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Climate Change and Food Security in Dryland Region of the World

Netra B. Chhetri[1] and William E. Easterling[2]

[1] School of Geographical Sciences and the Consortium for Science, Policy, Outcomes, Arizona State University, PO Box 875302, Tempe, AZ 85287, USA

[2] College of Earth and Mineral Sciences, Penn State University, University Park, PA 16802, USA

Abstract: Some of the most profound and direct impacts of climate change over the next few decades will be on systems of food production. The sensitivity of crop production to climate makes agriculture vulnerable to the risks associated with climate change. While it is generally acknowledged that climate change may not imperil the ability of world's agriculture to maintain food security, it does, however, challenge farmers to adapt in regions where it may be stressful, such as dryland areas of the world. World's dryland farmers with limited capacities to adapt to climate variability and change are faced with the new threats, which could have serious impacts on food security. The vulnerability of agriculture to climate change in dryland regions of the world also comes from factors associated with socioeconomic, political, and technological conditions limiting their ability to adapt to change. However, adaptations to climate change could reduce the impact considerably.

Key words: Climate change, dryland agriculture, food security, impacts and adaptation.

One of the challenges of the 21st century is to ensure food security for a population estimated to reach 10 billion by the end of the century. While the world in general has made remarkable progress in production of food and fiber during the second half of the 20th century, food security remains an unfulfilled dream for about 776 million people, most of who are in developing world (FAO, 2005). Based on the understanding of current vulnerability to food insecurity, the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change, IPCC, concludes that climate change is likely to further shift the geography of food insecurity to climatically marginal areas of the world such as dryland regions (FAO, 2007; Easterling *et al.*, 2007). For example, Tubiello and Fischer (2007) and Tubiello *et al.* (2007) report that after factoring for the effects of climate change, the number of people vulnerable to food insecurity in Sub-Saharan Africa could triple by 2080. If agricultural production is adversely affected by climate change, then the livelihoods of even greater number of people is at risk and their vulnerability to food security is further intensified.

Agriculture's importance to food security is not only to provide food and fiber, but more importantly to ensure a primary source of livelihood for majority of the world's workforce. Yet, livelihood systems that are based on agriculture may face risk of increased crop failure, frequent incidences of pests and diseases, and loss of livestock due to climate change (Howden *et al.*, 2007). Its impacts will be both short term, resulting from more frequent and intense climatic events, and long term, caused by changing patterns of temperatures and precipitation (FAO, 2008). Aside from climate change smallholder agriculturists in dryland regions, where up to 70% of the working population still makes their living from agriculture (ILO, 2007), are currently experiencing a number of interlocking stressors emanating from global economic change, HIV AIDS, land degradation, and population growth (Easterling *et al.*, 2007; Morton, 2007). At the same time they also possess strong adaptive capacity such as improved efficiency in the use of household labor (Lipton, 2004), diversification of livelihoods (Ellis, 2000) and management of indigenous knowledge, which collectively make them more resilient. The combination of stressors and resilience factors makes them experienced to cope with and adapt to unforeseen events, but climate change also poses novel risks often outside the range of experience such as impacts due to extended and frequent droughts, intensive rainfall, and heat waves (Adger *et al.*, 2007).

Understanding the potential impact of climate change on agriculture in the drylands is critical for two reasons. First, the existing system of food production is highly climate sensitive because of its low level of capital and technology. Second, agriculture is the main source of livelihood for majority of the population where it is the only activity in which 90% of the poor and very poor can earn some cash in the dryland region. Nearly two-thirds of the rural household income is derived from agricultural activities and 8 out of 10 people working in agriculture are self-employed farmers (ILO, 2007). The consequences of an adverse climate change could therefore significantly affect food security and the well-being of the people of dryland region, in which the average per capita calorie intake is already among the lowest in the world.

