Local solutions to global problems: the potential of agroforestry for climate change adaptation and mitigation in southern Africa †

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Abstract

Climate change is a global phenomenon that imposes economic, social, and ecological challenges to the global community and, to smallholder farmers particularly in low-income countries. Sustainable land use practices offer opportunities for smallholder farmers to adapt to climate change and related risks, but the challenge is that the adoption of such practices by farmers is low due to policy and institutional constraints, among other key reasons. Drawing from the lessons learnt from research and development activities for about two decades in Malawi and Zambia, this paper uses the case study of agroforestry-based land use practices (fertilizer tree/shrubs) to highlight opportunities for assisting smallholder farmers respond to the effects of climate change. It then discusses institutional and policy challenges that constrain the full exploitation of the potential opportunities in southern Africa region. Strategies to address these constraints and facilitate adoption of sustainable land use practices that enhance climate change adaptation and mitigation are identified. These include targeted and conditional reward mechanisms for promoting sustainable agricultural practices that contribute to climate change adaptation among farming communities, appraisal of national and regional policies to evaluate the extent to which they are consistent with climate change adaptation, equipping new graduates and re-tooling extension officials with knowledge to respond to climate change phenomenon, and initiating science-policy linkages to bridge information gap on climate change between scientists and policy makers. It is recommended that climate change and food security are linked and should not be addressed in isolation. In the low-income, food-deficit regions, responses to climate change should be viewed from the perspective of livelihood, especially food security considerations.

Key words: *Adoption*, Climate change, *Ecosystem services, Externality, Malawi, Science-Policy linkages, Zambia.*

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1.0 Introduction

Climate change is linked to internal variability of the climatic system and external natural factors but much more to human activities. The potential fallouts of this phenomenon have been identified to include rise in temperature, much more erratic rainfall regimes, increased frequency and intensity of extreme events, and general unpredictability of agricultural operations among other effects. These have grave economic, social, and ecological consequences for agriculture and food security in many countries particularly, in sub-Saharan Africa where agriculture is largely rain-fed. Given that over two thirds of the population in African countries work within the agricultural sector, the environmental and social consequences of climate change, especially for the poor, endangers their livelihoods. In the quest to provide food and fibre to an expanding human population, the provision of agriculture-based ecosystem services that help to moderate climate change is increasingly under threat (FAO, 2007). As high potential land becomes less available and the rural human population increases, farming is extending into more fragile lands, undermining the natural resource capital base (Ajayi et al., 2007a). The damage to land-based ecosystems is exacerbated as agriculture is expanded to marginal and environmentally fragile areas. In addition, some conventional agricultural practices in many developing countries contribute significantly to greenhouse gas emissions. Thus, agricultural practices affect climate change and they are simultaneously affected by climate change.

In an effort to reconcile current food deficit against future environmental debt, most food deficit regions face the challenge to identify appropriate technological and policy approaches that are affordable, and best meet food security objectives and, provide opportunities for smallholder farmers to adapt to climate change. Sustainable agricultural development is widely acknowledged as an important component in a strategy to respond to the twin challenges of poverty and environmental degradation and adaptation to climate change (Antle and Diagana, 2003). One of the sustainable agricultural practices is agroforestry soil fertility practice (fertilizer tree/shrubs) that uses natural resource management principles to replenish soil fertility. While most sustainable agricultural development practices are feasible and technically sound, the level of uptake of the practices by farmers has been low in some parts of the world or attained a modest success in others (Ajayi et al., 2003; Honlonkou, 2004; Mercer, 2004; Lal, 2007).

Using information from field studies and development activities carried out in Zambia and Malawi for nearly two decades, the objectives of this paper are as follows: (i) discuss the opportunities of agroforestry fertilizer tree/shrubs to assist smallholder farmers to improve food security and respond to the effects of climate change; (ii) highlight the challenges to the full exploitation of the potential opportunities of the practices in southern Africa region and, (iii) identify options and scaling up approaches to facilitate smallholder farmers' adoption of sustainable practices that provide benefits to individual households (e.g. food production) while also helping them to adapt to climate change and generating ecosystem services (e.g. reduction of net GreenHouse Gas emissions).

