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Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change?

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Abstract

Rain-fed agriculture will remain the dominant source of staple food production and the livelihood foundation of the majority of the rural poor in sub-Saharan Africa (SSA). Greatly enhanced investment in agriculture by a broad range of stakeholders will be required if this sector is to meet the food security requirements of tomorrow's Africa. However, production uncertainty associated with between and within season rainfall variability remains a fundamental constraint to many investors who often over estimate the negative impacts of climate induced uncertainty. Climate change is likely to make matters worse with increases in rainfall variability being predicted. The ability of agricultural communities and agricultural stakeholders in SSA to cope better with the constraints and opportunities of current climate variability must first be enhanced for them to be able to adapt to climate change and the predicted future increase in climate variability. Tools and approaches are now available that allow for a better understanding, characterization and mapping of the agricultural implications of climate variability and the development of climate risk management strategies specifically tailored to stakeholders needs. Application of these tools allows the development and dissemination of targeted investment innovations that have a high probability of biophysical and economic success in the context of climate variability.

Keywords: Current climate variability; Climate change; Sub-Saharan Africa; Rain-fed farming; Climate risk management

1. Introduction

The impact of escalating human activity on greenhouse gas emission, global warming and changes in global climate patterns is almost certainly the most discussed issue of the first decade of the 21st century. And it is being discussed worldwide at all levels of society. From global, regional and national institutions through to development agencies and down to private citizens and to farmers in Africa.

In 2001, the Intergovernmental Panel for Climate Change (IPCC, 2001) provided strong evidence of accelerated global warming. In Paris in February 2007, they released their most recent assessment which dispersed beyond any reasonable doubt the link between human activity and global warming. In spite of the growing consensus amongst climate experts concerning the emerging reality of climate change, predicting the exact rate, nature and magnitude of changes in temperature and rainfall is a highly complex scientific undertaking and there currently remains considerable uncertainty with regard to the final outcome of climate change and its impact (IPCC, 2007). This is illustrated for regions of sub-Saharan Africa (SSA) in Table 1. The table presents the summary output of 21 General Circulation Models used by IPCC in their latest report to predict the annual changes in temperature and rainfall that will occur by

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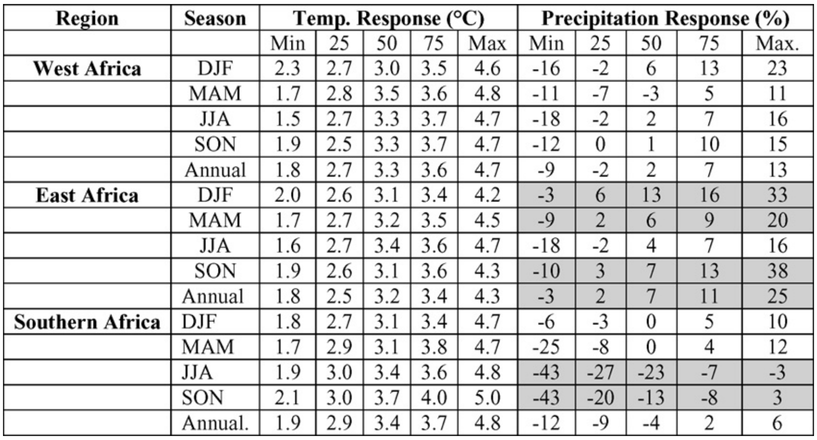
Table 1
Regional predictions for climate change in Africa by the end of the 21st century



Region	Season	Temp. Response (°C)					Precipitation Response (%)				
		Min	25	50	75	Max	Min	25	50	75	Max.
West Africa	DJF	2.3	2.7	3.0	3.5	4.6	-16	-2	6	13	23
	MAM	1.7	2.8	3.5	3.6	4.8	-11	-7	-3	5	11
	JJA	1.5	2.7	3.3	3.7	4.7	-18	-2	2	7	16
	SON	1.9	2.5	3.3	3.7	4.7	-12	0	1	10	15
	Annual	1.8	2.7	3.3	3.6	4.7	-9	-2	2	7	13
East Africa	DJF	2.0	2.6	3.1	3.4	4.2	-3	6	13	16	33
	MAM	1.7	2.7	3.2	3.5	4.5	-9	2	6	9	20
	JJA	1.6	2.7	3.4	3.6	4.7	-18	-2	4	7	16
	SON	1.9	2.6	3.1	3.6	4.3	-10	3	7	13	38
	Annual	1.8	2.5	3.2	3.4	4.3	-3	2	7	11	25
Southern Africa	DJF	1.8	2.7	3.1	3.4	4.7	-6	-3	0	5	10
	MAM	1.7	2.9	3.1	3.8	4.7	-25	-8	0	4	12
	JJA	1.9	3.0	3.4	3.6	4.8	-43	-27	-23	-7	-3
	SON	2.1	3.0	3.7	4.0	5.0	-43	-20	-13	-8	3
	Annual.	1.9	2.9	3.4	3.7	4.8	-12	-9	-4	2	6

IPCC (2007).

the end of the 21st century. Maximum and minimum predictions of change are given together with the 25, 50 and 75 quartile values from the 21 GCM's. Whilst all models agree that it will become warmer, the degree of warming predicted is quite variable. However, with regard to the %changes in rainfall amounts, the uncertainty is considerably greater and in many instances models do not even agree on whether changes in rainfall will be positive or negative. Regions in which the middle half (25–75%) of the model prediction distribution is of the same sign is shaded grey. Whereas there appears to be a consensus predicted trend of wetting in East Africa and of drying in the winter rainfall regions of Southern Africa, the position is much less clear in West Africa.

