Which would work better for improved soil fertility management in sub-Saharan Africa: Fertilizer Subsidies or Carbon Credits?

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Abstract

Why do many smallholder farmers fail to adopt improved land-use practices which can improve yields and incomes? The reason is not always because these practices are uneconomical but sometimes it is because resource poverty prevents farmers from taking advantage of yield and income enhancing agricultural practices. In this study we examine the relative merits of using a carbon payment scheme compared to a subsidy policy to help reduce the cost of specific best management practices (BMPs) with productivity and ecosystem benefits. Using a 30-year crop simulation model, we examine the impacts of different soil fertility management treatments (SFTs) on yields and soil carbon and proceed to compute discounted incremental revenue streams over the same period. We find that the SFTs simulated are on average profitable given the conditions assumed in the DSSAT simulations and subsequent net present value analysis and revenue-cost comparisons. When carbon was priced at \$8 or \$12/t, the increase in incremental incomes generated from a carbon payment were higher than those imputed from a 50% fertilizer subsidy. When carbon was priced at \$4/t, the increase was almost always equal and sometimes higher than that from the imputed income transfer from a 50% subsidy. If these indications hold in further research, it could imply that using fertilizer subsidies as the sole mechanism for stimulating adoption of improved soil fertility management practices may unnecessarily forgo other complementary and possibly superior alternatives. Given the fiscal burden on public finances and unavoidable opportunity costs of any substantial subsidy program, it is possible that a carbon payment system is a reasonable alternative even at low carbon prices especially if accompanied by measures to ameliorate the costs of fertilizer to farmers.

Keywords: fertilizer subsidy, carbon payments, sub-Saharan Africa

1.0 Introduction

There is widespread recognition that in Africa, perhaps more than anywhere else, land degradation is severe. This is especially true among smallholder farmers (Beinroth et al. 2001). Almost 51% of the poorest 20% of the rural population in Africa can be found on low potential degraded lands (Babier 2000). By some measures, this situation costs 3 – 9% in the loss of GDP (Requier-Desjardins 2006). As a result, the issue of land degradation and how to tackle it currently features prominently in policy discussions in Africa. Sustainable land management is the first pillar of Comprehensive Africa Agriculture Program (CAADP)'s four pillars of agricultural development in Africa. Nevertheless, adoption of improved land management practices remains low. For example, average application of fertilizer in sub- Saharan Africa (SSA) is only about 10kg of nutrients/ha, which is the lowest level in the world (FAOSTAT 2009; Pender 2009). Adoption rates of organic fertility management practices at the country level have been shown to be generally low (Pender 2009; Yesuf et. al. 2008, Benhin 2006).

Considering that it is their subsistence and wellbeing at stake, why do many smallholder farmers fail to adopt improved land management practices which can improve crop yields, food security and incomes? The reason is not always because these practices are uneconomical. One of the reasons for using land degrading practices is resource poverty. What then, can be done from a policy perspective to support adoption of best land management practices (BMPs) among smallholder staple food producers? Should input subsidies become part of the long term strategy in this equation? Are there alternative support mechanisms that merit consideration? If, as the literature suggests, wealth and income effects are significant in constraining adoption of agricultural technologies., what role can external injection of support for the adoption of these technologies have on their adoption so long as there are adequate equity rationales for providing such support Morris et al. (2007)? For example, can carbon payments ameliorate the need for expensive fertilizer subsidies to enable farmers adopt high input BMPs such as integrated soil fertility management (ISFM) systems? These questions are pertinent in view of the recent trends that have seen fertilizer subsidies have reemerged as important policy adjuncts in SSA. In this study we examine the relative merits of using a carbon payment scheme compared to a subsidy policy to help reduce the cost of specific soil fertility management practices including ISFM packages deemed to have productivity and ecosystem benefits.

In recent years a number of countries (including Kenya, Ghana, Malawi, Mali, Nigeria, Ghana, Tanzania and Zambia) have used subsidies in efforts to increase farm level fertilizer application. This has been especially so given the recent rally in global energy, fertilizer, food and other commodity prices. Consequently, public investments in subsidies has been considerable in countries that have chosen to implement them. For example, Malawi spent about 72% of its agricultural budget in 2008/09 on agricultural input subsidies (Dorward and Chirwa 2010). Nigeria has recently spent about 42% of agricultural budget on fertilizer subsidy (Mogues et al. 2008). This focus on subsidies has inevitably led to a number of challenges including high fiscal costs and crowding out investment in other areas of agricultural. Incidentally, land resource management, a critical element for attaining long term agricultural productivity is hardly integrated into these costly fertilizer subsidy schemes. Such concerns have prompted consideration of alternative methods of increasing farmer adoption of soil fertility strategies.

The alternative we wish to compare with subsidy is the concept of payments for environmental services (PES). There is growing interest in PES in development circles because they show some promise in the ability to mobilize non-traditional resources which can be channeled towards sustainable environmental management and to poverty reduction broadly. This potential is evident from the fact that Africa accounted for only 2% of the total 1186 CDM projects in 2008 and 5% of total carbon traded through the CDM pipeline (Robinson and O’Brien 2007; Capoor and Ambrosi 2008). The recent World Bank program aimed at building capacity of developing countries to participate in the carbon market – World Bank Carbon Finance Unit (WBFU) – has specifically targeted sub-Saharan African countries – which accounted for 16% of 90 WBFU projects were in SSA (Capoor and Ambrosi 2008).

