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ECONOMICS OF PGRFA MANAGEMENT FOR ADAPTATION TO CLIMATE CHANGE: A REVIEW OF SELECTED LITERATURE

by

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I. INTRODUCTION

There is a growing consensus in the scientific literature that the earth is warming due to anthropometrically increases in greenhouse gas emissions into the atmosphere. Together with increasing temperatures, climate change is expected to result in increasingly unpredictable and variable rainfall both in amount and timing, changing seasonal patterns and an increasing frequency of extreme weather events. As a result, it is generally recognized that climate change has very significant implications for agriculture. Many developing countries, which have economies largely based on weather-sensitive agricultural productions systems, are particularly vulnerable to climate change (Kurukulasuriya et al., 2007; Seo and Mendelsohn, 2007). But the magnitude of such damage will depend on how efficiently farmers adapt to the new climates (Mendelsohn, 2000). The challenge of adapting agriculture to climate change must be placed within the wider context of needed improvements in the sector to reduce food insecurity and achieve poverty reduction. The world's population is now expected to reach 9.1 billion by 2050. The largest increases are expected to occur amongst rural populations dependent on agriculture for food and income in developing countries. Generating the food and incomes needed to ensure food security for the global population will require significant increases in agricultural productivity and profitability (Bruinsma 2008; Foresight). Thus climate change adaptation requires more than simply maintaining the current level of performance from the agricultural sector, but rather developing a set of responses that allow the sector to improve performance under the changing conditions climate change implies. Because agricultural production remains the main source of income for most rural communities, adaptation of the agricultural sector to the adverse effects of climate change will be imperative to protect and improve the livelihoods of the poor and to ensure food security

Adaptation of agriculture to climate change requires consideration of both short and long term projected impacts. In the short run, up to 2030, climate change is expected to increase the volatility and intensity of weather related shocks such as drought and flooding. In the longer term, slow onset climate change is expected to lead to major shifts in temperature and rainfall regimes. Changes in management of plant genetic resources for food and agriculture (PGRFA) are key adaptation responses to climate change impacts in both the short and long run, however the nature of the change and the stakeholders involved vary. Houghton (2004) identifies three main ways in which climate change will affect the agricultural sector. First, changes in temperature and precipitation lead to changes in soil moisture. Second, temperature has a direct effect on crop yields. Different crops have different optimal growing conditions and high temperatures can damage those already close to their maximum toleration limits under current conditions. Third, experiments have shown that elevated concentrations of carbon dioxide may promote the growth of certain crops. One could argue that changes in the geographical range of pests and diseases caused by climate change might also affect agricultural productivity.

In all cases, adaptation will require farmers to make adjustments and employ a range of actions to enhance the resilience of local food systems that increase their net revenue by reducing the potential damage from climate change. Their capacity to make the required adjustments depends on the existence of policies and investments to support farmers' access to materials and information, as well as to provide the proper economic incentives to stimulate changes.

Management of plant genetic resources for food and agriculture (PGRFA) for adapting to climate change includes strategies such as diversification of crops and varieties, adoption of varieties tolerant to climate change shocks such as drought and flooding or early-maturing varieties adapted to changes in cropping season, as well as alterations in cropping patterns and rotations. Another major form of adaptation is transitioning to more resilient production systems such as conservation agriculture or systems with integrated nutrient and soil management and changes in PGRFA management are required for their successful implementation as well. It is important to note that PGRFA are not just one more option among a list of adaptation tools, but rather are a key catalyst for making other agricultural adaptation tools and strategies work better. Based on a wide range of literature review, this paper argue that an enabling condition for PGRFA management for adaptation is the broadening of the genetic resource base farmers can access to enable them to change crops, varieties and farming systems to meet changing climate conditions.

Assessing the adaptation implications of various farm level PGRFA options as well as analysis of the institutions and policies required to support adoption of strategies that increase farmers' capacity to adapt to climate change. This in turn, requires a better understanding of how farmers' perceive climate change, farmers' responses to climatic variation, ongoing adaptation measures, and the factors influencing the decision to adapt farming practices. Adaptation will require the involvement of multiple stakeholders, including policymakers, extension agents, NGOs, researchers, communities, and farmers. The call for intensified support for adaptation in the developing world has been reinforced by the report from the International Panel on Climate Change (IPCC), which reports evidence of climate impacts in the form of long term and widespread changes in wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones (Solomon et al., 2007).

The rest of the paper is organized as follows. Section 2 discusses the effect of climate change on farm level demand for plant genetic resource including the cost and benefits of plant genetic resource management. Section 3 highlights the different possible options available for climate adaptation while Section 4 focus on three main types of adaptation strategies that have clear implications for PGRFA management, namely changing cropping patterns, changing variety traits and adopting sustainable land management practices. Section 5 discusses factors affecting farmers' adaptation behavior mainly focusing on the role of information and social capital. Finally Section 6 highlights the conclusions and considerations for PGRFA policies.

II. IMPACT OF CLIMATE CHANGE ON CROP YIELD AND FARM INCOME

Climate change affects agriculture and food production in complex ways. It affects food production directly through changes in agro-ecological conditions and indirectly by affecting growth and distribution of incomes, and thus demand for agricultural produce (Schmidhuber and Tubiello, 2007). Changes in temperature and precipitation associated with continued emissions of greenhouse gases is expected to result in long term trend changes, including a rise in the global mean surface temperature from 1.8°C to 4.0°C by 2100 and large (and regionally variable) changes in rainfall which in turn will bring changes in land suitability and crop yields. Current research confirms that while crops would respond positively to elevated CO2 in the absence of climate change (e.g. Kimball et al., 2002; Jablonski et al., 2002; Ainsworth and Long, 2005), the associated impacts of high temperatures, altered patterns of precipitation and possibly increased frequency of extreme events such as drought and floods, will probably combine to depress yields and increase production risks in many world regions, widening the gap between rich and poor countries (e.g. IPCC, 2001).