2.0 Overview of agroforestry-based fertilizer trees/shrubs and their contributions to food production and climate change

2.1 Overview of agroforestry-based fertilizer trees/shrubs

Low soil fertility is a major problem to food production and one of the key biophysical constraints to increase agricultural growth in sub-Saharan Africa (Sanchez, 2002; Kwesiga et al., 2003; Vanlauwe and Giller, 2006). According to the estimates reported by Smaling et al. (1997), the soils in the sub-Saharan African sub-continent are depleted at a rate of 22 kg/ha of nitrogen, 2.5 kg/ha of phosphorus and 15 kg/ha of potassium annually. In Malawi, over US$ 6.6 million worth of nutrients have been estimated to be lost each year through soil erosion (Bojo, 1996). The decline in soil fertility has been caused by two main reasons: the breakdown of the traditional natural fallow system that farmers used to naturally replenish the fertility of their soils and, low rate of use of mineral fertilizer due to unaffordability and lack of timely access of the inputs by most smallholder farmers. The problem of accessibility to fertilizers was more acute especially after the removal of fertilizer subsidies and the collapse of public farm inputs distribution channels.

Fertilizer trees/shrubs is an agroforestry-based soil fertility replenishment practices that was developed in the late 1980s in southern Africa in response to the declining soil fertility and low macro-nutrient levels prevailing in many sub Saharan African countries. The practice involves planting fast growing and nitrogen-fixing leguminous trees and shrubs whose biomass produce large quantities of biomass that easily decomposes and release nitrogen for crop growth (Kwesiga and Coe, 1994). The practice is based on the knowledge that nitrogen is highly abundant in the atmosphere but is the most limiting macro nutrient in the soil. Through nutrient recycling principles, leguminous trees are planted to capture atmospheric nitrogen and release it into the soil upon decomposition and subsequently nourish crops that are planted in the field. There is a consensus in the literature that fertilizer trees/shrubs are sustainable, technically sound and ecologically relevant (Kwesiga et al., 2003; Akinnifesi et al., 2006; Mafongoya et al., 2006; Akinnifesi et al., 2008).

2.2 Contributions of fertilizer trees/shrubs to ecosystems services and climate change

Fertilizer trees/shrubs increase maize yield (staple food in southern Africa) about two times compared with farmers' *de facto* practice in which maize was cultivated continuously without external fertilization (Kwesiga et al., 2003, Akinnifesi et al., 2008). A recent meta-analysis demonstrated that the superior maize yield performance under fertilizer trees/shrubs technology is consistent across most of sub-Saharan Africa (Sileshi et al., 2008). An assessment of the impact of fertilizer trees/shrubs in eastern Zambia shows that it enhances household food security and can reduce seasonal household hunger period by 2-4 months per year depending on the type of tree or shrub species planted (Ajayi et al., 2007c). Agroforestry-based land use practices enhance household food security through higher yields resulting from soil fertility improvement and provisioning services such as source of energy and fodder and, ultimately improving local livelihoods. At the same time, Agroforestry-based land use practices provide ecosystem services such as carbon sequestration and storage, biodiversity conservation and protection of watershed among other services that help to adapt to and mitigate climate change effects. Details of the ecosystem services that fertilizer trees/shrubs provide that may contribute to improving environmental quality and respond to climate change are described in the next section.

2.2.1 Carbon sequestration services and its influence on climate change mitigation

One of the most important contributions of agroforestry in general is to respond to climatic change through sequestration of carbon in above-ground plant biomass and the soil (Unruh et al., 1993; Kaonga, 2005; Verchot et al., 2007). The analysis of C stocks from various parts of the world shows that 1.1–2.2×10^{15} g C could be removed from the atmosphere over the next 50 years if agroforestry systems are implemented on a global scale (Albrecht and Kandji, 2003). Average carbon storage by agroforestry practices, of which fertilizer trees is an integral part has been estimated as 9, 21, 50, and 63 Mg C ha^{-1} in semiarid, sub humid, humid, and temperate regions respectively (Montagnini and Nair, 2004). Based on assessments of national and global terrestrial carbon sinks, two primary beneficial attributes of agroforestry have been identified (Wise and Cacho, 2005). The first is direct near-term carbon storage in trees and soils through accumulation of carbon stocks in the form of live tree biomass, wood products, soil organic matter and protection of existing products. The second involves potential to offset greenhouse gas emissions through energy substitution (e.g. fuelwood from woodlots) and fertilizer substitution (through biological nitrogen fixation and biomass production). Agroforestry can also have an indirect effect on carbon sequestration when it helps decrease pressure on natural forests, which are the natural sinks of terrestrial carbon. Although pure forests sequester higher amounts of carbon per unit land area and contribute more to improved climate change, the opportunity cost in terms of food production of initiatives that take land out completely for forestation for many years may be high in some southern African countries that experience seasonal food deficit. Such initiatives may also not be attractive to smallholder farmers in countries such as Malawi where the average land holding per household is less than 1 hectare.

