Rivista di Economia Agraria, Anno LXXI, n. 1 (Supplemento), 2016

Linking food security, climate change adaptation and mitigation: the case of sustainable land management in Malawi[1]

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Abstract

Climate-smart agriculture (CSA) aims at enhancing the capacity of farming systems to sustainably support food security in the context of climatic changes (CC). Questions arise about the profitability of alternative farming options and their cost-effectiveness in mitigating CC. A large dataset has been built through household surveys, key informant interviews and focus group discussions conducted in different agro ecological zones of Malawi. Farmers adopt a wide combination of sustainable land management (SLM) practices, earning often higher yields, profits and returns to labor than under conventional farming. Differences are more significant in dry areas indicating potential for CC adaptation. However, this may come at excessive costs in terms of capital and labor. Negative marginal abatement costs for most SLM options show synergies between increased farm incomes and CC mitigation. Cost-effectiveness of agriculture management practices is proposed as policy decision criterion to prioritize CSA interventions on the basis of economic efficiency in greenhouse gases abatement.

Key words
Climate-smart agriculture, farming practices, on-farm costs, social cost-effectiveness

Introduction

Earlier literature suggests that Sustainable Land Management (SLM) could increase food production without degrading soil fertility and maintaining water storage (Lal, 1997; World

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[1] This paper is being produced as part of a FAO research project on ‘Climate-smart agriculture in Malawi, Zambia and Vietnam (http://www.fao.org/climatechange/epic/projects/en/), co-funded by the European Commission for the 2012-15 period.

DOI: 10.13128/REA-18669
ISSN (print): 0035-6190
ISSN (online): 2281-1559

www.fupress.com/rea

Bank, 2006; Woodfine, 2009; Pretty, 2008 and 2011) therefore improving farmers' adaptive capacity to climate change. Many of these practices can also deliver co-benefits in the form of reduced greenhouse gas (GHG) emissions and enhanced carbon storage in soils and biomass, providing mitigation benefits. SLM technologies can therefore improve the capacity of farming systems to sustainably support food security in the context of climatic changes and to be key components of Climate-smart agriculture (CSA) (Asfaw et al., 2014; FAO, 2010). This is particularly important in areas that face serious food security problems and which are exposed and vulnerable to climatic shocks like Sub-Saharan Africa (SSA).

In a recent review of 160 studies from different areas of the world reporting original field data on the yield effects of sustainable cropland management practices sequestering soil carbon, Branca et al. (2013) found that SLM generally leads to increased yields, although the magnitude and variability of results varies by specific practice and agro-climatic conditions. They also found that mitigation effects of adopting SLM practices are higher in humid areas than in dry ones. However, while biophysical and land productivity benefits of SLM have been widely investigated, questions arise about the costs and overall profitability of investing in SLM practices, whereby very little empirical evidence exists. Also, there is the need to investigate about the cost-effectiveness of different mitigation options, providing policy makers with key information for CSA policy planning.

This paper presents the results of a case study in Malawi where farmers adopt a variety of SLM practices, including: Conservation agriculture (CA) – which cuts across all the three main principles minimum soil disturbance (MSD), permanent soil cover with live or dead plant material and crop association or rotation, particularly with legumes; mulching (crop residue management); herbaceous legume integration (crop association/rotation) and weed management (herbicide application). Adoption of MSD (ripping/zero-tillage or planting basins) and the practice of direct seeding involve growing crops without mechanical seedbed preparation and with minimal soil disturbance since the harvest of the previous crop. Other practices include: Agro forestry systems (AF), which include the use of fertilizer trees grown on cropland under different sequential arrangements (e.g. intercropping, relay cropping, boundary or strip cropping); Soil and water conservation (SWC), including physical structures such as box/tied ridges, infiltration trenches, weirs, swales and plot level *Vetiver* or *Elephant* grass embankments (Branca and Kathaza, 2014).

We look here at private costs and benefits of target SLM farm practices with CC adaptation potential in different agro-ecologies in the country; we investigate about the profitability of such practices as opposed to 'conventional' farming; we verify the potential of SLM to improve crop yields controlling for other determinants; we look at social cost-effectiveness of SLM investments aimed at mitigating CC deriving implications for CSA policies and actions.