However, whilst the exact nature and extent of the impacts of climate change on temperature and rainfall distribution patterns remain uncertain, most key investors and stakeholders in agricultural development in the Third World have agreed that it is the poor and vulnerable who will be the most susceptible to changes in climate as they occur. This is particularly true for those communities in sub-Saharan Africa who rely largely or totally on rain-fed agriculture or pastoralism for their livelihoods. Such communities, already struggling to cope effectively with the impacts of current climatic variability, will face a daunting task in adapting to future climate change. Whilst rural communities are the primary 'investors' and risk-takers in rain-fed production, there are also a wide range of associated support agents upon whose strategies, decisions and operations they often depend. Farmers and agricultural stakeholders will need to adapt their tactical and strategic planning to these evolving climate risks, but given the magnitude of the existing poverty, food security, environmental and health challenges that are faced in sub-Saharan Africa, adaptation to climate change should not and cannot be divorced from those current development priorities.

In this paper we suggest that enhancing the ability of such rural communities and associated stakeholders to cope better with the constraints and opportunities of present day climatic variability is, in fact, a necessary 'dress rehearsal' for adapting to future climate change.

2. Rain-fed agriculture in sub-Saharan Africa will remain vital for food security

Recent reviews have considered an impending global water crisis in the context of continued population growth and predicted climate change. They suggest that the projected trends in world population growth and dynamics will place substantially greater multi-sectoral demands on water, leading to greater competition between sectors for an increasingly limited supply of abstracted water (Cosgrove and Rijsberman, 2000). In Africa specifically, the projected combined impacts of climate change and population growth suggest an alarming increase in water scarcity for many countries, with 22 of the 28 countries considered likely to face water scarcity or water stress by 2025 (UNECA, 1999). This in turn will curtail the ability of irrigated agriculture to respond to the expanding food requirements of tomorrow's Africa. In contrast to the aspirations of the Millennium Development Goals, this raises the specter of a worsening food security crisis (Rosegrant et al., 2002a).

To reverse such a scenario, it has been concluded that much greater emphasis will have to be given to increasing the productivity of global rain-fed agriculture which currently provides 60% of the world's food. This is especially true in sub-Saharan Africa where currently nearly 90% of staple food production will continue to come from rain-fed farming systems (Rosegrant et al., 2002b). In such an endeavor, there are special challenges in Africa's rain-fed farming systems. It is here that some of the poorest and most vulnerable communities live. They manage and largely rely upon rain-fed agriculture and pastoral systems for their livelihoods and are the custodians of the natural resource base upon which such enterprises depend. Added to the constraints imposed by extreme poverty and often a degrading resource base is the inherent risk associated with the seasonal variability of rainfall amounts and distribution. Furthermore, in many instances rural communities have been devastated by the HIV/AIDS pandemic that has further exacerbated their vulnerability through loss of productive labour, knowledge, income and the rising dependency burden of taking care of orphans (Yamano and Jayne, 2004).

Recognizing the importance of rain-fed agriculture in SSA for both individual as well as national food security, agricultural research and development initiatives have, for decades, developed and promoted agricultural and pastoral innovations that aimed to increase the value and productivity of assets at hand, be they land, labour or capital. In many instances, such innovations not only target increased productivity, but also attempt to mitigate climatically induced uncertainty of production through specific soil, crop and rainfall management strategies.

Such research has often shown great potential on research stations and in farmers' fields, with 'achievable' yields often several times greater than those obtained by farmers. However adoption has been low. Whilst 'islands of success' continue to provide hope for the future, little scaling up of such successes is reported, and widespread impact is not evident. Indeed, in many situations, production and the health of the natural resource base upon which it depends are declining. As a result, cereal deficits in SSA, currently standing at around 9 million tonnes annually, are projected to more than triple to 35 million tonnes by 2025 leading to SSA being identified as a "food trade hotspot". It is unlikely that SSA will be in a position to finance such a level of food imports. In such a scenario, either international food aid must be increasingly called upon; clearly an undesirable option, or policies must be put in place and decisions taken to greatly accelerate the current trends of investment within the agricultural sector beyond the 'business as usual scenario' upon which such projections are based (Rosegrant et al., 2002c).

3. Why does investment in rain-fed agriculture remain so low?

There are many complex and inter-related issues that contribute to the current lack of investment and the resultant stagnation of rain-fed production in sub-Saharan Africa. The green revolution that made dramatic contributions for improving agricultural productivity and reducing poverty in Asia and Latin America has largely by-passed sub-Saharan Africa. The outcomes of lack of investment and stagnation of agricultural production reinforce each other – leading to poverty traps and vulnerability of livelihoods to climatic and other shocks (Reardon and Vosti, 1995; Collier and Gunning, 1999). The market-led innovation model of agricultural transformation (Ruttan and Hayami, 1998) did not materialize in sub-Saharan Africa mainly because of interplay of market and policy failures (World Bank, 2000). Whilst agricultural investment by smallholder farmers in risk-prone environments has occurred to some extent over the last few decades (LSE, 2001), for such investment strategies to blossom and produce the needed impact, favorable policies, institutional arrangements and basic development infrastructure (including irrigation, roads, electricity and ICT) needed for proper functioning of markets are required. An enabling investment policy environment would thus include the existence of proper incentives, market access, information, input supply systems and institutions (Barrett et al., 2002). Low per capita incomes, debt servicing and negative balance of payments at the national level have undermined the ability of governments to invest in basic infrastructure needed for markets and the private sector to operate efficiently and effectively. These issues all impinge on investment decisions taken by a range of stakeholders within the rain-fed agricultural sector.

There is, however, one fundamental factor which cannot be ignored, and that is the rainfall variability both within and between seasons and the underlying uncertainty that it imposes on production. This uncertainty constrains beneficial 'investment' decisions required, not only from farming communities, but also from a wide range of additional agricultural stakeholders. They show understandable reluctance to invest in potentially more sustainable, productive and economically rewarding practices when the outcomes and returns seem so uncertain from year to year.

