Environmental conservation and food security in developing countries: Bridging the disconnect

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Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, Australia, August 12-18, 2006

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Abstract:

In many developing countries, environmental issues are often sacrificed for immediate food production requirements because of perceived tradeoff between the two. Some production systems exist however that offers opportunities for achieving the two seemingly divergent objectives because they have the characteristics to produce joint outputs; food production and environmental conservation, but their adoption in farming communities is socially sub-optimal despite proven technological success. Using natural resource economics framework, this study highlights the reasons for the low adoption of such technologies taking agroforestry technologies as a case study and, uses externality theory to provide environmental economic logic for developing incentives to internalize environmental services "produced" to enhance their adoption and unlock their potential to satisfy both food production and delivery of environmental services for the benefit of the wider public. Taking agroforestry as a case study, this paper examines environmental conservation through sustainable agriculture development lens and, concludes by outlining strategies for achieving this, taking cognizance of the socio-economic context of farmers in low income countries.

Key words: Externalities, Agricultural policy, Agricultural technology, Sustainability, Ecosystem services

1.0 Introduction

In many developing countries, agricultural production issues are critical and, in the dilemma that the countries faced to reconcile environmental debt of tomorrow with the food security deficits of today, some countries have supported rapid pay-off production systems which may inadvertently negatively affect the environment and natural resource capital base. In regions where per capita food production has remained stagnant or increased only marginally in the past decades, environmental issues are perceived as lesser problems or even in direct conflict with the goal of solving problems of food insecurity. There exist some production technologies that have the characteristics of producing positive joint outputs (PJOs) and thus offer potential opportunities for achieving these two seemingly polar objectives. However, the uptake of such technologies by farming communities has been generally low relative to their social optimum levels and as a result, their potential has generally been untapped. The objectives of this paper are three folds: (i) highlight agricultural production land use technologies that offer opportunities for achieving food production and environmental goods using agroforestry as a case study, (ii) use natural resource economics framework to highlight the divergence between private and social optimum and how this contributes to the socially sub-optimal adoption of the technologies (iii) identify strategies to bridge the gap taking cognizance of the context of small scale farmers in low income countries.

2.0 Agroforestry and its role in food production and environmental conservation

Agroforestry is a set of land use practices involving the deliberate combination of trees and agricultural crops and or animals on the same land management unit in some form of spatial arrangement or temporal sequences such that there are significant ecological and economic interactions between tree and agricultural components (Sinclair, 1999). Agroforestry technologies include “improved tree fallow” (for soil fertility

replenishment), rotational woodlots (for solving fuel wood problems) and indigenous fruit trees (for enhancing indigenous plant genetic materials and fruits). In this paper, particular emphasis is placed on improved tree fallow, highlighting its relevance in the production of food and environmental goods.

2.1 Description of "improved tree fallows"

"Improved tree fallows" is a soil fertility replenishment technology that was developed in southern African in the late eighties in response to the continuous depletion of soil fertility and the increasing challenges that smallholder farmers have to access inorganic fertilizer. This option involves planting fast growing plant species that are (usually) nitrogen-fixing, and produce easily decomposable biomass (Kwesiga and Coe, 1994). Based on nutrient recycling, the trees replenish soil fertility by transforming nitrogen from the atmosphere (where it is abundant) into the soil where it is needed to contribute to higher crop production. The technology involves planting (mainly) tree species, leaving them for about two years after which they are cut and the biomass incorporated into the soil during land preparation. The tree biomass easily decomposes and releases nutrients for crop production in the next 2-3 years without adding any external fertilizer. Technical detail of the technology is described elsewhere (Kwesiga et al, 2003; Mafongoya et al, 2003).

2.2 Joint output characteristics of improved fallows

2.2.1 Effects on soil fertility and crop yield

Research results from on-station and on-farm trials of improved tree fallows consistently show significant increases in maize yields improved fallow fields compared with common farmers' practice of continuous maize production without fertilizer. A synthesis of the results (Kwesiga et al., 2003) reveals that the yield increases from improved tree

fallow fields range between two and four times compared with those from continuous maize field without nutrient inputs. An example of the yield increase is given in Table 1.

Insert Table 1 "Maize grain yield after 2 year ... during 1998-2000" here

In addition to improved food production, the technology also "produces" other environmental services some of which are enumerated below. While farmers may not care for these services, they are important for other members of the society.

2.2.2 Carbon sink

Soil carbon sequestration through changes in land use and management is one of the important strategies to mitigate the global greenhouse effect (Tan and Lal, 2005). Agroforestry is an importance carbon sequestration strategy because of 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 C ha^{-1} in semiarid, sub humid, humid, and temperate regions respectively (Montagnini and Nair, 2004).