Method

Survey design and data description

Primary data, completed with available secondary information, have been used in the analysis. *Ad hoc* household (HH) surveys have been conducted. Data have been integrated through key informant interviews and focus group discussions with extension workers and village representatives. Questionnaires have been specifically developed to collect primary data from farming HHs and villages to estimate benefits and costs of agricultural practices and to be used as survey instruments in the country, with reference to 2012-13 cropping season. Only main season and rain-fed crops are considered.

Data was collected at a single point in time through a 'one-shot' survey. Stratified Random Sampling (SRS) procedure was used in the study in order to obtain efficient and consistent estimates of the target population. In order to identify the sample of survey respondents, the relevant population of farmers adopting target SLM practices in selected Extension Planning Areas (EPAs) was identified. A probability sampling method was used to compile the list of actual respondents. Every HH listed in each stratum (EPA) had equal probabilities of being chosen for the survey. Actual respondents have been randomly selected to be interviewed. Randomisation has been achieved through the use of random number table generated using Microsoft Excel. Results are considered as representative of the HHs in the stratum.

The sample was built using population weights so that districts and EPAs with higher population of SLM adopters proportionately contributed more respondents than those with less SLM adopters. We used proportionate stratification to calculate the required sample in each district and EPA. With proportionate stratification, the sample size of each stratum is proportionate to the population size of the stratum. The following equation was applied:

$$n_i = (N_i/N) * n$$

where n_i is the sample size for stratum i, N_i is the population size for stratum i, N is the size of population of SLM adopters in the districts, and n represents overall sample size. Given budget and resource constraints it had been estimated that overall sample could have not exceeded 504 HHs, giving a confidence interval of 4% for a confidence level of 95%[2]. Crop and livestock production data (socio-economic, agronomic, farm management) was collected for 1,433 fields by 505 smallholders over 11 EPAs located in 4 districts (*Mzimba, Kasungu, Balaka, Ntcheu*) and different agro ecological zones.

Four-step methodology for the empirical analysis

First, food security increase of the selected 'improved' practices with respect to 'conventional' farming has been estimated by computing gross margin and profitability parameters in different agro ecologies using partial budgeting technique and following equations:

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[2] This means that if, for example, 50% percent of our sample picks an answer, we can be "sure" that if we had asked the question to a % of the entire relevant population between 46% (50-4) and 54% (50+4) they would have picked that answer. The 95% confidence level indicates how often the true percentage of the population who would pick an answer lies within the confidence interval.

$$GM_{jT} = TR_{jT} - TVC_{jT} \tag{1}$$
$$TR_{jT} = P_j Q_{jT} \tag{2}$$
$$TVC_{jT} = \sum_{i=1}^{n} P_{xi} X_i \tag{3}$$
$$GM_{jT} = P_j Q_{jT} - \sum_{i=1}^{n} P_{xi} X_{iT} \tag{4}$$
$$NI_{jT} = TR_{jT} - TC_{\ jT} \tag{5}$$
$$TC_{jT} = TVC_{jT} + (Cost\ of\ family\ labor)_{jT} \tag{6}$$
$$UC_{jT} = TC_{jT}/Q_j \tag{7}$$
$$RC_{jT} = TR_{jT}/TVC_{jT} \tag{8}$$
$$RL_{jT} = TR_{jT}/Total\ labor_{jT} \tag{9}$$
$$L_{jT} = Q_j/Total\ labor_{jT} \tag{10}$$
$$BCR_{jT} = (TR/TVC)_{j_T} \tag{11}$$

Where:

GM_{jT}=gross margin ($/ha), for crop j and technology T
TR_{jT} = total revenue ($/ha), for crop j and technology T
TVC_{jT}=total variable costs ($/ha), for crop j and technology T
Q_{jT}=crop yield obtained under different technologies (Kg/ha)
P_j=farm-gate price of crop j ($/kg)
X_{iT}=quantity of input i (per ha) used in production of crop j, under technology T
P_{xi}=farm-gate price of input i ($/kg)
NI_{jT}=net income ($/ ha), for crop j and technology T
TC_{jT}=total costs ($/ha), for crop j and technology T
UC_{jT}= production costs per unit of output ($/Kg), for crop j and technology T
RC_{jT}= Returns to cash capital ($/$), for crop j and technology T
RL_{jT}= Returns to labor ($/person day), for crop j and technology T
L_{jT}=labor productivity (Kg/person day), for crop j and technology T
BCR_{jT}=Benefit-cost ratio[3], for crop j and technology T.