2.2.2 Potential reduction in the rate of deforestation

Field trials carried out in Zambia in the early years of the development of the practice show that the tree species used in fertilizer trees can provide up to 10 tons of wood biomass per hectare (Kwesiga and Coe, 1994). The quantity of ppotential harvestable fuelwood obtainable from different agroforestry-based land use practices in Southern Africa countries is presented (Table 1). It is hypothesized that the additional fuelwood that households obtain from fertilizer trees/shrubs fields could lower the amount of wood that farm households would have sourced from communal forests and thus offer potential opportunities to reduce deforestation.

Table 1: Potential harvestable fuelwood produced by trees species planted in different agroforestry-based land use practices in Southern Africa countries

Agroforestry practice	Country	Site	Tree species	Age of tree (years)	Fuelwood Quantity (t ha^{-1} Yr^{-1})
Contour strip	Tanzania	Lushoto	*Calliandra*	4.5	3.2
		Lushoto	*Casuarina*	4.5	1.8
		Lushoto	*Croton*	4.5	1.5
		Lushoto	*Grevillea*	4.5	2.7
Woodlots	Tanzania	Mganga	*A. crassicarpa*	5	22.4
		Kiwango	*A. crassicarpa*	4	24
		Dotto	*A. crassicarpa*	4	19.5
		Sanania	*A. crassicarpa*	4	21.0
		Shinyanga	*A. nilotica*	7	1.2
		Shinyanga	*A. polycantha*	7	10.1
		Shinyanga	*Leucaena*	7	12.7
		Morogoro	*A. crassicarpa*	5	51.0
		Morogoro	*A. mangium*	5	40
		Morogoro	*A. polycantha*	5	39
		Morogoro	*A. nilotica*	5	27
		Morogoro	*Gliricidia*	5	30
Coppicing fallows	Zambia	Chipata	*Senna*	3	10.7
		Chipata	*Leucaena*	3	9.7
		Chipata	*Sesbania*	3	8.0
		Chipata	*Gliricidia*	3	7.0
Non-coppicing fallows	Zambia	Chipata	*Sesbania*	1-3	7.3

Source: Adapted from Sileshi et al. (2007).

Total annual deforestation for some southern Africa countries is estimated at 55,000 ha for Malawi, 323,000 ha for Tanzania, 264,000 ha for Zambia and 50,000 ha for

Zimbabwe (Geist, 1999). In addition, the ready availability of fuelwood reduces the burden and the time that household members especially women, would have spent walking long distances in search of fuelwood in the forests.

2.2.3 Improvement in soil health and biodiversity

Fertilizer trees/shrubs improve the physical properties of soils. In particular, soil aggregation is higher in fields where fertilizer trees are being grown, and this enhances water infiltration and water holding capacity of soils thereby reducing water runoff and soil erosion (Phiri et al., 2003). As a result, fertilizer trees/shrubs have the potential to help reduce the impact of droughts, a common seasonal phenomenon in southern Africa where agriculture is mainly rain-fed. The repeated application of tree biomass increases the soil organic matter that leads to important increases in soil water retention capacity.

The tree biomass and roots also provide favourable environment for soil microbes and fauna which in turn break down the biomass and release plant nutrients. Fertilizer trees/shrubs enhance soil activity of soil fauna and flora that perform important ecosystem functions (Sileshi and Mafongoya, 2006). In some cases, fertilizer tree systems harbour about the same diversity and abundance of soil invertebrates as the miombo woodland. This diversity can, in time, provide ecological resilience and contribute to the maintenance of beneficial ecological functions such as pest suppression. Fertilizer trees also help to reduce incidence of noxious weeds such as *Striga* and termite problems (Sileshi et al., 2005) which become more serious under conditions of low soil fertility.

2.2.4 Minimizing runoff and soil erosion

Soil aggregation is higher in fertilizer trees/shrubs agroforestry system and this enhances water infiltration and water holding capacity (Phiri et al., 2003). *Leucaena* contour hedges have effectively controlled soil erosion on steep slopes in Malawi (Banda *et al*., 1994). The benefits of fertilizer trees/shrubs to household food security and their potential to contribute ecosystem services and respond to climate change is summarized in Table 2.