FAO in it's *The State of Food and Agriculture 2007* highlighted the role that potentially exists for agriculture to contribute to the provision of ecosystem services that are not usually compensated for by the market. This report (FAO 2007) states that agriculture has the potential to degrade the Earth's land, water, atmosphere and biological resources – or to *enhance them* – depending on the decisions made by the more than 2 billion people whose livelihoods depend directly on crops, livestock, fisheries or forests.

1.1. Contribution of this study to policy discourse

In this study we sought to answer the question as to what is the best way to support the adoption of integrated soil fertility management packages which have been shown to have large positive impacts on soil fertility and yields. If high-return ISFMs are not being adopted by farmers, what justification exists for the public sector to help such farmers adopt them through fertilizer subsidies (fertilizer being a critical and perhaps the most expensive element of ISFM) or other forms of support?

In this study, we look at the costs and benefits of adopting a variety of ISFM packages that have the potential to sequester carbon, improve soil nutrient conditions and enhance land quality in the long run. This can constitute an ecosystem service that can be sold to farmers for extra incomes. In the analyses, we treat the extra carbon sequestered due to the adoption of ISFMs as a source of extra income to the farmer. The premise of our approach is that one of the important things that many resource-poor farmers need is an infusion of resources (not least financial resources) to enable them to adopt BMPs such as the various SFTs we analyze in this study. The extra income from the sale of sequestered soil carbon (through an appropriate carbon market) can boost their incomes thereby improving their ability to adopt profitable ISFMs in those cases where they lacked the key resources (cash and labor) for adopting these packages. Therefore the core aim of this study is to compare two idealized policy options; one involving providing fertilizer subsidies as part of an ISFM package or paying for sequestered soil carbon conditional on the adoption of ISFMs. Either policy has the net effect of improving the affordability of the ISFM packages, with a subsidy lowering the per unit cost of the package and a carbon payment increasing farmer's incomes per unit of output all else equal.

2.1. Role of ISFM in Carbon Sequestration

In this section we outline briefly how ISFM practices can contribute to soil carbon sequestration. Experts report that atmospheric carbon concentration is rising at a rate of 4 billion mt (2 parts per million) per year. These transfers into the atmosphere come primarily from fossil fuel, biotic, and soil pools (Lal 2009). The elevation of atmospheric carbon dioxide is harmful on two fronts. The loss of soil carbon reduces the ecosystem services that these soils provide. Examples include decline in soil quality which reduces returns to inputs, decreases agronomic yields, and exacerbating food insecurity and poverty (Marenya and Barrett 2009). The second effect has to do with the effects of carbon dioxide concentration in the atmosphere and global warming. Experts suggest that one solution to this problem is to sequester atmospheric carbon dioxide into other long-lived soil and biotic pools (Lal 2009)

Farming practices that involve practices such as minimum tillage with crop residue retention can reduce soil erosion rates and increase soil carbon balance quite rapidly. The loss of soil carbon in continuously cultivated systems can be as high as 30% (Bationo et. al. 2007). While even the application of mineral fertilizer alone can lead to significant gains in soil organic carbon due to greater biomass yields, soil science research has shown that what is needed most is the combination of organic material such as green manures, crop residues, compost, or animal manure with mineral fertilizers (Bationo et al. 2007). Soil scientists recognize that to maintain intensive arable farming an efficient system of recycling of organic materials is crucial.

2.2. What then can be done to enhance farmer participation in carbon offset markets?

As seen above, participation of SSA in carbon markets is limited. One of the major challenges facing African farmers is their limited capacity to meet the standards and other rules and regulations set in these markets. The most daunting of these challenges are the high transaction costs associated with Measurement, Reporting and Verification (MRV) and monitoring of carbon. The MRV of a large number of small producers with small farms, most of whom are located in remote areas – constitute high transaction costs making it difficult to certify their carbon credits. According to Cacho et al. (2005), the transaction costs of MRV include search costs (the costs incurred by investors and project developers), negotiation costs (or the costs of reaching an agreement), approval costs (include time delays after submission of a project), administration costs (keeping records, delivering payments), monitoring costs (verifying compliance), enforcement costs and insurance costs.

Experience from around the world has shown some success stories that demonstrate some innovative approaches to addressing these challenges and ensuring profitability and efficiency in monitoring and verification of ecosystem services. Some of such measures and strategies include farmer group participation which can reduce costs and enable economies of scale by pooling small parcels of land into one entity that can produce the minimum required carbon stock. The other strategy is to bundle ecosystem services (co-benefits). Coordination of a bundle of ecosystem services can help increase benefits and subsequently lower monitoring and measurement costs. For example the UN-REDD program is considering bundling forest carbon with biodiversity conservation, soil and water protection and wood and non-wood products, cultural and spiritual benefits.

2.3. What future for fertilizer subsidies?

In places where it has been implemented, fertilizer subsidy has been chosen as a second best policy alternative to increase fertilizer adoption in Africa. For this objective a number of issues of interest emerge from tour review of these policies as implemented in SSA: 1) it is necessary to include the private sector in any fertilizer policy; 2) targeting is a critical component of success to avoid crowding-out private sales; 3) good timing is necessary to increase the impact of subsidies; 4) good cost-benefit analysis of applying fertilizer subsidies is necessary to compare it with other alternative policies; 5) subsidies need to have credible exit options.

