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Climate change mitigation, adaptation, and sustainability in agriculture

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Abstract—Sustainability conveys the idea of a balance between human needs and environmental concerns. A common theme amongst definitions of sustainability is that sustainable agricultural systems remain productive over time. They should provide for the needs of current, as well as future generations, while conserving natural resources. The enhancement of environmental quality and careful use of resource base on which agriculture depends is viewed as a requisite for sustained agricultural productivity. The notion that sustainable agricultural systems maintain output in spite of major disturbances, e.g., such as those caused by projected climate change, is relevant to vulnerable areas, especially in the semi-arid and sub-humid regions of developing countries.

According to the Fourth Assessment Report of the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC) released in 2007, semi-arid regions of Asia, Africa, and Latin America are likely to warm during this century, and freshwater availability is projected to decrease. Agricultural productivity in tropical Asia is sensitive not only to temperature increases, but also to changes in the nature and characteristics of monsoon. In the semi-arid tropics of Africa, which are already having difficulty coping with environmental stress, climate change resulting in increased frequencies of drought poses the greatest risk to agriculture. In Latin America, agriculture and water resources are most affected through the impact of extreme temperatures and changes in rainfall.

Climate change mitigation strategies which include interventions to reduce the sources or enhance the sinks of greenhouse gases have a marked management component aiming at conservation of natural resources such as improved fertilizer use, improved ruminant digestion, use of water harvesting, and conservation techniques. These strategies are equally consistent with the concept of sustainability. Adaptation strategies include initiatives and measures to reduce the vulnerability of agroecosystems to projected climate change, such as changing varieties, altering the timing or location of cropping activities, improving the effectiveness of pest, disease and weed management practices, making better use of seasonal climate forecasts, etc. It is essential to develop and integrate agriculture mitigation and adaptation frameworks for climate change into sustainable development planning at the national and regional levels to cope with the projected impacts of climate change.

Key-words: mitigation strategies, adaptation strategies, IPCC, mitigation and adaptation frameworks

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1. Introduction

Climate change, a key global biophysical indicator, is widely accepted as the single most pressing issue facing society on a global basis, and the growing awareness of the impacts of climate change on agriculture is forcing decision makers to refocus on the sustainability of agricultural production. Broad concepts in sustainable agriculture encompass ecological, economic, and social parameters, whereas more narrowly defined concepts are mostly concerned with environmental issues such as optimal resource and environmental management (*McCracken* and *Pretty,* 1990). The notion that sustainable agricultural systems "maintain output in spite of major disturbance, such as caused by intensive stress or large perturbation" (*Conway,* 1985) is of particular relevance in the current concerns with the possible impacts of climate change on agroecosystems.

2. Observed climate change

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988, by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), to assess scientific information on climate change, as well as its environmental and socioeconomic impacts, and to formulate response strategies. Climate change is defined by the IPCC as any change in climate over time, whether due to natural variability or as a result of human activity (*IPCC,* 2007b). Evidence from observations of the climate system has led to the conclusion that human activities are contributing to a warming of the Earth's atmosphere. This evidence includes an increase of 0.74 ± 0.18 °C in global average surface temperature over the last century, and an even greater warming trend over the last 50 years than over the last 100 years. Eleven years of the 12-year period between 1995 to 2006 are among the 12 warmest years since the instrumental record of global surface temperature was started in 1850 (*IPCC,* 2007b). Furthermore, higher temperatures along with decreased precipitation have been associated with observations of more intense and longer droughts over wider areas since the 1970s.

Changes in climate have also been manifested in altered precipitation patterns. Over the last century, the amount of precipitation has increased significantly across the eastern parts of North America and several other regions of the world (*IPCC,* 2007b). Many land areas have likely experienced an increase in the number and intensity of heavy precipitation (5 cm of rain or more) events (*IPCC,* 2007b). About half of the increase in total precipitation observed nationally in the United States has been attributed to the increase in intensity of storms (*Karl* and *Knight,* 1998).

