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Impacts of Climate Change on Smallholder Farmers in Africa and their Adaptation Strategies

What are the roles for research?

by
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International Symposium and Consultation
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Pan-Africa Bean Research Alliance
PABRA

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Contents

1. Introduction

Prior to the rise of climate change to prominence on the global agenda, tensions between smallholder livelihoods, national food security, poverty and environmental integrity in Africa were already substantial. Social and political instability have compounded these tensions in many places, as have structural adjustment programs and globalization of markets. The complex interactions of these multiple stressors have often stretched systems beyond their coping capacities. Enter climate change. Regional climate models[2] project that on average the whole of Africa is likely to, on average, warm between 3° C and 4° C (roughly 1.5 times the global mean) in the next 70 years (Christensen, Hewitson et al. 2007). The drier subtropical regions are expected to experience greater temperature increase than the moister tropics (Christensen, Hewitson et al. 2007). Rather than eclipsing earlier development challenges, climate change will instead act as a shifting backdrop for those already moving targets. Sustainable agriculture research, prevalent in recent decades, must now be conducted in the context of ecological baselines that are being altered by new climate patterns.

The large and highly vulnerable portion of Africans who are already eking out marginal livelihoods from arid and semi-arid lands are of particular concern. According to the World Water Forum (2000), one-third of African people already live in drought prone areas and are vulnerable to the impacts of drought. By the 2080's, it has been estimated that there will be an increase of 5-8% in the proportion of arid and semi-arid lands in Africa (Boko, Niang et al. 2007). This, in turn, means that the African population projected to be exposed to increased water stress by 2020 will be between 75 to 250 million people and this will increase to between 350 and 600 million people by 2050's (Boko, Niang et al. 2007). According to Working Group II of the IPCC's Fourth Assessment Report (Boko, Niang et al. 2007), changes in ecosystems are already being detected and agricultural production yields in some countries are projected to drop by as much as 50% by the year 2020, with revenues falling by as much as 90% by 2100. This forecast, based on a model that does not anticipate substantial changes in agricultural practices, clearly lays out just one of the pressing adaptation challenges for African agriculture in the coming decades. However, by not acknowledging the potential for changes in agricultural practice, such models ignore the presence of farmers as adaptive and creative agents in coping with dynamic environments. In response to this lacuna, this paper seeks to explore farmers' on-going adaptation practices as well as their adaptive capacities in response to future climate change. In so doing, it aims to take a step toward seriously engaging with farmers as actors and partners in climate change adaptation, rather than as victims or as recipients of exogenously developed solutions.

This paper is organized into five sections. Following the introduction, Section 2 briefly discusses details of current and forecast climate variability in Africa, as well as an overview of how climate changes are anticipated to affect agriculture. Information in Section 2 is sub-divided into Eastern and Central Africa, Southern Africa, and West Africa. Section 3 explores key existing adaptation strategies employed by farmers in Africa in response to climate variability and uncertainty that they cope with. Section 4 examines the future of climate change adaptation, both in formal programmes and informal efforts. Finally, Section 5 discusses the findings in terms of implications for scientific research on adaptation as well as opportunities for synergistic partnerships.

2. Climate variability and climate change in African agriculture

In order to understand the context in which farmers' adaptation strategies and scientific research should be applied, it is useful to look at current climate variability as well as future projections and anticipated impacts. This is covered in each of the PABRA regions below.

2. Based on MMD-A1B scenario projections for years 1980 to 1999 and the years 2080 to 2099 as outlined in the Working Group I in the IPCC's Fourth Assessment Report (Christensen, Hewitson et al. 2007)

2.1 Eastern and Central Africa[3]

Eastern and Central Africa have diverse climates ranging from desert to forest, where rainfall seasonality is highly complex and varied over relatively short distances. In the region, large water bodies (Lake Victoria, Lake Tanganyika and the Indian Ocean) and varied topography (Mount Kilimanjaro, Mount Kenya) influences climatic conditions from humid tropical along the coast to arid in the low lying inland elevated plateau regions (in Tanzania, Kenya, Somalia, Ethiopia and Djibouti) (KNMI 2007). Much of the region has a bimodal seasonal pattern that has two rainy periods, namely short rains in October to December and long rains in March to May. Rainfall is correlated to topography where areas of high elevation receiving over 1139 mm per annum while the lower plateau regions, making up over two thirds of the region, receive less than 500mm (Jones and Thornton 2000; Osbahr and Viner 2006). Much of the interannual rainfall variability stems from the short rains (WWF 2006).

The mean temperatures vary with geographical elevation. According to recent studies in Kenya and Tanzania, an acceleration in the increase of daily minimum temperatures is suggested (Christy, Norris et al. 2009). However, there is large variation in temperature variability patterns across the region, but it is noted that a significant feature is the recurrence of extreme values in the patterns.

An intensification in Eastern Africa's dipole rainfall pattern has been observed over recent decades, where the average rainfall has increased in the northeastern sector (Ethiopia, Somalia, Kenya and northern Uganda) with opposite conditions over the southwestern sector (Tanzania, southern parts of the Democratic Republic of the Congo and southwestern Uganda) (Schrek and Semazzi 2004; Solomon, Qin et al. 2007).

In recent years, Eastern Africa has been known to be prone to climate variability and extreme climate events (such as drought and floods). Anomalous strong rainfall events seems to have increased (Shongwe, Van Oldenborgh et al. 2008). According to the Human Development Report (2007), the region has experienced drought in 1984, 1992, 1995, 2000, 2005/2006, putting climate sensitive sectors such as agriculture, livestock, water resources and health at high risk (ICPAC 2010). Overall, the frequency and severity of droughts are projected to increase. It has been established by various studies (as cited in (Solomon, Qin et al. 2007)) that climate variability in Eastern Africa is influenced by El Niño (ENSO), however there has been much speculation whether a relationship exists with prolonged drought or significant wet periods (Thornton, Jones et al. 2006; Anyah and Semazzi 2007).

According to regional climate projections, the increase in the annual mean rainfall and the number of extremely wet seasons (defined as high rainfall events occurring once every 10 years) during both the September to December rain season and the March to May rain season is projected to continue (Christensen, Hewitson et al. 2007; KNMI 2007; Shongwe, Van Oldenborgh et al. 2008).

In summary, the following projections are based on the IPCC's climate scenarios (Christensen, Hewitson et al. 2007):

- Eastern African climate is likely to become wetter, particularly in the Short Rains (October to December) and particularly in northern Kenya, in the forthcoming decades.
- Eastern Africa will almost certainly become warmer than present in all seasons in the forthcoming decades.
- Changes in rainfall seasonality over forthcoming decades are unlikely.

3. Eastern and Central Africa Bean Research Network (ECABREN) includes member countries of Burundi, , Democratic Republic of Congo (DRC-the eastern part), Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania (the northern part) and Uganda.

- Droughts are likely to continue (notwithstanding the generally wetter conditions), particularly in northern Kenya, in the forthcoming decades. In many model simulations, the drought events every 7 years or so become more extreme than present.
- The wetting component evident in observed Kenyan rainfall may well be a forerunner of a longer term climate change.

These projections will potentially have major impacts across all economic and social sectors in the region. The net effect on many parts of the region presents higher probabilities of seasonal crop failure due to the unpredictability of annual rainfall cycles (Thornton, Jones et al. 2006). Resulting impacts of climate change include: health status, water availability, energy use, biodiversity and ecosystem services. These are likely to have a strong distributional pattern, i.e. amplifying existing inequities (e.g. in health status and access to resources), as vulnerability is exacerbated by existing developmental challenges, and especially because many groups (e.g. smallholders) already have low adaptive capacity.

2.2 Southern Africa[4]

Southern Africa is considered to be particularly vulnerable to climate change, primarily because of its high level of dependence on natural resources (especially water), as well as rain-fed agriculture and subsistence based farming, all of which underpin livelihood and economic development strategies in the region. This vulnerability is further exacerbated by a complex mix of other socio-economic and socio-political stressors, interacting with climate variability and change across the region.

Southern Africa, being a semi-arid tropical region, is vulnerable to climate stress, particularly drought (Leichenko and O'Brien 2002). This effectively means that about 50% of the sub-humid and semi-arid parts of the region have a moderate to high risk of desertification (Reich, Numbem et al. 2001; Biggs, Bohensky et al. 2004). Drought prone-areas (Namibia, Botswana, Zimbabwe) are more vulnerable to climate change than more humid areas (Tanzania, Zambia). Water availability thus plays a key role in many activities in the region.