The inclusion of the private sector (private importers, distributers, and retailers) in any fertilizer policy in order to provide more efficient fertilizer supply chains and ensure sustainability of fertilizer use seems to be an important ingredient for a successful and sustainable input sector development. Where the private sector is relatively active and average wealth is high, Xu et al. (2009) have found that subsidies have substantially crowded out the private sector and in some cases have actually lowered overall fertilizer use. What is still missing in the literature is a good cost-benefit analysis of applying fertilizer subsidies. As argued by World Bank (2007) “fertilizer subsidies used as a safety-net measure in marginal production environments should not be recommended since other instruments for providing income support or ensuring food security will almost always be more effective”.

3.0. Model

This section lays out the broad microeconomics conceptual framework of soil degradation including a section on how payment for an environmental service can be used to encourage adoption of BMPs. This is followed by a description of the crop simulation framework and finally the section concludes by describing the ISFM treatments used in the crop simulation and the price and labor cost data used in valuing the yield and soil carbon outcomes from the crop simulation model.

3.1. Conceptual framework

In the case of soil carbon, note that the benefits of its accumulation may only come after the passage of what the farmer might consider a long time. Therefore the incentive to implement any recommended practice with a strong carbon sequestration component is affected by factors such as farmers’ rates of time preference and financial positions (Antle and Diagana 2003).

This is where payments to sequester soil carbon could also provide some financial incentive for adoption of recommended practices. Under situations where farmers are compensated for the amount of carbon sequestered, the farmer receives a payment of p_c per ton of *C* sequestered in each time period. So if the farmer changes from practice *b* to practice *i* and soil *C* increases by $\Delta C(b,i)$ tons per hectare per period, the farmer receives a payment of $p_c \Delta C(b,i)$ per hectare per period. The net present value (*NPV*) of changing from system *b* to system *i* for *T* periods is given by

$$NPV(b,i) = \sum_{t=1}^{T} \rho_t \left[R(p_{t,},i) + p_c \Delta C(b,i) - M(b,i) - FC(b,i)\right] \qquad 5$$

where $\rho_t = \left(1/(1+r)\right)^t$ with *i* being the annual discount rate, $R(p_t, k_t, z_t, b)$ is the net revenue function describing returns from *i* per hectare for the new system over period *T,* given product price $p_{\boldsymbol{yt}}$, input prices $\boldsymbol{w_t}$. Let $M(b,i)$ be the maintenance cost per period for changing from system *b* to *i*; and $FC(b,i)$ be the fixed cost of making the same change. For non-adopting farmers $p_c \Delta C(b,i), M(b,i)$ and $FC(b,i)$ are all zero with only crop revenues described by revenue function $R(p_t, b)$ being relevant for the non-adopters. The farmer enters the contract if the net present value from adopting *r* is greater than that from retaining *b* i.e. $NPV(b,i) \geq NPV(b)$.

For the sake of simplicity let us assume that $R(p_t, i)$, p_c, p_y, ΔC , and $M(b,i)$ are constant in each period and we let $fC(b,i)$ (as derived from $FC(b,i)$) represent an annuity of the fixed costs per period. These assumptions allow us to rephrase $NPV(b,i) \geq NPV(b)$ as:

$$R(p_t,i) + p_c \Delta C(b,i) - M(b,i) - FC(b,i) > R(p_t,b) \qquad 6$$

From Eq. 6 it is clear that if farmers do not have the extra compensation represented by $p_c \Delta C(b,i)$ then the net returns from crop revenues alone must be higher for *i* than for *b* if they are to implement *i* based solely on crop incomes.

Even where $NPV(b,i) \geq NPV(b)$ farmers may fail to adopt practice *i* if credit markets are absent and the farmers lack the necessary capital, given the fixed and maintenance costs inherent in adopting the improved practice. However, at a minimum it is paramount that a positive financial incentive should be present to induce and maintain adoption so that the problem becomes only that of procuring the financial or labor resources needed to implement these options.

3.2. Indices used in evaluating the SFTs

As will be clear later in later sections, fertilizer and labor were the two cost components of the SFTs simulated for this study. The cost of organic inputs (manure and crop residues) are assumed to have been produced on-farm and therefore do not have a market price. The resulting revenues and costs (discounted appropriately) attributable to implementing each specific SFT package were then calculated based on the price and cost information assembled for this study. This led to calculations of two key indicators to show how each package performs in terms of net present value of revenues derived from crop yields as well as those from carbon credits. We also computed the average costs of each ISFM package by determining the average amount of labor that would be needed for a business as usual scenario (base practice) as well as the costs that would be needed to implement the other SFT packages. This cost revenue comparison enabled us to do "all else equal" scenarios and to compare the incremental incomes from the each simulated SFT package but also to compare these incremental incomes with incremental costs to calculate revenue-cost elasticities for each of the packages. This gave a sense of the impact of the extra costs on the revenues generated at specific prices.