2.2.3 Effect on biodiversity and drought

Improved fallow trees enhance biodiversity and increase the population of soil invertebrates which perform important ecosystem functions that can affect plant growth (Sileshi and Mafongoya, 2006). In addition, the technology reduces the effects of droughts. This is because soil aggregation is higher in tree fallows fields, and this enhances water infiltration and water holding capacity which reduces water runoff and soil erosion (Phiri et al 2003). These environmental services are beneficial to other farmers within the landscape beyond the field of a farmer who has planted the agroforestry fields.

2.2.4 Effect on deforestation of public woodlands

Improved fallow has an indirect effect on Carbon sequestration when it helps decrease pressure on natural forests, which are the largest sink of terrestrial C (Sanchez and Jama,

2002; Montagnini and Nair, 2004). To the extent to which 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 and hence deforestation may be reduced. In addition to the above effects, improved fallow has multi-faceted direct and indirect effects details of which are presented in Table 2. While we cannot rule out completely the existence of negative externality from agroforestry (see for example Ajayi and Kwesiga, 2003); most of the externalities of agroforestry are generally positive.

Insert table 2 *"Types of benefits and costs associated with improved fallows"* ***here***

2.3 Farm profitability of improved fallows

Taking account of maize yield only, an analysis of the financial performance of improved fallows compared with conventional continuous cropping production systems (with and without fertilizer) show that over a five-year cycle, improved fallow options yield a net profit (Net Present Value or NPV) ranging between $233 and $309 per hectare (Table 3). This compares with a net benefit of $499 per hectare when fertilizer was subsidized and $349 when fertilizer was valued at market prices i.e., not subsidized. Thus, valued at real costs, the fertilizer option becomes much less profitable (reduced by 30%) and its net present value is very close to one of the fallow options (NPV of 349 compared to 309). The relative profitability of improved fallow land use systems would change if the non yield environmental services are incorporated

Insert Table 3 "Net profit of maize production per hectare …in Zambia" here

The results of financial profitability of the different land use systems indicate that changes in subsidies on fertilizer and other different policy scenarios affect the financial attractiveness and potential adoptability of land use systems by farmers even when crop yield and agronomic coefficients between inputs and outputs remain constant.

3.0 Conceptual framework for private and social optimum adoption of technologies with positive joint outputs

For technologies that produce joint outputs, optimal decisions are made when *both* the direct benefits of food production and the associated indirect environmental benefits are optimized and, exclusion of production externalities can overstate (understate) gains if some costs (benefits) are not counted. In practice, despite the multiple types of outputs that they produce, economic analysis and decision making regarding technologies having joint outputs (PJOs) have been based almost exclusively on their direct contribution to food production without taking cognizance of the environmental services that they perform. This is further explained in Figure 1. The horizontal axis represents the level of adoption of a given farm technology while the vertical axis is the costs and benefits associated with its adoption. The cost of adoption is represented by the cost curve. This curve represents the total cost of land, labor, seeds and other resources that are used up in the adoption of the technology and follows the normal production cost curve. For individuals, the benefits accruing from adoption of such farm technology (i.e. value of crop produced) is represented by the (green) "private benefit" line. It has a constant slope because the value of crop output increases in proportion to the physical quantity of crop production. For an individual farmer, the economic optimum level of adoption occurs at point "A" where the marginal cost equals marginal benefit, i.e., slope of cost curve and benefit lines are parallel. At adoption level below "A", a farmer gets higher incremental benefit than cost from the use of the technology and so it pays to increase adoption to a higher level. The opposite occurs when adoption level is beyond "A". Thus for an individual farmer, the domain of adoption that is economically rationale is located between O and A. This is true for a single individual and for farm technologies that produce only direct benefits that are appropriated fully at the farm level.