Agriculture plays a dominant role in 75% of the regions' population, where the majority of the farmers rely on traditional agricultural methods. In this region, inter and intra-annual rainfall variability is a key determinant of agricultural productivity. In the wet season, normal rainfall ranges from 50mm to over 1,000mm. However, variability has been observed since the end of the 1960s. In different parts of southern Africa (e.g. Angola, Namibia, Mozambique, Malawi, Zambia), a significant increase in the number of heavy rainfall events have been observed (Usman and Reason 2004), including changes in seasonality and extreme weather events (Tadross, Jack et al. 2005; New, Hewitson et al. 2006) . This makes the Southern African region prone to both droughts and floods (as seen in Mozambique in recent years).

Temperature increases of between 0.1 and 0.3°C have been observed in South Africa (Kruger and Shongwe 2004), while it has also been noted that since 1950, the wider region has seen an increase of between 0.5°C and 1°C. It was noted in the IPCC's AR4 (Boko, Niang et al. 2007) that between 1961 and 2000, there was an increase in the number of warm spells and a decrease in the number of extremely cold days in the region. The influence of El Niño (ENSO) on regional weather patterns have been identified, specifically linked to severe droughts (i.e. prolonged and frequent) in the recent decades (Fauchereau, Trzaska et al. 2003; Collier, Conway et al. 2008).

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4. SABRN includes member countries of: Angola, DRC (southern part) Lesotho, Malawi, Mauritius, Mozambique, South Africa, Swaziland, Tanzania (the center and south), Zambia and Zimbabwe.

According to regional climate projections for Southern Africa, climate variability may increase with extremes becoming more frequent (Tadross, Jack et al. 2005; Hewitson and Crane 2006). With a global mean temperature increase of 1.5°C (or higher) expected by 2050, this could translate into a general increase in desertification, which will see grasslands shrinking and thorn savannah and dry forests expanding. It is suggested that crop yields may drop by as much as 20% in some parts. As noted in the IPCC Working Group I report, rainfall is likely to decrease in the winter rainfall areas on the western margins of the southern African region (Solomon, Qin et al. 2007).

The increase in climate variability means that the range of weather conditions experienced annually will be larger, exposing the region to a less predictable and more variable rainfall season. Such changes will bring about impacts on weather-related events and environmental conditions, including changes in temperature thresholds such as frost, heat waves, chill units, potential evaporation, transpiration and floods, droughts and fires. Soil and water resources will be severely impacted, with soil moisture decreasing or increasing depending on run-off, resulting in changes to water quality, for example.

2.3 West Africa[5]

West Africa comprises two major geographical areas, namely the Sahelian countries and the Gulf of Guinea countries. Severe endemic poverty is characteristically rural with primary livelihood dependence on agricultural production and pastoralism. Seventy four percent of the region's poor are involved in agricultural production, but this is in a process of change where migration to urban areas and other off-farm activities are increasingly combined with rural livelihoods (IFAD 2001). Agriculture in the arid and semi-arid regions is particularly sensitive to environmental variability, particularly rainfall variability, which affects crop productivity and the dependent farming livelihoods.

The Niger River Basin, a particularly large and important watershed area in West Africa, covers various eco-geographical zones, from floodplains to swampland to arid areas and extensive desert zones. It is distinguished by five different climates, which essentially representative of West Africa, namely, (i) Sahara desert (arid desert climate with an average annual rainfall of less than 150mm), (ii)Sahel (arid climate with steppe vegetation with an annual rainfall of 150-400mm), (iii)Sudan (semi arid Sudano-Sahelian with annual rainfall of 400-600mm and (iv) sub-humid Sudanian with annual rainfall of 600-900mm) and (v) Wet tropics (equatorial monsoon with annual rainfall ranging from 900-over 1500mm) ((Kottek, Grieser et al. 2006; Niasse 2007) as cited in (Gantois 2009)). The steppe and desert climates have annual mean temperatures above 18°C and the mean annual rainfall (averaged across the basin) is 690mm per year. The West African Sahel – a transition zone between the Sahara desert in the north and the savannah regions in the south – experiences recurring and extreme droughts. Only 8% of this land area is suitable for farming, and irrigated agriculture occupies about 5% of this land (Siebert and al 2005; Lotsch 2006). Average rainfall in this region decreases steeply from south (1000mm per year) to north (150mm per year) gradient. There is a short single wet season lasting 3 to 4 months between May and September.

According to the IPCC AR4 Working Group I (2007), West Africa has experienced marked decadal rainfall variability. In the 1950s and 1960s it was wet, while subsequent decades (1970s, 1980s and 1990s) it experienced significantly reduced rainfall events with devastating droughts. This long term decline in rainfall resulted in a 25-35km southward shift of the Sahelian, Sudanese and Guinean ecological zones (Gonzalez 2001). The decreasing rainfall has also resulted in southward pastoralist migration into sedentary farmer lands. In the tropical rainforest areas, it has been noted that there is a mean annual precipitation decline of 4% in West Africa from 1960 to 1998 (Malhi and Wright 2004) while a 10% increase has been

5. WECABREN includes member countries of Central African Republic, Cameroon, Togo, Congo Brazzaville, Burkina Faso, Guinea-Conakry, Senegal, Sierra Leone, Mali and Ghana.

noted along the Guinean coast during the last 30 years (Nicholson and Selato 2000). The 17[6] West African countries share 25 transboundary rivers. Combined with the decline in annual rainfall, this creates a high water interdependency in the region (Niasse 2007). The IWMI (2000) predicts that by 2025 there will be 'economic water scarcity'[7] in most of West Africa[8].

Climate change scenarios indicate that current climate variability will increase and intensify, where both droughts and floods will increase in frequency and scope and declining trends in rainfall and average flows are expected to continue (Niasse 2007). The region is thus highly vulnerable to environmental variability that is compounded by environmental and resource degradation and hazards, scarcity and biophysical changes, although among countries, social groups and households.

According to regional climate projections for West Africa, temperature increases of between 3° C to 4° C for the period 2080 to 2099 can be expected (compared to 1980 – 1999 period) (Christensen, Hewitson et al. 2007). However, the IPCC notes that regarding future rainfall projections in the Sahel, the Guinean Coast and the southern Sahara there is no agreement among climate models (some project drying while others project wetting) and thus difficult to project (Christensen, Hewitson et al. 2007). However, there is enough reason to believe that climate conditions for agriculture in the region will deteriorate, resulting in food scarcity and increasing vulnerability.

3. Current coping and adaptation strategies in African agriculture

3.1 Key concepts and issues

In order to discuss the various socio-ecological processes which constitute adaptation to climate change, Figure 1 briefly defines the key concepts used to describe the activities, strategies and interventions related to adaptation to climate variability and change. The concepts in Figure 1 already allude to the embeddedness of climate change adaptation in social and technical processes more broadly. Due to this complexity, it is sometimes difficult to discern what emerging forms of behaviour and organization are specifically adaptations to climate change. This is not just an abstract or theoretical question, because it speaks to the ways that climate change adaptation will be conceptualized and practiced by policy-makers, researchers and development practitioners, as well as by agrarian communities themselves.

First of all, many parts of Africa have long been known for high interannual variability, as well as broad swings in mid-range cycles (in the order of decades or centuries). Anthropogenic climate change, as visualized in models, generally predicts gradually shifting averages around which interannual variability fluctuates. From a climatological point of view, long-term climate change and interannual climate variability are fundamentally different things. However, from a farmer's point of view, they are practically indistinguishable, except perhaps in retrospect. A successful agrarian livelihood is based on managing environmental variability on a continuous temporal scale that ranges from daily to seasonal to interannual. Consequently, the immediate environmental conditions are more important than the grand arc of data into which they fit.

Put another way, from the perspective of those pursuing agrarian livelihoods, adapting to future climate conditions is of secondary importance relative to adaptive response to the current state of climate variability, the one which will impact this year's harvest. This is an essential, and often overlooked, point

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6. Benin, Burkina Faso, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo.
7. Economic Water Scarcity, according to the IWMI, means "countries will have to increase water supplies through additional storage, conveyance and regulation systems by 25% or more over 1995 levels to meet their 2025 needs".
8. Togo and Sierra Leone were not included in the study.

