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Review

Balancing agricultural production goals with environmental stewardship

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One of the greatest challenges in many Sub-Saharan Africa countries especially where seasonal food deficits occur frequently, is how best to achieve a balance between the goals of food security and agricultural production on the one hand, and the concerns for the conservation of environmental quality and natural resources capital on the other. A number of agricultural production technologies (based on natural resource management principles) exist that offer opportunities for achieving the two seemingly divergent goals because they have the characteristics to produce joint multiple outputs, i.e, they produce food and provide environmental services. However, farmer adoption of these technologies has generally been limited. Drawing from natural resource economics, this study presents a conceptual framework that provide environmental-economic logic for establishing incentives that internalize the environmental services produced by multiple-outputs land use technologies. Using a land use practice based on agroforestry principles (that is, "improved tree fallows") as a case study, this paper synthesizes studies carried out in southern Africa region for over a decade. It then discusses how the potential impacts of the technological advances made in research and development are affected by policy and institutional constraints, among other challenges. With particular emphasis on the socio-economic context in southern Africa, the paper identifies options for addressing these institutional and policy constraints in order to facilitate adoption of multi- output land use practices by farmers and unlock their potential to meet food production goals for individual households and environmental services for the wider society.

Key words: Adoption, Agri -Environmental quality, Environmental services, Natural resource economics, Payment for environmental services, Science-policy linkages.

INTRODUCTION

In low- income countries especially in Sub-Saharan Africa where seasonal food deficits are recurrent, one of the greatest development challenges is how best to balance seemingly conflicting goals of agricultural production with environmental stewardship. In the quest to reconcile the food security deficit of today with the environmental debt of tomorrow, there is the tendency to prioritize food security over the concern for the environment. Despite this challenge, there exist agricultural land use practices that produce multiple outputs that offer potential opportunities for achieving the two seemingly polarized objectives. The adoption and diffusion of such technologies among

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smallholder farmers have however lagged behind scientific and technological advances made in such practices thereby reducing their potential impacts (Ayuk, 2001; Ajayi et al., 2003; Mercer, 2004). Focusing on southern Africa region, this paper has three objectives, (i) highlight an agroforestry land use practice (that is “improved tree fallows”) as an example of a multi-output land use practice (MOLUP) that has the potential to help farmers meet food production for their households and conserve environmental quality for the benefit of the larger society, (ii) present a conceptual framework that explains how the costs and benefits of investments in MOLUP differ from the private and public perspectives and how this difference gives insights for understanding the sub-optimal level of investment and adoption of MOLUPs, (3) identify options to enhance the adoption of MOLUPs through facilitating conducive policies, recognizing and rewarding environmental service(s) generated by MOLUPs that are of value to a wider society.

Soil fertility problems and the role of “improved tree fallows” land use system

Economic Importance of Soil Fertility Problems In Southern Africa

Declining soil fertility and low macro-nutrient levels is a fundamental impediment to agricultural growth and a major negative social externality in sub-Saharan Africa (Sanchez, 2002; Vanlauwe and Giller, 2006). The soils in sub-Saharan Africa are being depleted at annual rates of 22 kg/ha for nitrogen, 2.5 kg/ha for phosphorus, and 15 kg/ha for potassium (Smaling et al., 1997). The low soil fertility base is caused by two factors. The first is that the methods used to restore the fertility of soils under traditional shifting agriculture, have become ineffective, and in some cases, they have disappeared altogether. 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. The second is that, most smallholder farmers continuously cultivate crops without using fertilizers or they have drastically reduced the use of inorganic fertilizer after the removal of farm inputs subsidies and the collapse of para-state agricultural inputs and output marketing agencies. For example, in Zambia, the ratio between the prices of nitrogen and the major crop (maize) increased four-folds after the removal of price subsidies on nitrogen fertilizer and this led to a 70% decline in fertilizer use by farmers (Howard and Mungoma, 1996). Similar results were reported elsewhere in Africa (Honlonkou, 2004). In southern African region, fertilizer market is further constrained by the geographically landlocked nature of many countries, and the poor road infrastructure which hinders access to agricultural inputs at costs that are affordable to small- holder farmers. The cost of inorganic nitrogen fertilizers at the farm gate is estimated to be between two to six times higher in sub-Saharan Africa than in Europe or North America (Donavan, 1996; Sanchez, 2002). In addition, to its primary effects of declining per-capita food production, poor soil fertility triggers other effects such as reduction in fuelwood and high deforestation rates (as farmers are forced to abandon poor soils and encroach on forests which are more fertile). These have the predictable consequence of accelerating degradation of the natural resource capital and compromise environmental stewardship by farmers.