During the 20th century, the changes in temperature and precipitation described above caused important changes in hydrology over large regions. One change was a decline in spring snow cover. This trend was observed throughout the Northern Hemisphere starting in the 1920s and accelerated in the late 1970s (*IPCC*, 2007b). Less snow generally translates to lower reservoir levels. The earlier onset of spring snowmelt exacerbates this problem. Snowmelt started 2–3 weeks earlier in 2000 than it did in 1948 (*Stewart et al.*, 2004).

Another manifestation of changes in the climate system is a warming in the world's oceans. The global ocean temperature rose by 0.10 °C from the surface to 700 m depth from 1961 to 2003 (*IPCC*, 2007b). Warming causes seawater to expand and thus contributes to sea level rise. This factor, referred to as thermal expansion, has contributed 1.6 ± 0.5 mm per year to global average sea level over the last decade (1993–2003). Other factors contributing to sea level rise over the last decade include a decline in mountain glaciers and ice caps (0.77 ± 0.22 mm per year), losses from the Greenland ice sheets (0.21 ± 0.07 mm per year), and losses from the Antarctic ice sheets (0.21 ± 0.35 mm per year) (*IPCC*, 2007c).

Other observations at smaller geographic scales lend evidence that the climate system is warming. For example, in the Arctic, average temperatures have increased and sea ice extent has shrunk (*IPCC*, 2007b).

3. Future climate change

Climate change projections indicate it to be very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent. Looking ahead, the *IPCC* (2007a) expects the warming in the 21st century to be greatest over land and at the highest northern latitudes. For the next two decades a warming of about 0.2 °C per decade is projected. Increases in the amount of precipitation are very likely in high latitudes, while decreases are likely in most subtropical land regions. For many parts of Africa the length of the growing period is projected to decrease over time (*Thornton et al.*, 2006) and projected losses in yield amount to 50% by 2020 for some countries (*IPCC*, 2007a).

Annual average river runoff and water availability are projected to increase by 10–40% at high latitudes and in some wet tropical areas, and decrease by 10–30% over some dry regions at mid-latitudes and in the dry tropics. The areas suitable for rainfed agriculture are expected to significantly decrease affecting adversely the land productivity potential of the continent (*Fischer et al.*, 2002).

4. Climate change impacts

An emerging but growing body of literature indicates that over the past three decades, the changes in the climate system described above—including the anthropogenic component of warming—have caused physical and biological changes in a variety of ecosystems (*Root et al.*, 2005; *Parmesan*, 2006; *IPCC*, 2007a) that are discernable at the global scale. These changes include shifts in genetics (*Bradshaw* and *Holzapfel*, 2006; *Franks et al.*, 2007), species' ranges, phenological patterns, and life cycles (reviewed in *Parmesan*, 2006). Most (85%) of these ecological responses have been in the expected direction (e.g., poleward shifts in species distributions), and it is very unlikely that the observed responses are due to natural variability alone (*IPCC*, 2007a).

Croplands, pastures, and forests that occupy 60 percent of the Earth's surface are progressively being exposed to threats from increased climatic variability and climate change. Abnormal changes in air temperature and rainfall and resulting increases in frequency and intensity of drought and flood events have long-term implications for the viability of these ecosystems (*FAO*, 2007).

IPCC (2007a) detailed many impacts on global and regional agriculture which impacts depend on the specific location and the magnitude of the warming.

- In general, the report states that increases in the frequency of droughts and floods are projected to affect local crop production negatively, especially in subsistence sectors at low latitudes.
- Globally, the potential for food production is projected to increase with increases in local average temperature over a range of 1–3 °C, but above this range, food production is projected to decrease.
- At lower latitudes, especially in the seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1–2 °C), which would increase risk of hunger.
- Crop productivity is projected to increase slightly at mid- to high latitudes for local mean temperature increases of up to 1–3 °C depending on the crop, and then decrease beyond that in some regions.
- With the virtually certain likelihood of warmer and more frequent hot days and nights, there are projected to be increased insect outbreaks impacting agriculture, forestry, and ecosystems.
- Adaptations such as altered cultivars and planting times allow low- and mid- to high-latitude cereal yields to be maintained at or above baseline yields for modest warming.