Adaptation can be defined as the adjustment in ecological, social or economic systems in response to observed or anticipated changes in climate stimuli and their effects and impacts in order to alleviate negative impacts of change or take advantage of new opportunities (Adger, Arnell et al. 2005)).
Maladaptation happens when interventions to cope and adapt to climate conditions are no longer viable or are even more harmful than beneficial.
Adaptive Capacity can be understood to be the ability or capability of human social systems (across households, communities, farming systems, and governments) to effectively adjust to changing circumstances. This can be represented both in coping with negative effects as well as taking advantage of new opportunities. Adaptive capacity integrates technical and institutional processes with biophysical circumstances. As such, it is necessarily negotiated through complex social interactions, and is context specific (Gallopín 2006).
Vulnerability is the degree to which an ecological, social or economic system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (Adger 2006; Janssen and Ostrom 2006)
Sensitivity is the degree to which a system will respond to a given change in climate; it is a measure, for example, in some agro-ecosystems a 200mm decrease in annual average rainfall would have a modest effect on output, in other systems, it would be devastating. In this way, sensitivity is closely tied to the idea of threshold effects (Adger 2006; Gallopín 2006; Smit and Wandel 2006).
Resilience the ability of a system to absorb and recover from the effects of shocks (i.e. multi-stressors presented by climate variability and change) in a timely and efficient manner, preserving or restoring its essential basic structures, functions and identity (Folke 2006; Janssen and Ostrom 2006). Note that resilience is not always good, as even dysfunctional or maladaptive systems can have resilient qualities.

Figure 1: Key concepts in climate change adaptation

in research using modelling approaches to forecast the future challenges of agriculture, and designing potential adaptive strategies. Any efforts to model adaptive agricultural practices for conditions anticipated in 2050 must not neglect the fact that farmers and agrarian communities must make a living through every year and every condition encountered between now and then. Consequently, farmers' processes of adaptation to interannual variability are important aspects of adapting to long-term climate change (Cooper, Dimes et al. 2008).

The importance of focusing on farmers' empirically observable processes of adaption cannot be overstated. If research and policy seek to support a viable agrarian sector, they must put the existent agrarian sector, with all its diversity and dynamics, at the centre of adaptation, including on-going processes of farmers' innovation and creative responses to climate variability and uncertainty. Putting farmer practice at the centre of adaptation interventions increases the likelihood that research and policy act in a fashion that is complementary to and synergistic with an agrarian sector that is empirically real, rather than one that is theoretically modelled and simplified. The distinction here is essential not only in benefitting from farmers' ingenuity, but also in research and policy, contributing to responses that are both technically and socially effective in the real circumstances of farmers' livelihoods.

A second key issue is that climate change is not occurring in a vacuum. Consequently, any adaptations to climate variability/change must also prove adaptive within on-going economic, political, technological and environmental dynamics, many of which are not driven by climate (Crane, Roncoli et al. 2010). Some technical behaviours, such as planting drought resistant varieties, can be clearly linked to climate variability. However, broader social behaviours, such as shifting labour migration patterns in response to (partially climate-induced) livelihood uncertainty, may be more indirectly linked. Analytically speaking, this often makes it difficult to isolate behaviours and practices as explicit climate adaptations. Moreover, trying to isolate the "climate-ness" of an adaptation is not advisable, because it reifies the false divide between adaptation to climate and adaptation to other variables.

> "Putting farmer practice at the centre of adaptation interventions increases the likelihood that research and policy act in a fashion that is complementary to and synergistic with an agrarian sector that is empirically real, rather than one that is theoretically modelled and simplified."

Following on previous points, a third issue must be considered: where are the boundaries between climate change adaptation and sustainability? Can they be distinguished as forms or modes of development? Climate change adaptation is debatably in the process of eclipsing sustainability as a research and development paradigm. However, what precisely is the difference? Both share a large central core of topics and objectives. The key concept in sustainability is that the socio-ecological systems should be resilient through time and in the face of environmental variability. Climate change adaptation has the same objective while simply adding a shifting climatological backdrop for the arena of action as another encompassing variable. In effect, virtually all previous and on-going research on sustainable agricultural systems could be characterized as aspects of climate change adaptation. This broad, inclusive view of adaptation may be debated in some circles which construe adaptation more narrowly, but if the concept and practice of climate change adaptation is to be grounded in farmers' livelihood practices, it must be matched by a broad notion of the process.

3.2 What is being adapted to?

In general, the climate variables discussed in Section 2 and summarized in Figure 2, result in biophysical impacts on farming systems, such as the quality and quantity of crops, forage, forests, livestock, changes in the quantity and quality of land, soil and water resources (crop suitability), increased weed and pest challenges and shifts in spatial and temporal distribution of impacts. Biophysical effects subsequently result in socio-economic impacts on farming systems, such as reduced livelihoods, reduced food security, declines in marginal GDP from agriculture, changes in geographical distribution of trade regimes, fluctuations in world market prices, all of which results in increased number of people at risk of hunger and food insecurity as well as migration and civil unrest (FAO 2007). The effects of climate change are extremely far reaching, and so the adaptations to these far-reaching effects must likewise be highly varied. However, in the interest of focus, for the purpose of this paper we limit the exploration of current coping and adaptation strategies to those that respond to the climatic factors and the biophysical impact on agricultural farming systems identified here.

Temperature: increased heat and cold stress, with impacts such as increased evapo-transpiration; decreased soil moisture, soil erosion, land degradation, thus affecting soil fertility, soil organisms and soil productivity, weed and pest problems, etc.
Precipitation: unpredictability of/erratic rainfall patterns with impacts such as, water stress (water scarcity (shortage) and abundance (e.g. water logging; landslides), drought/aridity and land degradation, weeds and pests dynamics; etc..
Seasonality: date of onset of rains, length of growing seasons with impacts on weed and pest dynamics, ecosystem shifts and species shifts (especially crop relocation) and possible extinctions (e.g. fynbos and succulent Karoo biomes in Southern Africa), etc.
Extreme climatic events: prolonged droughts, damaging storms and heavy floods, will occur with greater frequency and severity.
Synergistic effects of multiple variables: interaction between climatic factors and non-climatic factors. For example, the IPCC (2007) outlines the impacts on Mt. Kilimanjaro's glaciers and snow cover, which have lost as much as 80% of glacier surface area between 1912 and 2003, as a result of a number of interacting factors (e.g., solar radiation, vegetation changes and human behavior). The loss of cloud forests through fire since 1976 has resulted in a 25% annual reduction of water sources derived from fog (equivalent to the annual drinking water supply of 1 million people living around Mt. Kilimanjaro).

Figure 2: Major variables in agricultural adaptations to climate change

3.3 Coping and adaptation strategies – Overview and key examples

Agricultural practice not only depends on the appropriate biophysical and climatic stimuli for success, but also on other non-climatic variables – e.g. market forces, government policy, availability of labour, land or property rights, availability of credit or insurance, access to appropriate technology, management capacities, and population density to name but a few. These non-climatic variables may either compound or diminish the impacts of climate-related stress. Due to the climate sensitive nature of small-scale agriculture in Africa, agricultural communities are particularly vulnerable due to their sensitivity to any changes in these non-climatic stimuli. Thus sustainable agricultural management must account for both climatic and non-climatic factors. As climate change does not occur in a vacuum, any strategy that aims to manage climate stress cannot be isolated from strategies that also aim to manage risks presented by other socio-political, environmental or economical contexts. Thus, in developing adaptation strategies, one can look more broadly to existing research on sustainable agricultural systems and farmer practice in managing these multiple risks, as a basis for building the adaptive capacity of small-scale farmers to cope with *future* climate stress.

Most agricultural research has focused on one or more scales (plant, plot, field, farm, sector, region, nation and global) and on various aspects of farmer practice (decision-making, risk management,

> "As climate change does not occur in a vacuum, any strategy that aims to manage climate stress cannot be isolated from strategies that also aim to manage risks presented by other socio-political, environmental or economical contexts."

technology choice, resource management, etc.) (Smit and Skinner 2002). In a review of existing literature on farmers' practices in relation to risk management in Africa, a number of successful efforts involving various techniques used to cope with various environmental stimuli, including the protection and rehabilitation of water and land resources, have been documented. However, expanding the search to include emerging adaptation measures reveal that it is difficult to distinguish between cases of strategies broadly oriented toward coping with/adapting to multiple stressors (environmental and non-climatic) and those that are specifically responding to climate variability and change. Thus documented cases of successful adaptation strategies directly linked to climate change, especially at a local community or farming level, are still somewhat limited, although with increasing political recognition and associated availability of adaptation finance, this is expected to become more prominent in future literature. Emerging types of adaptation practices are discussed in more detail in Section 4.