In response to the challenges highlighted above, an agroforestry-based land use practice, “improved tree fallow” (*sensu* Sanchez, 1999) was developed in southern Africa region in the late 1980s. The practice involves planting fast growing plant species, mainly nitrogen-fixing shrubs and trees that produce large quantities of biomass that easily decompose to meet the nitrogen demands of crops such as maize (Kwesiga and Coe, 1994; Mafongoya et al., 2006). It builds on the fact that while nitrogen is the most limiting macro nutrient in the soil, it is highly abundant in the atmosphere. The trees replenish soil fertility by fixing atmospheric nitrogen in the soil, thus contributing to higher crop productivity and enhancing food security (Kwesiga et al., 1999; Mafongoya et al., 2003). A typical improved tree fallow begins by planting tree (or shrub) species as a pure stand or intercropped with food crops and allowed to grow for two or more years. After this period, the leguminous trees are cut and the biomass is incorporated into the soil during land preparation. The tree biomass easily decomposes and makes nutrients available for crops (usually maize) for subsequent 2 - 3 years without adding external fertilizer.

Joint Output Characteristics of Improved Fallow Land Use Practices

Improved tree fallow increases maize yield (the staple food crop in the region) and thus contributes to improving food security. Results from on-station and on-farm trials of improved fallows consistently show significant increases in maize yields compared with farmers’ practice (continuous maize production without fertilizer). Maize yield increases from improved fallows reach two or more times higher than smallholder farmers’ practice of continuous maize cropping without nutrient inputs (Kwesiga et al., 2003; Akinnifesi et al., 2006). Detailed impact assessment conducted in Zambia showed that based on an average of 0.20 hectares of land presently devoted to the technology, and using per capita maize consumption, the technology enhanced food security for households by providing between 57 and 114 extra person days of maize consumption per household per year. Thus, the seasonal hunger that most households in the country experience is reduced by about 2-4 months depending on the type of tree species used and length of the fallow per-iod (Ajayi et al., 2007a).

Irrespective of the primary reason farmers have for planting trees, such action usually fulfils several functions including food production, protecting the soil from soil erosion, protecting the river from eutrophication, enhancing soil biodiversity and carbon sequestration (Schroth and Sinclair, 2003). As a tree-based land use practice, in addition to food production, improved tree fallow practice provides environmental services that contribute to improving environmental quality. Some of these are described in the next section.

Carbon sequestration

Carbon sequestration through changes in land use and management is one of the important strategies to mitigate the global greenhouse effect (Unruh et al., 1993; Tan and Lal, 2005). Agroforestry has been described as an important land use system suitable for carbon sequestration strategy because of the carbon storage potential in its multiple plant species and soil. Average carbon storage by agroforestry practices has been estimated as 9, 21, 50, and 63 Mg $ha^{-1}$of carbon per year in semiarid, sub humid, humid, and temperate regions, respectively and in smallholder agroforestry systems in the tropics, potential annual carbon sequestration rates range from 1.5 to 3.5 Mg ha^{-1} of carbon per year (Montagnini and Nair, 2004). Similarly, Albrecht and Kandji (2003) have estimated the C sequestration in tropical agroforestry systems to range between 12 and 228 Mg $ha\text{-}^{1}$, and a mean of 95 Mg $ha\text{-}^{1}$. In recent study in Malawi, Makumba et al (2007) estimated that Gliricidia/maize intercropping system sequestered between 123 and 149 Mg $ha\text{-}^{1}$ in the 0 - 200cm soil depth via root turnover and cumulative effect of pruning application. As in other land use practices, the extent of carbon sequestered depends on the amounts of carbon in standing biomass, recalcitrant carbon remaining in the soil, and carbon sequestered in wood products. Although pure forests sequester higher amounts of carbon and contribute more to improved climate change, taking land out completely for forestation for many years to produce environmental goods may not be attractive to smallholder farmers. This is particularly true among small-scale farmers in food deficit nations where the opportunity cost of doing so (in terms of the amount of food production that will be forgone) are substantially high. Improved fallow has an indirect effect on carbon sequestration by decreasing pressure on natural forests, which are the largest sink of terrestrial C (Sanchez and Jama, 2002; Montagnini and Nair, 2004).