The fourth Intergovernmental Panel on Climate Change (2007) states that at lower latitude, in tropical dry areas, crop productivity is expected to decrease "for even small local temperature increases (1 – 2° C)." In temperate latitudes, higher temperatures are expected to be mostly beneficial to agriculture. The areas potentially suitable for cropping are expected to expand, the length of the growing period will increase, and crop yields may rise. A moderate incremental warming in some humid and temperate grassland may increase pasture productivity and reduce the need for housing and for compound feed (Schmidhuber and Tubiello, 2007). These gains have to be set against an increased frequency of extreme events, for instance, heat waves and droughts in the Mediterranean region or increased heavy precipitation events and flooding in temperate regions, including the possibility of increased coastal storms (IPCC, 2001, Howden et al., 2007). In drier areas, climate models predict increased evapotranspiration and lower soil moisture levels. As a result, some cultivated areas may become unsuitable for cropping and some tropical grassland may become increasingly arid. In sub-Saharan Africa alone, projections predict a loss of 10-20 million hectares of land suitable for double cropping and a loss of 5-10 million hectares of land suitable for triple copping as a result of climate change (Fischer et al., 2005; Schmidhuber and Tubiello, 2007). At a regional level, under climate change, the biggest losses in suitable cropland are likely to be in Africa, whereas the largest expansion of suitable cropland is in the Russian Federation and Central Asia. Temperature rise will also expand the range of many agricultural pests and increase the ability of pest populations to survive the winter and attack spring crops (Challinor et al., 2007).

The links between climate change and crop yield have largely been explored focusing on the relation between climate variables and the productivity of food crops. Indeed, there is a large and growing body of literature that uses agronomic models, agro-economic models or Ricardian analysis to investigate the magnitude of these impacts (e.g. Kurukulasuriya and Rosenthal, 2003; Seo and Mendelsohn, 2008; Deressa, 2006). Agronomic models attempt to estimate directly, through crop models or statistical methods, the impacts of climate change on crop yields (Gommes et al., 2009). Thus, they rely on experimental findings that indicate changes in yield of staple food crops such as wheat as a consequence of warming (e.g., Amthor, 2001; Fuhrer, 2003; Gregory et al., 1999; Reilly et al., 1994; Rosenzweig and Parry, 1994). Then, the results from the model are used with behavioral models that simulate the impact of different agronomic practices on farm income or welfare. Agro-economic models allocate crops to particular ecological zones according to climatic suitability (Mendelsohn and Dinar, 1999). As the climate changes, land is then reallocated and changes in producer and consumer surplus are calculated. The Ricardian model compares the net returns to land in locations which have already adapted. The great strength of the Ricardian approach is that it deals effectively with the problem of accounting for an almost infinite number of adaptation possibilities. Its weakness lies in the need to control for many variables in addition to climate, and the failure to account for the carbon dioxide fertilization effect (Mendelsohn and Dinar, 1999).

Projections of crop impacts across Africa are diverse, with yield impacts ranging from -98% to +16% depending on crop type, region, and climate scenario. Most predictions suggest the vast majority of farmers will see losses (e.g. Kurukulasuriya and Mendelsohn, 2007; Tingem and Rivington, 2009). According to IPCC (2007) in many African countries access to food will be severely affected, “yields from rain fed agriculture could be reduced by up to 50% by 2020”. Kurukulasuriya and Mendelsohn (2007) found that net revenues fall as precipitation falls or as temperatures warm across all the surveyed African countries. Specifically, the elasticity of net revenue with respect to temperature is -1.3. This elasticity implies that a 10% increase in temperature would lead to a 13% decline in net revenue. The elasticity of net revenue with respect to precipitation is 0.4. In addition to examining all farms together, the study also examined dryland and irrigated farms separately. Dryland farms are especially climate sensitive. The elasticity of net revenue with respect to temperature is -1.6 for dryland farms but 0.5 for irrigated farms. Irrigated farms have a positive immediate response to warming because they are located in relatively cool parts of Africa. The elasticity of net revenue with respect to precipitation is 0.5 for dryland farms but only 0.1 for irrigated farms. Irrigation allows farms to operate in areas with little precipitation, such as Egypt. Seo and Mendelsohn (2008) also showed that increases in temperature encourage farmers to adopt mixed farming. As temperatures increase, farm incomes from crop-only farms or livestock-only farms fall whereas incomes from mixed farms increase. With precipitation increases, farm incomes from irrigated farms fall whereas incomes from rainfed farms increase. With a hot dry climate scenario, the Ricardian model predicts that farm income will fall 50-70 percent. Jones and Thornton (2003) found that aggregate yields of maize in smallholder rain-fed systems in Africa and Latin America are likely to show a decrease of about 10% by 2055, but that these results hide enormous variability and give cause for concern, especially in some areas of subsistence agriculture.

Across all sub-regions, a higher frequency of extreme events will severely challenge the agricultural system, as the historical record from rural Africa suggests that shocks have a greater impact than slower stresses (Bharwani et al., 2005; Schmidhuber and Tubiello, 2007).

Another important change for agriculture is the increase in atmospheric carbon dioxide (CO_2) concentrations. Higher CO2 concentrations may improve yields for some crops, but the magnitude of this effect is less clear, with important differences depending on management type (e.g., irrigation and fertilization regimes) and crop type (Tubiello et al., 2007).

In sum, the state of knowledge and experience to date implies that we need to be thinking of adaptation and PGRFA management to both increase in shocks/extreme events and slow onset changes in temperature/rainfall patterns. These two things have different implications for farmers demand for PGRFA and thus policies and institutions to support needed supply response.