Currently, adaptation measures cover a diverse range of approaches, usually in conjunction with one another. They aim to:

- reduce the immediate threat of environmental and climate hazards (e.g. rainwater harvesting, soil and water conservation)
- sustain and improve productivity of the land (e.g. crop and rangelands conservation and management)
- increase skills (e.g. literacy and numeracy training, extension services),
- promote empowerment and participation in decision-making activities (e.g. a range of capacity building activities – on skills, rights, ensuring an enabling policy environment, etc.)
- improve the financial conditions of local communities (e.g. crop insurance, revolving credit funds, marketing assistance)

Together, or in combination, these coping strategies can contribute to increasing communities' resilience to multiple stressors, including climate variability. Other strategies include seeking off-farm income and activities (livelihood diversification), migrating to urban areas, changing farming type and using new technologies. All of these strategies are driven by resource availability, policy changes, technology, human resource capacity and capability, and are implemented at various scales.

The very nature of coping and by implication, adaptation, is multi-dimensional. However, this multi-dimensionality presents quite a challenge in attempts to categorize adaptation strategies and thus any artificial separation into categories and levels should not detract from the integrative nature necessary for effective coping with and adaptation to climate variability and climate change. For the purpose of this background paper, however, a sample of documented agricultural adaptation strategies and technologies that address the immediate threat of environmental hazards and that sustain and improve agricultural productivity have been selected. Key or compelling examples have provided a relevant basis that will address the anticipated / future climate hazards, namely, temperature changes, precipitation changes, seasonality changes and increases in extreme events (droughts and floods). These adaptation strategies and technologies directly address the biophysical impacts of environmental hazards and involve the farmer and their farming communities.

3.3.1 Water management and climate change adaptation

Small-scale dryland agriculture in Africa is predominantly rain-fed and thus the management of continued availability and access to water (including both quality and quantity) for food security becomes crucial in maintaining and enhancing current agricultural practices under ever increasing unpredictable climate conditions. In general, long range climate forecasts call for more extreme events: longer dry spells, heavier rainfall, longer droughts and more flooding. Consequently, techniques for evening out the effects of erratic water availability will be important adaptive responses to the increasing uncertainty and variability of rainfalls. Some common techniques used in rainwater harvesting include the construction of tie and mound ridges to resist runoff, shaping fields into a series of shallow pans to assist ponding, hillside terracing, rock catchments, earth pans, sand damming, shallow wells and boreholes, underground water tanks and surface and stubble mulching as a combined approach to organic matter recycling and runoff control (Broekhuijsen 2009; UNFCCC 2010; IWMI nd).

Key Example: Sand Dams, Kitui District, Kenya

In the semi-arid Kitui district in Kenya, up to 80% of received precipitation is lost as surface run-off. The Sahelian Solutions Foundation has supported seasonal water capture in sand dams for increased water retention in the catchment areas. The dams are based on a simple, inexpensive technology where an above ground dam is constructed using sand, in a river. During rainy periods, the sand is infiltrated with water where evaporation is reduced. Sand dams are constructed in layers or sequence to allow sand to be deposited and to avoid the damaging effects of an individual unit. They can be constructed (and maintained) with locally-available materials by the local community. The dams can vary in size depending on valley dimensions and peak flows, and can be between 2 to 4 meters in height and about 20 meters in length[9]. The positive impacts include ecological regeneration as well as providing a source of water during dry periods (Nzomo Munyao, Muinde Munywoki et al. 2004; Ertsen and Hut 2009). It should be emphasized, however, that the creation of infrastructural works such as micro-dams automatically raises questions about the ownership and management of such resources, as well as the downstream effects, as well as political and ecological issues in up-scaling (Ertsen and Hut 2009).

Key Example: Traditional flood diversion systems and spate irrigation – Ethiopia, Mali, Mauritania, Niger, Nigeria

Ironically, for as much attention as drought receives, when the climate swings to the other extreme, water abundance and flooding become another substantial hazard that farmers need to cope with. Floodwater diversion and spreading (i.e. spate irrigation) involves diversion of water into canals through channels into fields and earth dams (for water retention), for use in crop production and livestock watering. Making use of water when it is abundant leads to increase in crop yields as well as improved soils (IWMI nd).

3.3.2 Sustaining and improving productivity of the land

Land degradation results in the loss of long term productivity and ecosystem function, namely soil erosion, decline in soil carbon, poor water infiltration and subsequent decline in soil moisture and weed and pest infestation and invasion. This makes degraded land much more susceptible to the impacts (increased temperature and more severe droughts) of climate variability and change. Under conditions of both drought and floods, changes in land management practices are necessary to prevent land degradation and ensure agricultural productivity and food security. The most common coping strategies triggered by environmental stress include the use of different crops or varieties, use of drought-tolerant crops, and the planting of trees/agro-forestry. Soil conservation is also key: through the restoration of degraded lands via re-vegetation and establishing live barriers/fences for crop protection] ; application of nutrient amendments [manures, bio-solids, compost];use of reduced or zero-tillage practices, changing of planting dates, use of improved crop/fallow rotations, use of legumes in crop rotations, employ of alternative cultivation methods and plot diversification, and practice of improved post-harvest management through the incorporation of crop residues, and small-scale irrigation (UNFCCC 2010).

Key Example: Zaï Technique - Burkina Faso

Recurrent drought and frequent harvest failures in the northern part of Burkina Faso's Central Plateau were the drivers for promoting the use of a locally driven farmer innovation: the zaï ('hole' or 'basin')

9. www.sanddam.org/node/74

technique. It involves planting crops or trees in shallow pits dug (during the off/dry-season) into degraded soils (20-30cm in diameter and 10-15/20cm deep) enriched with manure (or crop residues), to attract termites which improve soil porosity and water retention capacity, on gentle slopes prone to heavy runoff (IFPRI nd; IWMI nd). When rainfall begins, pearl millet or sorghum seeds are planted in the pits. This is not only a simple, though laborious, technique for capturing rainwater that would otherwise be lost, but is also a way of bringing marginal or degraded lands back into production in a sustainable manner. The zaï technique has proven to be an effective tool for environmental stabilization (i.e. water and nutrient management) in the Sahel, where it has helped to establish trees, even under conditions of poor rainfall (Sawadogo, Hien et al. 2001). Most of these methods are not widely practiced or there exists variations in different communities (e.g. Nigeria, Morocco, and Sudan).

Key Example: Green Manuring and Maize - Benin, Kenya, Malawi, Nigeria, Tanzania and Zimbabwe
Green manures are cover crops (i.e. legumes: e.g. *Vetch, Canavalia, Mucuna, Tithonia, Crotalaria*; and non-legumes: e.g. ryegrass, buckwheat, oats) grown primarily to add nutrients and organic matter to the soil (AHI brief 2004; IWMI nd). It is grown for a specific period, for example, planted in the season before maize, and then plowed under and incorporated into the soil. This also reduces *Striga* infestation and improves soil moisture holding capacity (IWMI nd).

Key Example: Improved Fallows - Western Kenya (also Benin, Nigeria, Tanzania and Zambia)
Western Kenyan rainfall and soils are generally good but suffer from low soil nutrients. To overcome this, a pilot project designed to facilitate improved fallows had significantly positive impacts on increased crop production and soil fertility. In the short term, improved fallows, leguminous shrubs and trees (e.g. *Sesbania sesban, Sesbania macrantha, Cajanus cajan and Tephrosia vogeli*) are planted from 6 to 12 months (1-3 seasons) on a plot, after which land is cleared, with the incorporation of biomass from the trees and shrubs, and then replanted with crops from 2-3 seasons (IFPRI nd; IWMI nd).

Key Example: No-till farming - Benin, Cameroon, Ghana, Kenya, Tanzania, Zambia
In the no-till system, crops are planted in untilled soil in which narrow slots or trenches of appropriate diameter are managed for proper seed coverage and fertiliser placement. Plant residues from previous crops and/or cover crops remain on the surface of the soil before and after seeding. This process requires less labour while maintaining or increasing yield, restoring soil fertility, increasing water retention capacity of soil, and controlling water runoff and soil erosion (IWMI nd).