Second, Ordinary Least Squares (OLS) regressions have been run in order to control for the impact of other variables on crop yields and isolate the effect of farming practices. The following log-linear Cobb-Douglas function is considered:

$$lnQ = lnB_o + \beta_1 lnX_1 + \beta_2 lnX_2 + \beta_3 lnX_3 + \cdots + \varepsilon^{\mu_i} \tag{12}$$

where:

Q=crop yield
X_i=the following variables have been considered: field size (ha), total labor (days), quantity of chemical fertilizers (kg), quantity of herbicides (lt), dummy variable for use

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[3] In principle, BCR represents a ratio of the present value of the economic benefits stream to the present value of the economic costs stream (net benefits divided by net costs). A BCR of more than 1 indicates that a project is expected to produce positive net benefits. Here, the ratio is simply built as total revenues over total costs.

of improved seeds (1=yes), dummy variable for adoption of MSD technology (1=yes), dummy variable for AEZs (1=yes).

Third, adopting a mixed-method approach based on statistical GHG emission models and databases of GHG emission coefficients was applied in order to estimate average GHG emissions from each combination of production technologies and practices. The employed approach was mainly based on the methodology for field-related nitrous oxide emissions from Stehfest and Bouwman (2006) and an adapted application of the IPCC 2006 guidelines for National Greenhouse Gas Inventories, complemented by further methodologies. The covered GHG emission and carbon stock change impacts include: soil organic Carbon stock changes on agricultural land, carbon stocks in biomass, direct field nitrous oxide emissions (fertilizer, crop residues), volatilization of ammonia, indirect nitrous oxide emissions from nitrogen leaching and runoff, fertilizer and agrochemical production and application. A dedicated mixed 'tier 2' methodology to access the variable GHG impact of various agricultural practices was developed, also utilizing spatial explicit data with regards to initial soil carbon stocks and further soil variables at a resolution of 30 arc-seconds using the Harmonized World Soil Database. Average typical fertilizer intensities, crop yields and residue quantities as identified through HH survey data have been considered.

Fourth, Marginal Abatement Cost (MAC) curves are built in order to identify the optimal (least cost) mitigation technology option. They represent the relationship between the cost-effectiveness of different abatement options and the total amount of GHG abated. The 'bottom-up' approach presented in Branca et al. (2015) is used here. This approach can deal with the heterogeneity of agriculture technologies and with the variability in cost and abatement potential within different land use systems. Marginal abatement cost of each option is computed on the basis of the unitary abatement potential, expressed in terms of \$/t CO_2e abated, and estimated against what would be expected to happen in a 'business as usual' (BAU) baseline (Branca et al. 2015). MAC curve for target technologies is built using net incomes from the cost-benefit analysis and the mitigation potential estimated as described above. It reports the incremental costs with respect to baseline scenario (i.e. 'conventional' tillage system). MAC curve reports costs of different abatement measures (per unit of CO_2e abated) on the vertical axis and the total GHG volumes abated (annual emission savings generated by adoption of the measure) on the horizontal axis, showing a schedule of abatement measures ordered by their specific costs per hectare and unit of CO_2e abated. The curve is upward-sloping, showing how marginal costs rise with the increase of the abatement effort, therefore indicating which solutions are most cost-effective. Moving along the graph from left to right worsen the cost-effectiveness of technology options since each ton of CO_2e mitigated becomes more costly. Negative abatement costs are found for cost-saving technology opportunities, i.e. the adoption of such measures will increase profits. Cost-effectiveness is proposed here as a possible eligibility criteria for supporting specific CSA options.

Results

Data about farming practices applied on each field have been analyzed in order to classify SLM practices in homogeneous technologies (i.e. packages of mutually exclusive agriculture practices). Tillage practice (MSD or Tillage) is considered the discriminator between SLM and 'conventional' technologies, the latter representing the baseline scenario of the analysis. This will state the point of view from which costs and benefits will be assessed. MSD is somehow 'improved' and represents SLM systems. Since the questionnaires allowed reporting multiple practices applied on the same field, many different combinations of practices have been found and a classification in terms of absolute and relative frequency has been made in order to select only most represented technologies (table 1).