They are too many region-specific climate change impacts on agricultural production to describe. For example, in many parts of Africa, it seems that warmer climates and changes in precipitation will destabilize the agricultural production. This is expected to undermine the systems that provide food security (*Gregory et al.*, 2005). *IPCC* (2007a) indicates that crop yields could decrease up to 30% in South Asia by the end of the century even if the direct positive physiological effects of CO_2 are taken into account. Several global studies indicate a probability of 10–40% loss in crop production in India with increases in temperature by 2080–2100 (*Rosenzweig et al.*, 1994; *Fischer et al.*, 2002; *Parry et al.*, 2004). From an analysis of climate risks for crops in 12 food-insecure regions conducted to identify adaptation priorities, based on statistical crop models and climate projections for 2030 from 20 general circulation models, *Lobell et al*. (2008) conclude that South Asia and Southern Africa are two regions that, without sufficient adaptation measures, will likely suffer negative impacts on several crops that are important to large food-insecure human populations.

In the Atlantic south, Continental south and Mediterranean zones of Europe, the greatest risks are reduced crop yields and conflicts over reduced water supply (*AEA Energy and Environment*, 2007). But in the Alpine, Boreal, Atlantic, and Continental north agro-climatic zones, a lengthened growing season and an extension of the frost-free period may increase the productivity of some crops and enhance the suitability of these zones for the growth of other crops. However, these changes will only be possible if there is sufficient water available (*AEA Energy and Environment*, 2007). Climate change is affecting many species attributes, ecological interactions, and ecosystem processes. Habitat change is already underway in some areas, leading to species range shifts, changes in plant diversity which includes indigenous foods and plant-based medicines (*McClean et al*., 2005).

5. Climate change and sustainability

Sustainable agricultural systems remain productive over time (*Senanayake*, 1991) and should provide for the needs of current, as well as future generations, while conserving natural resources (*NRC*, 1991). The enhancement of the environmental quality and careful use of the resource base on which agriculture depends is viewed as a requisite to sustained agricultural productivity (*ASA*, 1989).

One important environmental force is climate, which can change over the long term and whose variation (with or without climatic change) has major implications for farming and sustainability. Agriculture's sensitivity to climate is influenced both by the nature of climatic variation and the nature of farming. Disasters are "caused" by the juxtaposition of a vulnerable activity and particular climatic conditions. For example, lack of economic activity and poverty renders African countries, especially the poorest communities in these countries, disproportionately vulnerable to climate change impacts.

The issues of climate change and sustainability have become well known worldwide, following the adoption of the United Nations' Agenda 21 and the United Nations Framework Convention on Climate Change (UNFCCC) at the 1992 Earth Summit in Rio de Janeiro, Brazil. Development, equity, and sustainability are integral elements of sustainable development. Hazards associated with climate change have the potential to undermine progress with sustainable development (*Berke*, 1995; *Wang'ati*, 1996). Therefore, it is important for sustainable development initiatives to explicitly consider hazards and risks associated with climate change (*Apuuli et al*., 2000). The capacity to mitigate and adapt to climate change, and the associated mitigation and adaptation costs, depend critically upon the underlying development path, which in turn would be significantly influenced by sustainable development policies and actions.

Swart et al. (2003) point out that climate change and sustainable development have been addressed in largely separate circles in both research and policy. Nevertheless, there are strong linkages between the two in both realms. They argue that since the feasibility of stabilizing greenhouse gas concentrations is dependent on general socio-economic development paths, climate policy responses should be fully placed in the larger context of technological and socio-economic policy development rather than be viewed as an add-on to those broader policies.