Key Example: Conservation Farming - Zambia
Conservation farming employs a dry-season minimum tillage system (which only displaces about 15% of soil in the planting zone), which uses fixed planting stations to build up soil organic matter, has leguminous crop rotations and crop residue retention and minimum chemical fertilizer usage. This technique leads to better water infiltration and retention in the soil, increased efficiency in fertilizer use, and increased organic matter. In Zambia, this technique has led to improved yields and incomes. (Haggblade and Tembo 2003; IFPRI nd).

3.3.3 Biodiversity management

Agrobiodiversity has long been an important tool in farmers' efforts to adapt to climate variability and environmental change. Anticipated changes in African climates will undoubtedly present challenges for breeders and farmers in the application of biodiversity in adaptation efforts (Kotschi 2007; Jump, Marchant et al. 2009). Varieties that have been adaptive under recent conditions may become unsuitable in future scenarios. More extremely, in some areas entire cropping systems may become increasingly untenable, requiring shifts not just in varieties, but in the species grown (Burke, Lobell et al. 2009).

Key Example: Crop systems change - Zimbabwe

While maize was heavily promoted and adopted in the 1980's and 90's, recent drying trends are starting to see a return of small grains. Millet and sorghum, which had been the traditional staples in southern Africa prior to the rise of maize, are seeing a comeback. Not only are they more drought tolerant than maize, but they also are hardier in storage, keeping long without needing chemical treatment. Millet and sorghum are not without their problems, however. They require more labour in processing and don't fetch as high a price in markets. Furthermore, they are susceptible to predation from birds, which is an increasingly acute issue as more and more children who used to be responsible for scaring away birds, are going to school.

Key Example: Change in varieties - Kenya and Southern Africa

The diversification of production systems by promoting drought tolerant crops is a central approach to adaptation in Kenya (CSTI 2007). Interventions like the New Seed Initiative for Maize, a multi-national project in Southern Africa that provides poor farmers with drought-resistant seed, in is gaining popularity as potential adaptation solutions (McGray, Hammill et al. 2007).

Key example: Seed fairs in Kenya

Severe droughts wreak havoc on farmers' seed systems. As extreme events are anticipated to increase under climate change, developing recovery mechanisms in the seed system represents important adaptation measures in relation to severe and prolonged droughts. Following the droughts of 1998-2000, community seed fairs were organized by the local people with the support of NGO's. These seed fairs promoted farmer-to-farmer exchange of many species of seeds. By bypassing the formal commercial sector and top-down aid distribution processes, the seed fair approach was able to reach poorer farmers with more agrobiodiversity and more quickly. It also contributed to developing local economies and informal networks, which also promote resilience (Orindi and Ochieng 2005).

3.3.4 Social transformations

While technical responses to climate stresses at the level of plants and fields and households represent obvious adaptation measures, the transformation of social structures and social practices is sometimes more difficult to directly link to climate change. However, in as much as climate change leads to greater uncertainty and livelihood insecurity, such transformations are inevitable. Temporary migration is a classic example of a social adaptation to climate variability. For non-sedentary herders, migration away from drought and toward better rains and pastures has been a core adaptive strategy for a long time (Galvin 2009). Among agricultural communities, crop failures and subsequent food shortages have triggered the migration of people (usually young adults) rural areas to urban areas in search of alternative means of subsistence, at least until circumstances improve (Findley 1994; Barrett, Reardon et al. 2001). This temporary pattern can be expected to become more permanent, as the long-term climate change further destabilizes rural livelihoods (Barrios, Bertinelli et al. 2006).

Key example: Migration

In rural Ghana, farmers have taken a multi-pronged approach to climate change adaptation. While on-farm technical adaptations have been a top priority, farmers have also diversified their livelihood strategies to include more off-farm activities, including increasing reliance on longer term migration. Remittances from household members working in cities and abroad act as a stabilizing force against the interannual fluctuations of farming incomes and enable the continuation of agriculture-based livelihoods (Dietz, Millar et al. 2004).

3.4 Summary of adaptation

Climate change adaptation is not a process that is discrete from other processes of livelihood changes. Climate is simply another dynamic variable in the complex web of variables within which farmers make a living. While the changing climate baselines undoubtedly create new challenges, adapting to these baselines is not detached from other livelihood needs. While there are agronomic techniques which are adaptive to climate stresses, adaptation to climate change is not simply a technical issue, nor one which operates uniquely at the farm level. But, when looking to the future of climate change adaptation, both in policy, in research and in practice, it is important to understand precisely how technical components of the system interact with broader social processes. Just as adaptation is a social process, adaptive capacity is a social variable which is both informed and affected by many factors outside of climate or technical practice. As such, putting farmers' practices and processes of adaptation and innovation the centre of adaptation science, is a logical step. Accepting this approach means calling for multi-scalar and interdisciplinary empirical research which are capable of integrating and addressing social, technical and ecological considerations. Interventions which grow out of this approach have the best chance to be both socially and technically effective.

4. Beyond coping: The future of adaptation

4.1 Limitation of current coping strategies

Africa's high dependence on marginal lands, sensitive rain-fed agriculture and strained natural resources for economic development create a challenging future in the face of climate change. In addition, existing conditions of poor access to information and knowledge, inefficient institutions, limited empowerment, limited economic resources and infrastructure all put increasing pressure on the existing agricultural coping mechanisms and strategies. This in turn limits the effectiveness and sustainability of strategies, as well as the productivity of the agro-economic system. As most of these strategies are effectively meant to cope with short terms changes in climate, the question remains as to what strategies can be used to enable future adaptation to climate change over the longer term. The need to strengthen effective coping strategies and move beyond others is therefore more urgent, because the impacts of increased and unpredictable climate variability are already being observed and felt.

4.2 The nature of adaptation

The UNFCCC's Nairobi Work Programme on impacts, vulnerability and adaptation to climate change outlines nine work areas to increase the ability of countries to adapt. This is illustrative of the integrative nature and multi-disciplinarity requirements of appropriate and effective adaptation strategies. Adaptation is thus essentially an interaction of various actors and processes that aims to build resilient systems. Building resilience into agro-economic systems requires various types of interventions (e.g. technical, socio-political, economic, legal, etc.) to be identified, designed and implemented at various levels (e.g. field, livelihood, farm system, policy, infrastructure, etc.). Thus considering the political/policy, legal, institutional and economic aspects of African societies, as they actually exist and function, is crucial for the success of adaptation. If actual contexts and processes are not taken into account, adaptation options that are developed and implemented by exogenous actors will fail. While the documentation and analyses of these aspects are beyond the scope of this paper, these contextual and systemic considerations do apply to agricultural research for development and climate change adaptation.

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10. Nairobi Work Programme: 1. Methods and Tools, 2. Data and Observations, 3. Climate modeling, scenarios and downscaling, 4. Climate related risks and extreme events, 5. Socio-economic information, 6. Adaptation planning and practices, 7. Research, 8. Technologies for adaptation, 9. Economic diversification.

Strategy	Number of Cases
Changing Natural Resource Management Practices Emphasizes new or different natural resource management practices	57
Building Institutions Creates new or strengthens existing institutions (e.g. establishing committees, identifying mechanisms for sharing information across institutional boundaries, training staff responsible for policy development).	43
Launching Planning Processes Sets in motion a specific process for adaptation planning (e.g. developing a disaster preparedness plan, convening stakeholders around vulnerability assessment findings).	35
Raising Awareness Raises stakeholder awareness of climate change, specific climate impacts, adaptation strategies, or the environment in general.	33
Promoting Technology Change Promotes implementation or development of a technology new to the location (e.g., irrigation technology, communications technology).	31
Establishing Monitoring/Early Warning Systems Emphasizes the importance of creating, implementing and/or maintaining monitoring and/or early warning systems.	25
Changing Agricultural Practices Focuses on new or different agricultural practices as adaptation strategies	23
Empowering People Emphasizes literacy, gender empowerment, or the creation of income generation opportunities as a basis for adaptation.	22
Promoting Policy Change Promotes establishing a new policy or adjusting an existing policy.	14
Improving Infrastructure Focuses on creating or improving built infrastructure (e.g. roads, sea walls, irrigation systems).	13
Providing Insurance Mechanisms Creates, modifies or plans an insurance scheme.	4
Other Strategies Consists of three instances of relief work and one focused on eradication of climate-related diseases.	4

Figure 3: Categorization of adaptation strategies identified in global review (McGray, Hammill et al. 2007)

"Serendipitous" adaptation: implemented development activities 'incidentally' achieve adaptation objectives or improve adaptive capacity.
Climate-proofing: additional activities supplement existing development efforts as a means of ensuring sustainability under climate change. In this way, adaptation serves as a means to achieve development objectives.
Discrete adaptation: specific activities are implemented to achieve adaptation objectives, thus development activities serve as a means to achieve adaptation objectives.