3.2.1. Net present value (NPV)

In calculating NPV we define y^b as the yield in year *t* under the base (degrading practice) and $c^b(y_t^b)$ as the corresponding cost of production of this practice per annum. The returns that accrue under the degrading practice (TR0 in our case) is given by $\pi_t^b = p_t\, y^b - c^b(y_t^b)$. Let us define y^i as the yield from treatment *i* where *i* =1-5 indexing the five treatments simulated. The returns in year *t* of the treatment would be $\pi_t^i = p_t\, y^i - c^i(y_t^i)$. The net benefit from adopting the new practice at time *t* is given by

$\pi_t^i - \pi_t^b$ and *t* in our case is counted from 1-30. Over the 30-year time period we discount this to get the net benefit at present values of adopting the improved practice, (in equation below, *r* is the discount rate).

$$NPV = \sum_{t=2001}^{2030} \frac{\left(\pi_t^i - \pi_t^b\right)}{(1+r)^t}$$

The adoption of the improved practice is profitable so long as $NPV(b,i) > 0$ indicating that the cumulative returns are greater with the improved practice than if the base degrading practice were to be continued. This NPV however depends on three key factors: the difference in yields between the two practices, the price of the output, the costs of production for the crop in question, the cost solely due to the improved practice and the discount rate. This can be seen from the following expanded equation:

$$NPV(b,i) = \sum_{t=2001}^{2030} \frac{p_t\left(y_t^i - y_t^b\right) - \left[c^i\left(y_t^i\right) - c^b\left(y_t^b\right)\right]}{(1+r)^t}$$

3.2.2. Revenue-cost elasticity (RCE)

Using the 30-year average profits for each treatment π^i and for the base practice π^b as well as the 30-year average costs for each treatment $c^i\left(y^i\right)$ and for the base practice $c^b\left(y^b\right)$ we can calculate the benefit-cost elasticity to determine the degree with which revenues increased compared to that at which costs increased.

$$RCE = \left. \frac{\left(\pi^i - \pi^b\right)}{\pi^b} \middle/ \frac{\left(c^i(y^i)\right) - c^b(y^b)}{c^b} \right.$$

3.3. Crop Simulation Framework

In order to generate dynamic yield data that enabled us to compare the different SFTs analyzed in this study, we used a crop simulations model, the Decision Support System for Agrotechnology (DSSAT).

DSSAT is a microcomputer software designed to facilitate the evaluation and application of the crop models for different purposes and essentially is a collection of independent programs that communicate with each other. (Jones et al. 2003; Hoogenboom et a. 2004). DSSAT has three major parts. The first is a database management system for data assembly, inputting, storage, analysis and retrieval. The second component is a set of crop models that simulates crop growth, development and yields. The third component consist of programs to analyze, display and evaluates the model outcomes with observed data.

The data set for running the DSSAT model such as soil, climate, and management practices, were defined for each grid cell accordingly. Based on global soil database-we retrieved coverage of soil mapping units, a representative soil profile for each grid cell in each country was created. For each grid cell, its soil property was defined by three specific categories, soil texture, rooting depth, and organic carbon content, which DSSAT crop models respond to the most in general. Table 2 below shows the districts in each country and for each crop that were used. This identification was important in order to calibrate DSSAT simulation with the most accurate agro ecological data for crop simulation as reported in DSSAT internal data bases.

Table 1

DSSAT has been a useful tool for policy-makers in developing decision-making criteria and to develop scenario analyses related to specific cropping systems and has been customized and modified as a suite of models to represent a system or simulate one or more crops with a systems approach based on the soil and climate conditions. The crop simulation model itself was meant to account for changes in soil nutrients and other factors and then computes yields through crop growth routines which in our case was done over a 30-year period. We then take the resultant crop and soil carbon results and value them using country specific crop and fertilizer prices and wage rates to assess the relative returns to each combination. Our implementation of the DSSAT model in a smallholder sub-Saharan Africa context has precedence in similar applications such as those by Jones et al. (2003).

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3.3.1 SFT scenarios and their justification

Using DSSAT platform we simulated a series of five different SFTs using DSSAT crop simulation model as mentioned in the previous section. The SFT combinations were varied in terms of the relative quantities of manure, fertilizer and crop residues. For each crop we simulated five different scenarios as described in the Table 2 below. We simulated the six SFT packages to represent varying proportions of fertilizer, crop residues and manures.

TR0 was chosen as the baseline scenario for benchmarking the other treatments. TR1 was chosen to represent the next treatment involving fertilizer at an intermediate level which although still modest, is an intermediate improvement over TR0. TR2 was meant to illustrate a package that typified the implementation of the full recommendation of the SFT package. The rate of 80kg N/ha from fertilizer, 5t/ha manure and 100% retention of crop residue represent the best in ISFM as far as agronomic recommendations in the region go (Nkonya et al. 2010). TR3 was meant to compare the application of the recommended fertilizer rates with a system that does not have access to manures and relies only on retained crop residues as the main organic input. TR4 was meant to illustrate a system that has access to neither fertilizer nor manure and relies only on crop residues to maintain soil health. TR5 illustrates a system that depends on only organic resources (residues and manure). The input rates depicted in TR2 and TR3 represent the treatments closest to actual recommendations in many parts of SSA (see Nkonya et al. 2010)[2]. These five treatments are therefore useful in testing the core ideas in this study; that of comparing subsidies and carbon credits as tools for providing liquidity for facilitating the adoption of SFT packages (where liquidity may be impeding the ability to implement these practices). We used three crops in our simulation. Maize was chosen to represent a common, mostly rain fed staple crop, rice was used to represent an irrigated common food crop and sorghum is an indigenous drought resistant crop that can be an important supplement to maize and rice in household calorie supply especially in drier areas.