III. ADAPTATION TO CLIMATE CHANGE

According to the IPCC, adaptation means adjustments to current or expected climate variability and changing average climate conditions, which can serve to moderate harm and exploit beneficial opportunities (IPCC, 2007). It involves both disaster risk management focusing on preventing, mitigating and preparing to deal with shocks and adaptive change management that aim to modify behaviors and practices over the medium-to long-term. Most ecological and social systems have in-built adaptation capacity, but the current climate variability and rapid rate of climate change will impose new and potentially overwhelming pressures on existing capacity, i.e. the pressure exceeds the current coping range more frequently and more severely (IPCC, 2007). Adaptation activities can reduce the impacts of climate change and buffer their effects, reducing the negative impacts on humans and the environment. Adaptation is expected to reduce vulnerability and strengthen resilience of local food systems to floods, droughts and extreme weather events through the use of both ex-ante and ex-poste measures.

Adaptation strategies encompass a wide range of activities including:

- Modifying planting times and changing to varieties resistant to heat and drought (Swearingen and Bencherifa, 2000; Mortimore and Adams, 2001; Southworth et al., 2002; Howden et al., 2007; Phiri and Saka, 2008),
- Development and adoption of new cultivars (Rosegrant and Cline, 2003; Eckhardt et al., 2009),
- Changing the farm portfolio of crops and livestock (Mortimore and Adams, 2001; Howden et al., 2007; Morton, 2007),
- Improved soil and water management (Kurukulasuriya and Rosenthal, 2003),
- Integrating the use of climate forecasts into cropping decisions (Bharwani et al., 2005; Challinor et al., 2007; Howden et al., 2007),
- Increased use of fertilizer and irrigation (Eakin, 2005; Howdenet al., 2007),
- Increasing labor or livestock input per hectare (Mortimore and Adams, 2001),
- Increased storage of food/feed or reliance on imports (Swearingen and Bencherifa, 2000; Schmidhuber and Tubiello, 2007),
- Increasing regional farm diversity (Reidsma and Ewert, 2008) and,
- Shifting to non-farm livelihoods (Mortimore and Adams, 2001; Morton, 2007).

Essentially all of these strategies may have some implications for changes in PGRFA management. In the subsequent section, we focus on some of these adaptation strategies and discuss them in detail.

The economic benefits of adaptation can be defined as the discounted sum of the damages avoided by the adaptation measure considered relative to what would have happened in the absence of this measure. The key difference is that adaptation measures usually reduce damage in a single sector, a single region, or a single sector/activity within a specific region (Lecocq et al., 2007). As a result, both the counter-factual against which the benefits of adaptation are estimated and the direct effects of the adaptation measure on damages have to be estimated at the local level. But the existence of impacts, the sign of these impacts, their magnitude, their time horizon, and their frequency are all uncertain at the local level (Lecocq et al., 2007). As the IPCC notes, uncertainties are much larger at the local/sectoral level than at the global level.

It is possible in principle to compare the performance of adaptation measures by evaluating their 'net benefits in terms of avoided damages'. This solution is not practical yet given the current state of knowledge about damages and adaptation measures. The benefits of adaptation activities are often highly uncertain and thus very difficult to estimate reliably ex ante (Lecocq et al., 2007). Evaluating avoided damages relative to normal patterns/baselines ex post is, conceptually at least, relatively easy for single extreme weather events—for example, by comparing areas where adaptation measures were implemented with areas where they were not, or by analyzing historic records of damages associated with comparable climate events. However, ex post evaluation becomes more difficult for gradual changes in climate, especially if these changes do not have historical precedents locally (Lecocq et al., 2007). The absence of a common metric for assessing adaptation implies that resources devoted to adaptation will probably be more difficult to allocate via global market mechanisms than resources devoted to mitigation (Lecocq et al., 2007; Smale et al., 2004).

IV. CHANGES IN PGRFA MANAGEMENT FOR ADAPTATION TO CLIMATE CHANGE

Improving PGRFA management at farm level is a current and pressing policy objective from the standpoints of supporting productivity, decreasing vulnerability and enhancing resilience to climate change and associated stresses (Lipper and Cooper, 2009; Lipper et al., 2009; FAO Climate Smart Ag. 2010). As noted in the section above – there are several strategies for adaptation and PGRFA management comes into most of these directly or indirectly. In this section we focus on three main types of adaptation strategies that have clear implications for PGRFA management: 1) changing cropping patterns, 2) changing variety traits, and 3) adopting sustainable land management practices. These strategies are not mutually exclusive and in fact adaptation may require combining them. Their effectiveness in any particular situation depends not only the specific nature of the impacts climate change is likely to have, but also on the willingness and capacity of farmers to undertake such changes, which in turn is affected by socio-economic conditions, policies and institutions. In this section we sketch out the key features of each of these three main adaptation strategies. In following sections we address in more detail the issues of farmer adoption and enabling policy environments.

4.1 Changing cropping patterns

Crop choice is frequently mentioned in the adaptation literature as a potential adaptation strategy to climate change. Farmers make crop selections based on several criteria, including available inputs such as labor (both hired and household), experience, availability of seed, input and output market prices, government policy and a host of environmental factors such as climatic and soil conditions and available water resources. The increased likelihood of crop failures can jeopardize the livelihood of smallholder farmers that depend on their yearly crop production for food, animal feed and income. The cultivation of a diversified crop selection and the yearly rotation of legumes and grasses can reduce the risk of failure and increase crop yields (Kurukulasuriya and Mendelsohn, 2006). A diversified selection of crops also provides greater opportunity for generating income from the sales of produce at the local market and by providing the farmers' family with a more balanced diet. However diversification entails costs as well, in the form of lost benefits from specialization in crops with the highest potential benefits – e.g. the classic "risk-return" tradeoff (Heal et al., 2004).

Basic agronomics as well as centuries of experience with agriculture indicate that climate is key in determing the crops farmers can feasibly plant and their potential productivity – and thus the distribution of crop choice. Kurukulasuriya and Mendelsohn (2006) have shown that crop selection among farmers varies significantly in cooler, moderately warm, and hot regions. For example, farmers select sorghum and maize-millet in the cooler regions of Africa, maize-beans, maize-groundnut, and maize in moderately warm regions, and cowpea, cowpea-sorghum, and millet-groundnut in hot regions. Further, farmers choose sorghum, and millet-groundnut when conditions are dry, cowpea, cowpea-sorghum, maize-millet, and maize when medium wet, and maize-beans and maize groundnut when wet. As temperatures warm, farmers will shift towards more heat tolerant crops.