Malawian farmers adopt a wide combination of land management practices, applied to various (food and cash) crops. Most farmers rely on conventional agriculture for crop production but are testing SLM technologies on some fields, mainly on maize and some other food crops, with the support of government and non government projects and programs. There is high heterogeneity of SLM technology packages: farmers are experimenting different combinations of SLM principles. The wide variety of technologies recorded among farmers show that farmers are experimenting (same farmer is adopting SLM and conventional on different plots of the same farm) and probably different messages have been conveyed by extension officers and projects.

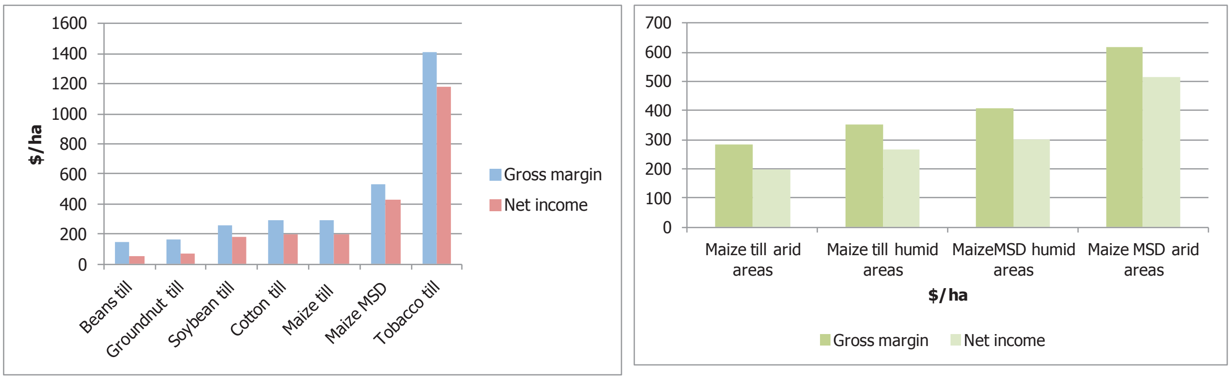
Different crops and agro-ecologies are taken into account in the analysis. Results are shown in figures 1-3. Maize cropped under minimum soil disturbance systems earns higher yields, profits and returns to labor than what can be obtained using conventional tillage practice. Net incomes for maize under MSD are higher than under tillage system. They are also higher than any other crop, except for tobacco. Differences are more significant in dry areas, indicating potentials to increase adaptation to extreme climate events (droughts). However, this may come at excessive costs in terms of capital and labor. Overall production costs for maize MSD are higher than till maize, as well as soybean, beans and cotton. Although it can be argued that production costs can be offset by higher gross margins realized under SLM systems, incurring additional capital costs can be a disincentive for adoption of no till systems for majority of smallholder farmers in Malawi. Interventions to prevent farmland areas from soil erosion, desertification and floods (e.g. agro forestry, soil and water conservation structures) are found to be costly and labor-intensive although they seem to provide higher outcomes than conventional land management systems. Under certain conditions, 'conventional' systems might therefore be preferred for effective design of agriculture policies should these results be taken into account.

Table 1: Classification of the practices in appropriate technology packages (MSD vs. Tillage systems) and diffusion among farmers in the sample (national level)