Enhancing soil biodiversity

Although improved fallow trees are promoted primarily as low-input approach suitable for soil fertility replenishment in resource-poor smallholder agriculture, they also help to improve soil biodiversity. A long term study con-ducted in Zambia (Sileshi and Mafongoya, 2006; Sileshi et al., 2006) concluded that the tree legume fallows have an overall net positive impact on the soil invertebrates. The soil invertebrates perform important ecosystem functions that can affect plant growth. Some improved fallow species reduce pests such as termites (Sileshi and Mafongoya, 2003; Sileshi et al., 2005) and noxious weeds including *Striga* species which limit cereal crop production (Kwesiga et al., 2003; Sileshi and Mafongoya, 2003; Sileshi et al., 2006).

Effects on drought

Improved fallow mitigates the effects of droughts in addi-tion to improving the fertility and physical properties of the soil. This is because in tree fallows, soil aggregation is hig-her and this enhances water infiltration and water holding capacity which reduces water runoff and soil erosion (Phiri et al., 2003). Further details on the improvement of soil physical properties by improved fallow through increases in infiltration rates and reduced runoff and soil losses have been described elsewhere (Chirwa et al., 2003; Chirwa et al., 2007) . Improved fallows decrease soil ero-sion by maintaining a ground canopy during dry season and more vigorous growth during the rainy season (San-chez and Jama, 2002). These environmental services ext-end to other farms beyond the fields of a farmer who has planted the legume trees.

Effect on deforestation

The harvest of fuel wood amounting to over 10 ton ha^{-1} has been recorded in *Sesbania sesban* improved tree fallow plots within two years of growth of the trees (Kwesiga et al., 1999).

To the extent that farmers are able to source for fuel and other wood requirements for their households from improved fallow fields, cutting of wood from communally owned forests may be minimized and hence reduce deforestation. A study in southern Africa region established that of the total amount of firewood consumed by rural households (3.1 ton per household per year), improved fallow fields contributed 11% on average (Govere, 2002). This proportion is assumed to increase if more farmers adopt improved fallows.

Table 1 summarizes the multiple direct and indirect costs and benefits of improved tree fallows. Several of the items listed as costs and benefits occur on the same fallow depending on the type of tree species planted. For many of these items, a more rigorous study will be needed to quantify their economic value. While there exists some negative spill-over effects from agroforestry land use practice (Ajayi and Kwesiga, 2003), many of the effects of the land use practice are beneficial. The benefits

Table 1. Multiple effects of “improved fallow” land use practice.

	Private	Social
Cost	Land Labour Tree seeds and nursery establishment Increased pest control (e.g. in *Sesbania sesban* plant) Working equipment Risk of fire outbreak	Incidence of pests e.g. Mesoplatys beetle and root-knot nematodes (in *Sesbania* species) Reduction of free grazing area during dry season Risk of uncontrolled fire outbreak
Benefit	Yield increase of subsequent crop Increase in fodder and maize stubble (for livestock) Fuel wood- available in field, and so reduces time spent searching for firewood Leaves of *Tephrosia vogelii* used as “pesticides” in crop and livestock production. Suppresses the growth of weeds Potential to mitigate the effects of drought during maize season Stakes for curing tobacco leaves Opportunity for farm diversification (e.g. compatible with fish farming and growing of high-value vegetables)	Carbon sequestration Suppression of weeds Improved soil infiltration and reduced runoff Enhanced biodiversity Serves as wind breaks More fuel wood available to reduce deforestation

Source: Ajayi and Matakala (2006).