Robinson et al. (2006) argue that manifold linkages exist between climate change and sustainable development, and that the focus has typically been on examining sustainable development through a climate change lens, rather than vice versa. They refer to the work of a panel of business, local government, and academic representatives in British Columbia, Canada, who were appointed to advise the provincial government on climate change policy. The panel found that sustainable development may offer a significantly more fruitful way to pursue climate policy goals than climate policy itself. Hence it is important to understand clearly the concept of sustainable agriculture and how it might help in coping with the projected climate change.

6. Climate change mitigation and adaptation

Climate change adaptation includes both short- and long-term responses to climate change, whereas mitigation refers to methods of reducing greenhouse gas emissions.

6.1. Climate change mitigation

When the topic of climate change is usually discussed, the focus is on the impact of the future climate changes on the agricultural sector. However, there is another aspect of climate change and agriculture, and that is the contribution of GHG emissions from agricultural sources (*Das*, 2004; *Desjardins*, 2004; *Smith et al.*, 2007; *Desjardins et al.*, 2007). According to the IPCC AR4, agriculture accounted for 10–12% (5.1 to 6.1 Gt CO_2-eq/yr) of total global anthropogenic emissions of greenhouse gases GHGs (*Smith et al*., 2007). In separating the contribution from each GHG, agriculture accounted for about 60% of global anthropogenic emissions of N_2O and about 50% of CH_4.

Table 1 shows the percentage of world GHG emissions from agriculture by source in 2000 (*Vergé et al.*, 2007). This analysis for this table focused only on methane and nitrous oxide emissions. *Vergé et al.* (2007) state that carbon dioxide emissions from agriculture are mainly due to changes in land use such as clearing forests for agricultural development. Nitrous oxide emissions from agricultural soils represent the largest source of GHG emissions from agriculture. Nitrous oxide is produced in the soil during the process of converting ammonia to nitrate (nitrification) by soil microbes and by the conversion of nitrate into gaseous nitrogen (denitrification). Methane emissions by enteric fermentation (by-product of livestock digestion) is the second largest, and methane emissions from the fermentation of decomposing organic matter from rice paddies is the third. These three sources account for 86.2% of the GHG emissions from global agriculture. Globally, agricultural CH_4 and N_2O emissions have increased by nearly 17% from 1990 to 2005 (*Smith et al.*, 2007).

Table 1. Percentage of world GHG emissions from agriculture by source in 2000 excluding CO_2 (*Vergé et al.*, 2007)

Source	**World GHG emissions from agriculture (%)**
Agricultural soils (N_2O)	41.4
Enteric fermentation (CH_4)	30.1
Rice (CH_4)	14.7
N fertilizers (N_2O)	7.3
Manure management (CH_4)	3.4
Manure storage (N_2O)	3.1

6.1.1. Mitigation strategies

The IPCC AR4 (*Barker et al.*, 2007) defines mitigation as the technological change and substitution that reduces resource inputs and emissions per unit of output. Although several social, economic and technological policies would produce a reduction in emissions with respect to climate change, the term mitigation is defined as implementing policies to reduce GHG emissions and enhance sinks. The IPCC AR4 Working Group III Chapter on Agriculture (*Smith et al.*, 2007) noted that the most prominent mitigation options of GHG emissions in agriculture are improved crop and grazing land management such as improved agronomic practices, nutrient use, tillage, and residue management, restoration of organic soils that are drained for crop production, and restoration of degraded lands. Other options that offer significant mitigation potential include improved water and rice management; set-asides, land use change such as the conversion of cropland to grassland and agro-forestry; as well as improved livestock and manure management. The AR4 chapter on agricultural mitigation stresses that a practice effective in reducing emissions at one location may be less effective or even counterproductive elsewhere. Therefore, there is no universally applicable list of mitigation practices and that practices need to be evaluated for individual agricultural systems based on climate, soil, social issues, and historical patterns of land use and management.