4. Rainfall variability, production uncertainty and climate change

In systems reliant on rainfall as the sole source of moisture for crop or pasture growth, seasonal rainfall variability is inevitably mirrored in both highly variable production levels as well as in the risk-averse livelihood and coping strategies that have emerged over time amongst rural populations.

This is particularly evident in the semi-arid tropics (SAT) of Africa. Home to approximately 80 million of the continent's most impoverished and marginalized communities (Shapiro and Sanders, 2002), the SAT are also increasingly under pressure from expanding livestock numbers and an in-migration of peoples from more favourable agro-ecosystems where population pressure, reduced farm size and resource degradation are resulting in agriculture no longer being a viable livelihood option. Added to this, it is in the SAT of Africa that climate variability and climate extremes have their most profound impacts on production. Long-term rainfall records from Eastern and Southern Africa (Fig. 1) indicate that inherent

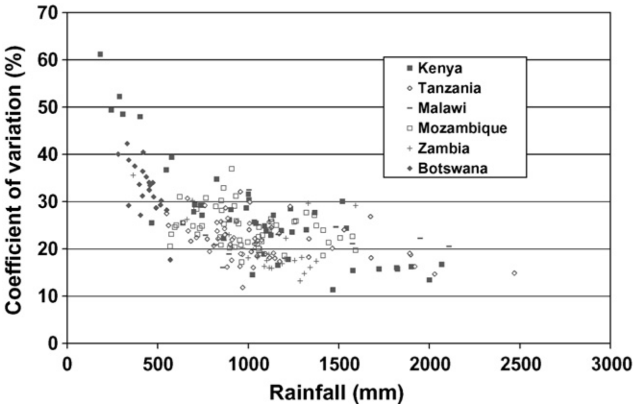


Fig. 1. Seasonal rainfall means and their coefficient of variation in Eastern and Southern Africa.

variability in seasonal rainfall totals increases disproportionally as one moves from wetter locations to the semi-arid regions that receive between 250 and 600 mm of seasonal rainfall.

Whilst seasonal rainfall totals and their season-to-season variability are in themselves important, the nature of 'within season' variability can also have a major effect on crop productivity. This can be illustrated by simulating maize (*Zea mays*) yields for Machakos, a semi-arid location, in Kenya using a crop growth simulation model, the Agricultural Production Simulator (APSIM), driven by nearly 80 seasons of historical daily climate data. As would be expected, there is a general trend of increasing maize yields as seasonal rainfall totals increase from 100 to 500 mm, but there is also considerable yield variation within that relationship resulting from the contrasting patterns of within season rainfall distribution experienced in any given season. This is particularly evident in drier seasons receiving below 200 mm (Fig. 2).

The dependence of crop yields on variable rainfall, and the increasing production uncertainty experienced in progressively drier environments can be further illustrated by comparing the long-term variability in yields of crops generally grown in wetter environments with those of crops more normally grown in drier environments. For example, an analyses of national average yields, derived from FAO statistics, for maize, grown in wetter environments and pearl millet (*Pennisetum glaucum* L.), grown in drier environments in Kenya, for the period 1980–2002 indicates both the inherent variability of rain-fed cereal production and the lower and more variable yields of pearl millet (range 250–1100 kg ha^{-1} with CV of 33%) compared with maize (1200–2050 kg ha^{-1} with CV of 13%). Such data will, in fact, underestimate the yield variability experienced by individual farmers since (a) national average yields even out the spatial variability of rainfall within any given season, and (b) FAO statistics are derived from 'harvested area' and thus will over-estimate average yields in poor years when crop failure, especially in the drier areas, is widespread.

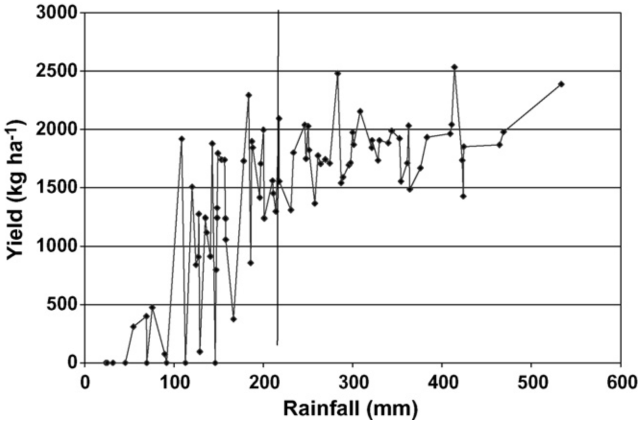


Fig. 2. Seasonal rainfall totals and simulated maize yields (40 kg N ha^{-1}), Machakos, Kenya.

As discussed earlier, overlaid on this challenging scenario is the accepted prediction that, whatever happens to future greenhouse gas emissions, we are now locked into global warming and inevitable changes to climatic patterns which are likely to exacerbate existing rainfall variability in SSA and further increase the frequency of climatic extremes (IPCC, 2007). Indeed, evidence of changes in climate extremes, in particular with regard to temperature, is already emerging in Southern and West Africa (New et al., 2006).

'Adaptation to climate change is therefore no longer a secondary and long-term response option only to be considered as a last resort. It is now prevalent and imperative, and for those communities already vulnerable to the impacts of present day climatic hazards, an urgent imperative' (IISD, 2003).

5. Farmers cope with climate variability, but can they adapt to change?

5.1. Coping strategies

Over generations, and especially in the more arid environments where rainfall variability impacts most strongly on livelihoods, farmers have developed coping strategies to buffer against the uncertainties induced by year-to-year variation in water supply coupled with the socio-economic drivers which impact on their lives. However, such coping strategies are 'risk spreading' in nature and are designed to mitigate the negative impacts of poor seasons and usually fail to exploit the positive opportunities of average and better than average seasons. In addition, farmers often over-estimate the frequency of negative impacts of climate variability and under-estimate the positive opportunities (Fig. 3).

