solutions to the problems in agriculture need to be local. But, most impoverished regions don't have the financial or research capacity to make improvements. Traditional and local knowledge with modern science will provide the best hope for these people.

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