Most of the mitigation strategies involve reducing nitrous oxide and methane emissions in agriculture. With regards to reducing CO_2 emissions in agriculture, increasing energy efficiencies in the transportation and building sector are important, but soil carbon sequestration is a mitigation strategy in which agriculture can directly plays a significant important role. The IPCC (*Smith et al.*, 2007) stated that soil carbon sequestration can provide an estimated 89% contribution to the total mitigation potential, while mitigation of CH_4 emissions and N_2O emissions from soils only account for 9% and 2%, respectively, of the total.

Desjardins (2004) provided an overview of agricultural practices to reduce GHG which include the following categories: livestock management; animal waste and nutrient management; crop management; soil management; and energy. *Edwards* (2007) notes that organic agricultural practices can reduce GHG emission in agriculture. These practices include the systematic application of manure and compost from animal and crop residues; crop-legume rotations; green manure with legumes; and agroforestry with multipurpose leguminous trees.

The AR4 report noted that the interactions between mitigation and adaptation in the agricultural sector need to be examined but differ in their spatial and geographic characteristics (*Smith et al*., 2007). The report goes on to state that in many regions, non-climate policies related to economics, agriculture, and environment will have a larger impact on agricultural mitigation than climate policies. Also, current GHG emission rates may increase due to future population growth and changing diets. The report concluded that there is significant potential for GHG mitigation in agriculture and that current initiatives suggest that synergies between climate change policies, sustainable development, and improvement of environmental quality will be in the forefront in realizing mitigation potential in agriculture.

6.2. Climate change adaptation

As described earlier, climate change is expected to present new combinations of risks and potentially grave consequences. The secondary changes induced by climate change are expected to undermine the ability of people and ecosystems to cope with extreme climate events and other natural hazards. According to *Thomas* (2008), the world's drylands will face not only increasing temperatures with climate change but more importantly also disruptions to their hydrological cycles resulting in less and more erratic rainfall that will exacerbate the already critical state of water scarcity and conflicts over water allocation. In many regions of Africa, where small farmers depend on natural environment for their livelihoods, the high levels of poverty combined with rather poor infrastructure increases the vulnerability of local communities to climate change. Adaptation is a key factor that will shape the future severity of climate change impacts on food production (*Easterling et al.*, 2007) and is most relevant when it influences decisions that exist irrespectively of climate change, but which have longer-term consequences (*Stainforth et al.*, 2007).

According to *FAO* (2007), the two main types of adaptation are autonomous and planned adaptation. Autonomous adaptation is the reaction of, for example, a farmer to changing precipitation patterns through changing crops or planting dates. Planned adaptation measures, on the other hand, are conscious policy options or response strategies, often multisectoral in nature, aimed at altering the adaptive capacity of the agricultural system, or facilitating specific adaptations. Judicious use of water using supplementary irrigation systems, more efficient irrigation practices, and the adaptation and adoption of existing and new water harvesting technologies have been suggested as appropriate strategies to cope with these problems.

6.2.1. Adaptation strategies

Human adaptation to climate change impacts is increasingly viewed as a necessary complementary strategy to mitigation—reducing greenhouse gas emissions from energy use and land use changes in order to minimize the pace and extent of climate change (*Klein et al.*, 2007). Because adaptive strategies undertaken will have associated effects on carbon dynamics, it is important to consider carbon impacts of any proposed adaptive strategy.

In agriculture, forestry, livestock operations, water resources management, public health, and other fields impacted by climate change, there are typically a multiplicity of adaptation measures that may be taken (*Table 2*). In any given situation or context, though, the choice of adaptation measures may be difficult and constrained by their expense, the lack of knowledge on how to implement them, traditional beliefs, cultural practices, and others. Notwithstanding these impediments, farmers and others at risk from climate change (and including variability and extremes) can be provided with external help in a number of ways: insurance or other forms of financial assistance and risk spreading; drought relief in the form of cash or kind; information and advice; information and guidance; free or cheap seeds or replacement seed for seeds consumed, and so on (*Yohe et al.*, 2007). These are actions than can be taken to reduce exposure, vulnerability, or risk. For example, farmers in regions subject to drought can select the time of planting appropriate to their cropping systems.

