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Agricultural land allocation in small farms around Maasai Mau forest, Kenya and the implications on carbon stocks

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Recent assessment of the Maasai Mau forest-part of the largest remaining natural forest in Kenya revealed that direct expansion of small farms into the forest in response to population and climate induced land use pressures, largely contributed to a 42% loss in forest cover between 1995 and 2008. In response, the Kenyan government plans to integrate farmers into forest management initiatives through incentive schemes such as on-farm carbon payments. To contribute to the envisaged carbon payment scheme(s), a regression model depicting the most efficient land use design with higher net carbon addition was derived based on existing land use types, respective allocations and carbon stocks in 30 small farms of 2 to 6 ha occurring within 5 km from the forest boundary. Results confirmed that smallholder land allocation is a function of first, food crops for subsistence ($p \leq 0.01$) followed by cash crop for income ($p \leq 0.01$) while tree planting is least prioritized. Aboveground carbon stock per farm, on average, amounted to 13.2 t/ha. Based on a linear model (R^2=68%), trading off 10% of open grazing land for farm forest, while unchanging the traditional land allocated to food crops and cash crops, doubles carbon stocks per hectare of these farms. While incorporating carbon sequestration potential into small farms require careful tradeoffs between environmental, social and economic land demands, it presents a win-win incentive oriented strategy to restore Maasai Mau and the larger Mau forest. However, such initiatives must be informed by ordered empirical research on land use demands and associated costs and benefits within the forest and its surrounding.

Key words: Carbon payments, forest management, land use tradeoffs, on-farm, smallholders.

INTRODUCTION

As global human population increases, so is the demand for agricultural products resulting in continuous subdivision of land into small farms in addition to extended pressure on forest resources (Lambina and Meyfroidt, 2011). The global anthropogenic land demand is projected to reach 282 to 792 million ha by which 80% will go into agricultural expansion (Lambina and Meyfroidt, 2011). To meet this demand, Lambina and 2030, of Meyfroidt (2011) project that 227 million ha of natural forest will be deforested globally. Already direct conversion of forest land to permanent small scale agriculture contributed a 57% loss in forest cover in developing countries between 1980 and 2000 ideally raising concerns on the sustainability of forest based ecosystem services, in ecologically sensitive economies such as Kenya (UN-REDD, 2008).

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Kenya loses about 12,000 ha of forest each year to agriculture and to a lesser extent, public or private development projects (FAO, 2010). Agriculture contributes about 25% of Kenya's GDP, and supports livelihoods of 80% of Kenyans. In the last decade; however, two elements namely population pressure and climate change have intensified agriculture-driven forest destruction in Kenya. Due to population increase, forest surroundings have experienced the greatest decline in land holding from 3.05 ha in 1997 to 2.1 ha a decade later (Kibaara et al., 2008). Kenya's Maasai Mau forest is a trust land and part of the wider Mau forest, the biggest remaining natural forest in the country. The surrounding community draws multiple benefits from the forest. 78% of the households obtain graze/animal feeds from the forest, 74% draw fuel wood, 64% cultivate crops in the forest while 93% depend on water from the forest (Thenya and Kiama, 2008). The forest also has cultural value attached to it by the Maasai community which is part of Kenya's traditional heritage (Homewood, 2005). Cash crops such as wheat and barley are grown in the forest surrounding at the same time; it is part of the rich Rift Valley hinterlands known to be Kenya's bread basket (Homewood, 2005).

About 70% of wheat (cash crop) produced in Kenya comes from the surroundings of the Maasai Mau forest, half of which is cumulatively contributed by smallholders (Eric, 2005). The Maasai Mara national reserve and Lake Nakuru national park, major tourism destination areas, depend on the ecosystem services from the forest (Tome and Kioko, 2008). Tourism sector contributes about 63% of Kenya's total GDP (Kenya National Bureau of Statistics, 2010). Lately, pressure on Maasai Mau forest resources intensified with changing climatic conditions. While climate change is a gradual process entailing fluctuations in average weather conditions over a long period of time (Ngaira, 2010), its role in forest degradation for a long time remained 'a non factor'. Records of the 20th century show that Africa warms at about 0.05°C per decade (Hulme, 2001). At the same time, precipitation decline in Africa's rainforests was recorded at 2.4±1.3% per decade since the mid 1970s (Mahli and Wright, 2004). Such climatic uncertainties alter cropping seasons, cause drought and flooding, thus making agricultural productivity uncertain (Somorin, 2010; Lema and Majule, 2009). Devereux and Edward (2004) report that countries in East Africa are already among the most food insecure in the world and that climate change will intensify yield declines.