			Freq.	**Percent**
Tillage	T0	only	47	3.28
	T1	+ crop rotation no legumes	127	8.86
	T2	+ crop rotation with legumes	185	12.91
	T3	+ swc + other combinations (rot/cover crop/intercrop/residue ret)	323	22.54
	T4	+ agroforestry + other combinations (rot/cover crop/intercrop/residue ret)	129	9
	T5	+ agroforestry & swc + other combinations (rot/swc/cover crop/intercrop/residue ret)	105	7.33
	T6	+ crop rotation no legumes + residue retention/cover crop/intercropping	131	9.14
	T7	+ crop rotation with legumes + residue retention/cover crop/intercropping	121	8.44
	T8	+ residue retention	27	1.88
	T9	+ other combinations	6	0.42
	T	**Total tillage**	**1,201**	**83.81**
MSD	M1	+ residue retention	29	2.02
	M2	+ crop rotation no legumes + residue retention/cover crop/intercropping	39	2.72
	M3	+ crop rotation with legumes + residue retention/cover crop /intercropping	20	1.4
	M4	+ crop rotation + residue retention/cover crop /intercropping/swc +agrof (CF)	45	3.14
	M5	+ swc + other combinations (rot/cover crop/intercrop/residue ret)	54	3.77
	M6	+ crop rotation + other comb	27	1.88
	M7	+ agrof + swc + other comb	12	0.84
	M8	+ agroforestry + other comb	6	0.35
	M	**Total MSD**	**232**	**16.19**
Total			**1,433**	**100**

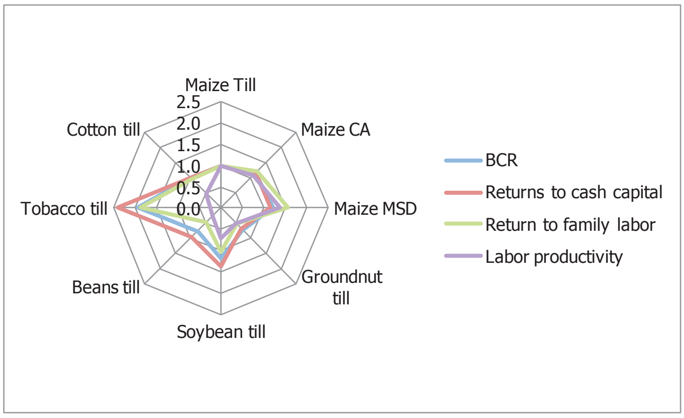
Source: own elaboration

Figure 1: Gross margins and net incomes by crop, technology and AEZ



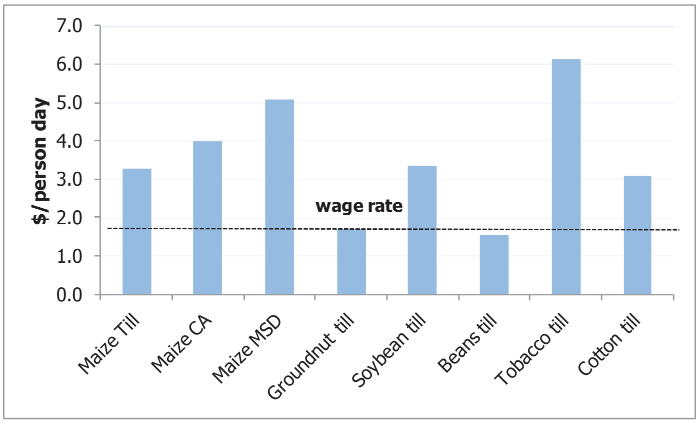
Source: own elaboration

Figure 2: Returns and productivity, ratios with respect to baseline (Maize till)



Source: own elaboration

Figure 3: Returns per day of labour by crop/technology, compared to average rural wage rate



Source: own elaboration

Results of the OLS estimation of the log-linear production function for maize are reported in table 2 (due to limited number of observations, regression results are statistically significant only for maize). Column (1) reports the coefficients of the production function in its log-linear Cobb-Douglas form (see equation 12 above): all inputs (land, labour, fertilizers, herbicides, improved seeds) as well as dummy variable for MSD are significant. Column (2) shows results when controlling for fertilizer: we have added the interaction of the MSD dummy with fertilizer in order to control if the yield increase depends on fertilizers instead of technologies; since the dummy is significant but the interaction no, we conclude that impact of MSD technology on crop yields is significant per se. The same does not happen when controlling for improved seeds (column 3) as coefficients of the three variables become non significant; this can be put in relation with the fact that use of improved seeds is widespread and it is common no matter what the technology is. We have also looked at the same variables in the different AEZs. Results are reported in columns (4), (5) and (6) of the same table. Essentially they do not change[4].

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[4] We have also run regressions for MSD technology disaggregated in CA, CF, SWC and other MSD, by adding a dummy for each of the options, following the same procedure, i.e. also adding the interaction with fertilizers and seeds. Since results do not vary, we do not report them here.