Depending upon whether precipitation increases or decreases, farmers will also shift towards drought tolerant or water loving crops, respectively. In a case study covering villages in three South African provinces, Thomas et al. (2007) found that during dry spells farmers tended to reduce their investment in crops or even stop planting and focus instead on livestock management. Because climate change scenarios predict an increase in climate variability in many parts of Africa, farmers probably will turn to this temporary coping strategy more frequently and thus turn it into adaptation.

Seo et al. (2008) tried to quantify differential farm adaptation taken by cropland farmers in Africa in 16 Agro-Ecological Zones. The results indicate the importance of climate as well as a range of other factors in farmers' decision of which crops to grow. These results are then used to forecast how farmers might change their irrigation and crop choice decisions if climate changes. The model predicts African farmers would adopt irrigation more often under a very hot and dry climate scenario but less often with a mild and wet scenario. Area under fruits and vegetables would increase Africa-wide with the very hot and dry climate scenario, except in the lowland semi-arid agro-ecological zone. Millet would increase overall under the mild and wet scenario, but decline substantially in the lowland dry savannah and lowland semi-arid agro-ecological zones. Maize would be chosen less often across all the agro-ecological zones under both climate scenarios. Wheat would decrease across Africa. The authors recommend that care must be taken to match adaptations to local conditions because the optimal adaptation would depend on the agro-ecological zone and the climate scenario.

In a study of rural farmers in the Shire Valley, southern Malawi, Phiri and Saka (2008) found that, at farm level, two broad adaptation options were being implemented for both the crop and livestock sectors: changes in land use, and changes in crop management strategies. As a means of adapting to the long term effects of drought, communities have institutionalized certain practices. Such mechanisms include changes in land use along the river banks, adoption of drought-tolerant crops or crop varieties and use of irrigation. Furthermore, there has been a steady shift over the years to crop types or varieties that have higher thermal requirements or short season crops that are also tolerant to droughts or are specifically adapted to harsh climatic conditions and therefore responsive to changed environmental and climatic conditions. In another attempt to adapt to the dry conditions in the valley, a number of irrigation systems have been introduced to take advantage of the Shire River.

4.2 Changing variety traits

Changing crop varieties to ones more adapted to changing climate conditions is another major adaptation strategy farmers may opt for, particularly where key crops have an established market demand and channels or where there are strong consumption preferences for a specific crop (e.g. maize over sorghum/millet in many sub-Saharan African contexts).

Several studies have examined the potential impacts of changes in variety traits under climate change. In a modeling study for Modena, Italy (Adam et al., 2003), simple and feasible changes in farming system management altered significant negative impacts on sorghum (-48% to -58%) to neutral to marginally positive ones (0 to-12%). In that case, the changes included altering varieties and planting times to avoid drought and heat stress during the hotter and drier summer months predicted under climate change. When summarized across many adaptation studies, there is a tendency for most of the benefits of adapting the existing systems to be gained under moderate warming (-2°C) then to level off with increasing temperature changes (Howden and Crimp, 2005). Additionally, the yield benefits tend to be greater under scenarios of increased than decreased rainfall.

Howden et al. (2007) have conducted synthesis of climate change impact simulations for the recent Intergovernmental Panel on Climate Change review, spanning the major cereal crops wheat, rice, and maize, and representing a wide range of agroclimatic zones and management options. This synthesis indicates that benefits of variety based adaptation vary with crop (wheat vs. rice vs. maize) and with temperature and rainfall changes. For wheat, the potential benefits of management adaptations are similar in temperate and tropical systems (17.9% vs. 18.6%). The benefits for rice and maize are smaller than for wheat, with a 10% yield benefit when compared with yields when no adaptation is used. These improvements to yield translate to damage avoidance of up to 1–2°C in temperate regions and up to 1.5–3°C in tropical regions, potentially delaying negative impacts by up to several decades, providing valuable time for mitigation efforts to work (Howden et al., 2007; Lobell, D., 2009).

As can be seen from the literature summarized above, much of the current understanding of the potential effectiveness of PGRFA management for adaptation is based on simulation model results. However, simulation models have not yet adequately represent potential impacts of change in pest and disease effects or air pollution, and there remains uncertainty as to the effectiveness of the representations of CO2 responses (Tubiello et al., 2007). Additionally, many of these studies changed neither the variability of the climate nor the frequency of climate extremes, both of which can significantly affect yield (Tubiello et al., 2007). There is also often the assumption that capacity to implement adaptation is in place, whereas this may not be the case, particularly in regions where subsistence agriculture is predominantly practiced (Morton, 2007).

Collectively, these factors could reduce the beneficial effects, such as those associated with elevated CO2, and increase the negative effects, such as those from increased temperatures and rainfall reductions. This would reduce the amount of time that adaptation would delay significant negative impacts, i.e., adaptation would ‘‘buy less time’’ than is indicated above. On the other hand, the adaptation actions assessed were only a small subset of those feasible, usually focusing on marginal change in practices to maintain the existing system such as changing varieties, planting times, and use of conservation tillage. Inclusion of a broader range of adaptation actions, including more significant and systemic change in resource allocations, would presumably increase the benefits, particularly if they include alternative land use and livelihood options. For instance, the Ricardian studies that implicitly incorporate such adaptation routinely find impacts of climate change that are lower than those assessed using crop models. The balance between these opposing tendencies is currently unclear; more comprehensive analyses to identify the limits of adaptation are warranted.