Table 2

3.4. Data on prices, wages and labor

The economic data (Table 3 and 4) we used in these analyses came from FAOSTAT (2008), Nkonya et al. (2010), Cramer, Oya and Sender (2008), Haggblade and Dewina (2010), Chianu et. al. (2008), KACE (2009). In order to provide a common denominator for the labor used in manure and other land preparation activities, we averaged these costs across the three countries, based on the fact that the agronomic recommendations are comparable for the three study countries. Table 4 shows the prices for fertilizer (normalized as the price of nitrogen using the most important basal fertilizer used in each country) and agricultural wage rates (at June 2010 prices) also reported by country. In Kenya and Uganda the basal fertilizer is diammonium phosphate (DAP) with 18% N content. In Malawi the basal fertilizer is compound urea with 23% N. All the nominal prices were converted to their June 2010 equivalent using the exchange rate prevailing at the time the price was reported and those prevailing as at June 2010. Using the fertilizer, residue and manure specifications in Table 2, the labor information in Table 3 and price and

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[2] TR1, TR2 and TR3 combine inorganic and organic inputs and therefore represent ISFM by this definition.

wage data in Table 4 it was possible to compute the revenue implications of DSSAT yield and carbon output as well as the cost implications of these inputs.

Table 3

Table 4

3.5. Source and rationale for carbon prices used

The carbon prices we used in this study are based on similar prices used in Lecocq and Capoor (2003), CIE (2010) and World Bank (2008). A World Bank (2008) report stated that prices for carbon in the certified emissions reductions (CER) increased in 2007 to 2008, with most of the transactions ranging between $10-16, with an average contracted price of US$13.60 (up 24% from 2006). The same World Bank report also showed that there had been continued interest in CDM and increased competition during 2007, evidenced by the fact that the minimum price for CERs rose to US$9 in 2007 from US$7 in 2006 representing a 26% increase. Based on these reports, we use carbon prices ranging from $4/t to $12 in our analyses.

4.0. Results and Discussions

This section presents the results from DSSAT simulations, NPV and RCE calculations and discusses how carbon revenues compare with subsidies in increasing NPV and RCEs. Finally, lessons are drawn on how these policies can inform the discourse on fertilizer support programs and other initiatives for soil fertility improvement.

4.1. Simulated physical impacts on yields and carbon accumulation

Tables 5 presents the average crop yields and soil carbon for TR0 over the simulation period. Figure 1 and 2 show the impact of the five treatments on yield and soil carbon respectively. Incremental yields were all positive ranging from 1.4t/ha/yr for TR4 under maize in Malawi to 6.3 and 6.4t/ha/yr for TR2 and TR5 for sorghum in Uganda. (Fig. 1). All the five treatments had positive addionality on soil carbon ranging from just below 3.7t/ha/yr for maize in Uganda and reaching up to approximately 17t/ha/yr of CO_2e for TR2 for rice in Malawi[3] (Fig. 2).

Table 5

The results in Fig. 1 and 2 show that under the treatments we simulated, there are clear advantages from these treatments in sequestering significant amounts of carbon into the soil. Our simulations illustrate that if farmers can implement these and similar practices, a positive carbon sequestration potential exists and this can open up latent opportunities for agricultural carbon trading. There are a variety of land improvement packages that can have similar effects on soil carbon and yields. The consensus in the research community is that degraded lands in Africa offer additional opportunities for carbon sequestration on the continent. In the humid tropics potential soil carbon gains are still substantial since agricultural production has depleted soil C (e.g. about 50% loss in many places) so there is a large 'gap' of soil carbon to be filled (Scholes and van der Merwe, 1996). In all crops and countries, TR4 which relied on crop residues alone produced the smallest incremental yields and soil carbon (Fig. 1 and 2). Comparing TR2 and TR5, the average incremental yields was comparable even though TR5 relied on manure and crop residues only and TR2 relied on manure and fertilizer. The annual application of 5t/ha of high quality manure (the quality of manure we assumed was 5% N) could easily provide large amounts of nitrogen. A scenario that involves 5t/ha of manure per year for 30 years can theoretically substitute for fertilizer. However such a system is not realistic. Manure application in the region is typically less than 1t/ha (Potter et al. 2010). This is why an ISFM strategy of combining inorganic and organic fertilizers in ratios that reflect their relative abundance and agronomic impact is an attractive one. We consider TR1 as an illustration of such a mix. Although the incremental yields are lower for TR1 than TR2 or TR4, the latter treatments are likely to be economically infeasible.

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[3] The carbon sequestered in treatments involving fertilizer was adjusted downwards by subtracting from the CO_2 amount the amount of kilograms of fertilizer applied times 3.875kg. According to Vlek et al. (2004) this adjustment is because production, transportation and application of 1 kg of nitrogen emit 3.875 kg CO_2. This adjustment is built into the subsequent ratio analyses as well.