Figure 4: Types of adaptation. From McGray et al. (2007)

4.3 Classifying emerging adaptation practice

In order to move closer to defining the nature of future adaptation strategies in a changing climate context within African agro-economic systems, we need to reflect on the broad categories of coping strategies and adaptation strategies already being implemented. Table 1, adapted from McGray et al. (2007), outlines a number of general strategies currently being classified as adaptation strategies as well as the number of projects in sub-Saharan Africa. From this table it is clear that adaptation goes beyond the traditional coping strategies to include interventions targeted at raising awareness, empowerment, establishing monitoring and early warning systems and providing insurance mechanisms, all of which require climate science information and knowledge. However, emerging adaptations at the farm-level include changes in land use and management to maximize yield under variable climate conditions; development of new technologies (esp. crop breeding for drought-tolerance), modification of old or development of new water management techniques, total change in farming systems, change in seeds and cropping systems, change in timing of agricultural activities, etc., all of which also depend on climate information. Adaptation options though, should reflect the multi-faceted nature of Africa's farmers and farming systems in that the challenge is to address the localized nature of climate impacts and incorporating the existing capacities and responses in an ongoing process of increasing the resilience of farming systems and farmers.

The characterization of adaptation practice is still highly contested by those in the development and disaster risk management field. It could be argued that there is no difference between development and adaptation practice, except the separate funding stream now becoming available at a global level. In fact, impacts of both climate variability and climate change as previously discussed are difficult to distinguish from each other in terms of the responses in practice. However, some draw a distinction between coping (i.e. reactive or autonomous adaptation or intervention in response to observed and experienced climatic variability and changes) and adapting (proactive or planned adaptation or intervention by anticipating future climate change by reducing risks or taking advantage of opportunities).

The World Resources Institute's review of online information about on-going formal development projects, policies and initiatives which explicitly label themselves as doing "climate change adaptation", sheds some light on linkages between development and adaptation (McGray, Hammill et al. 2007). The review not only found significant overlap between the practice of adaptation and development, but also outlined three models where the objectives and activities of both adaptation and development overlap (Figure 2).

The authors state that adaptation practice can be divided into (as well as falling in between) approaches that address climate impacts reactively and those that seek to pro-actively address vulnerability to climate (McGray, Hammill et al. 2007). The continuum of approaches to frame adaptation efforts, according to McGray et al. (2007), can be characterized into four types, namely: i) those addressing the drivers of vulnerability, ii) building response capacity, iii) managing climate risk or iv) slowing climate change itself. The existing vulnerabilities and capacities of those affected by climate impacts play key roles in shaping the nature of the adaptive response. The specificity and reliability of modeled climate conditions of the future could also play a role, but it should be noted that whatever its quality, such information on biophysical systems will not in itself change the state of vulnerabilities and adaptive capacities.

The WRI study highlights the diversity of what constitutes climate change adaptation. Being a multi-faceted problem, adaptation to climate change will occur in many ways, sometimes as a "knock-on" effect of other activities. However, one major limitation of this study (and the categories that it develops) is that it only looks at climate change adaptation as a function of formal programmes, as exogenous interventions undertaken through the practices of development agencies and the like. While these large scale institutional actors and programmes should be taking climate change into consideration, it would be a mistake to limit analysis of climate change adaptation to their actions. Such analyses, and indeed the activities themselves, must articulate with organic, on-the-ground adaptation processes in which rural land managers themselves have ownership and agency.

4.4 The role of climate information

In many regions, especially Southern and Eastern Africa, the use of seasonal climate forecasts based on the El Niño Southern Oscillation (ENSO) is seen as having great potential in managing risk associated with climate variability (Vogel 2000; Ziervogel, Bharwani et al. 2006; Ziervogel, Taylor et al. 2008). ENSO, which has only recently become well understood, is an approximately 7-year cycle of climate variation, which is driven by seas surface temperatures in the central Pacific Ocean and which significantly affects weather patterns in many corners of the world. Modelling patterns of ENSO variation contributes to the production of probabilistic forecasts of 90 days or more. This enables some degree of identification of years that will be relatively wet or relatively dry. The forecasting technology is relatively new, and the applications are still in their infancy. While the development of decision support tools based on ENSO is a growing area of research in agro-meteorological applications, it is not without its challenges on the ground. Any new information stream which is intended to improve risk management must integrate with existing information streams as well as other risk management practices (Roncoli, Ingram et al. 2003; Roncoli 2006; Crane, Roncoli et al. 2010).

5. What are the implications for research and partnerships?

Given the complexity of agrarian responses to climate change's interaction with other environmental, social, political and technical variables, how can research in support of adaptation proceed? How can the scientific world adapt itself to African farmers' climate change adaptation needs? In recent years, "sustainability science" has developed as a field which deals with some of these complex interactions in socio-ecological systems. As mentioned earlier, research on climate change adaptation in agricultural systems is not distinct from research on sustainability. Broadly speaking, healthy soils and stable incomes through diversified livelihoods will both promote resilience in the face of climate variability.

In fact, the newly emerging notion of "adaptation science" is described as

> … the process of identifying and assessing threats, risks, uncertainties and opportunities that generate the information, knowledge and insight required to effect changes in systems to

> increase their adaptive capacity and performance. Adaptation science can be seen as specialised form of sustainability science that occupies the boundary space between science and society (Meinke et al. 2009:69-70).

Sidestepping the debatable proposition that there is a boundary between science and society at all, this conceptualization of "adaptation science" promotes an entirely new approach to science, one that is oriented on practical problems rather than disciplinary predilections, one which emphasizes increasing adaptive capacity and performance over abstract, theoretical knowledge or short-sighted technical fixes. Furthermore, as a part of this reconceptualized practice, adaptation science should not only analyze, but also proactively engage socio-political controversies which emerge through adaptation processes (Meinke et al. 2009). The pursuit of adaptation science, as conceptualized by Meinke et al., has profound implications for existing scientific institutions, both in terms of how they structure their own practices and how they partner with other social institutions, including agrarian communities.
The emphasis on affecting change though "increased adaptive capacity and performance" of systems implies, among other things, that research and development efforts should engage with and enhance farmers' practices.

Putting farmer practice at the centre of agricultural adaptation science has several benefits. First, it ensures that farmers' innate innovative capacities are acknowledged and integrated into the formal sector's development of adaptation technologies. This will facilitate the quick generation and implementation of new adaptive practices in the agricultural sector. Second, it promotes holistic consideration of the many dynamic and complex forces which shape farmers' risk management and livelihood strategies, rather than compartmentalizing problems through reductionist framing. Finally, and stemming from the previous points, putting farmers' practices at the centre of adaptation research that also acknowledges contextual variables can help to recognize when technical, farm-level adaptations are not the most effective way forward. In some instances, policy level interventions can improve farmers' livelihoods more than technical changes. By way of example, it has been widely and convincingly argued that one of the best ways to improved farmers' livelihoods in West Africa would be for the US to cease subsidizing its domestic cotton sector (Watkins and Sul 2002; Heinisch 2006).

5.1 Climate information and modeling

As previously mentioned, some have proposed "climate proofing" (Bouwer and Aerts 2006) as a means of engaging in adaptation. The concept of climate-proofing is that an existing or proposed practice, project or policy can be cross-checked against climate models to see if its proposed benefits still stand up under projected future climate conditions. As a risk management strategy, such an approach may be useful in long-term planning for large-scale infrastructure (i.e. coastal management or water-intensive development), but climate proofing on its own is inadequate as a general means of engaging in adaptation. The assumptions upon which climate-proofing is based imply that climate change adaptation is primarily a function of formal development projects and national level policies. While both of these are undeniably important in their own right, they make an incomplete approach to adaptation. Acknowledging that macro level analyses and interventions do have their uses, a balanced approach to climate change adaptation in agrarian systems must also include direct engagements with the practices and adaptive capacities of actual land managers.