In the context of agricultural failures, small scale farmers around the forest who largely depend on rainfed agriculture are forced to make difficult land use choices between livelihood and forest conservation (Eastaugh et al., 2010). Obvious choices involve opening up moist sites in the forest for farming and charcoal burning to fill the resulting climate induced food and income gaps. As a result, the rate at which Maasai Mau forest cover declined increased from 40 ha/year before 1995 to 1,755 ha/year by 2003 and 2005 (Nkako et al., 2005). Cumulatively, the forest lost 42% of its cover between 1995 and 2008. To address the forest-agriculture conflict, the Kenyan government initiated shifting cultivation in the 1960s and 70s, but post-independence population surge shortened fallow periods and accordingly, forest regeneration (Kenya Indigenous Forest Conservation Programme, 1995). The forest zone approach which involved buffering natural forests with plantation forests and/or perennial crops such as tea and coffee was adopted in the early 1990s; but the initiative intensified the conversion of natural forest into plantation forest and subsequently to permanent agriculture. Global and local stakeholders have therefore voiced the urgent need to harmonise agricultural land use with forest conservation.

As a first step, the integrated forest management approach-involving participatory reforestation/afforestation, alternative livelihood and most importantly payment for ecosystem services is currently embraced in Kenya's forest conservation policies (Kenya Forest Service, 2005). The Kenya Constitution 2010 and National Land Policy also target to formulate and implement strategies to increase the current forest cover of 1.5 to 10% of the Country's area (Republic of Kenya, 2010a). The Kenya National Climate Change Response Strategy, (NCCRS, Republic of Kenya 2010b), supports on-farm carbon payments as an incentive to increase the country's forest cover. The strategy recognizes that Kenya is one of the sub-Saharan countries which have been hit the hardest, by impacts of climate change going through recurring droughts and food shortage. Specifically, NCCRS mentions rainfall unreliability and reduced famine cycles from 20 years (1964 to 1984), to 12 years (1984 to 1996) to two years (2004 to 2006) and currently, to yearly interval (2007/2008/2009).

To contribute to the preparatory work for the envisaged farm-level carbon payments, the main objectives of this study were to assess land allocations and carbon stocks in small farms around the Maasai Mau forest and recommend a cost-effective land use readjustment with higher net carbon gains that could be paid for as an incentive to reduced pressure on forest resources while taking into account the subsistence needs of these farmers. Frameworks such as REDD+ and climate smart agriculture by the World Bank are likely to benefit from case studies such as the one presented here.

MATERIALS AND METHODS

Study area

Maasai Mau forest occurs in the South-western part of the wider Mau forest (Figure 1). The forest belongs to the Narok District, Rift Valley Province in Kenya and is a trust land covering 460 km^2. It lies close to the border of Kenya and Tanzania connecting the Maasai Mara and Serengeti ecosystems. The area's precipitation is bimodal and varies from 1000 mm per annum with a seasonal regime in the