As a result most farmers remain poor and vulnerable to future climate shocks. Whilst these farmer strategies have been of greatest importance and have evolved over many generations in the drier and more risk prone environments, they have perhaps only recently become of importance in

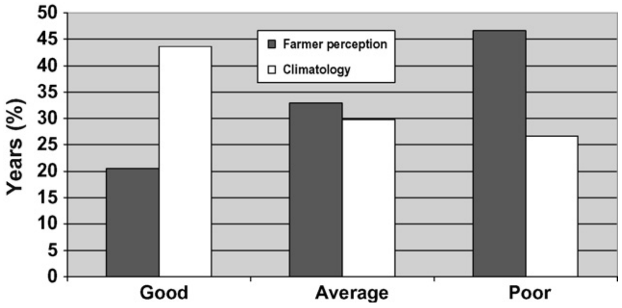


Fig. 3. Farmers' perceptions of the frequency of good, average and poor years in the SAT of Kenya compared with the analysis of long-term climatic records.

many of the wetter and more assured environments as a range of factors (population pressure, declining soil fertility, weed invasion, decreasing farm size, disease, lack of markets or access to markets for high value produce, lack of off-farm employment, etc.) are resulting in agriculture becoming a less viable foundation for rural livelihoods (Jayne et al., 2003).

Depending on subjective assessment of risks and vulnerability, farm households make certain adjustments in their choice of technologies, and production and consumption decisions. Such coping strategies can be broadly grouped into three categories: (a) *ex-ante* risk-management options such as choice of risk-tolerant varieties, investment in water management, and diversification of both farming and other associated livelihood enterprises prior to the onset of the season, (b) in-season adjustment of crop and resource management options in response to specific climatic shocks as they evolve, and (c) *ex-post* risk management options that minimize livelihood impacts of adverse climatic shocks (e.g., distress sale of assets, borrowing, cut expenditures on non-essential items). Matlon and Kristjanson (1988) provide an example of such a matrix to describe coping strategies in the semi-arid tropics of West Africa and also consider the 'spatial scale' at which the various strategies operate (Table 2).

Whilst this matrix provides a useful general regional picture, it is recognized that there will be region-to-region, village-to-village and household-to-household variation in coping strategies that have evolved. For example, in a study of over 100 households in Kezi village of Matabeleland, Zimbabwe, Alumira (2002) confirmed the broad range of contrasting diversification strategies employed between different types of households headed by either females (*de jure* or *de facto*) or males, with the ownership or lack of ownership of cattle being a key factor which cut across household types and which provided considerable additional flexibility.

In the even drier environments cropping is largely impossible and certainly highly risky both with regard to production and environmental degradation. Here pastoralism dominates. In such environments coping strategies assume even greater importance, but are perhaps less diversified due to the more restricted asset base and the more marginalized nature of such communities. McIntire (1991) notes that mixed species herds, widespread and seasonally available pastures, splitting animals into discrete herds and mobility in response to seasonal variation in pasture productivity are key strategies. Where the opportunities exist, working as wage labourers, trading commodities and growing crops are also common. He argues that the risk associated with livestock production in such dry environments inflates incentives to invest, and since animals are the only asset, herders tend to hold more than the 'profit maximizing' number of head in order to insure that they will remain viable after any given disaster. Such a strategy often leads to overstocking and overgrazing and can eventually prove a serious threat to the resource base (Cooper and Bailey, 1991).

5.2. Adaptive strategies, adaptive capacity and livelihood assets

Thus far, we have highlighted 'diversification' and 'response' coping strategies that have evolved to deal with both expected rainfall uncertainty and evolving within season fluctuations in rainfall. In many parts of the world however, longer-term changes have and are impinging on the livelihoods of rural communities and thus the nature and relative importance of such coping strategies cannot remain unchanged. Adaptation to these longer-term changes is required both by farming communities as well as those stakeholders with whom they interact and on whom they

Table 2
Coping strategies used by farmers in semi-arid West Africa (Matlon and Kristjanson, 1988)

Scale	Time frame		
	Before the season	During the season.	After the season.
Plant	Variety selection for stress tolerance/resistance	Replanting with earlier maturing varieties.	
Plot	Staggered planting dates. Low density planting. Intercropping. Run-off management. Delayed fertilizer use.	Changing crops when re-planting. Increasing or decreasing plant density at re-planting or by thinning	Grazing of failed plots for animal maintenance.
Farm	Diversified cropping. Land type diversification. Plot fragmentation	Shifting crops between land types	Late planting for forage
Household, village, region	Cereal stocks. Livestock/assets. Social and Off-farm employment networks	Matching weeding labour inputs to expectations of the season	Asset sales for cereal purchases. Food transfers. Migration employment.

often depend. The extent to which people and institutes are able to successfully respond to a new set of circumstances that they have not experienced before, such as a changed climate, will depend upon their adaptive capacity.

Central to the concept of adaptive capacity is the idea of livelihood assets. These are the means of production available to a given individual, household or group that can be used in their livelihood activities. These assets are the basis on which livelihoods are built. Five types of livelihood assets have been described, namely (i) Natural capital, (ii) Social-political capital, (iii) Human capital, (iv) Physical capital and (v) Financial capital (DFID, 1999). Taken together, knowledge of these assets helps us understand how livelihoods work, and in the context of this paper how people respond to climatic variability and adapt to change (IISD, 2003). In general, the stronger, more resilient and more varied the asset base, the greater is people's adaptive capacity and the level of security and sustainability of their future livelihoods.