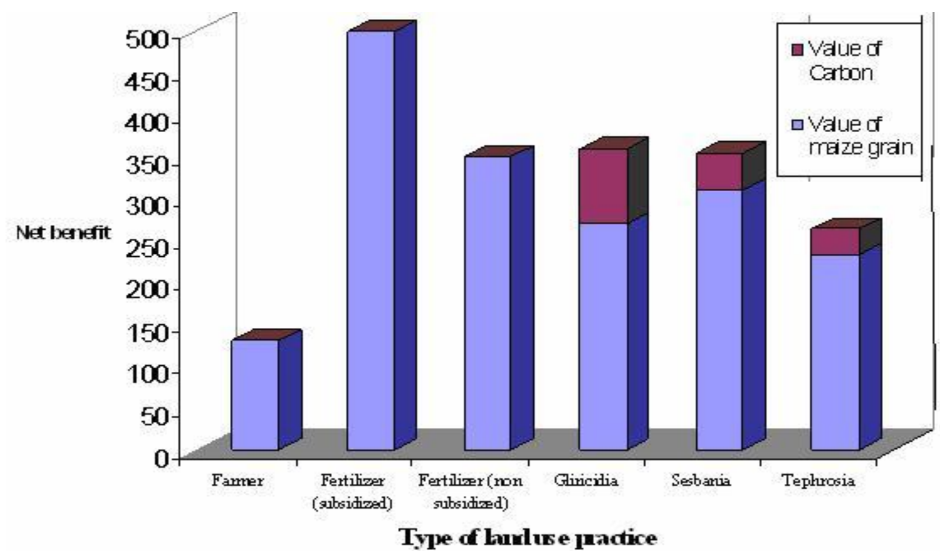

Figure 1. Net benefit (US$/ha) of land use practices

mentioned above apply to most plant species used for improved tree fallows, but the magnitude of such benefits vary across species, location and the number of years that the trees grow before they are cut (Table 1).

Financial profitability of land use practices

Taking into account food production (maize yield) only, financial analyses carried out on different land use practices (Place et al., 2002; Franzel, 2004) show that agroforestry land use practice is more profitable than farmers' practice of continuous maize cultivation without external nutrient supplement but it is less profitable than mineral fertilizer, especially when the latter is subsidized. In a recent study, detailed field monitoring of farm inputs used (labour, fertilizer, seeds, etc) and outputs (maize yield) data were collected from 193 maize fields where different land use practices were used was carried out in Zambia (Ajayi et al., 2007a) Figure 1.

The financial analysis of improved tree fallow compared with continuous cropping production systems (with and without fertilizer) showed that over a five-year cycle (2 years of fallow and three years of cropping), improved tree fallow option yielded a net profit (Net Present Value) ranging between $233 and $309 per hectare. This is represented by the blue colour in the bar graph in Figure 1. This compares with a net benefit of $499 ha^{-1} where subsidized fertilizer was used and $349 ha^{-1} when fertilizer was valued at non-subsidized market prices. The result shows that based on maize yield (food security) criterion alone, the net profit (and hence potential adoptability) of subsidized mineral fertilizer is superior to MOLUPs such as improved fallows land use practice. For individual farmers who are seeking to satisfy food security goals alone, it follows therefore that the rationale choice of land use practice will be in favour of fertilizer rather MOLUPs.

When environmental “outputs” and stewardship of land use practices (the benefits of which accrue to the public rather than individual farmer alone) are taken into account, the outlook of the net profit of the different land use practices changes. In Figure 1, the red portion of the chart represents the value of one of the environmental services (carbon sequestered). When the value of carbon is included, the net benefit of MOLUP (improved tree fallow) increases and is comparable to that of mineral fertilizer option. With the increased net profit, the potential attractiveness and adoptability of MOLUP among farmers are expected to increase accordingly.

This implies that with the inclusion of environmental “outputs”, two classes of land use practices can be distinguished: one whose benefits can be appropriated primarily by farmers at the field level and another which offers benefits both to farmers and the society (but in which the benefits accruing to the latter cannot be appropriated by individual farmers at the field level). For the two types of land use practices, their net benefit and potential adoption by farmers will vary depending on the extent to which the environmental services “produced” are recognized and rewarded.