Figure 1

Figure 2

4.2. NPV of selected treatments over base scenario

Following from the positive incremental yields in the previous section, all the treatments generated positive net income streams compared to the base scenario (Table 6). Note that these are net revenues and all variable costs have been netted out. This means that compared to the base scenarios the extra costs expended on the labor and fertilizer inputs to implement TR1-TR5 are well justified by the yield and revenue outcomes. These patterns have been reported in the literature. For example, Place et al. (2002), Mekuria and Waddington (2002) find positive returns for integrated mineral-organic systems. In comparing manure-fertilizer combinations on maize in Zimbabwe, Mekuria and Waddington (2002) report returns to labor of about $1.35 per day compared to $0.25 for single fertilizer or similar return for manure treatment alone. The integration of rock phosphate and plant biomass incorporation into the soil showed returns to labor of between $2.14 to $2.68 as compared to a best return of $1.68 when only one of the options were used on vegetables and tomatoes (Place et al., 2002). Similarly , Freeman and Coe (2002) both show that organic and mineral fertilizer inputs use responds positively to improved output markets and crop prices.

In Kenya a 50% subsidy on TR1 led to a 7.7%, 3.5% and 5.3% increase in NPV for maize, rice and sorghum respectively. At a price of $4/t carbon revenues from soil carbon accumulation could increase NPV by 6.9%, 3.5% and 3.9% for maize, rice and sorghum simulations respectively and at a carbon price of $8/t carbon revenues consistently generates higher revenues than even a 75% subsidy even for Kenya rice and sorghum respectively and carbon revenues at $4/t could respectively raise NPV by 9.4%, 5.2% and 9.8%. Treatment TR3 had the largest possible increments of 25.8%, 6.1% and 12.4% for NPV and potential carbon revenues under this treatment could increase NPV by 12%, 3.4% and 4.9% for maize, rice and sorghum respectively (Table 6).

Table 6

In Malawi, a 50% subsidy under TR1 could increase NPV by 28%, 4.2% and 2% compared to potential carbon revenues at $4t which could boost NPV by 28% 7.9% and 3.6% for maize rice and sorghum respectively,. Similarly TR2 could raise NPV by 6.5%, 3.3%, 21.7% with a 50% subsidy and 15.3%, 5.3%, and 29.7% with a carbon payment at $4/t. Treatment TR3 could raise NPV by 102%, 9.3% and 4.1% under a 50% subsidy compared to 67%, 9.3% and 3.6% from a $4/t sale of carbon in maize, rice and sorghum simulations under this treatment for TR3 (Table 6).

In Uganda the results showed that TR1 under a 50% subsidy scenario could increase NPV by 13.8%, 3.3% and 1.6% compared to 17.5%, 9.2% and 3.8% possible increases in NPV from a $4t/t carbon payment for maize, rice and sorghum respectively. The results for TR2 are 21.7%, 4.9%, and 2.5% in the case of a 50% subsidy and 29.7%, 13.5% and 4.3% in the case of carbon revenue for maize rice and sorghum simulations respectively. The same pattern for TR3 showed that a 50% subsidy for fertilizer in this scenario could raise NPV by 48.6%, 7.1% and 5.1% compared to 33.1%, 10.9% and 4.7% possible increases from $4/t carbon revenues in maize, rice and sorghum simulations (Table 6). The results for all countries in Table 6 also show that when carbon was priced at $8 or $12/t the increase in incremental incomes generated from a carbon payment were higher than those imputed from a 50% fertilizer subsidy.

4.3. Revenue Cost Elasticities

Within the cost conditions and crop price scenarios assumed here, the returns to the simulated SFTs are invariably high. Table 7 presents the results for the RCEs for the treatments under full cost, subsidy and carbon payments. Only for rice under TR2 in Kenya is the RCE less than one under all cost scenarios. The other instance was the case of maize in Malawi under TR2 with full costs. The RCE results appear to suggest that low profitability or low returns may not necessarily be the overriding impediment to the adoption of ISFMs. The major problem that is likely most responsible for low adoption of these practices is resource poverty manifest in scarce liquidity to purchase fertilizers or hire labor to prepare or purchase manure and to do the other things needed to implement these practices. Capital constraints and labor supply bottlenecks can also explain a great deal of farmer's lack of adoption irrespective of the economic advantages of the proposed technologies.

Table 7

5.0. Conclusions and policy implications

In this study we set out to compare the relative merits of using a carbon payment scheme compared to a subsidy policy to help reduce the cost of specific best land management practices (BMPs) with productivity and ecosystem benefits. We largely confirmed the main premise of our study: that ISFMs can be remunerative on average and that poor returns need not be the main factor behind farmers' failure to adopt these practices. The treatments we implemented in this study were meant to be illustrative of the SFTs and ISFM components that can make much difference for yield and soil health and to compare a stylized subsidy program with a potential carbon payment system.

While it is true that fertilizer subsidies have recently gained currency in SSA, this study suggests that their impact in terms of income transferred to farmers is rather modest compared to a carbon payment scheme. The increase in incremental incomes generated from a carbon payment were always higher than those from a 50% fertilizer subsidy when carbon was priced at \$8 or \$12/t. When carbon was priced at \$4/t the increase was, in several occasions, equal and sometimes higher than the imputed income transfer from a 50% subsidy.

If these indications can be confirmed in further research, it could imply that using fertilizer subsidies as the sole incentive mechanism for an agricultural productivity growth strategy may unnecessarily forgo other complementary and possibly superior alternatives. A variety of incentive mechanisms or even combinations of incentives should be used in those cases where it is necessary to help farmers with the purchase of fertilizers or implementation of other elements of ISFM. Considering that the development of fully fledged carbon markets in SSA agriculture may still be in the future, taking a broader view of environmental services emanating from smallholder farms and exploring ways of paying for these is one way that the ideas from this study can be tested in practice.