For Europe, *AEA Energy and Environment* (2007) identified priority risks at the sector and farm level in the assessment of impacts and evaluated a number of possible adaptation responses (at both sector/policy level and farm level) with respect to the following issues: technical feasibility, potential costs of implementation, cost-effectiveness, ancillary benefits, and cross-sectoral implications (e.g., water, tourism, energy). Adaptation measures were further categorized as technical (e.g., introduction of new cultivars), management (e.g., changes in cropping patterns, soil, landscape, water), or infrastructural (e.g., changes in drainage, irrigation systems, access, buildings).

Table 2. Available adaptation measures

Sectors	**Adaptation measures**
Agricultural cropping	Choice of crop and cultivar: Use of more heat/drought-tolerant crop varieties in areas under water stress; Use of more disease and pest tolerant crop varieties; Use of salt-tolerant varieties; Introduce higher yielding, earlier maturing crop varieties in cold regions. Farm management: Altered application of nutrients/fertilizer; Altered application of insecticide/pesticide; Change planting date to effectively use the prolonged growing season and irrigation; Develop adaptive management strategy at farm level.
Livestock production	Breeding livestock for greater tolerance and productivity; Increase stocks of forages for unfavorable time periods; Improve pasture and grazing management including improved grasslands and pastures; Improve management of stocking rates and rotation of pastures; Increase the quantity of forages used to graze animals; Plant native grassland species; Increase plant coverage per hectare; Provide local specific support in supplementary feed and veterinary service.
Fishery	Breeding fish tolerant to high water temperature; Fisheries management capabilities to cope with impacts of climate change must be developed.
Development of agricultural biotechnologies	Development and distribution of more drought, disease, pest and salt-tolerant crop varieties; Develop improved processing and conservation technologies in livestock production; Improve crossbreeds of high productivity animals.
Improvement of agricultural infrastructure	Improve pasture water supply; Improve irrigation systems and their efficiency; Improve use/store of rain and snow water; Improve information exchange system on new technologies at national as well as regional and international level; Improve sea defense and flood management; Improve access of herders, fishers and farmers to timely weather forecasts.

Source: *Yohe et al.* (2007)

In a synthesis of research on adaptation options in Canadian agriculture, *Smith* and *Skinner* (2002) identified four main categories of adaptation options: (i) technological developments, (ii) government programs and insurance, (iii) farm production practices, and (iv) farm financial management. Most adaptation options were identified as modifications to on-going farm practices and public policy decision making processes with respect to a suite of changing climatic (including variability and extremes) and non-climatic conditions (political, economic, and social).

7. Conclusions

Western governments currently prioritize economic growth and the pursuit of profit above alternative goals of sustainability, health, and equality. Climate change and rising energy costs are challenging this consensus. The realization of the transformation required to meet these challenges has provoked denial and conflict, but could lead to a more positive response which leads to a health dividend; enhanced well-being, less overconsumption, and greater equality (*McCartney et al.*, 2008).

There is a need for better assessment of risks associated with variable and uncertain environmental conditions. This likely would involve documentation of climatic variation (temporal and spatial) so that probabilities of climatic conditions can be better estimated. This is different from mapping "normal" conditions, and it should focus on those climatic variables that are pertinent (for example, moisture during critical time periods) rather than readily available (such as mean annual temperature). This assessment of risks should include consideration of variation in other relevant external forces, including economic and policy conditions.

There is also a need for developing and promoting enterprises and management practices that are adaptive and sustainable in the variable and uncertain environment. Evaluations of existing and potential production systems according to their ability to sustain production and economic returns, as well as the consideration of policy vehicles (i.e., alternatives to the set of policies likely to be withdrawn) that might promote more sustainability, would help address this need.

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