Details of the environmental economic logic underlining the conceptual framework to explain the importance of exclusion/inclusion of environmental stewardship in economic assessment of land use practices and how this affects the adoption of MOLUPs is presented in section 3.0

Environmental-Economic Conceptual Framework For Understanding Investment In Molups

In Figure 2, the cost of adoption of a land use practice (LUP) that produces a single product (e.g. maize yield only) is represented by the “cost” curve and it follows the normal production cost curve. The benefits of the LUP (i.e. value of crop produced) is represented by the “private benefit” line. It has a constant slope because the value of crop output increases commensurately with the physical quantity of crop production (that is, assuming a perfect competition market scenario) . The optimum level of adoption is obtained at point “A” where the marginal increase in cost and benefit are the same (that is, where the slope of cost and benefit lines are parallel). At adoption level below “A”, a farmer gets higher net incremental benefit than cost from the use of the technology and so it pays to adopt more of that LUP. The opposite occurs when adoption level is beyond “A”. Thus for LUPs that produce only a single product, the rationale domain of adoption for an individual farmer lies between O and A only Figure 2.

For MOLUPs however, the benefits of their adoption by farmers shifts from the “private benefit” line to the “social benefit” when the additional environmental “outputs” that they produce are considered. With the addition of the environmental benefits, marginal benefit equals marginal cost at a higher level and as a result, the social optimum of adoption increases to “B”. The optimum level of adoption of MOLUPs from community perspectives is always higher than that of the individual for two related reasons. Firstly, private and social costs of soil fertility depletion (a problem that MOLUPS address) and the private and social benefits of investments in soil fertility improvements differ from the perspective of individual farmers and that of the society as a whole. The difference arises because individual farmers tend to under-estimate the real user-cost of soil depletion and as a result, they tend to discount future costs and benefits of investment in soil fertility improvements at higher rate than that which the social policy makers, acting on the behalf of the society, would use. This situation leads to higher current rates of soil depletion which from the individual’s (private) perspective is rational, since farmers would prefer to defer costs to the future, but not necessarily so from the public perspective (Izac, 1997; Ayuk, 2001; Izac, 2003).

Second, given that the benefits from the adoption of MOLUPs spill over to the wider society at large, the resulting beneficial impact represents positive externality to the public (who benefits without necessarily sharing in the cost of adoption). Where such positive externalities exist, and there is no incentive system to reward individual farmers (investors), then the level of investment (in this context, adoption of MOLUPs by farmers) will be less than optimal (FAO, 2001; Ajayi and Matakala, 2006). As a result, to attain a shift in the level of adoption of MOLUPs from “A” to “B” may require facilitation of public investment policies that recognize and reward investors for the environmental stewardship and benefits that are produced by MOLUPs to the society. The existence of such supportive policies will contribute to helping meet the challenge of food security and environmental stewardship by enhancing the adoption of MOLUPs by smallholder farmers.