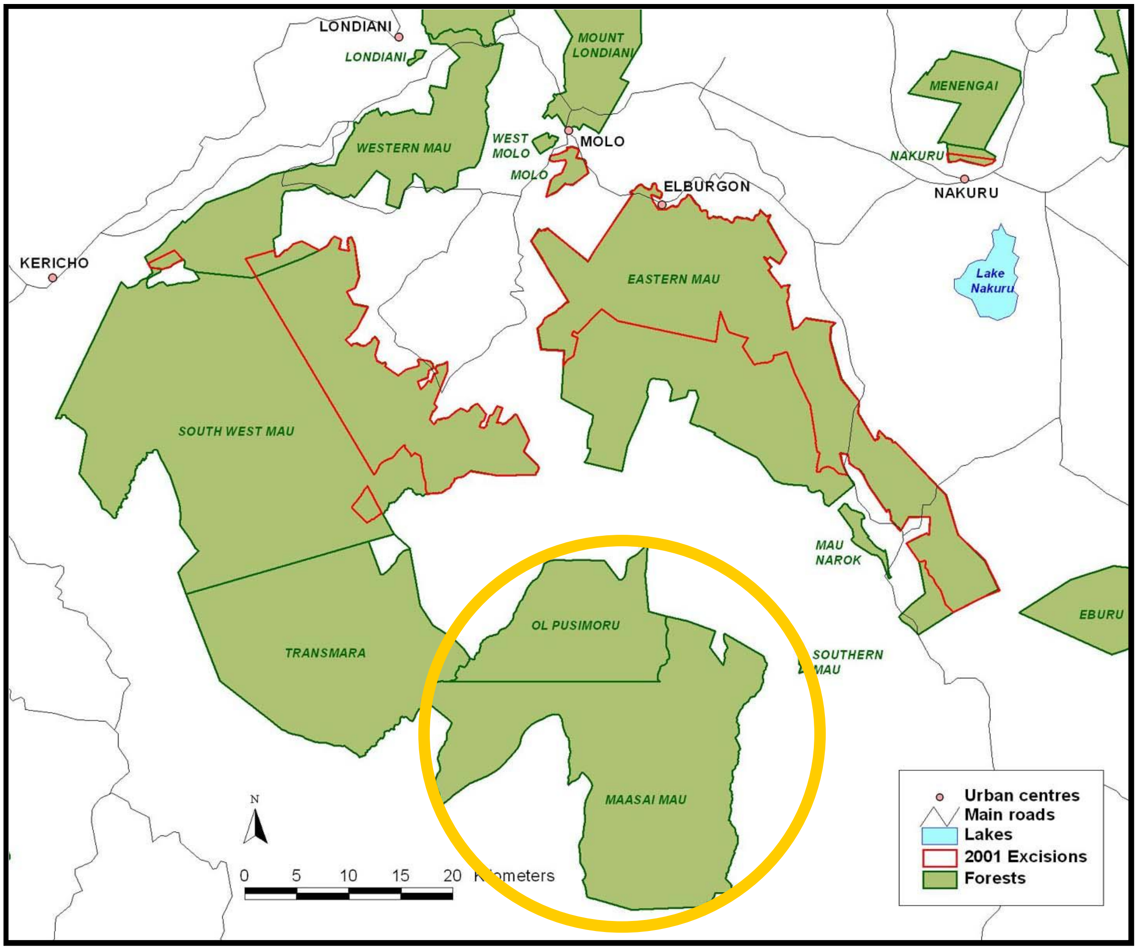

Figure 1. Location of Maasai Mau Forest block (encircled) within the Mau forest. Other forest blocks include Transmara, South-west Mau and Eastern Mau among others. The Maasai Mau forest block covers 460 km^2 and is a trust land as opposed to other blocks which are state managed. Source: Nkako et al. (2005).

Eastern part to 2000 mm per annum equally distributed over the year in the Western part and a temperature range of 10 to 25°C (Nkako et al., 2005). It forms the upper catchments of Ewaso Ngiro River which feeds into Lake Natron – designated international water body (Nkako et al., 2005). The forest surrounding was initially under group ranches but immigrants introduced extensive crop farming in the 1970s (Kituyi, 1990; Homewood, 2005).

In 2001, the Kenyan Government also excised part of the forest to settle victims of the 1990s land conflicts and forest dependent people-Ogieks (Ndungu Land Commission Republic of Kenya, 2004). During the resettlement, some ecologically sensitive parts of the forest were sold to agricultural immigrants (Republic of Kenya, 2004). The forest interior is covered with closed canopy indigenous trees dominated by *Cedar* and *Podocarpus* species while under storey open grazing is eminent in the exterior parts (Githiru et al., 2008). The surrounding farms constitute human settlements, field crops, scattered indigenous trees and a few exotic tree species planted in boundary or woodlot system.