Another key issue in the consideration of changing variety traits is the availability and accessibility of adapted varieties. The literature suggests that both improved and traditional varieties will have an important role to play here, but there are important gaps to address in both (SOWPGR 2010pp 116-117). Maintenance of high levels of inter- and intra-species diversity is a strategy to decrease vulnerability and enhance resilience to climate change and associated stresses. Adaptation in this context could include the maintenance and reintroduction of traditional varieties, the adoption of new species and varieties to meet newly developed production niches, and the development of ways of ensuring that materials remain available and accessible (e.g. community seed banks) and adapted (e.g. participatory plant breeding).

Improved crop varieties have considerable potential for strengthening the adaptive capacity of farmers in developing countries. A prominent example of the development of improved drought-resistant varieties is the Hybridization Project of the Africa Rice Centre (WARDA), which begun in 1992. Scientists combined the useful traits of two rice species and developed interspecific lines with desirable traits tailored to African conditions, naming them New Rice for Africa (NERICA). NERICA constitutes a wide range of varieties with different characteristics. Many are high yielding, early maturing, weed competitive, and tolerant of Africa’s major pests, drought, and iron toxicity (Rodenburg et al., 2006). During the past few years, Melinda and Bill Gate foundation have been funding breeding program (e.g. Stress-Tolerant Rice for Africa and South-East Asia (STRASA)) specifically for adaptation to climate change through CGIAR centers.

Indigenous and local crops and varieties, particularly drought-, salt- and flood-tolerant, fast-maturing and early- or late sowing crops and varieties, are also increasingly cultivated as a result of climate change. Reports from drought-prone regions of Zimbabwe, India, Nicaragua, Kenya, Vietnam, the Philippines, Mali, the Timor Islands and other countries show an increasing importance of drought-tolerant crop varieties of millet, sorghum and rice (Platform for agrobiodiversity research, 2010). In the areas experiencing an increased level of flooding and salinization of freshwater and agricultural land; salt- and flood-tolerant crops and varieties have been introduced. In India, community seed banks with a focus on rice have been established to strengthen the community seed supply of flood-resistant varieties in Bihar and Bengal and saline-resistant varieties in Orissa (Navdanya, 2009). In India, in areas where crops had failed due to heavy rainfall during the pod formation stage, farmers have switched to short-duration varieties and adjusted sowing depth and date (Platform for agrobiodiversity research, 2010). In Cambodia, there is a shift in the planting date of rice; rice seedlings are planted in November instead of in September (Mitin, 2009). In Ghana, farmers are planting early maturing crops and sowing the seeds earlier than in previous years (Mapfumo et al., 2008).

4.3 Sustainable land management practices

The promotion of sustainable land management (SLM) practices has been suggested as another key adaptation strategy for countries in the developing world, particularly in sub-Saharan Africa to mitigate growing water shortages, worsening soil conditions, and drought and desertification (FAO 2010b Climate Smart Agriculture; FAO 2009 Options for capturing synergies; Branca et al., 2011; McCarthy et al., 2011; Kurukulasuriya and Rosenthal, 2003). Typical SLM technologies used in most developing countries have been outlined in McCarthy et al. (2011) and include the use of soil bunds, stone bunds, grass strips, waterways, trees planted at the edge of farm fields, contours, and irrigation (chiefly water harvesting) (Kato et al., 2009). Both soil and stone bunds are structures built to control runoff, thus increasing soil moisture and reducing soil erosion. Considering it is costly to protect wide areas of land with soil and stone bunds and difficult to construct continuous bunds, alternative methods of erosion control are being employed as well, including grass strips and contour leveling, sometimes with trees or hedgerows (Kato et al., 2009). Grass strips reduce runoff velocity, allowing for water to infiltrate and trap sediments. Waterways help to direct precipitation flows along specified pathways in farm fields. Water-harvesting structures include dams, ponds, and diversions to ensure water availability during the dry season (Kato et al., 2009).

Although in many cases SWC technologies generate net positive benefits over an extended time frame, they often involve significant costs in the short run – which can extend up to 10 years (McCarthy et al., 2011; FAO 2010b). In addition these practices can be too risky for very low-income, risk-averse households, which are typical in rural areas of many developing countries (Dercon, 2004; Yesuf and Bluffstone, 2007). Thus, in the adoption of technologies, farmers consider not only impacts on crop yields but also risk effects (Shively, 2001; Shiferaw and Holden, 1999; Kassie et al., 2008; Graff-Zivin and Lipper, 2008). SWC techniques are used in many areas to adapt to the drier, degraded conditions brought on in part by changes in climate. According to household survey data by Kato et al. (2009), more than 30% of farmers in Ethiopia took up SWC measures in response to changes in climate related factors e.g. perceived changes in temperature and rainfall over the last 20 years. Their findings suggest that farmers are using SWC technologies as one of the adaptation options to cope with climate change, which is also one of the climate change micro-level adaptation investments recommended by the Center for Environmental Economics and Policy in Africa (2006) for Ethiopia.

Conservation agriculture comprised of reducing or eliminating tillage, use of crop rotations and use of crop residues for mulching and soil cover is another type of SLM practice that has implications for PGRFA management. The practice requires introduction of rotation crops, generally legumes. A forthcoming review of key barriers to adoption to conservation agriculture, and more generally sustainable land management techniques, identifies seed supply constraints as a major issue (McCarthy et al., 2011). Conservation agriculture can also require the development of new crop varieties, such as the case of cassava in Zambia.

Thomas et al. (2007) found that farmers are increasingly trying to exploit the spatial diversity of their landscape. By comparing cases in the Roslagen area of Sweden and the Mbulu Highlands of Tanzania, Tengö and Belfrage (2004) uncovered similarities in practices aimed at dealing with temporary drought at field level. For example, farmers in Sweden and Tanzania both use cover crops to enhance seedling survival. On the other hand, controlling erosion by using contour planting, mulching, and the construction of cutoff drains and sluices was popular only in the Mbulu highlands, where the fields are on a slope (Tengö and Belfrage, 2004).