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Tables

Table 1: Districts on Which DSSAT simulation was made by country and crop

	Maize	Rice	Sorghum
Kenya	Bungoma	Mwea	Kitui
Malawi	Dedza	Nkhotakota	Balaka
Uganda	Iganga	Iganga	Arua

Table 2. ISFM treatments used in simulation

Treatment	Input Combination
TR0	Normal practices, all zero inputs, no fallow in dry seasons
TR1	40kgN/ha + 1.67t/ha Manure+ 50% Crop Residue
TR2	80kgN/ha + 5t/ha Manure + 100% Crop Residue
TR3	80kgN/ha + 100% Crop Residue
TR4	100% Crop Residue
TR5	Manure 5 tons/ha +100% Crop residue

SFM scenarios simulated in DSSAT

Table 3: Physical quantities of labor required for various crop operations

	Labor input for crop production/ha		
	Cotton	**Rice**	**Maize**
Land preparation with oxen	6	5	5
Harrowing	0	5	0
Seeding	10	10	2
Weeding x 2	13	20	10
Harvest, threshing & marketing	48	30	5
Manure or compost application	11	11	11
Compost preparation (labor days per ton)	0.2	0.2	0.13
Spraying insecticides	4	0	0
Fertilizer application	3	3	3
Thinning	2	0	0
Transportation of harvest	6	2	2
Total labor	**103**	**86**	**38**

Sources: Nkonya et al. (2010), Takane (2008), Ellis-Jones and Tengberg (2000), Government of Uganda (2000)

Table 4: Summary of prices for nitrogen, labor and crops used in the study

Country	Price of N ($/kg)	Wage rate ($/person/day)	Price of Maize ($/kg)	Price of Rice ($/kg)	Price of Sorghum
Kenya	2.7	1.3	0.29	0.67	0.32
Malawi	1.9	1.0	0.17	0.30	0.66
Uganda	1.4	0.8	0.11	0.33	0.40

Sources: FAOSTAT (2008), Government of Malawi (2007), Nkonya et al. (2010), Cramer, Oya and Sender (2008), Haggblade and Dewina (2010), Chianu et. al. 2008, KACE (2009),

Table 5: Simulated crop yields

		Simulated Crop yields	Soil carbon
Kenya	Maize	2008.5	19620.3
	Rice	2966.7	16529.0
	Sorghum	1518.8	21921.8
Malawi	Maize	2482.7	16199.6
	Rice	2594.2	18428.0
	Sorghum	1497.1	17868.8
Uganda	Maize	1725.6	17765.6
	Rice	1635.2	17347.7
	Sorghum	2088.1	18244.3

Source: Simulated crop yields are from authors' computations and farmers' yields are from FAOSTAT (2009)

Table 6: Percent increase in net present values (NPVs) from subsidies compared to carbon payments

		Kenya			Malawi			Uganda		
		Maize	**Rice**	**Sorghum**	**Maize**	**Rice**	**Sorghum**	**Maize**	**Rice**	**Sorghum**
TR1	**25% Sub**	3.8	1.8	2.7	14.3	2.2	1.1	6.4	1.7	0.8
	50% Sub	7.7	3.5	5.3	28.1	4.2	2.0	13.8	3.3	1.6
	75% Sub	11.7	5.2	7.9	41.9	6.3	3.0	21.1	5.0	2.4
	C credit @$4/t	6.9	3.5	3.9	28.1	7.9	3.6	17.5	9.2	3.1
	C credit @$8/t	17.9	8.6	10.2	69.4	17.8	8.1	43.3	20.2	7.0
	C credit @$12/t	21.0	10.3	11.4	83.1	23.6	10.6	54.4	27.7	9.3
TR2	**25% Sub**	4.7	2.5	5.6	29.6	3.3	1.6	11.0	2.5	1.2
	50% Sub	9.5	4.9	11.1	59.6	6.5	3.3	21.7	4.9	2.4
	75% Sub	14.2	7.4	16.5	89.7	9.7	4.9	32.5	7.4	3.7
	C credit @$4/t	9.4	5.2	9.8	77.2	15.3	5.3	29.7	13.5	4.3
	C credit @$8/t	23.6	12.8	24.9	184.8	33.8	12.2	69.9	29.3	9.8
	C credit @$12/t	28.4	15.6	29.1	232.4	45.8	15.9	88.6	40.2	12.9
TR3	**25% Sub**	12.9	3.1	6.3	51.1	4.8	2.1	23.5	3.6	2.5
	50% Sub	25.8	6.1	12.4	102.1	9.3	4.1	48.6	7.1	5.1
	75% Sub	38.6	9.1	18.6	153.1	13.9	6.2	73.7	10.6	7.7
	C credit @$4/t	12.0	3.4	4.9	67.2	9.3	3.6	33.1	10.9	4.7
	C credit @$8/t	36.7	9.9	15.9	185.4	22.9	9.3	92.7	25.2	12.1
	C credit @$12/t	35.7	10.3	14.6	201.5	27.4	10.9	102.2	32.5	14.3