This is well illustrated by a village level study conducted in the semi-arid tropics of India over a 25-year period in 10 villages (Bantilan and Anupama, 2002). Evidence from the villages of Aurepalle and Dokur in Andhra Pradesh reveals the acute effects of persistent drought and increasing water scarcity on livelihood strategies. Almost all dug wells in both villages have dried up and village irrigation tanks (previously filled through run-off) have not filled for a decade. Farmers are now forced to leave much of their land fallow and the %income derived from agriculturally related activities has declined dramatically – from 88 to 47% in Aurepalle and from 94 to 35% in Dokur. However, farm families have successfully adapted and diversified their livelihood strategies though increased off-farm activity, caste occupations and seasonal job migration. Indeed, in real terms, they have higher incomes today as a result. In other words, the communities in these two villages, under the particular new stresses that they have experienced, have had a high adaptive capacity (Table 3).

Table 3
Changes in the %contribution of different sources and the levels of household net income in two villages in the semi-arid tropics of India

Sources of income	Aurepalle		Dokur	
	1975–1978	2001–2002	1975–1978	2001–2002
Crops	30	15	46	3
Ag. labour	33	23	46	14
Livestock	25	9	2	18
Off-farm activities	12	13	1	24
Caste occupations	0	28	0	6
Seasonal migration for work	0	8	0	20
Others	0	4	5	15
Net household income (rupees)[a]	15205	31561	19107	36757

Bantilan and Anupama (2002).

[a] Incomes for the period 1975–1978 represent equivalent values of base year incomes at current prices.

Whereas these households have adapted to changes induced by recurrent drought through diversification into off-farm activities, this may not be a feasible alternative for many smallholder farmers in isolated and less-favored areas of rain-fed systems in Africa. This implies the need to develop new options and innovations that enhance the resilience of agricultural production and reduce vulnerability to such shocks in rural areas. For example, research investments to enhance crop tolerance to drought stress, improving water productivity, and integrated management of land and water resources (e.g., watershed management) have the potential to reduce vulnerability to climatic shocks whilst also improving productivity. This is illustrated in a second study in the SAT of India which evaluated the effects of integrated watershed management in Kothapally village (close to Auropalle and Dokur) which has contributed to improved resilience of agricultural incomes despite the high incidence of drought (Table 4). Whilst drought-induced shocks reduced the average share of crop income (as % of total household income) in the non-project villages from 44 to 12%, this share remained unchanged at about 36% in the adjoining watershed project village of Kothapally (Shiferaw et al., 2005).

Such evidence from the SAT of India is relevant to SSA. It demonstrates that where rural communities have a strong livelihood asset base, adaptation to negative changes in climate is not only feasible, but can result in positive outcomes. It also demonstrates that with appropriate investment in their farming practice, rural communities can do much to protect their agricultural productivity in the face of climate changes. Based on a proper understanding of the temporal and spatial implications of climate variability for rain-fed agriculture, the same can be true for SSA.

6. New and proven tools can facilitate investment by a range of stakeholders

In recent years, a range of innovative climate analytical tools have been developed and proven. These tools allow for a far greater understanding of the temporal and spatial agricultural implications of short and medium-term climatic variability. Such an understanding can facilitate broad-based investment in the uncertain sector of rain-fed agriculture from two complementary perspectives, namely (i) through the shorter-term seasonal weather forecasting and (ii) through the characterization and mapping of the medium-term agricultural implications of climate variability.

6.1. Seasonal weather forecasting

Recent advances in understanding and modeling of the oceanic atmosphere system at the global and regional scales are important developments that result in the evolving potential of seasonal weather forecasting being evaluated and demonstrated in Asia (Balusubramanian et al., 2002; Huda and Packham, 2004) as well as in several regions of

Table 4
The effect of integrated watershed interventions on alternative sources of household income in the semi-arid tropics of India (Rs 1000) (Shiferaw et al., 2005)

Year	Village group[a]	Statistics	Crop income	Livestock income	Off-farm income	Household income
2001 (average year)	Non-project	Mean income	12.7	1.9	14.3	28.9
		Share of total income (%)	**44.0**	**6.6**	**49.5**	**100.0**
	Watershed project	Mean income	15.4	4.4	22.7	42.5
		Share of total income (%)	**36.2**	**10.4**	**53.4**	**100.0**
2002 (drought year)	Non-project	Mean income	2.5	2.7	15.0	20.2
		Share of total income (%)	**12.2**	**13.3**	**74.5**	**100.0**
	Watershed project.	Mean income	10.1	4.0	13.4	27.6
		Share of total income (%)	**36.7**	**14.6**	**48.7**	**100.0**

[a] The sample size ($n = 60$ farmers) for each group.

SSA (IRI, 2005). These developments have an important role to play in assisting farmers and other investors optimize their immediate decisions and tactical planning with regard to the approaching season. Whilst the potential for seasonal forecasting of rainfall for parts of Africa is amongst the highest anywhere in the world, currently the predictability of seasonal rainfall remains variable within different regions of Africa (Washington et al., 2004) (Table 5). The high level of predictability of the October, November and December rains in East Africa are illustrated by the results of a study undertaken at Machakos in Kenya (Fig. 4).

Surveys and pilot studies in Eastern and Southern Africa show that farmers see opportunities to benefit from seasonal forecasts (Table 6).

It is interesting, but perhaps not surprising, to note the similarity of management responses to seasonal variation in the semi-arid tropics of SSA between those observed 20 years ago in West Africa (Table 2) and those of today by East African farmers. However, such studies have also shown that farmers are often constrained by the timing, scale and format of available forecasts, lack of trust or comprehension of the forecasts, and need for competent guidance for livelihood responses as requirements for rural communities to use seasonal forecasts effectively (O'Brien et al., 2000; Ngugi, 2002; Patt and Gwata, 2002; Rao and Okwach, 2005).

Effective agrometeorology extension can address these challenges and facilitate the effective use of forecast information by supporting dissemination, interpretation, education, technical guidance, and feedback to forecast providers. This generally requires close collaboration between agricultural and meteorological institutions.