V. FACTORS AFFECTING FARMERS' ADAPTATION BEHAVIOR

The need to make changes in farming decisions in response to changing circumstances, is not new to farmers, and there is a considerable body of literature analyzing the factors that affect farmers' adoption of new technologies and practices. These same factors are also likely to be relevant in affecting farmers' adaptation behavior, although the temporal and spatial scale of changes expected under climate change are different. In this section we review the literature on factors that affect farmers' adaptation behavior within the overall context of factors that affect technology adoption on farms. We then focus on two key factors that are well known to affect farmers' adoption behavior that are also likely to increase in importance under climate change: access to information and collective action.

A set of studies making use of household datasets to empirically examine the factors influencing farm-level adaptation to climate change provides important insights into adaptation behavior. These studies of farm-level adaptation confirm that farmers respond not only to climate stimuli but a number of other factors as well (Smit et al., 1996; Brklacich et al., 1997; Bryant et al., 2000; Bradshaw et al., 2004; Belliveau et al., 2006; Maddison, 2007; Nhemachena and Hassan, 2007). Therefore, farm-level changes that might be expected given a certain climate signal may not actually occur due to other intervening factors, such as human capital (e.g. level of education, age, ethnicity, gender), economic conditions (e.g. relative prices, input and output market development, credit availability etc.), and the policy environment (Bradshaw et al., 2004). This latter factor includes plant breeding and sector management to produce an adequate availability of seeds of a diverse range of crops and varieties, as well as more general technology development and dissemination, as well as property rights regimes.

Supporting the notion that personal characteristics and economic conditions influence adaptation, several studies find that farming experience, socioeconomic position, and access to resources, credit, and extension services increase the probability of uptake of adaptation measures to climate change (Maddison, 2007; Nhemachena and Hassan, 2007). Furthermore, the nature of farmers' response to climate change and variability also depends on the socioeconomic position of the household— poor farmers are likely to take measures to ensure their survival while wealthier farmers make decisions to maximize profits (Ziervogel et al., 2006).

These results are consistent with the results from the broader literature on factors affecting farmers' adoption of new practices and technologies (see for example Feder et al., 1995; Morse and McNamera, 2003; Gilleret et al., 2009; McCarthy et al., 2011), however climate change poses new challenges due to the speed and magnitude of projected changes. This in turn has implications for the nature of the supporting institutions required to support adoption.

In order to adapt to climate change, farmers must first perceive that changes are taking place. Farmers' choice of crop, variety and farming practices are based on a set of expectations about weather, markets and other factors. These expectations are based upon their own experience, as well as information they may obtain from a range of sources – including family, neighbors, extension services, rural radio etc. A number of studies focus on farmers' perception, use of information, and other factors influencing the decision-making process to adapt to climate change at the farm level (Granjon, 1999; Roncoli et al., 2002; Hansen et al., 2004; Vogel and O'Brien, 2006; Ziervogel et al., 2005). The literature suggests that farmers' perceptions of climate change and their behavioral responses may be more related to recent climate events or trends as opposed to long-term changes in average conditions (Thomas et al., 2007; Smit et al., 1997; Granjon, 1999 in Bryant et al., 2000). Thomas et al. (2007) village and household level analyses in South Africa demonstrate that the trends and variability's in precipitation parameters were clearly recognized by people living in the areas in which they occurred. A range of specific coping and adaptation strategies are employed by farmers to respond to climate shifts, some generic across regions and some facilitated by specific local factors.

Moreover, many studies stress the importance of local knowledge in decision making regarding climate risk (Roncoli et al., 2001, 2002; Vogel and O'Brien, 2006; Thomas et al., 2007). That is, farmers base their decision to adapt their farming practices not only on changes in average conditions, but on a number of other climate factors observed through personal experience such as extreme events; rainfall frequency, timing, and intensity; and early or late frosts (Smithers and Smit, 1997;

Roncoli et al., 2002; Vogel and O'Brien, 2006; Thomas et al., 2007). Using data from farm survey of South Africa and Ethiopia, Brayan et al. (2009) have shown that a large share of farmers in both countries perceive an increase in temperatures over time, accompanied by a decrease in rainfall. Brayan et al. (2009) found that farmer's perceptions of climate changes appear to be in line with actual climate data.

Smit et al. (1996) find that some farmers in southwestern Ontario adopted short-term managerial adjustments or more strategic adaptation in response to having experienced recent dry years, while most farmers reported no purposeful response. The propensity to respond was related to farmers' perceptions of dry-year frequencies, indicating that the strength of the climate signal influences adaptation.

Two important considerations emerge from this literature in terms of PGRFA management for adaptation climate change. First, climate change presents circumstances that are new to all of us (both at the local level and at the global level), and hence new and innovative mixes of time-tested local knowledge and new techniques and technologies will be necessary to overcome it. Secondly, disseminating new information through local channels is likely to be very important to promote adaptation behavior.

5.1 Improved information

Based on the abundant evidence that seasonal climate variability plays an important role on the risks faced by producers, it is natural to conclude that improving the access to reliable climate forecast information is key to facilitating adaptation in the form of crop, variety and farming system choices adopted by farmers. Climate projections are often based on a variety of scenarios, models and simulations which contain a number of embedded assumptions. Central to much of the discussion surrounding adaptation to climate change is the claim – explicit or implicit – that decision-makers (including both farmers and policy-makers) need accurate, timely and increasingly precise, assessments of the future impacts of climate change in order to adapt successfully. According to Füssel (2007), 'the effectiveness of pro-active adaptation to climate change often depends on the accuracy of regional climate and impact projections, which are subject to substantial uncertainty'. Similarly, Gagnon-Lebrun and Agrawala (2006) note that the level of certainty associated with climate change and impact projections is often key to determining the extent to which such information can be used to formulate appropriate adaptation responses. If true, these claims place a high premium on accurate and precise climate predictions at a range of geographical and temporal scales.