In this paper, we focus on the impacts of climate change on agriculture in the arid and semi-arid climatic regions that are predicted to be particularly hit hard, given highly variable temperature and precipitation patterns of these regions. The paper starts with an overview of global trend in food production and with specific highlight to food security scenario of developing countries. It then provides a brief review of the potential impacts of climate change in dryland regions. This is followed by the discussion of the vulnerability of dryland agriculture in the context of climate and other ongoing changes. We then review the sensitivity studies conducted to understand the impacts of climate change in the dryland agriculture. In this section we have made an attempt to review recent studies that have quantified the impacts of climate change on crop production in semi-arid and arid region of the world. Finally, we conclude with some suggestions to improve future assessments to enhance their overall robustness and their relevance for policy makers.

Global Trends in Food Production

During the second half of the last century, global food production outpaced population growth as a result of crop improvement, adoption of improved of agricultural practices, use of inorganic fertilizers and pesticides, and development of infrastructures (Pinstrup-Anderson and Pandey-Lorch, 1998; Gilland, 2002). Cereal production doubled during the period between 1960-1990, per capita food availability increased by 37%, and per capita calories available per day increased from

2,420 kcal per day in 1958 to 2,808 kcal in 1999 (McCalla *et al.*, 1999: 97). Though evidence continues to support the fact that global agricultural production could be maintained relative to the demand, progress toward reducing hunger has been slow in recent decades (von Braun, 2005). Although the number of undernourished people, in aggregate, declined worldwide from 815 million in 1990 to 776 million in 2000, the number of undernourished people in Sub-Saharan Africa increased from 168 million to 194 million during the same period (FAO, 2005), indicating the enormity of challenge in securing food security for all. In this region cereal production grew at a meager 1% over the past decades, while the population expanded at an estimated 2.7% at the same time (von Braun, 2005). According to Shah *et al.* (2008), overall 40% of the countries in Sub-Saharan Africa will be at risk of significant decline in food production.

Scholars show that declining trends of per capita food availability in Sub-Saharan Africa comes from combined effects of increasing population, lack of investment in agricultural R&D, outbreak of epidemic, and slow or sometimes negative growth in agricultural production (McCalla *et al.*, 1999; Dyson, 1999). The same trend has been reflected in South Asia where malnourishment has increased significantly among the population in recent decades. In 2006, global cereal stocks were at their lowest levels since the early 1980s. Grain stocks in China, which constitute about 40% of the total stocks declined significantly from 2000 to 2004 and have not recovered in recent years (von Braun, 2007). Most of the recent decrease in global cereal production is attributed to reduced plantings and adverse weather in major crop growing regions of the world.

As food insecurity is closely intertwined with poverty, countries that are overwhelmingly poor also have high levels of hunger. The 2008 Global Hunger Index (GHI) released by the International Food Policy Research Institute shows that the world has not made much progress in decreasing food insecurity in the past two decades, though this trend differs significantly across nations. The level of GHI remains high for the world in general. In Sub-Saharan Africa the GHI is significantly high, especially in the Democratic Republic of Congo, Eritrea, Burundi, Niger, and Sierra Leone (von Grebmer *et al.*, 2008). The GHI in South Asia remains high despite some headway made in this region. So the progress of reducing hunger has been very slow and uneven across the world. Recent hike in food prices has compounded the problem with uneven effects across countries, depending primarily on whether countries are net importers or exporters of food.

In addition, developing countries with limited capacities to adapt to climate variability and change are faced with further threats which could have serious impacts on important dimensions of food security such as food availability, food accessibility, food utilization and food system stability (FAO, 2008). In much of developing world, especially in Sub-Saharan Africa and South Asia, agricultural production and access to food are projected to be severely compromised by climate variability and change. Hence production losses resulting from climate change will further worsen the prevalence of hunger and malnutrition.

Climate Change, Agriculture, and Food Security

The AR4 provides strong evidence that the earth's climate is changing and that much of this change is very likely (more than 90% confidence level) due to increase in greenhouse gas (GHGs) concentration associated with human activities. This change is evident from observations of increased global average temperature of 0.74°C (+/-0.18) over the past century; altered precipitation patterns; declining snow cover; and an increased global average sea level of 1.8 mm (+/-0.5) per year (IPCC, 2007). Based on compiled historical surface temperature data from tree rings, marine sediment, ice cores, and other sources, Mann *et al.* (2008) provide further evidence that observed average global temperature is at an all-time high. The authors also find that the past decade has stood out as the warmest in at least 1,300 years and perhaps up to 1,700 years, if tree ring data are included. In the seasonally dry regions even a slight warming (1-2°C) may have significant negative effects on livelihoods of people (Easterling *et al.*, 2007).