Table 5
Qualitative assessment of potential predictability of seasonal forecasts in Africa (Washington et al., 2004)

Region	Rainfall period	Potential predictability
West Africa	July to September	High
East Africa	October to December	High
East Africa	March to May	Low to Medium
Southern Africa	January to March	Medium
North Africa		Low
Congo, Mozambique, Angola		Unknown

In addition, evidence suggests that farmers are most likely to trust and act on information and advice when it comes from sources that they already know and trust (Hansen, 2002). Thus, depending on the context, the impact of agrometeorology extension may be most effective through existing agricultural extension services, meteorological services, development NGOs, agribusiness, farmer associations or community leaders.

Equally important to the potential benefits that can accrue to farming communities themselves, seasonal climate forecasts also assist in national and/or regional disaster preparedness through an approach that links seasonal forecasts with the use of crop growth simulation models that provide probabilistic crop yield and production estimates well in advance of harvest (Hansen and Indeje, 2004). Weather data linked to changes in crop yields can also be instrumental in expanding crop insurance schemes to smallholder farmers in risk-prone environments (Skees et al., 1999).

6.2. *Characterizing and mapping the agricultural implications of climatic variability*

The use of long-term daily climatic data combined with field based research results, spatial weather generators, crop growth simulation and soil and water management models, geographic information systems and improved access to and use of climate analysis software allow for the development of robust climate risk assessment frameworks. Such frameworks can facilitate and guide risk assessment and management, longer-term strategic planning and decision making by all investors involved in rain-fed farming. Such work can incorporate various degrees of complexity, and is usually based upon the use of long-term daily climatic records. Crops principally respond to daily or sequences of daily rainfall, and thus daily rainfall becomes the key parameter in rain-fed agriculture. Such records have been collected throughout SSA for decades, and in this context are now proving to be invaluable. The use of such records allows the determination of the probability of occurrence of a wide range of parameters of importance to agriculture and hence the risk associated with them.

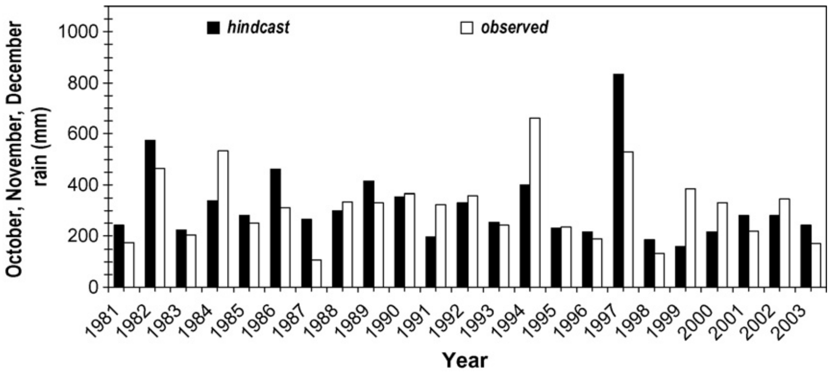


Fig. 4. IRI weather hindcasts and observed rainfall for October, November and December at Machakos, Kenya (1981–2003).

Table 6
Some farmer identified management options for below normal and normal to above normal seasons at Machakos, Kenya

Management decisions	
Dry season	Normal to wet season
1. Use low plant density (2.2 plants m^{-2})	1. Use higher plant density (3.5–4.5 plants m^{-2})
2. Reduce labor and other input use	2. Apply fertilizer
3. Increased use of drought tolerant crops such sorghum, millet, green grams, and cassava	3. Plant hybrid maize varieties.
4. Plough and plant early before the start of the rain	4. Adopt intercropping
5. Adopt water conservation measures	5. Strengthen terraces
6. Reduce area under cultivation	6. Increase area under cultivation

Rao and Okwach (2005).

At one level of analyses, research can focus on the probability of climatic events of known importance to farmers and their support agents such as the start of the growing season, the frequency of dry spells within the season, the frequency of high intensity erosive rainfall events, the impact of prolonged wet spells on plant disease or the length of the growing season itself (Sivakumar, 1988; Virmani and Shurpali, 1999). Such analyses are becoming increasingly easy to undertake as initiatives to provide more user-friendly software, and the training to go with it, take place. The outputs of such analyses provide a useful framework for making medium-term strategic choices concerning agricultural practices that are directly influenced by single or a combination of climatic events.

A further step is the use of simulation models that integrate the impact of variable weather with a range of soil, water and crop management choices. Such simulation models, usually driven by daily climatic data, can be used to predict the impact of medium-term climate variability on the *probability of success* of a range of crop, water and soil management strategies. The use of such models, with long runs (30 years or more) of daily climatic data thus provides a quicker and much less costly opportunity of 'accelerated learning' compared with the more traditional multi-location, multi-seasonal and multi-factorial field trails. One such model that is becoming increasingly used in SSA is the Agricultural Productions Systems Simulator (APSIM). APSIM can simulate various soil and water management practices together with the growth and yield of a range of crops amongst which maize, sorghum (*Sorghum bicolor*), pearl millet, chickpea (*Cicer arietinum*), pigeon pea (*Cajanus cajan*), soybean (*Glycine max* L.), groundnut (*Arachis hypogea* L.) and sunflower (*Helianthus annuus* L.) are likely to be of most interest in SSA. When properly calibrated for these crops, APSIM provides an accurate simulation of actual crop yields across a range of soil types and seasons. Fig. 5 presents an example for maize grown in Kenya (Dimes, 2005).