Table 2: Yield and ecosystem service benefits of agroforestry-based fertilizer trees/shrubs at farm and community levels

Farm level	Community
• 2-3 folds maize yield increase • Increase in maize stover for livestock • Fuel wood available in field, reduces time spent searching for wood • Potential to mitigate the effects of drought during maize growing season • Stakes for curing tobacco leaves	• Carbon sequestration • Reduced soil erosion through better soil water conservation • Enhanced biodiversity • Wind breaks • Sources of fuel wood and potentially avoided deforestation

3 Adoptability and dissemination of fertilizer trees/shrubs in southern Africa

The potential of fertilizer trees/shrubs to generate ecosystem services for the benefit of the wider community is dependent on the extent to which individual land users decide to invest in (adopt) the practice. While some success stories have been recorded in some locations but in general, farmer adoption of fertilizer trees/shrubs has lagged behind scientific advances attained thereby reducing the potential impact of the practices to generate ecosystem services and contribute to adaptation and mitigation potential to climate change. Field studies carried out in Zambia (Franzel, 2004; Ajayi et al., 2007c) reveal that fertilizer trees/shrubs are more financially profitable than continuous maize production without external fertilizer addition, which is the *de facto* land use practiced by most smallholder farmers who have no access to fertilizer.

However, as common with most sustainable agricultural practices, there exists a time lag between the time that investments are made to adopt the practice and, the realization of the benefits. This creates an adoption threshold and has important implications for low income farmers. The time lag is particularly long for tree-based land use management practices such as agroforestry. From a farmer's perspective, the time lag is important because it has two implications: (i) immediate investment has to be made upfront while expected returns occur at a relatively longer-term, (2) there is a tradeoff between current maize yield and the yield obtainable in the future. While fertilizer trees/shrubs are profitable over time, i.e. its net present value is positive. Farmers often have to wait for about 2 years before they begin to realize these benefits. However, they begin to accrue some benefits from conventional land use practices from the first year of investment, even though some of the conventional land use practices are less profitable over the five-year period (Figure 1).

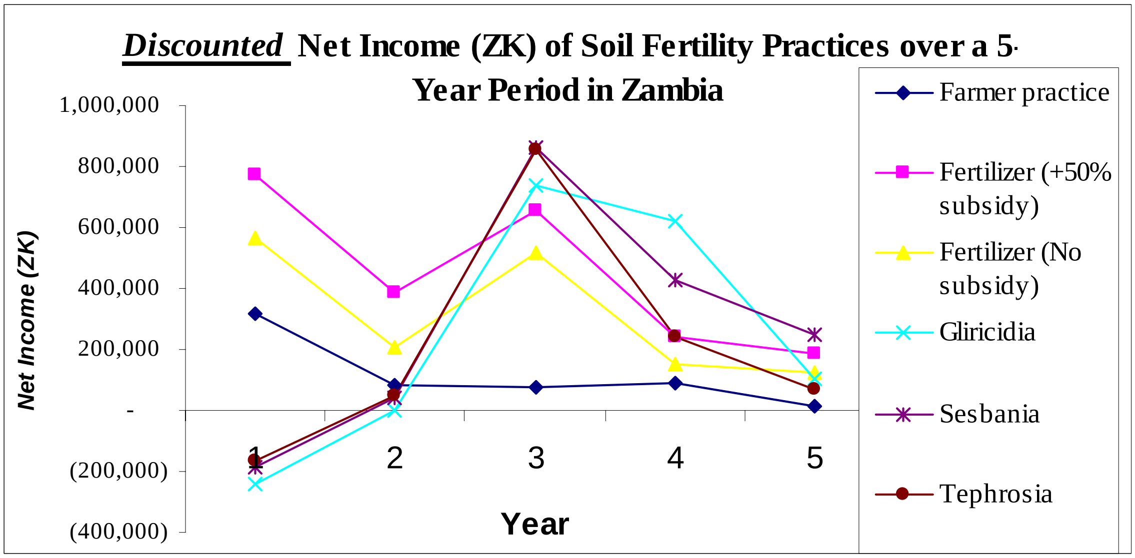

Fig. 1: Cash flow for different land use practices in Zambia

This implies that smallholder farmers must absorb net losses for two or more years before receiving profits from their investment. During the "waiting" period, farmers are at their most vulnerable, financially and may need some support. Where farmers' immediate agenda is short-term production for survival, then it is likely that they will not adopt sustainable land use practices even though such practices are natural resource-conserving and more compatible with environmental quality. Intra-annual cash flow is one of the key constraints to realizing the potential high adoptability of fertilizer trees/shrubs. The need to bridge this gap is important in poor countries where the level of poverty and social discounting rate are high and, opportunities for credit are low.