In the next two decades an average warming of about 0.2°C is projected, after which potential increases may vary depending on development pathways society may adopt. According to IPCC AR4, the emission of GHGs, at or above current rates, "would cause further warming and induce other changes in the global climate system during the 21st century that would very likely be larger than those observed in the 20th century (IPCC, 2007). It is very likely that heat extremes, heat waves and heavy precipitation events will become more frequent. Increases in the amount of precipitation are very likely in high-latitudes, while decreases are likely in most sub-tropical land regions, continuing observed patterns in recent trends.

Studies also show increasing trends of surface temperature in arid and semi-arid tropics of Asia. For example, southern and central India shows warming trends in recent decades (Sivakumar *et al.*, 2005). According to Rupakumar *et al.* (1994) warming of 0.57°C has been reported in the last 100 years. Likewise, most of Middle East, Pakistan, and Sri Lanka also show an increasing trend of temperature (Choudhury, 1994; Rupakumar and Patil, 1996). There is no discernible trend in long-term change in precipitation for the region. However, many countries have shown a decreasing trend in rainfall in the past three decades (Sivakumar *et al.*, 2005). In India, for three consecutive decades, rainfall departures are found above and below the long-time averages (Kothyari and Singh, 1996), with recent decades exhibiting an increase in extreme rainfall events over northwest India notably during the summer monsoon (Singh and Sontakke, 2002). Lal *et al.* (1995) suggested that the surface air temperature over the Indian subcontinent (area-averaged for land regions only) is likely to rise from 1.0°C (during the monsoon) to 2.0°C (during the winter) by the middle of the next century. The rise in surface temperature could be quite significant across the semi-arid regions of NW India. Populations in arid or semi-arid areas of South Asia are most vulnerable because of their heavy dependence on rainfall. Any change in monsoon will have severe consequences in food production.

Africa, which has roughly equal landmasses within both hemispheres, is characterized by a wide range of climatic regimes. Rainfall is one of the most important natural resources for many of mainland Africa's 48 nations (Hulme, 1992). Rainfall variability, inter and intra-annual, is perhaps the key climatic element that determines the success of agriculture in these countries. Extensive droughts have caused distress in Africa. Through the analysis of recent rainfall data from West Africa, Nicholson *et al.* (2000) showed a significant departure of rainfall in Africa. For example, over tropical North Africa, during the period of 1961-1990, the rainfall has declined by up to 30% compared with 1931-1960. In West Africa, there has been a pattern of continued aridity since the late 1960s that is most persistent in the more western regions (Nicholson *et al.*, 2000). This change has been dominated by the reduction of rainfall in June-August in the Sahel with widespread decrease of well over 0.4 mm per day (Hulme, 1992).

Climate change could adversely impact food security through reduced crop yields, geographical shifts in optimum crop-growing conditions, reduced water resources for agriculture and human consumption, loss of cropping land and yields through floods, droughts and sea-level (Lobell *et al.*, 2008). In Africa, by 2020, between 75 million and 250 million people are projected to be exposed to increased water stress due to climate change. Irrigation demand for water is projected to increase in a warmer climate, bringing increased competition between agriculture, already the largest consumer of water resources in semi-arid regions, and other uses (Gitay *et al.*, 2001). This will further exacerbate water-related problems.

Generally, researchers engaged in climate change impact studies agree that climate change would have modest negative impact on global agriculture, but at the regional level the impacts may vary widely, with some regions benefiting from altered climate and others being adversely affected. Food production would likely decline in the developing countries, whereas the more developed countries may actually benefit from global warming, at least in the early stages (Gitay *et al.*, 2001; Easterling *et al.*, 2007; Tubiello and Fischer, 2007; Lobell *et al.*, 2008). The regions likely to be adversely affected by climate change are those already most vulnerable to food insecurity and malnutrition, notably Sub-Saharan Africa, which may lose substantial agricultural land. Impacts on the production of cereals also differ by crop type. The numbers of people affected will be largest in the mega-deltas of Asia and Africa (IPCC, 2007).