About 15,000 individuals live within 5 km from the forest boundary most of whom undertake mixed farming. The farmers seasonally trade farm produce while in the further outskirts, agro-pastoralism is common (Republic of Kenya, 2009). The main cash crop is wheat especially in the Eastern and South-western parts, while dairy farming substitutes wheat in the Western part. Maize, beans and Irish potatoes are farmed for subsistence consumption but are traded by some farmers depending on the level of harvest. The average household size in the area is five persons with males as the predominant household heads (Thenya and Kiama, 2008). About 59% of the population, live below the poverty line of less than 1 US$ a day (Kenya National Bureau of Statistics, 2010).

Land use measurements

Initial survey was undertaken to establish the general farm designs around the forest (Figure 2). The forest surrounding was delineated into upper, middle and lower sections based on hydrological flow. A combination of multistage and random sampling was used to select 30 small farms of 2 to 6 ha within 5 km from the forest boundary. Ten (10) farms were selected from the lower parts, 5 from the middle part and 15 from the upper part. The farms were privately owned with socio-ecological features common in most small farms in the area. They were mapped using mobile GPS model *GPSMAP76CSX*.

Land use types within the 30 farms were then classified based on the national greenhouse gas accounting procedures documented under the IPCC (2006). The GPS was used to measure area covered by each land use type in the farms. Details related to farm

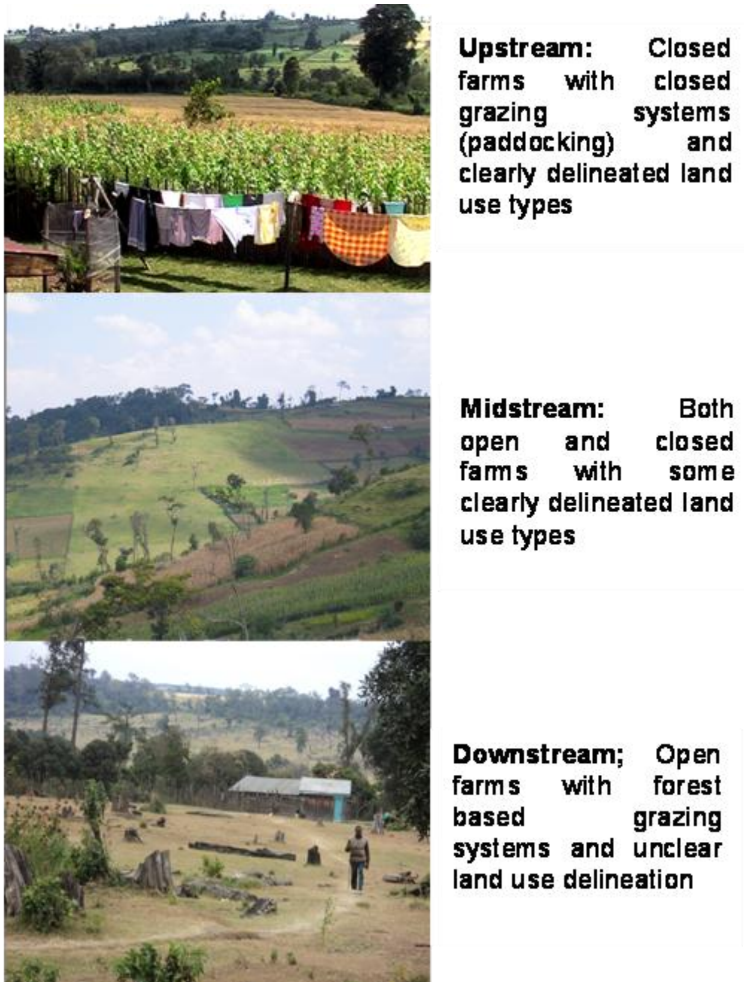

Figure 2. Farm designs observed around Maasai Mau forest.

size, land management practices and history as well as land use decision factors were either observed and/or obtained from discussion with farmers and agricultural extension staff.

Biomass measurements

Guidelines recommended in Pearson et al. (2005)- were used in biomass measurements. The approach entails a combination of multipurpose field survey and regression equations to estimate aboveground biomass in specific localities. Based on the approach, nested plots of 10, 5 and 1 m^2 were applied to sample trees, shrubs and herbaceous components respectively.