Table 7: Revenue-cost elasticities

		KENYA			MALAWI			UGANDA		
Revenue-Cost Elasticity		**Maize**	**Rice**	**Sorghum**	**Maize**	**Rice**	**Sorghum**	**Maize**	**Rice**	**Sorghum**
At full Costs	**TR1**	3.9	1.3	6.1	2.5	3.7	17.0	8.9	8.9	18.7
	TR2	3.4	0.7	1.4	0.7	1.8	7.3	3.9	3.8	9.4
	TR3	2.0	1.5	5.0	2.8	3.8	17.4	6.6	10.5	12.4
	TR4	NA	NA	NA	NA	NA	NA	NA	NA	NA
	TR5	7.4	1.1	4.5	2.6	3.4	13.4	10.5	6.7	19.6
At 25% subsidy	**TR1**	4.8	1.5	7.4	3.1	4.3	19.6	10.9	10.1	21.5
	TR2	4.0	0.7	1.8	1.0	2.0	8.3	4.9	4.2	10.5
	TR3	3.2	2.0	7.2	4.4	5.2	23.5	10.7	14.3	17.0
At 50% subsidy	**TR1**	6.0	1.8	9.2	4.1	5.2	23.1	13.6	11.9	25.4
	TR2	4.7	0.9	2.4	1.4	2.4	9.4	6.2	4.8	12.0
	TR3	5.7	3.0	11.6	7.6	8.0	35.8	18.9	21.9	26.1
At 75% subsidy	**TR1**	7.7	2.2	12.1	5.4	6.5	28.3	17.7	14.3	31.1
	TR2	5.7	1.0	3.1	1.9	2.8	11.1	8.0	5.6	14.0
	TR3	13.1	6.2	24.9	17.2	16.4	72.5	43.5	44.7	53.4
At $4/t carbon revenue	**TR1**	4.7	1.3	6.7	3.4	4.1	18.0	11.6	9.9	19.8
	TR2	4.0	0.7	2.0	1.6	2.2	7.9	6.0	4.5	10.0
	TR3	2.7	1.5	5.6	3.9	4.2	18.4	9.4	11.7	13.6
	TR4	NA	NA	NA	NA	NA	NA	NA	NA	NA
	TR5	8.5	1.2	5.7	4.4	4.1	14.6	14.8	7.9	21.1
At $8/t carbon revenue	**TR1**	5.4	1.4	7.4	4.3	4.6	19.0	14.3	10.9	20.9
	TR2	4.6	0.7	2.5	2.5	2.5	8.5	8.1	5.2	10.7
	TR3	3.4	1.6	6.3	5.1	4.6	19.3	12.2	12.9	14.7
	TR4	NA	NA	NA	NA	NA	NA	NA	NA	NA
	TR5	9.7	1.3	6.9	6.1	4.7	15.7	19.1	9.1	22.5
At $12/t carbon revenue	**TR1**	6.2	1.4	8.0	5.2	5.0	20.0	17.0	11.9	22.0
	TR2	5.2	0.8	3.0	3.3	2.9	9.1	10.2	5.9	11.4
	TR3	4.1	1.6	7.0	6.2	5.1	20.3	15.0	14.1	15.9
	TR4	NA	NA	NA	NA	NA	NA	NA	NA	NA
	TR5	10.9	1.3	8.0	7.9	5.4	16.8	23.4	10.3	24.0

Fig. 1: Inremental yields above TR0 (base) treatment

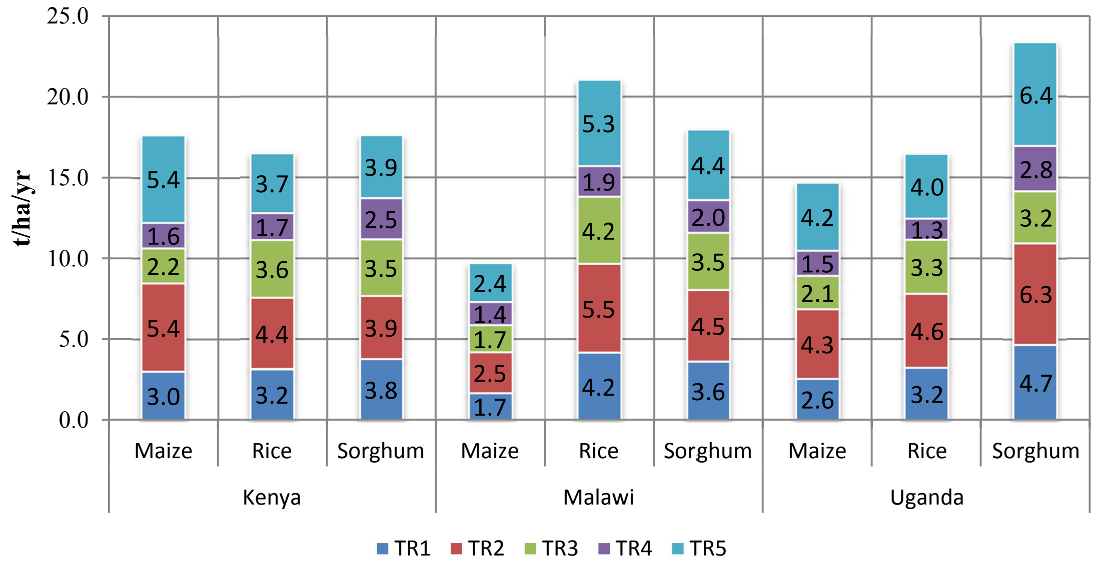

Fig. 2: Inremental soil carbon above TR0 (base) treatment