Two reasons underlie the differential impacts that climate change is expected to have in agricultural productivity between the developed and developing countries. The first is the physical factor. In developed countries, most of which are located within the higher latitudes (temperate zone), agriculture would benefit from the longer growing season that would accompany a warmer climate. However, in developing countries situated in the lower latitudes (tropics), most crops have already attained their climatic threshold and therefore crop yields would likely to be adversely affected even with a small change in climate. The second reason is the socioeconomic factor. Compared with the developed countries, developing countries have lesser economic resources to help farmers adjust to climate change. The technical capabilities and institutional structures in developing nations needed to cushion the adverse effects of climate change are comparatively less developed or may even be non-existent. These comparative disadvantages, whether physical or socioeconomic, underscore the greater vulnerability of developing countries to climate change, and subsequently its effect on food security.

Vulnerability of Dryland Agriculture to Climate Change

According to Rao and Ryan (2004), almost 40% of the earth's total land surface (6.1 billion hectare) is dry. Of this, approximately 0.9 billion hectare is hyper arid desert and the remaining is semi-arid and sub-humid lands and are collectively known as drylands. These drylands are found in more than 110 nations and are a vital part of the earth's human and physical environments. Drylands include all terrestrial regions where water scarcity limits the production of crops, forage, wood, and other ecosystem provisioning services (Hazell, 2001; MA, 2005). It is also home to over 2 billion people, most of who are smallholder agriculturists.

Variability in climate has been the principal source of risk for food security in drylands. In the past, extreme climatic events such as extended droughts and floods have caused significant disruption in food production systems (Sivakumar *et al.*, 2005). Often soils in the dryland regions are sandy and generally shallow, contributing to a low water holding capacity which makes it more difficult to deal with the detrimental effects of erratic and limited precipitation (Rao *et al.*, 2004). Temperature extremes also limit productivity in many dryland areas (FAO, 2008). Since the agricultural productivity of dryland regions are mainly determined by precipitation, the vulnerability of food security increases with a decrease in total precipitation. Poverty and food insecurity are also exacerbated by depletion or poor management of natural resources (e.g. soil and water) and in most countries, by rapid population growth. A study by Rao *et al.* (2004) estimated that 70% of the drylands are undergoing some form of degradation, impacting the well-being of one-sixth of the world's population. Smallholder agriculturists in the dryland regions are particularly vulnerable to increasing frequency and severity of droughts because of their low level of adaptive capacity, exacerbated by low level of technology and lack of access to resources. These may lead to a higher likelihood of crop failure; increased diseases and mortality of livestock, indebtedness, out-migration and dependency on food relief; and impacts on human development indicators such as health, nutrition and education (Easterling *et al.*, 2007).

The vulnerability of agriculture to climate change in dryland regions of the world also comes from factors associated with socioeconomic, political, and technological conditions limiting their ability to adapt to change (Adger *et al.*, 2003; Easterling *et al.*, 2007). For example, ongoing stresses related to demographic change, HIV/AIDS, land degradation, economic globalization, property rights, and conflicts increases exposure to greater food insecurity. Morton (2007) lists a series of stressors affecting livelihood of agrarian populations. Some of the stressors are very likely to worsen the effects of climate change. For example, population growth not only demands additional food from the land, in rural areas it drives land degradation and fragmentation (Blaikie and Brookfield, 1987). A change in resource endowments due to the effects of climate change aggravates resource degradation and fragmentation effects. Likewise, environmental degradation caused by population growth and ill-defined property right may hinder the adaptive capacity of smallholder agriculturalists in rural area. A study by Butt *et al.* (2005) analyzing the consequences of various options for adapting to climate change in Mali found that the country's natural resource base has been seriously degraded owing to high population growth rate, the pressure to grow more food, and the low rate of adoption of improved technologies.