Tree biomass

Trees were identified at species level within 10 m^2 plots and their diameter at breast height (DBH) in centimeters and ages in years determined. Scattered and/or boundary planting of exotic and indigenous tree species occurring in the farms were counted and grouped into age-sets for the different species. The protocol applied in land use and carbon measurements had provisions for inquiring about land use decision factors. During land use and carbon measurements on farmers fields, a holistic discussion was undertaken with farmers and this revealed significant information of land use priorities and decisions. Estimating the age of old trees was based on information from farmers while most young trees of less than 8 years were aged based on extension records.

Extension officers, especially those belonging to the Greenbelt Movement who have been supplying seedlings to farmers who normally record the time and number of seedlings distributed to farmers in the area. Average DBH for each species in a given age set was then used for biomass calculation. Although the combination of DBH and tree height is recommended to be more informative than DBH alone in estimating tree biomass; Pearson et al. (2005) report that highly significant regression equations have been used to accurately calculate the tree biomass based on the DBH alone. Further, DBH can easily be measured with higher accuracy to give precise biomass estimates (Keith et al., 2000). Previous studies in Laikipia, Kenya which falls in the same ecosystem as the study area show strong correlation between woody biomass and DBH (Okelo et al., 2001).

Regression Equations 1 and 2, developed by Brown et al. (1989) from farm-level samples of 5,300 trees in addition to 101 forest stands in four tropical countries, were used to calculate tree biomass based on DBH. The equations are widely applied with reasonable accuracy for tropical trees growing in areas with more than 900 mm of rainfall per annum. Our study area annually receives more than 1000 mm of rainfall, on average:

Table 1. Land use types identified in the sample farms across the upper, middle and lower parts of Maasai Mau forest.

Land use type	Upstream (n=15)		Midstream (n=5)		Downstream (n=10)	
	Frequency of farms	% of farms	Frequency of farms	% of farms	Frequency of farms	% of farms
Cash crops	13	87	2	40	10	100
Farm forests	10	67	4	80	6	60
Fodder	14	93	5	100	7	47
Food crops	15	100	5	100	10	100
Grazing land	15	100	5	100	10	100
Scattered trees	15	100	5	100	10	100
Water points	6	40	0	0	0	0

Table 2. Summary of relative land use allocations across the upper, middle and lower parts of Maasai Mau forest surrounding.

Land use type	Upstream	Midstream	Downstream
Cash crops	29.0 ± 4.1	3.1 ± 1.9	28.0 ± 2.7
Farm forest	9.4 ± 2.9	12.9 ± 4.3	7.1 ± 2.7
Fodder	9.1 ± 1.8	23.3 ± 5.4	6.9 ± 1.8
Food crops	34.9 ± 6.1	46.5 ± 2.1	32.4 ± 3.8
Grazing land	15.6 ± 2.2	14.2 ± 3.7	25.6 ± 3.8

$$Y=42.69-12.800(D)+1.242(D^2) \qquad R^2 = 0.84 \ldots\ldots D=5\text{-}148\text{cm} \ldots\ldots (1)$$

$$Y=\exp\{-2.134+2.530+\ln(D) \qquad R^2 = 0.94 \ldots\ldots D<5\text{cm} \ldots\ldots (2)$$

where; Y=Biomass per tree (kg), D=Diameter at breast height -DBH (cm).

Non tree biomass (herbaceous components)

Herbaceous components included food crops such as maize, cover crops such as beans and Irish potatoes, cash crop mainly wheat, natural grass and fodder. Since most farms across the catchment had similar varieties of herbaceous vegetation, the samples were averaged for each of the three catchment levels (lower, middle and upper parts). A total of 15 averaged samples equally distributed across the catchment were obtained for laboratory analysis. The samples were dried at 70°C to a constant weight in an oven (MEMMERT) at the National Agricultural Research Laboratories of Kenya. Respective dry weights represented biomass per 1 m^2 of land. The dry weights were then extrapolated to the total area covered by a particular herbaceous component.