The potential for producers to benefit from seasonal forecasts depends on factors that include the flexibility and willingness to adapt farming operations to the forecast, the timing and accuracy of the forecast, and the effectiveness of the communication process. A common perception is that advances in seasonal climate prediction alone will be enough for societal benefits to accrue. However, simply documenting the effects of climate variability and providing better climate forecasts to potential users are not sufficient (Jones et al., 2000). Meinke and Stone (2005) discussed the importance of differentiating between the quality of a forecast and its value or impact. Climate information only has value when there is a potential response and a clearly defined benefit, once the content of the information is applied. It is important to recognize that its effective application means making a decision that takes a probabilistic forecast into account.

Examining the role of forecast climate information in decision-making, Hansen et al. (2004) suggest that information derived from personal experience and information from external description yield different choice results under conditions of climate risk and uncertainty - decisions based on personal experience are likely to give greater weight to recent events. Ziervogel et al. (2005) find that the use of accurate climate forecasts can improve household well-being while poor forecast information can actually be harmful to poor farmers. Overestimating the accuracy of a forecast system can lead to excessive responses that are inconsistent with decision makers' risk tolerance, and can damage the credibility of the forecast provider (Hansen et al., 2004). These results suggest that linking farmers to new sources of information on climate change will be important, but "translating" the risks and potential margin of error that exist in a way that farmers can understand and use in making decisions is equally important.

The ability to respond to climate forecasts and the benefits obtained from their use are determined by a number of factors including the policy and institutional environment and the socio-economic position of the household (Ziervogel et al., 2005; Vogel and O'Brien, 2006). Given the potential for rural climate information to support adaptation and manage climate risk, there is a need to make climate information more accurate, accessible, and useful for farmers (Roncoli et al., 2002; Ziervogel et al., 2005; Hansen et al., 2007). Promoting the use of climate information for adaptation among the poorest farmers also requires resources needed to implement adaptation options (Vogel and O'Brien, 2006). Looking for ways of disseminating this information through local information sharing channels is likely to be important, given the findings reported above on the primary role of such sources in decision-making.

5.2 Role of social capital in PGRFA management for climate adaptation

Social capital and the ability to undertake successful collective action has long been identified as an important factor affecting PGRFA management decisions by farmers. The social networks farmers interact within and their effectiveness has been found to be an important determinant of crop and variety selection on farm (Eyzaguirre and Dennis, 2007; Rene et al., 2007). Social capital enhances access to both information as well as genetic resources in the form of seed exchange, which in turn affects PGRFA management on farm. How climate change may affect the role and the form of social capital to facilitate effective adaptation behavior by farmers is thus an important question.

Both research and practice have shown that institutions to facilitate collective action are important to enhance technology transfer in agriculture and natural resource management among smallholders and resource-dependent communities. Many studies underscore the importance of formal and informal institutions and social relationships in facilitating or hindering adaptation to climate change (Agarwal, 2008; Agarwal and Perrin, 2008; Isham, 2002; Eakin, 2005). These studies also highlight the potential for rural institutions to strengthen adaptive capacity and facilitate local level adaptation to climate change (Adger, 2000; Agarwal, 2008; Agarwal and Perrin, 2008).

PGRFA requires collective action for effective management because it has both public and private good characteristics. While the individual farmer obtains a private good from cultivating a particular plant variety, the maintenance of genetic diversity resulting from his private decision produces a non-rival public good of maintaining that variety. The decision can affect future generations by conserving possibly-useful genetic traits and supporting healthier ecosystems (Smale et al., 2002). This unique combination of public-private good characteristics gives rise to inefficiencies in the provision of crop genetic diversity, and also difficulties in designing adequate institutions to manage them.

For example, maintaining diversity of crops and varieties at a local level to maintain pest and disease resistance can be characterized as a local public good – any one person's benefit from reduced vulnerability does not reduce the possibility of others benefiting, and it is difficult to exclude people from these benefits even if they do not participate in generating them. In situ conservation generates a global public good in the form of conserved evolutionary processes. Collective action at local and global scale is thus required to generate these types of public goods.

However collective action and social capital have also been found to be important for farmers to realize the private benefits of PGRFA management as well. An increasing body of literature finds that participation in social networks is strongly associated with access to markets and is a key determinant of PGRFA management on farm. Social capital is associated with access to information about the availability and characteristics of PGRFA and thus choice of crop and varieties farmers make (Lipper et al., 2006)

One way that communities have operationalized the collective management of plant genetic resources is by developing institutions that explicitly and implicitly manage the resource. Institutions to explicitly manage PGR are often user groups or other specific organizations as NGOs or religious organizations, seed savers groups, and indigenous communities that have asserted or have been assigned rights over biologically diverse landscapes (Eyzaguirre and Dennis, 2007; Rene et al., 2007).

A good example of collective management of plant genetic resources for adaptation is community seed banks, that increase the stock and information available of landrace seed and simultaneously provide farmers simplified access to local seeds (Worede et al., 2000). More common are institutions that implicitly conserve plant genetic resources by promoting their propagation and the exchange of plant varieties. The use of biodiversity is often tied to the social and cultural traditions of communities that directly affect criteria for selecting and conserving local seed varieties (Eyzaguirre and Dennis, 2007). Collective management of PGR through traditional gender and social relations that maintain the movement of plant genetic resources within a community is one such example (Howard and Nabanoga, 2006). Traditional norms determining which social groups make decisions about particular species helps farming communities to maintain local knowledge associated with particular crops. In rural communities, information-sharing groups are often segregated along gender lines, and knowledge about species associated with traditional gender-specific activities is accumulated accordingly. For instance in Vietnam, male household heads exercise decision-making authority over economically valuable crops such as upland vegetables, citrus species, mango, and coffee. Women are more likely to make decisions over tubers and roots, medicinal plants, and lower value crops (Hodel and Gessler, 1999; Eyzaguirre and Dennis, 2007). Similarly, Amazonian peasants exchange planting stock along kinship lines and knowledge about crop varieties are passed along matrilineal kinship lines (Boster, 1986; Coomes, 2004; Eyzaguirre and Dennis, 2007). Traditional property rights defining gender-crop roles are important to the institutionalization of knowledge within rural communities. Cultural norms contribute to the maintenance of plant genetic diversity by rewarding patterns of seed movement that collectively maintain the resource and make it available to others (Eyzaguirre and Dennis, 2007).