Climate models and coupled climate-ecological models provide a large part of our capacity to visualize future impacts of climate change. In an effort to understand the impacts on and responses of human systems, it is tempting to try and better incorporate social behaviors into ecosystem models. Quite some work in theoretical agricultural economics has engaged this approach. The logic is that this enables more precise predictions and designs for adaptive responses. This logic is problematic, however, primarily because it applies an overly narrow view of adaptation as a mechanistic and linear process. The complexity of human behavior – which is embedded in and informed by numerous cross-cutting social institutions, networks and processes, as well as diverse environments – defies modeling except in the very broadest of ways. Because modeling is always a simplification of complex systems, it cannot take into account human agency and creativity in the face of uncertainty, variability and stress. This shortcoming is important in work on adaptation to climate change, because human agency and creativity are key components of adaptive capacity. In short, when used in this fashion, modeling can become a disempowering technology for rural people rather than an empowering technology. This need not be the case.

Rather than trying to better integrate human behaviors into systems models, it may be more constructive to explore ways that systems models can be used as tools to effectively inform farmers' adaptation decision-making (Crane in review). Because models allow a quick visualization of complex systems, their utility is often expressed in terms of their uses for policymakers. A challenging line of future research lays in exploring ways that system models can be designed as useful tools for land managers themselves. How can models, of climate and/or agro-ecosystems, be used as tools to inform and create responses by farmers themselves? Seasonal climate forecasting is one area where this type of work is beginning, but there is also potential in coupled climate-ecosystem modelling as well.

> "Rather than trying to better integrate human behaviours into systems models, it may be more constructive to explore ways that systems models can be used as tools to effectively inform farmers' adaptation decision-making."

5.2 Integration of farmer capacity

Farmers have been adapting to environmental variability, including but not limited to climate, as long as agriculture has existed. As such, there is a powerful endogenous capacity for observation, experimentation, and creative response to stresses of all sorts. Farmers' capacity for innovation is by no means a panacea, but it is far too often neglected by techno-centric approaches which seek to develop solutions ex-situ, and then deliver them to farmers. The multifaceted demands of climate change adaptation represent an opportunity for integrating farmers' capacities for innovation with scientific knowledge production.

When discussing the role of research in adaptation, it is important to distinguish between developing adaptive technologies for or with farmers, and developing farmers' collective capacities to generate their adaptations on their own. Neither is sufficient on its own and both have a role, but how can they best be balanced? The research community has historically focused on the creation of technologies for application in agricultural systems: new varieties, more efficient tools, soil management practices, etc. While the movement for participatory agricultural research has taken an important step in getting beyond old "technology transfer" approaches, participation in itself is not enough. Participatory research implicitly emphasizes that formal science owns the process of producing knowledge and technology, in which farmers are permitted to participate. Instead of simply looking for ways to integrate farmer knowledge into scientific research, we should be also look to strengthen and valorise endogenous adaptation practices through policy and technical backstopping.

Farmers' capacity for experimentation and adaptation is not limitless and is not a cure-all. Not every African farmer is an ingenious innovator and there is definitely a role for formal science. However, recognizing that there are substantial adaptive capacities built into agrarian social systems, some involving aptitudes for conscious innovation and others embedded in day-to-day practices is an important first step for realizing their potential in climate change adaptation.

For example, the African Rice Center's recent hybridization of African rice (*O. glaberrima*) and Asian rice (*O. japonica),* previously believed to be impossible, has been hailed as a technical breakthrough for breeding, as well as for African food security. It is believed to have such potential to contribute to food security in West Africa that the developers of "Nerica" have won the World Food Prize. Through genetic analysis, however, it has been recently discovered that spontaneous hybridization of African rice and Asian rice has also occurred in farmer fields and been selected for in several locations independently across West Africa (Nuijten, van Treuren et al. 2009). The lesson here is that the observation and selection practices of countless anonymous farmers led to what is recognized as a new and powerful form of biodiversity management worthy of the World Food Prize. Such endogenous scientific capacities have heretofore remained largely unrecognized, untapped and unsupported in development processes.

Endogenous adaptation and innovation practices are going on all the time, though their visibility to the world of formal science and governance is often poor. As such, an exclusive focus on formal science as the means of developing agricultural adaptation technologies risks neglecting a potentially powerful ally, the farmers themselves. The question should not simply be how to deliver adaptation technologies to farmers, but how to more effectively enable endogenous adaptive capacities. How can they be nurtured, empowered, and facilitated through formal public recognition, scientific backstopping, and enabling policy environments? Moreover, how can exogenous development interventions avoid disrupting on-going informal adaptation processes? For example, the above case of farmer hybrids could benefit from scientific backstopping for analysis and further development of the informal seed system (Richards, De Bruin-Hoekzema et al. 2009).

Bolstering farmer science is certainly not suggested as a replacement for formal scientific research in agriculture. However, farmer science is a long-neglected resource which should not be overlooked in the struggle to adapt to climate change in Africa. Reshaping the relationship between the research community and agrarian communities, however, will require a re-conceptualisation of scientific practice itself, one in which formal science bolsters farmers' capacities to engage in their own innovative processes rather than simply generating technologies for consumption by farmers.

> "Putting farmers' adaptive capacities as a focal point of scientific practice will necessitate interdisciplinary research which is able to meaningfully thread together social, technical and biophysical data streams."

5.3 Interdisciplinarity

Agriculture is essentially an interface between social systems, biophysical systems and technical practices. Analyzing biophysical components and agro-ecological systems requires grappling with a host of complex interactions. Including social components in the analysis, from households' labour dynamics to global political economy, compounds this complexity by orders of magnitude. Climate change further sets these analyses on shifting footing, adding yet another layer of complexity. Scientific research's greatest power, however, lies in analyzing complex systems, identifying mechanisms through which systems function, as well as the nodes or leverage points where systems may be altered for desired outcomes. Consequently, given the complexity of adapting social and agronomic practices to climate variability and climate change, relevant analyses will require interdisciplinary approaches, as will the development of effective adaptation measures (Roncoli, Jost et al. 2009).

Putting farmers' adaptive capacities as a focal point of scientific practice will necessitate interdisciplinary research, which is able to meaningfully thread together social, technical and biophysical data streams. As previously discussed, much of this work should focus on understanding, enabling and backstopping farmers themselves to forge livelihoods under challenging conditions. This involves management and generation of agro-biodiversity, social embedding of endogenous and exogenous innovation processes, and the dynamics of informal knowledge networks. While this may sound dauntingly complex, the complexity of the problem is precisely what makes it important.

5.4 Ongoing efforts and programs

Effective partnerships require that the different partners and institutions bring complementary knowledge, skills and objectives to the table. This is particularly true in complex endeavours like climate change adaptation in agrarian systems. As agricultural research centres increasingly engage in work oriented toward climate change adaptation, it will be important to explore potential synergies with the on-going adaptation programmes and projects already underway in Africa. The scope, focus and scale of these programmes vary from local capacity building and risk assessment, to "in-field" technologies, policies and infrastructure. The programmes and projects mentioned below are intended as a snapshot of current initiatives in order to provide some context in how formal adaptation efforts are moving beyond coping strategies, and imagining opportunities for collaboration with agricultural research centres and programmes. In the following sub-sections, a brief overview of current programmes is discussed in terms of three general categories, though it should be recognized that these categories are not mutually exclusive and the list of projects is not exhaustive.

5.4.1 Building scientific and research capacity

The Climate Change Adaptation in Africa (CCAA) is a prominent joint programme of the International Development Research Centre (IDRC) in Canada, and the Department for International Development (DFID) in the United Kingdom. The program focuses on developing research and capacity of African scientists, organisations, policy and decision-makers and others, by funding diverse short and longer term adaptation projects that aim to build on existing initiatives and past experiences so that the most vulnerable benefit (IDRC/DFID nd). The CCAA program will end in March 2012. Since it was launched in 2006, however, the African Advisory Board as well as IDRC and DFID have always had the intention of handing over coordination of the program to African organizations. Consequently, the Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles/ West and Central African Council for Agricultural Research and Development (CORAF/WECARD) is leading a 3-yr project "Platform for exchange between African research scientists and policy makers on climate change adaptation" funded by IDRC. The devolution of the CCAA program to CORAF/WECARD provides an opportunity and support to link a broad range of African stakeholders including civil society, policy makers, donors and the private sector working on adaptation to climate change issues.