4. Strategies for promoting sustainable land use practices and their contributions to climate change

For a long time, efforts to scale up fertilizer trees/shrubs among farmers in southern Africa have been based on the assumption that information and appropriate inputs are the main constraints. It was implicitly assumed that lack of information and farmer awareness are the key constraints to the wider uptake of the practice and as a result, scaling up approaches were geared towards filling the gap in farmers' knowledge through moral persuasion efforts such as farmer sensitization programmes, farmer training, field demonstration and, farmer exchange visits. But we still perceive sub-optimal levels of investment and adoption of the same, and this may not be explained exclusively on the basis of biophysical and financial performance or lack of farmer awareness. In addition to increased farmer awareness and dissemination of information about sustainable land use practices, we identified important strategies as stated below to address for addressing the problem of low adoption of technically proven sustainable land use practices such as fertilizer trees/shrubs and, promoting their adoption in order to that provide individual benefits- e.g. food production- while contributing to ecosystem services, e.g. reducing net GHG emissions.

4.1 Conditional reward and incentive mechanism

Agricultural activities to produce food and fibre may also generate other impacts

– positive or negative – on ecosystem services but, if these impacts are not reflected in farmers' incomes, they will not likely be important considerations in most farmers' choices (FAO, 2007). From the individual farmer's perspective, the ecosystem services including biodiversity conservation and carbon sequestration benefits of fertilizer tree/shrubs are externalities and thus, farmers are not likely to take them into consideration in making their land use decisions (Izac, 1997). As a result, the probability that smallholder farmers will take into consideration or adopt land use practices that produce these environmental services is reduced. The reason is because farmers make decisions on alternative agricultural practices based on the incentives they perceive as individuals, without taking cognizance of the ecosystem benefits (Pagiola et al., 2004).

In efforts to respond to this problem, conditional incentives mechanisms were proposed through which farmers are rewarded for the environmental services that they generate.

The mechanism creates systems in which the users of one or more of these ecosystem services reward resource managers for continuous generation and or improved conservation of these services. The logic underlining Payments for Ecosystem Services (PES) is that the rewards made to farmers for the ecosystem service produced by a given sustainable land use practice enhances the likelihood that farmers will make a choice in favour of such sustainable practices rather than otherwise. The PES is thus an approach to align the incentives of individual land users with those of society as a whole. For farm households in degraded environments and especially in poorest countries, incentive mechanisms (e.g. for carbon sequestration) in agricultural soils could simultaneously contribute to rural poverty alleviation, improved agricultural sustainability, and mitigating the effects of climate change (Antle and Diagana, 2003).

A conceptual framework based on environmental economics and externality theory to underlining the use of conditional reward mechanisms as an additional approach for promoting the adoption of fertilizer trees/shrubs in southern Africa have been described in detail elsewhere (Ajayi and Matakala, 2006; Ajayi et al., 2007b; Ajayi et al., 2007c). Although most of the experimentation with conditional incentives for land use practices and ecosystem services took place in Central America (Pagiola et al., 2004), it is recently being experimented increasingly in Africa. Examples of initiatives (mainly Carbon payments) to encourage the adoption of agri-environmental land use practices in Malawi and Zambia include the government of Malawi Tree planting (for carbon) initiative, Clinton-Hunter Foundation carbon initiative and the Carbon Poverty Reduction being initiated by COMESA.

4.2 Review of existing policies on land use practices

Several factors affect the incentives that influence smallholder farmers' land use management decisions which ultimately result in either soil conservation or soil degradation. These include property rights; market failures caused by a lack of well-functioning political, legal, and economic institutions. Government policies that inadvertently but explicitly encourage the production of food and fibre only, at the expense of other ecosystem services can cause ecosystem degradation and or make them to respond poorly to climate change adaptation and mitigation. In many countries, conventional agricultural practices are often subsidized by the government through various price and institutional supports. These policies may create structural shifts and path dependencies that make some land use practices less financially attractive to farmers.