The ability of traditional local institutions and collective action to facilitate access to PGRFA under rapidly changing socio-economic as well as climatic conditions is a key issue, given the high reliance of developing country farmers on the informal seed sector for their seed supply (Lipper et al., 2009). Lipper et al. (2009) explore the role of local market institutions in facilitating farmers' access to CGRFA through sales of uncertified seeds, where grain or product is sold for seed. Several studies indicate that local agricultural markets are an increasingly important source of seed in the informal seed sector, particularly in times of crisis or stress (Sperling et al., 2008; Lipper et al., 2009). The PGRFA exchanged through local markets includes both landrace and improved germplasm, with farmers and traders selling "recycled" seeds of improved varieties, as well as traditional varieties, quite often in a mix of the two (Lipper et al., 2009). In some cases, PGRFA exchanged in local markets was mostly local materials (Lipper et al., 2006) although in others, traders in local markets provided an important link to external sources of PGRFA, essentially increasing the range of PGRFA available to farmers (Lipper et al., 2010).

VI. CONCLUSIONS AND CONSIDERATIONS FOR POLICY

6.1 Conclusions

- Climate change is projected to change production conditions for agricultural producers globally. In the developing world, most of the projected changes will result in a reduction of agricultural productivity, with concomitant reductions in food security.
- Responding to a changing climate will require changes in PGRFA management to address both immediate and slow onset changes.
- There are a range of adaptation options involving changes in PGRFA management, including changing crops, varieties and farming practices. These options are not mutually exclusive, and in fact are most often used on combinations (e.g. changing farming practices also involves changes in crops and varieties).

- Several studies indicate that changes in PGRFA management can be a very effective means of adapting to climate change and significantly reduce the projected costs although effects vary by crop and the level of changes in temperature and rainfall experienced.
- The literature indicates that both improved and traditional, landrace crop varieties will have an important role to play in adaptation. Greater emphasis has been placed on the role of improved varieties and formal sector breeding programs for adaptation so far, but greater attention to identifying the potential role of landraces and the measures required to realize their potential contribution to adaptation is needed.
- Factors affecting adaptation behavior are generally the same as those which affect adoption behavior in general, including human capital, natural capital, financial capital and social capital, which in turn are affected by well as socio-economic and policy conditions. However climate change alters the nature of responses needed to strengthen these various forms of capital for adaptation. Two key areas highlighted in this paper are improvements to human capital and social capital.
- Enhancing human capital by improving information flows to farmers on climate change related factors is essential to facilitate adaptation. Relying solely on local and traditional sources of information is not likely to be adequate, due to the speed and magnitude of changes projected. However using local channels to disseminate new sources of information is key to enhancing effective use in decision-making. In addition, translating risk and uncertainty associated with new sources of information into a form understandable and usable by farmers is important.
- Social capital and collective action play a major role in facilitating farmers' access to PGRFA and their capacity to make changes necessary for adaptation. As with the case of human capital, traditional forms of social capital need to be enhanced to facilitate adaptation to climate change. Building on existing networks, but extending their reach by linking to external formal and informal institutions related to PGRFA development and exchange will be needed.

6.2 Considerations for PGRFA policy

This review has indicated that an enabling condition for PGRFA management for adaptation is the broadening of the genetic resource base farmers can access to enable them to change crops, varieties and farming systems to meet changing climate conditions. This requires both the development of new varieties of existing crops, as well as wider dissemination networks for existing crops and varieties. Both formal and informal seed sector institutions and mechanisms are currently set up to address existing spatial and temporal climate conditions - not ones that climate change is likely to bring. The question is what does climate change imply about how these need to change? Specifically:

- Do the projected changes in spatial distribution of rainfall and temperatures imply a need to rethink the scale at which plant breeding activities are conducted? In places where long term projected changes are likely to result in major shifts in cropping patterns to what extent can NARs provide an adequate response? Should the emphasis be on shifting the program of individual NARs – or shifting to a different scale breeding programs to better capture economies of scale?
- We know relatively little about the potential role of landraces and traditional varieties for adaptation, and how this would affect the institutions and policies to support adaptation, including the management of ex situ and in situ conservation as well as plant breeding efforts. What measures can be taken to get a better understanding as well as a plan of action for effective management of landraces for adaptation?
- Climate change will bring greater variability in the short run and thus greater risks to production. PGRFA management has a key role to play in managing these risks, both in terms of producing new varieties that are more resilient and in supporting the diversification of crops and varieties. What are the short term responses available to enhance these processes?

How do they relate to the changes required for dealing with slow onset changes – are they the same or is there a need to build a transition process?

- Most farmers in developing countries currently access their seeds in the informal seed sector which is based on local materials and knowledge, but also combines improved materials that are saved and reused on farm, as well as recycled through exchanges, mostly at local scale. The informal seed system will continue to be an important source of seed for the foreseeable future, but will it be capable of providing new crops and varieties needed to meet climate change? What are the possibilities of using the informal system to provide new information and planting materials and what measures need to be taken to achieve this?
- Does climate change imply a need to change or enhance the role and capacity of existing international mechanisms to support exchange and use of PGRFA? This includes international institutions such as the International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA) and the Global Crop Diversity Trust, as well as CGIAR centers. Should one assume the portfolios will shift when farms diversify at the regional level, and therefore need new PGRFA or is it possible that the increase in regional farm diversity would mean, rather, consolidation of land area under individual ownership, and subsequent specialization in a particular product?

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