The Assessments of Impacts and Adaptations to Climate Change (AIACC) is a similar global initiative funded by the Global Environment Facility, implemented by UNEP and jointly executed by START and the Third World Academy of Sciences (TWAS). The aim is to advance scientific capacity and understanding of climate change vulnerabilities and adaptation options in developing countries, through collaborative research, training and technical support, to generate and communicate information useful for adaptation planning and action (AIACC nd). The USAID's Global Climate Change team's adaptation program aims to build resilience to climate impacts by supporting activities that seek to improve global climate observations by working with the U.S. National Oceanic and Atmospheric Administration to translate data into useful information by bringing together climate scientists and consumers of climate information at quarterly Climate Outlook Forums in Africa. The forums enable scientists and stakeholders to discuss their information needs and capabilities; the result is a quarterly seasonal forecast that is used by decision makers in such fields as health, food security and hydropower (USAID nd).

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) (http://ccafs.cgiar.org/) is a 10-year research initiative launched by the Consultative Group on International Agricultural Research (CGIAR) and the Earth System Science Partnership (ESSP). CCAFS, which is led by the International Center for Tropical Agriculture (CIAT), seeks to overcome the threats to agriculture and food security in a changing climate, exploring new ways of helping vulnerable rural communities adjust to global changes in climate.

Through a project developing sweet potato production systems as drought-resistant climate change adaptation alternatives, the International Potato Centre (CIP) is aiming to build research capacities in the Ethiopian Institute of Agricultural Research (EIAR), Kenyan Agricultural Research Institute (KARI) and Makerere University in Uganda. In particular, the program is focusing on developing NARS' capacities for modeling the effects of climate change on agricultural systems, breeding sweet potatoes and conducting participatory workshops on climate change adaptation (CIP 2008).

With a focus on building research and adaptive capacity within civil society in Less Developed Countries (LDCs) , the CLACC (Capacity Strengthening of Least Developed Countries for Adaptation to Climate Change) network was initiated by IIED (International Institute for Environment and Development) in 2004. The network now focuses on 15 vulnerable countries in the LDC group (twelve in Africa and three in South Asia).Through various international, regional, national and local activities, the network strengthens the capacity of civil societies in LDCs to adapt to climate change by creating greater adaptive capacity among the most vulnerable groups;, whilst establishing information and knowledge systems and mainstreaming the National Adaptation Program of Action NAPA process with key non-governmental stakeholders (CLACC nd).

The World Agroforestry Centre (formerly ICRAF) is currently leading an exploratory research project titled "Climate Change Adaptation and Mitigation through Agroforestry". Partnering with numerous northern nation donors, plus IDRC, FAO, UNDP, World Bank and IFAD among others, the program seeks to bolster the scientific foundations, monitoring capacities and institutional mechanisms through which to implement development projects linked to carbon sequestration in agro-forestry systems. In addition to South American and Asian countries, the project is active in 16 African nations, encompassing most of Southern and Eastern Africa (ICRAF 2010). Another ICRAF program aims to improve the capacities of relevant researchers, policy makers and development practitioners in Kenya to analyze and evaluate the interactions between climate change and land-use change, especially in reference to REDD (Reduced Emissions from Deforestation and forest Degradation in Developing countries) mechanisms (ICRAF 2010).

5.4.2 Communicating and integrating climate risk information

Other large programs like ACCCA (Advancing Capacity to Support Climate Change Adaptation (ACCCA nd)), supported by the UK Department of Environment, Food and Rural Affairs (DEFRA), focus on addressing climate risks and adaptation in an integrated, multidisciplinary way by engaging stakeholders in long-term partnerships and then communicating relevant climate risk information to decision-makers. Similarly the recently launched UNDP-Japan Africa Adaptation Program, entitled Supporting Integrated and Comprehensive Approaches to Climate Change Adaptation in Africa, will assist 21 African countries in incorporating climate change risks and opportunities into integrated and comprehensive national and regional adaptation actions and resilience plans (UNDP 2010). Furthermore, UNDP is also funding a Community Based Adaptation program, along with GEF, which explores the ways of approaching climate change adaptation from the angle of locally-led grassroots rural development and capacity building (UNDP 2010). While the program's scope is global, it is being implemented in Morocco, Niger and Namibia, exploring approaches which may be adapted and applied elsewhere.

The International Livestock Research Institute (ILRI) is leading a consortium which is developing scenario-based tools for forecasting risk factors in livestock production under climate change, including rainfall variability, disease patterns, fodder production, water stress and crop-livestock interactions. The purpose of these models is to guide the development of technical and policy adaptation mechanisms in 9 countries across Southern and Eastern Africa, as well as 3 in West Africa; as well as to act as a platform for exchange between actors in these countries (IRLI nd).

In addition to national policy plans, other organizations like IISD, SEI, IUCN, Inter-Cooperation and CARE have developed various tools for combining local knowledge with scientific climate information. The process builds on people's understanding about climate risks and adaptation strategies in order to help project planners and managers to assess vulnerability to climate variability and change and thereby integrating climate adaptation and risk reduction aspects into new and existing community level projects in climate-sensitive sectors (CARE nd and IISD nd). CARE has developed the Climate Vulnerability and Capacity Analysis (CVCA) tool to engage all stakeholders in a participatory manner in understanding climate-related challenges, identifying adaptation solutions and taking steps to act on those solutions, while the IISD's CRiSTAL (Community-based Risk Screening Tool – Adaptation and Livelihoods) tool is designed to help project planners and managers integrate climate change adaptation and risk reduction into community-level projects.

5.4.3 Platforms for knowledge exchange

A number of virtual platforms have been established to meet the need to manage the prolific amounts of climate information, activities, news, events, case studies, tools, policy resources and even videos being generated by scientists, researchers, development practitioners, etc. The CBA-X (Community Based Adaptation Exchange), a shared online resource hosted by the Eldis Community (Eldis Community nd) is designed to bring together and grow the CBA community. The ALM (Adaptation Learning Mechanism) aims to provide a common platform for sharing and learning, map good practices, providing information, building knowledge and networks on climate change adaptation (ALM 2009). For example, the ALM is collaborating with the Nairobi Work Program, particularly the 'Methods and Tools' and 'Planning and Practices' areas of work, and the interactive weADAPT platform. The weADAPT platform (weAdapt nd), managed by the SEI (Stockholm Environment Institute) depends on contributions from its own staff and others (network of users and knowledge partners and information on various projects and initiatives) to provide the content which enriched by state-of-the-art semantic search technologies.

5.5 Implications for partnerships

The above programs represent a wide range of opportunities and actions in which agricultural research centers form partnerships at the global institutional level, building on synergies between technical innovation processes and improvement of rural livelihoods in the face of climate change.

Through collaborative, interdisciplinary work on adaptation, there is great potential for agricultural research centers to partner with African universities in ways that improve research capacities as well as farmer livelihoods. Overly-narrow, disciplinary thinking often impedes breakthroughs in analyzing and addressing complex real world problems. Creating opportunities for both social scientists and biophysical scientists to jointly address issues which intersect disciplines will promote problem-oriented education that is simultaneously situated in scientific debates as well as social needs. Conducting such research in the context of action research approaches – which explicitly speak to the socially-embedded needs and capacities (both technical and organizational) of agrarian communities – can further ensure that research is socially impactful as well as scientifically rigorous.

At the opposite end of the spectrum, grassroots farmers' organizations and rural development NGO's (both national and local) also represent potential partners for studies in agro-biodiversity management, seed system dynamics, participatory plant breeding. Community based adaptation (CBA) programs, such as those being funded by UNDP, allow local or regional NGO's to set the agenda for adaptation. In Namibia, this has led to an agenda which is a blend of adaptive technologies, especially around water conservation and efficiency, as adaptive capacities (Hotz 2010). In as much as agriculture is a point of concern, any such CBA, whether funded by the UN or local initiatives, represents a potential partner for agricultural researchers. However, the key element of this approach is that the communities set the development agenda and the research priorities.

While there are always logistical and administrative barriers, one substantial factor in the formation of partnerships is our imagination regarding the potential modes of articulation between scientific research, development programmes and rural society. In the world of global carbon emissions regulation and climate change mitigation, it is axiomatic that "Business as usual is not an option", and rightly so. The challenges of adaptation to climate change in rural Africa second the notion that "Business as usual is not an option". While at first consideration, this statement would appear to apply most readily to agricultural practice itself, it is equally true for both scientific practice and development practice as well.

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