Due to the additional environmental goods and services that they produce, the value of adoption for PJOs technologies shifts from the (green) “private benefit” line to the (blue) “social benefit” line. The magnitude of the differences between the two lines increases with adoption of PJOs. If the indirect environment services are incorporated, the marginal benefit of PJO technology will be equal to marginal cost at a higher level and as a result, the socially optimum level of adoption increases to “B”. The magnitude of the difference between “A” and “B” varies in proportion to the value of environment services produced and the extent to which such services are recognized in the reward system operating in an economy. The social optimum level of adoption of PJOs from the wider community perspectives is always higher than that of the private (individual) optimum and as a result, social optimum adoption of PJOs can be facilitated through commensurate public investment that is equal to the social benefits generated by the technologies. As seen in the foregoing, if adoption is below “A”, there is a possibility that different efforts (e.g. farmers training and other forms of extension methods) can be intensified to drive adoption towards its private optimum. As we approach “A”, adoption curve is expected to level off, hitting a plateau. It becomes more challenging for private individuals (farmers) to increase adoption beyond this level except where farmers do not take economically rationale decisions or in situations where they lack necessary information. From the point of view of individuals, any level of adoption beyond “A” is economically not rationale because by doing so, an individual person will be providing an unrecognized but important hidden subsidy to the public. Given that environment services generated by PJOs benefit the wider community rather than the single individual that produces them, there is need for internationalization of the positive externalities of the off farm public “products” produced by the technologies. Appropriate policies and institutional options for reaching social optimum need be identified.

4.0 Strategies for driving the adoption of technologies with positive joint outputs towards socially optimum level

The socially sub-optimal adoption of PJOs occurs as a result 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. There is a disconnection between the production of public environmental goods and the distribution of the benefits of the same. Single individual farmers may be unable to capture the full benefit from investment in public goods because it is impossible or too costly to exclude those who do not pay for the services created from such investment. The common property nature of environment services creates a social dilemma because an individual farmer lacks incentives to consider the implications of his/her production activities on the environment and climate change. It must be noted that land users make decisions on alternative agricultural production technologies based on the incentives they faced as individual land users without necessarily considering the biodiversity and other environmental benefits the various land use practices may have. The ratification of the Kyoto Protocol in 2005 gives rise to new opportunities to highlight issues on carbon trading and incentives for reward systems. Strategies for enhancing the adoption of agroforestry in particular and PJOs in general towards their social optimum are highlighted below:

(i) Smart incentive mechanisms for the production of pubic environment benefits: There is the need for incentive mechanisms to reward adopters of PJOs technologies for the environment services produced. Such supports should not be taken as subsidy or handout; rather they should be regarded as incentive mechanisms to reward farmers for the environmental goods that they produce which benefit a larger public. Such incentives could be built into the revised national and international policies. The ratification of the Kyoto Protocol on Climate Change and its coming into force in 2005 gives rise to new

opportunities to highlight issues on carbon trading and incentives for reward systems for PJOs. A recent study in southern Africa show that carbon stored in improved fallow land use practices varied between 2.5 to 3.6 tons ha^{-1} $year^{-1}$ (P Mafongoya, personal communications, 2005). At carbon prices estimated at about $5 per ton, the potential for improved fallows to increase small-holder farmers' incomes by $12.5 – $17.5 per hectare (or $6 - $8 per hectare assuming transaction cost of 50%) equivalent to 20-30 man-days (or 10-15 man-days) at the prevailing labor wages rate. This represents a big boost in farmers' income and provides incentives for them to shift decisions on technology choices in favor of land use practice PJOs and conserve the environment.

(ii) Appraise national policies that have direct and indirect effects on land use practice with PJOs and conventional technologies: In many cases, conventional farm production practices are often subsidized by the government through various price and institutional supports. Over several years, such government policies have created structural shifts and path dependences that shift farmers' decisions towards conventional production systems rather than PJOs. For example, national government policies on land tenure and subsidies on inorganic fertilizer may influence decision on tree-based soil fertility management technologies that produces joint output. Similarly, while the returns to some of these PJOs (e.g. agroforestry-based land use practices) are obtained in the medium and long run, it is expected that farmers will be less enthusiastic to invest their scarce resources in such technologies when they have not known how long they would stay on the land. Various national and international policies need be reviewed to assess their direct and indirect (dis)incentives to the adoption of PJOs.

(iii) Cushioning the effects of time lag between investment and accrual of benefits: Most land use practice with PJOs are profitable over time (positive net present values), but their break-even point occurs somewhere between 2 to 3 years, implying that farmers must absorb net losses for a couple of years before receiving profits from adoption of the

technologies. This poses a challenge for farmers in low income nations where the cost of capital and discounting factor is high. During this "waiting" period, resource-poor farmers are at their most financially vulnerable state and may need some backing as, the absence of such support increases the pressure for farmers to sacrifice long term (environmental) benefits for immediate (food security) gains. Revision of national policies should make provision for this relieving this constraint.

(iv) Information and training supports to adoption of PJOs: Most PJOs are knowledge and management intensive. In addition, they are incipient technologies, being "new" technologies having relatively little institutional supports in national agricultural extension systems The costs of providing information greatly decrease over time, but they are critical when helping farmers get started with the practice.