A recent, simple and successful example of the use of APSIM and the impact of such analyses occurred in southern semi-arid Zimbabwe where nitrogen deficiency is widespread in maize and yields are low and variable. Nitrogen fertilizer use is recommended at a rate of 52 kg ha^{-1}, but is

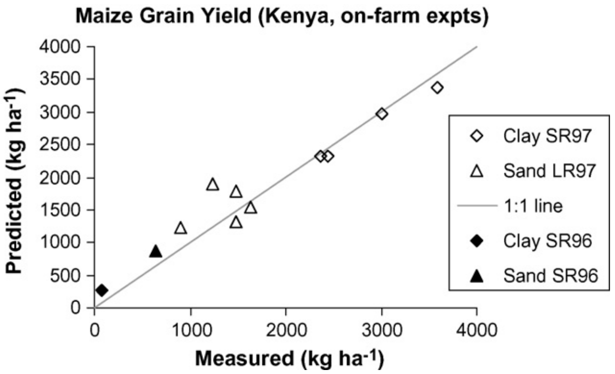


Fig. 5. Predicted (APSIM) and observed maize grain yields (kg ha^{-1}) on two soil types in Kenya during 1996 and 1997. (Dimes, 2005).

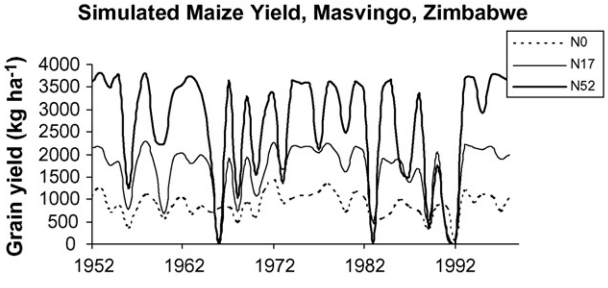


Fig. 6. Predicted (APSIM) response of maize to 0, 17 and 52 kg N ha^{-1} at Masvingo, Zimbabwe. 1952–1998 (Dimes, 2005).

seldom adopted by farmers as it is considered risky and too expensive. Researchers therefore asked farmers how much fertilizer they could afford and would actually be prepared to use under such conditions and were told about 17 kg N ha^{-1}, one-third of the recommended rate. 46 years of daily climatic data from Masvingo, a local meteorological station, were used to simulate maize yields with 0, 17 and 52 kg N ha^{-1}. The results of this simulation confirmed farmers perception of quite variable N-responses (Fig. 6), but also suggested useful responses to 17 kg N ha^{-1}. The outputs of this simulation were then calculated as 'economic rates of return' to fertilizer use and expressed in terms of *probability of success* (Fig. 7). Except in very bad years, rates of return to the farmer preferred rate of 17 kg N ha^{-1} were substantially better than the recommended rate. For the first time, the outputs of this simulation gave farmers, fertilizer traders, extension staff, NGO's, donors and researchers a quantification of the risk and opportunities of N-fertilizer use, and with it the confidence to successfully evaluate this 'micro-dosing' rate of N with 170,000 farmers in Zimbabwe in the 2003/04 cropping season. Despite poorer than average rains, micro-dosing increased maize grain yields by 30–50% and almost every farmer achieved significant gains. (Twomlow et al., 2006). The initiative is on-going and expanding. It is enabling farmers to adapt their attitude toward and their practice of fertilizer use as well as allowing their support agents to adapt their recommendations, packaging and distribution of N-fertilizer.

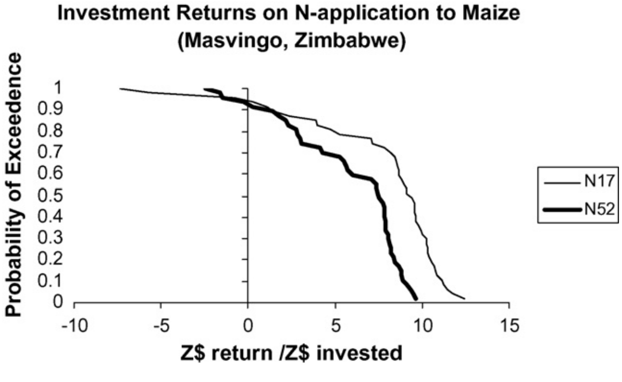


Fig. 7. The %chance of exceeding given rates of return (Z $'s) on ammonium nitrate-fertilizer investment on maize production at 17 and 52 kg N ha^{-1}. Masvingo, Zimbabwe. (Dimes, 2005).

One thing is clear. Such simulation modeling can be invaluable in posing a wide range of 'what if' questions which mirror those asked by farmers and can provide valuable insights and answers framed in the context of the long-term characteristics of climate variability in any given location. In other words, they can contribute directly to enhanced and more resilient coping and adaptive strategies. Indeed, recent village-based experience in Zimbabwe has shown that providing 'on the spot' answers to farmers' climate risk management concerns through the use of laptop computers and simulation models aroused enormous interest amongst farmer groups and has great potential to directly help farmers in their decision making. (Dimes et al., 2003).

The value of the type of research described above is however constrained to some extent by the fact that it relies upon 'point source' climate data collected at specific weather stations, thus making interpolation of the outputs between weather stations problematic. This can be overcome by the use of spatial weather generators such as MarkSim. MarkSim is a spatially explicit daily weather generator that was developed at CIAT and was released in 2004. The climate surfaces that are produced use data from 10,000 stations in Latin America, 7000 from Africa and 4500 from Asia. MarkSim relies on climatic data surfaces interpolated from weather stations and generates long-term weather records on a grid basis of 18 km × 18 km. The probability of long-term total seasonal rainfall distribution, derived from daily rainfall data generated by MarkSim, compares well with existing long-term daily climatic records for a number of meteorological stations in the semi-arid tropics of Kenya, as illustrated in Fig. 8a and b (Farrow, 2005).

The combined use of crop growth simulation models, historic climatic data sets and weather generators such as MarkSim is a powerful combination that allows both the characterization and the subsequent mapping of the agricultural implications of climatic variability (Jones and Thornton, 2002). It is also possible to integrate different climate change scenarios into MarkSim and, through crop growth simulation models, asses their potential impact on agricultural production (Jones and Thornton, 2003).