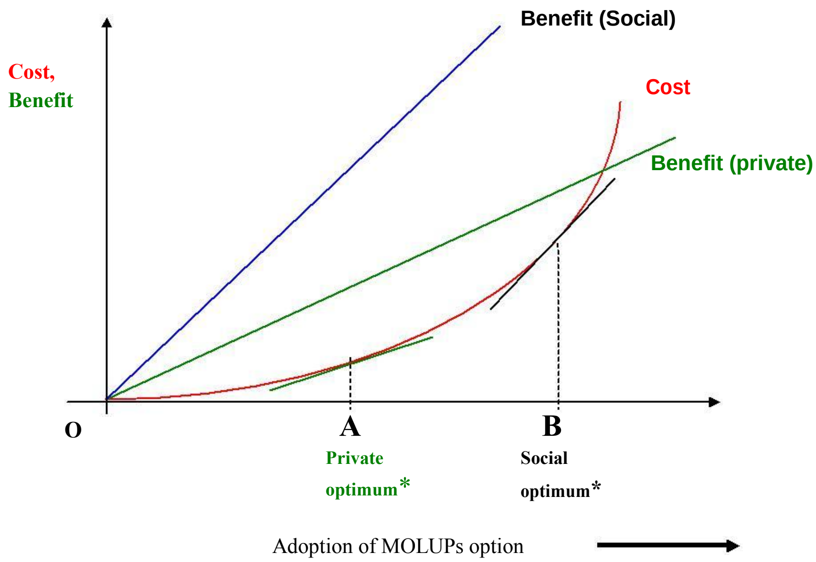

Figure 2. Framework for assessing adoption potential of multi-output LUPs under different reward systems.

A number of efforts towards a targeted reward and incentives to farmers for environment services provided by trees are being initiated in southern Africa region. These include the PRESA (Brent Swallow, Pers. Comms., 2007) for selected countries in Africa, Clinton-Hunter Foundation for Carbon in Malawi and the "Tree Planting Campaign" efforts by the Malawi Government and championed by the Department of Forestry. A Pilot Project on "Payment for Environmental Services in Africa (PESA)" has recently been initiated by the World Agroforestry Centre (ICRAF) and partners in selected countries in Africa (Brent Swallow, Sept 2007, Pers. Comms.) . Among other obj-ectives, the project assesses if there is a linkage between land use practices and the generation of an environ-mental service(s) that is of value to a beneficiary group and then identifies mechanisms for making payments only when some impacts on certain environmental ser-vice(s) can be demonstrated. A reward mechanism that rewards land users for the production of global environ-mental services that smallholder farmers generate has been on-going in South America for a number of years (Pagiola et al., 2004). The opportunities and challenges associated with the implementation of such schemes have been well documented.

Policies and Strategies for Rewarding And Enhancing Molups

Land users make decisions on alternative agricultural practices based on the incentives they perceive as individuals, without necessarily considering the environmental benefits that the various LUPs may offer (Pagiola et al., 2004). The adoption of MOLUPs is likely to remain at sub-optimal level from the perspectives of the society because of market and policy failures. Market failure occurs because a functioning market for buying and selling environment goods and arbitrating between producers (farmers) and consumers of environment services (the public) do not exist or has not been well developed. The common property nature of environment services creates a social dilemma because an individual farmer lacks incentives to consider environmental stewardship .

In section 4, we identified strategies and policy options to align smallholder farmers' incentives with those of society as a whole in making land use decisions, taking cognizance of the socio-economic context of farmers in southern Africa region.

Appraisal of current national policies that have direct and indirect effects on land use practices

Farmers' adoption decisions are strongly influenced by the policy and institutional context within which technologies are disseminated to potential users (Ajayi et al., 2007b; Ajayi et al., 2007c) . National policies and international trade policies may impact on the incentives for smallholder farm households to manage their soil resources in a sustainable manner such as modifying the relative (private) profitability and net returns from land use systems and altering the attractiveness and potential adoptability of soil fertility management practices. In many countries, some land use practices (e.g. those that offer immediate results) are often subsidized (directly or otherwise) by the government through various price and institutional supports. Over several years, these government policies have created structural shifts and path dependences that make MOLUPs less financially attractive to smallholder farmers. For example, improved fallow soil fertility technologies were considered impractical in some parts of West Africa some years back because the cost of fertilizers were artificially low, making them a cheaper and more rational option from the perspective of an individual farmer (Sanchez, 1999). A review of the impact of institutions and policies to support the adoption of soil fertility technologies in Zambia and Zimbabwe reveal that the low producer pricing policies adopted by several governments in the region heavily tax smallholders in favour of urban consumers, thus reducing the financial ability of farmers to invest in soil fertility management technologies (Mekuria and Waddington, 2004). Institutional arrangements such as land tenure will become important and need to be improved upon for the wider uptake of multi-output LUPs by farmers. This is because the financial returns to some MOLUPs are obtained in the medium and long run, and it is most likely that farmers will be cautious to invest their scarce resources in such practices when they do not know how long they will stay on the land.