(v) Science policy linkages: There is need to initiate new institutional forms to bring science and policy together with representation of broader public viewpoints to emphasize the need to examine climate change through a sustainable development lens. This involves examining the subject of environmental conservation from the perspectives of sustainable agriculture development and food security. Institutional arrangements to appropriately inform public policy are important because over the decade, there has been a noticeable narrowing of the gap between scientists and farmers, but a widening gap between scientists and policy makers.

The aim of the strategies given above is to encourage farmers to adopt PJOs primarily to improve food security for their household while they are given incentives to do so through various forms of support that takes cognizance of the public goods that they produce. We suggest limiting direct cash payments to farmers to the lowest minimum (if not altogether avoidable) because farmers may not understand agroforestry and PJOs as something that can benefit them if they are paid to practice it.

5.0 Conclusion

The perceived conflict between food production and environmental conservation can be minimized by taking advantage of existing production systems that produce not only food, but also environmental goods and conserve natural resource capital. The adoption of such technologies is sub-optimal from the societal perspectives because of the non recognition of the environmental services produced by the technologies. The challenge is to devise policies and mechanisms that will align small-scale farmers' incentives with those of society as a whole, and encourage them to take cognizance of environment issues in making agricultural production decisions..

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Table 1: Maize grain yield after 2 year *Sesbania sesban* and *Tephrosia vogelii* fallows in farmers' fields in Zambia, 1998-2000

Fallow species	Maize grain yield (tons ha^{-1})			
	Land use system	Year 1	Year 2	Year 3
Sesbania sesban fallows	Sesbania fallow	3.6	2.0	1.6
	Fertilized maize	4.0	4.0	2.2
	Unfertilized maize	0.8	1.2	0.4
	LSD (0.05)	0.7	0.6	1.1
Tephrosia vogelii fallows	Tephrosia fallow	3.1	2.4	1.3
	Fertilized maize	4.2	3.0	2.8
	Unfertilized maize	0.8	0.1	0.5
	LSD (0.05)	0.5	0.6	0.9

Source: Ayuk and Mafongoya (2002)

Table 3: Net profit of maize production per hectare using inorganic fertilizer and improved fallows options over a five-year cycle in Zambia

Land use system	Description of land use system	Net Profit (US$ / ha)	BCR
Continuous, NO Fertilizer	Continuous maize for 5 years, **no** fertilizer	130	2.01
Continuous + Fertilizer (subsidized at 50%)	Continuous maize for 5 years **with** fertilizer (fertilizer subsidized at 50%)	499	2.65
Continuous + Fertilizer (at non-subsidized market price)	Continuous maize for 5 years (at normal market price of fertilizer)	349	1.77
Gliricidia sepium	2 years of *Gliricidia* fallow followed by 3 years of crop	269	2.91
Sesbania sesban	2 years of *Sesbania* fallow followed by 3 years of crop	309	3.13
Tephrosia vogelli	2 years of *Tephrosia* fallow followed by 3 years of crop	233	2.77

Source: Ajayi et al 2004

Table 2: Types of benefits and costs associated with improved fallows

	Private	**Social**
Cost	• Land • Labor • Agroforestry seeds • Water for nursery • Pest (limited to specific tree species only) • Working equipments • Field operations coincide with those in other field crops	• Incidence of Mesoplatys beetle pest (restricted to specific species only) • Limit the possibility of free grazing during dry season • Risk of uncontrolled fire outbreak
Benefit	• Yield increase • Higher price premium for farm production • Increase in maize stover (helps livestock) • Stakes for tobacco curing • Fuel wood- available in field, and so reduces time spend searching for wood • Helps in fish farming- *Gliricidia sepium* is fed to fishes • Fodder for livestock • Used as bio-pesticides (*Tephrosia vogelii*) • Suppresses the growth of noxious weeds • Improved soil infiltration and reduced runoff • Potential to mitigate the effects of drought spells during maize season • Social equity - availability is not dependent on political connection or social standing • Provision of shade against the sun • Additional income from sale of agroforestry tree seeds • Diversification of farm production (e.g. mushrooms)	• Carbon sequestration • Suppression of noxious weeds • Improved soil infiltration and reduced runoff on the slopes • Potential to mitigate the effects of drought spells during maize season • Enhanced biodiversity • Diversification of income opportunities in the community • Serves as wind breaks • Reduction of risks of maize production • Provides shade against the sun in hot tropical regions

Fig. 1: Optimum adoption of PJOs under different reward systems