Table 2: Regression results, maize yield (Kg/ha)

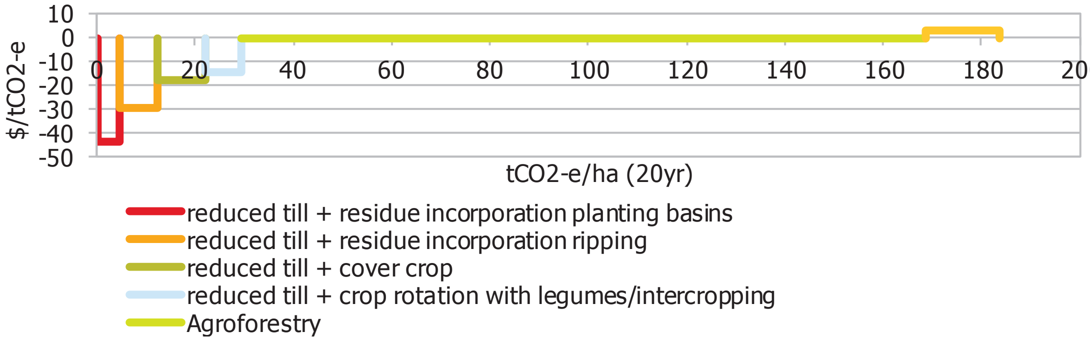
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	-	-	-	-	-	-
Log crop area (ha)	0.541***	0.533***	0.533***	0.554***	0.546***	0.546***
	(0.041)	(0.042)	(0.042)	(0.042)	(0.042)	(0.042)
Log total labor (days)	0.198***	0.199***	0.199***	0.209***	0.209***	0.209***
	(0.053)	(0.053)	(0.053)	(0.053)	(0.054)	(0.053)
Log chemical fertilizers (kg)	0.124***	0.130***	0.130***	0.126***	0.130***	0.130***
	(0.020)	(0.022)	(0.022)	(0.020)	(0.022)	(0.022)
Log herbicides (lt)	0.025**	0.027**	0.027**	0.027*	0.028**	0.028**
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Dummy improved seeds (1=yes)	0.127**	0.127**	0.128*	0.116*	0.116*	0.117*
	(0.063)	(0.063)	(0.071)	(0.063)	(0.063)	(0.071)
Dummy MSD (1=yes)	**0.204****	**0.324***	0.326	**0.193****	**0.296***	0.297
	(0.079)	**(0.191)**	(0.224)	**(0.080)**	**(0.193)**	(0.224)
Log chemical fertilizers (kg)*Dummy MSD		-0.031	-0.031		-0.026	-0.026
		(0.043)	(0.043)		(0.044)	(0.043)
Dummy improved seeds*Dummy MSD			-0.002			0.001
			(0.156)			(0.157)
Dummy AEZ==warm semi-arid				-0.049	-0.047	-0.048
				(0.108)	(0.107)	(0.108)
Dummy AEZ==warm sub-humid				0.04	0.0365	0.03
				(0.115)	(0.114)	(0.115)
Dummy AEZ==cool semi-arid				-0.013	-0.0180	-0.0180
				(0.128)	(0.127)	(0.128)
Constant	5.563***	5.555***	5.554***	5.53***	5.532***	5.532***
	(0.257)	(0.259)	(0.261)	(0.274)	(0.275)	(0.278)
Observations	*635*	*635*	*635*	*635*	*635*	*635*
R-squared	*0.330*	*0.331*	*0.331*	*0.332*	*0.332*	*0.332*

Robust standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Source: own elaboration

MAC curve is derived as a histogram where each bar represents a single agriculture technology option. The width of the bar represents the amount of abatement potential (ton of CO_2e saved as measured on the x axis). This amount is computed as difference between the mitigation potential of the technology and the mitigation potential of the 'conventional' technology (baseline). The height of the bar indicates the unit cost of the action (unit cost of abatement measured in US$ per ton of CO_2e saved as measured on the y axis). The area (height * width) of the bar shows the total abatement cost of the technology (measured in US$). Land reference unit is 1 hectare and each bar refers to that land unit. The bars have been placed in order of increasing unit cost. Technology with the lowest abatement cost is put as the first option, while the technology with the highest unit abatement cost is put as the last option. In this way the MAC curve shows the range of possible technology options that should progressively be implemented according to a criterion of cost-effectiveness. MAC curve is reported in figure 4.