As part of the efforts to “getting the policy right”, there is need to evaluate existing national and regional policies to determine whether they have inadvertently created direct and/or indirect (dis)incentives to MOLUPs. Such appraisal requires effective institutional arrangements and forums to appropriately inform public policy. This requires the participation of wider range of different public stakeholders because policies emerge from policy processes that are themselves embedded in political processes, and the political feasibility of expected institutional changes. The extent to which local and national policy-making processes accept and institutionalize MOLUPs (e.g. through specific policy documents and budgetary allocations) will play an important role in smallholder farmers’ adoption of the practices.

Targeted incentive-based system for the production of environmental services

There is need for appropriate mechanisms for incentives to reward adopters for the environmental services produced by MOLUPs. The ratification of the Kyoto Protocol on Climate Change and its coming into force in 2005 has given rise to new opportunities to highlight issues on carbon trading and incentives to reward multi-output LUPs. A recent study in southern Africa shows that carbon sto-red in improved fallow varied between 2.5 to 3.6 tons ha^{-1} $year^{-1}$ (Paramu Mafongoya, pers. comms, 2005). At current world prices for carbon, improved fallows have the potential to increase small-holder farmers’ income and provide incentives for them to make land use decisions in favour of multi-output LUPs and hence produce more environmental services. In a continental-wide survey to identify cases of successes in African agriculture, incentives were cited as the second most important trigger for inducing change towards success in the continent, surpassed only by expansion of production possibilities (Gabre-Madhin and Haggblade, 2004).

Cushioning the effects of time lag between investment and accrual of benefits

While most multi-output LUPs are profitable over time (positive net present values), their break-even point only occurs somewhere between 2 to 3 years of establishment of the fallow plots. This implies that smallholder farmers must absorb net losses for two years before receiving profits from adoption. This poses a challenge for farmers especially in a sub-region where the cost of capital and discounting factor is high. During the “waiting” period, smallholder farmers are financially vulnerable state and may need some support. A targeted and time-bound assistance to farmers in the early years of adoption will be important to assist in cushioning the effects of the time lag between investment and accrual of benefit.

Information and training support to farming communities to adopt

Many MOLUPs are incipient technologies, compared with conventional land use practices which farmers have been used to and have received training for a much longer period. Given the “new” status of multi-output LUPs in the sub-region, human capacity, infrastructure and institutional support for such technologies are low in national extension programs and thus the need for increased support to reach many more farmers to adopt the technologies. Such support may include improving input and output market to enhance access of small-holder farmers to ensure that they get the premium price for their crop produce. In addition, unlike annual crop production technologies and conventional LUPs, most MOLUPs are more knowledge-intensive, requiring skills in terms of management of the technology. The costs of providing information greatly decrease over time, but it is critical when helping farmers get started with the practice.

CONCLUSION

The seasonal food shortages that some sub-saharan African countries face poses a big challenge regarding the maintaining environmental stewardship and conservation of natural resources and how these can be mainstreamed in the implementation of agricultural production and food security policies. Opportunities offered by multi-output land use practices such as “improved tree fallow” system to meet this challenge have not been fully exploited, as the adoption of such land use practices has generally lagged behind technological advances attained in them thereby reducing the impact that the practices have to contribute to food security and environmental services. In addition to improving soil fertility to enhance food production; improved tree fallows contribute to the sequestration of carbon, enhance biodiversity, and provide fuelwood that can help reduce deforestation. However, land users generally receive no incentive for the production or consumption of environmental services that result from decisions made on land use practices, and therefore they have little economic incentive to take environmental stewardship into account in making decisions about land use. A number of inferences can be drawn from the synthesis regarding the bridging of gap between actual and potential contributions of MOLUPS. First, is that there is need for an appraisal of existing policies and institutions to assess if and how they have created (dis)incentives to farmers' decision to invest in MOLUPs. Secondly, appropriate national and sub-regional policies and strategies are required to align smallholder farmers' incentives with those of society as a whole, and encourage farmers to take cognizance of environmental quality when making agricultural production decisions. Part of this strategy include a system to reward farmers when there is a linkage between land use practices and the generation of an environmental service(s) that is of value to all or certain beneficiary groups in the society.

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