Sensitivity of Agriculture to Climate Change

IPCC AR4 carried out a synthesis of recent modeling studies for maize, wheat and rice from range of sites across the world. The report plotted yields against degrees of average local warming and associated changes in CO_2. Moderate warming in temperate regions is associated with marginal increases in yields, especially if assumptions about agronomic adaptations are factored into the models. In tropical regions, trends are clearly negative, with any degree of warming and even with some degree of adaptation factored in. For maize, the most important of the three crops in dryland regions, the downward trend in yields is the clearest. This means regional food security can be threatened with 1°C change in local temperatures.

According to AR4 of the IPCC crop yields from rainfed agriculture could reduce as much as 50% by 2020 (Easterling *et al.*, 2007). In more than 40 developing countries, mainly in Sub-Saharan Africa and Asia, cereal yields are expected to decline, with mean losses of about 15% by 2080 (Fischer *et al.*, 2005). In the world's dryland regions projected change in the patterns of rainfall and its amount, as well as rise in temperature could bring changes in land suitability (e.g., soil moisture regime, humidity, solar radiation) for crop growth and development. In Africa, an expansion of arid lands of up to 8% is likely by 2080 (Fischer *et al.*, 2005). Land suitability for crop production, too, may change significantly in the future. For example, land suitable for wheat production may almost disappear in Africa (Easterling *et al.*, 2007) and the number of people vulnerable to hunger in sub-Saharan Africa may triple between 1990 and 2080. South Asia is also expected to experience dramatic decline in cereal production by as much as 22% (Tubiello and Fischer, 2007).

Increasing number of regional simulation studies have been conducted to estimate the effects of climate change in agricultural productivity of dryland regions. All studies show that agricultural productivity could decrease substantially due to climate change, especially in the dryland regions of Africa and Asia. This is largely attributed to increased frequency of drought, despite positive benefit of the increase in CO_2 concentrations. Some crops (e.g. maize and wheat) could be forced out of production in some regions due to extreme aridity (Parry *et al.*, 2004). An important limitation of simulation studies is that they assess the impacts of climate change for a single snapshot, thereby lacking the temporal and causal dynamics that characterize the adaptive response of farmers in the field (Easterling *et al.*, 2007). Yet such studies are useful to provide first proximation of the impacts of climate change on crop yield, they are marred by uncertainty associated with scenarios of climate change and behavioral response of farmers and their supporting institutions.

Walker and Schulz (2008) conducted a sensitivity analysis of maize yield to climate change on three catchments of South Africa using scenarios of incremental temperature change of 1, 2, and 3°C, increase/decrease of precipitation by 10% and doubling of preindustrial atmospheric CO_2 concentration. On average doubling of CO_2 in association of 2°C increase in temperature and 10% decrease in rainfall results in 6% reduction of maize yields. With the scenarios of 3°C change in temperature, but no change in precipitation resulted in 8% decrease in maize yield. However, an increase of precipitation along with increase of temperature by 2°C resulted in an increase of 10% yield. The result from climate sensitivity analysis showed that maize production is more vulnerable to region with drier climate compared to the moderate to wet climate. In the driest of three study sites, the scenarios of enhanced temperature and reduced precipitation were shown to inhibit crop development.

A considerable number of process-based crop simulation models have been developed to simulate various aspects of global change impact on agricultural productivity at various spatial and temporal scales. According to the Murdiyarso (2000) rice production in Asia could decline by 3.8% over the current century. Similarly, a 2°C increase in mean air temperature could decrease rice yield by about 0.75 t ha^{-1} in India and rainfed rice in China could decrease by 5-12% (Lin *et al.*, 2004). Suitability for wheat growing could decrease in large portions of South Asia and the Southern part of East Asia (Fischer *et al.*, 2005). For example, a 0.5°C increase in winter temperature would reduce wheat yield by 0.45 t ha^{-1} in India (Kalra *et al.*, 2003) and Chinese rainfed wheat production could decrease by 4-7% by 2050 (Lin *et al.*, 2004). There is a general belief that climate change, through increased extremes, will worsen the food security situation in Africa and Asia.