Figure 4: Marginal Abatement Cost Curve for maize production in Malawi



Source: own elaboration

MAC curve shows that reduced tillage in combination with either residue retention or legume inclusion or cover crops provides the most cost-effective form of mitigation. By contrast, measures that involve, SWC structures or AF are less cost effective, which is due to their higher upfront investment cost requirements. Policy makers should promote the adoption of MSD technology options first, in order to act in a cost-effective way and gain efficiency.

Marginal abatement costs are negative for all MSD options (with slight differences among the different combinations of practices). SLM implementation will in fact generate higher benefits than under conventional agriculture, therefore showing a synergy between rural development (increased food security) and climate change mitigation (abatement potential). MSD technology options can therefore generate both private and public benefits and thus constitute a potentially important means of generating "win-win" solutions to addressing poverty and food insecurity as well as environmental issues (climate change mitigation). Such practices contribute to improving soil fertility and structure, adding relevant amounts of organic matter to the soil, conserving soil and water. This in turn translates into better plant nutrient availability, increased water retention capacity and better soil structure, leading to higher yields and greater resilience, thus contributing to enhancing food security and rural livelihoods. Marginal abatement cost for the second set of technologies shown in the MAC curve (agroforestry) amounts to only -0.63$/t CO_2-e. This means that costs offset the benefits. This technology requires bigger production costs (seedlings production and planting). Also, they are characterized by a longer implementation period where the costs are borne in the first years (building infrastructure and planting trees), while the benefits are gained in the medium-long term, therefore generating a negative flux of net benefits in the short-term (like the time frame of the present analysis). SWC shows positive abatement costs (+2.7 $/t CO_2-e). Structures for water and soil management are costly and costs are bigger than benefits.

In terms of the mitigation potential per hectare (width of the MAC curve) AF systems provide a structurally higher potential than all other systems. It was also found that the application of single practices in isolation leads to less mitigation impacts than practice combinations. Although technologies are alternative options, the generated economic and climate change mitigation benefits of areas where such options are implemented can be added up when engaging in a landscape analysis. By summing up the impacts in USD and climate change mitigation, it is therefore possible to derive the total abatement cost and mitigation benefits that are generated within a targeted area.

Conclusions

Supporting farm incomes growth is a way to address food security and contribute to improved rural livelihoods in Malawi. This requires, in the first instance, an increase in productivity of land and labor in the farming sector. Increasing the productivity of farm labor typically requires the introduction of new technologies (Paarlberg, 2010). MSD (specifically zero/minimum tillage and residue management/mulching) in arid areas has shown promising results in terms of increased yield, land, capital and labor productivity and could represent a valid option to increase food security in drier AEZs of Malawi. Thanks to the expected agronomic benefits – improved soil moisture and structure and overall fertility conditions – MSD represents a feasible option to face drought risk for resource constrained smallholders, showing CC adaptation potential. Such option would be cheaper (it requires fewer on-farm and off-farm investments), of easier adoption and better accessibility than more costly alternatives such as irrigation, especially for smallholders with limited access to markets.

Negative marginal abatement costs for all MSD options show synergies between increased food security, CC adaptation potential and mitigation. Cost-effectiveness of different land management practices is proposed as decision criteria allowing policy makers to rank and prioritize support interventions on the basis of the economic efficiency of GHG abatements. MSD systems are a profitable CSA investment in drier areas with greater rainfall variability. In such areas, farmers implementing MSD systems have higher incomes than under conventional systems (food security and adaptation). In humid areas, with lower benefits from SLM adoption, SLM can be coupled with higher Carbon sequestration (CC mitigation).

Going beyond field level testing to farm, district and agro ecological zone level, the analysis provides useful insights to the effective design of national agriculture policies. Public funds could be allocated in order to support policies promoting the adoption of CSA practices. However, since alternative investment options exist, together with the opportunity costs of switching from one system to another, the existence of high internal rates of returns for CSA investments should be demonstrated, also in a frame of uncertainty and inefficient markets.

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