6.3. Integrating climate risk management approaches

With the increasing availability, reliability and ease of use of such tools as described above, it now becomes possible for decision-makers and investors involved in agriculture to formulate a development agenda that integrates the following three key aspects of climate risk management that span across different time scales, namely:-

1. Decision-support frameworks that provide a *medium-term* strategic understanding of the temporal and spatial

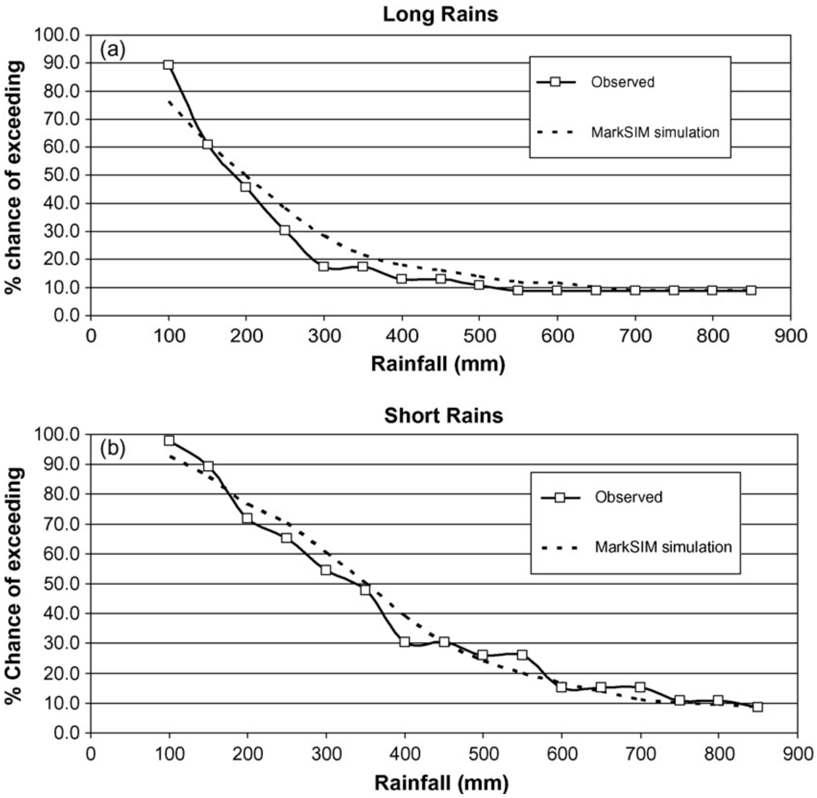


Fig. 8. A comparison of MarkSim generated seasonal rainfall totals with observed data at Makindu, Kenya. (1959–2000) for (a) the long and (b) short rainy seasons, (Farrow, 2005).

distribution of climatic variability and its impact on the probability of success of existing and innovative agricultural practices.

2. *Short-term* seasonal climate and agricultural forecasting to enable farmers and other stakeholders to ‘fine tune’ *medium-term* strategies in the context of the approaching season and thus to plan tactically and farm more effectively in context of the variable weather.
3. *Longer-term* information on the extent to which climate change is impacting, or is likely to impact, on the nature of climate variability and the implications for rain-fed farming systems and their future development and productivity.

The demand for integrated climate risk management strategies is increasingly being voiced by a broad range of investor stakeholders who are seeking to identify appropriate short and longer-term investment strategies, for example:

- National and district policy makers who are charged with making short and medium-term agricultural investment decisions on the types of development initiatives to promote and support in any given season and area.
- The private sector and micro-finance institutions wishing to have a clear picture of the medium-term implications of season-to-season variability in production and its implications for the establishment and sustainability of viable market enterprises and financing schemes.
- Extension services and development NGO’s working with farmers who wish to better target and test innovations that have been shown to have a medium-term acceptable level of probability of success and who would wish to advise their clients which innovations are likely to be most appropriate in the coming season.
- Farmers and farmer groups who wish to have information on the likely performance of an innovation in good, average or poor years before singly or jointly making short-term or medium-term investment in such an innovation.
- Disaster relief agencies and national policy makers who wish to have due warning of impending food shortages in any given season coupled with a longer-term temporal and spatial perspective on the probability of such shortages and appropriate post-disaster recovery strategies.
- National and regional meteorological services who are increasingly seeking opportunities to use their information and skills in the agricultural development arena.

7. Conclusions and the way forward

Progress towards achieving the Millennium Development Goals by 2015 in SSA has been disappointingly slow. Only seven years remain, and climate change will pose added challenges to those already faced by poor and vulnerable rain-fed rural communities.

For agricultural communities and agricultural stakeholders in SSA to adjust to climate change and the predicted increases in climate variability, their ability to cope better with the constraints and opportunities of current climate variability must first be enhanced. If this does not happen, the challenge of adapting to greater climate variability will prove daunting for most and impossible for many. To achieve the required improvements in rural livelihoods and adaptive capacity, there now exists an urgent imperative to accelerate investment in rain-fed agriculture through the identification and targeting of investment innovations that have a high probability of economic success, adoption and impact in the context of climate variability and change.

Climate risk management tools and approaches are now available that allow for a better understanding, characterization and mapping of the agricultural implications of climate variability and the development of climate risk management strategies specifically tailored to farmers' and stakeholders needs. Such tools have an important role to play and must be more widely applied to directly address such needs.

To this end, the International Crop Research Institute for the Semi-arid Tropics (ICRISAT) is working in partnership with a wide range of stakeholders in Africa who have expressed specific climate risk management concerns and who share our vision of 'enhanced and more resilient rural livelihoods in the SAT of Africa, better able to cope with current climate variability and adapt to future climate change.'

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