Studies simulating the effects of climate change using various forms of adaptation are limited. Studies by Yates and Strzepek (1998) and Butt *et al.* (2005) provides an example of the comparison of crop-yield response with temperature increase of about 1-2°C, typical of the next several decades, up to 4-5°C projected for 2080 and beyond. The studies clearly illustrate that even a small change in temperature is likely to have negative yield impacts for all major serial crops in dryland regions. This suggests that dryland agriculture is very sensitive to changes in temperature associated with global warming. Although the results from such simulations are generally highly uncertain due to many factors including large discrepancies in the prediction of models, poor representation of data and response to CO_2 fertilization.

Yates and Strzepek (1998) assessed the impacts of climate change on the agricultural economy of Egypt (with 2 x CO_2). Using outputs from three general circulation models (GFDL, UKMO, and GISS A1) the researchers found a decrease in yields from -5 to -51% for wheat, -5 to -27% for rice and -1 to -21% for soybean. The authors state that yield reductions could be lowered by up to 50% if proper adaptation measures (changes in crops, fertilizers, and planting and irrigation patterns) were implemented. Butt *et al.* (2005) assessed the impacts of climate change on agriculture productivity of Mali using output from two general circulation models (HADCM and CGCM). With 1°C change in temperature and slight decrease in rainfall, the study projected a decrease of 16% cereal yield by 2030. Likewise average increase of temperatures by 2.75°C and slight reduction of rainfall would lead to a decrease of 20% cereal yield. Sorghum, the major staple diet in Mali, is the most susceptible crop with a national average yield decrease of up to 17%. Study also showed that adaptations to climate change reduced the impact considerably. If modest adaptations were considered, the adaptation may offset the losses from climate change.

Conclusion

Climate change, through increased extremes, may worsen the food security situation in the world's dryland regions. Some of the most sensitive dryland regions of the world (e.g., Africa and Asia) are already experiencing food deficit, and potential change in climate could aggravate the situation. Climate change not only affects crop production per unit area but also the suitability of land for agricultural production. Globally an increased agricultural production potential due to climate change, in principle, should add to food security, but locally the situation can be very different. The vulnerability of the agricultural sector to climate change is well established in recent literature. The consensus is that global warming will alter crop growing conditions (e.g., soil moisture regime, humidity) thereby affecting plant growth and development, and subsequently agricultural productivity. While global food production may remain robust in the foreseeable future, at the regional level the impacts may vary widely, with some regions benefiting from altered climate and others being adversely affected. Generally, researchers engaged in climate change impact studies conclude that food production would likely decline in the world's dryland regions. A reduction of production potential (yields, land suitability) in dryland regions, which are already faced with a serious food insecurity situation, would add to the burden.

Potential negative yield impacts are particularly pronounced in almost all dryland regions where food security is already challenged and where the underlying natural resource base is already poor. Agricultural production, including access to food, in many African countries, particularly along the margin of semi-arid and arid areas, will be severely compromised by climate variability and change. This would further adversely affect food security and exacerbate malnutrition in the continent. Climate changes will be increase crop irrigation demand in the majority of world regions due to a combination of decreased rainfall and increased evaporation arising from increased temperatures. The capacity to plan and implement adaptation, at local, national, and regional levels, remains largely untested. Much of it is due to the fact that few public institutions have thus far made serious attempts to incorporate climate change considerations into their policy formation and implementation. This will provide a significant challenge to future water and food security in dryland regions. There is also a considerable uncertainty as to the impact of CO_2 fertilization effect, which could compensate for much of the yield reductions due to changes in temperature and rainfall. Recent research, however, shows that the impact of the CO_2 fertilization is considerably lower than assumed thus far. A large number of autonomous adaptations are possible in dryland agriculture. Most of the adaptation activities currently applied by farmers are extensions of existing risk management activities. The potential effectiveness of the adaptations varies from only marginally reducing negative impacts to more than fully offsetting them. Therefore, adaptation is a key factor that will shape the future severity of climate change impacts on food production.

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