The incentives needed for farmers to maintain a sustainable practice depend on a range of policies and other economic factors that affect profitability. As a result, changes in economic factors could make a previously profitable practice to become unprofitable and cause farmers to dis-adopt them. For example, alley farming was considered impractical as a soil fertility technology in some parts of West Africa some years back because the prices of mineral fertilizer were artificially low and this made fertilizers a cheaper and more rationale option from the perspective of individual farmers (Sanchez, 1999). The situation has changed in recent years with global rise in the cost of fossil fuels, and consequently on chemical fertilizers. Therefore, in addition to having the “right” land use practices that respond to climate change, it is important to have the “right” policy, market and institutional context that is conducive to promote the practices.

4.3 Science-policy forums to bridge information gap in policy making processes on land use and climate change

Although there are candidate land use practices that contribute to adaptation and mitigation of climate change in addition to promoting food security, the successful scaling up of these practices depends on the availability of accurate information to policy makers on the impacts of climate change and the potential solutions that specific land use practices offer to the challenges of climate change and enable farming communities make appropriate decisions in different regions. There is a need for new institutional forms to bring science (technology development) and policy making together to examine food security through a sustainable multi-faceted development lens. The forums should provide a knowledge base and form the basis for dialogue among representatives from broader public viewpoints including policymakers, researchers and other stakeholders. The need for the participation of broader public stakeholders is important because policies emerge from policy processes that are themselves embedded in political processes, and the political feasibility of expected institutional changes (Ajayi et al., 2007b).

As pointed out by Sileshi et al (2007), there has been lack of appreciation of the ecosystem benefits of agroforestry-based land use practices and as a result, little attention has been paid to accelerate their adoption and mainstreaming them into agricultural and natural resource management programmes in the region. One of the reasons for the lack of appreciation is inadequate dissemination of knowledge to policy makers on the ecosystem services provided by various agroforestry practices. Science-policy forums provide ample opportunities to bridge this information gap and enhance opportunities of agroforestry-based land use practices informed policy making processes in the region.

4.4 Equipping new graduates and re-tooling extension officers with knowledge to respond to climate change phenomenon

Climate change causes important changes in African agriculture and will continue to do so for the fore-seeable future. The farming community will be required to react to the changes through various means such as making adjustments in farming practices, crop varieties planted, modifying the cropping calendar, and engaging on other risk minimization strategies. These changes may pose challenges to agricultural extension services in many countries as their competence to deliver appropriate services to the farming communities under the changing scenarios may have been compromised due to limited knowledge. Educational and vocational institutions in agriculture and natural resource management should be geared towards reacting pro-actively to these changes and new expectations ensuring that agricultural graduates are well trained to appreciate and be able to respond appropriately and provide information on the effects of climate change to farmers and other stakeholders in the fields. This may imply re-tooling extension workers already in the field, and or modifying curriculum to include topics on "climate change and African agriculture".

One of the characteristics of fertilizer trees/shrubs and sustainable agricultural land use practices is that they are knowledge intensive and relatively new technologies compared with conventional land use practices that farmers have been using over a long period. In many cases, human capacity for fertilizer trees/shrubs is low in most national extension programs and thus the need for increased support to reach many more farmers to adopt the technologies. This information gap should be bridged.

5 Conclusion

Human activities are wreaking havoc on the atmosphere, and this poses a threat to communities globally, but particularly in poorer countries where the ability to adapt is lower. Sub-Saharan African countries and in particular, southern African region faces the challenge to implement policies for achieving livelihood needs, promote environmental stewardship and respond to the challenges of climate change. The challenge however is not so much the absence of science and technological options that can help improve their productivity and respond to climate change, given the availability of proven sustainable agricultural and land use practices such as fertilizer trees/shrubs to meet some of the challenges. Rather one of the greatest constraints is concerns for immediate livelihood survival and the failure of markets and policies which undermine the capacity of poor farmers to use available or prospective technologies.

Based on the analyses and discussion presented above we conclude that in low-income and food-deficit regions of southern Africa, livelihoods including food security and climate change cannot be tackled in isolation. We therefore recommend that responses to the challenges of climate change should be made within the context of sustainable development taking into consideration livelihood and food security needs of subsistence farmers. Beyond having the “right” field technologies and land use practices that adapt to climate change, there should be complementary “right” politics, market and policies that are conducive to the scaling up of these field practices. A key question is how the wider society- community, national and international- can motivate farmers to reduce negative side-effects and adapt to climate change while continuing to meet the increasing demand for agricultural produce.

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