Carbon calculation

Total biomass for each land use type was standardized in tons per hectare, and halved to obtain carbon stocks (Equation 3).

$$\text{Carbon (t/ha)} = 0.5 \times \text{biomass (t/ha)} \ldots\ldots (3)$$

Data analysis

Microsoft excel worksheet version 2007 was used to record and calculate relative land use allocations and carbon stocks. Backward stepwise regression was applied to derive a linear model, depicting the variation of carbon stocks with relative land use allocations at 95% confidence level. The fitness of the model was depicted by the R square measure. Researchers' understanding of the study area was also used to inform the selection of a suitable model.

RESULTS

Land use allocations

The selected farms varied within 2 to 6 ha and were on average 4.35 ha. Food crops, scattered trees and grazing land were present in all farms. About two thirds of the farms had farm forest while cash crops and fodder were present in more than two thirds of the farms (Table 1). Table 2 indicates that food crops were not only present in all farms, but also received a larger share of land in most farms while allocations to other land uses varied from one farm to another. Overall, food and cash crops have the largest share of land. The average land allocation to farm forest was about 10%, roughly a quarter of the allocation to food crops (Figure 4).

Table 3 shows results of correlations between farm size as predictor variable and relative land use allocations as dependent variable. The result depicted a negative correlation between farm size and land allocation to food crops significant at $p \leq 0.01$ level. On the contrary, land allocation to cash crops positively correlated to farm size significant at $p \leq 0.01$. Land allocation to food crops was

Table 3. Correlations between relative land use allocations and farm sizes (n=30, CI=95%).

Land use	Farm size	Food crops	Farm forest	Cash crop	Grazing land	Fodder
Cash crop	0.470***	-0.662***	0.171	-	-0.06	-0.569***
Farm forest	0.223	-0.248*	-	0.171	-0.058	-0.228
Fodder	-0.247*	0.17	-0.228	-0.569***	-0.265*	-
Food crops	-0.697***	-	-0.248*	-0.662***	-0.238	0.17
Grazing land	0.113	-0.238	-0.058	-0.06	-	-0.265*

Correlations *** significant at 0.01 level, **significant at 0.05 level, *significant at 0.1 level.

Table 4. Aboveground carbon stocks for different farm sizes.

Farm size category (ha)	Mean carbon stocks(t/ha) ±SE	Median
2.00 (n=3)	3.77 ± 0.44	4.16
3.00 (n=2)	2.96 ± 0.07	2.96
3.50 (n=5)	9.17 ± 2.87	7.33
3.75 (n=1)	8.04	8.04
4.00 (n=4)	12.25 ± 4.45	10.03
4.50 (n=1)	5.28	5.28
5.00 (n=6)	8.76 ± 2.35	7.72
5.50 (n=1)	3.21	3.21
6.00 (n=7)	27.83 ± 13.88	6.05

Table 5. Mean carbon stocks of the major land use types in the farms.

Land use type	Mean carbon stocks (t/ha) ± SE
Cash crops	2.6 ± 0.1
Farm forest	84.1 ± 26.5
Fodder	3.9 ± 0.2
Food crops	2.8 ± 0.2
Grazing land	0.3 ± 0.1
Scattered trees	1.1 ± 0.2

negatively correlated to the allocation to cash crop at (p≤0.01). At the same time, a negative correlation existed between allocation to food crops and farm forest (p≤0.1).

Land use decision factors

Livelihood (subsistence) need was the priority factor considered by most smallholders in land use decision making rated at a mean scale of 2.6 (very strong). Income needs came second at a mean rating of 2.0 (strong). Forest conservation was however least prioritized while soil and water conservation and homestead landscaping are considered only after the livelihood and income needs are satisfied.

Aboveground carbon stocks

Out of the 30 sample farms, 28 had carbon stocks in the range of 2 to 20 t/ha while two farms (P5L3 and P8L3) had 74.3 and 87.3 t/ha of carbon respectively. The average carbon stock for all farms was 13.18 t/ha, which reduced to 7.65 t/ha if the two statistically outlying farms are included. Table 4 shows the distribution of carbon stocks in various farm sizes. The median was used in presenting the mean deviations to indicate a clear measure of central tendency in such highly varied measurements (Coppi et al., 2006). In terms of carbon storage within the land use types, farm forest had the highest carbon stock, on average, while all herbaceous land cover had less than 5 t/ha of carbon on average (Table 5).

Correlation analysis showed that increasing spatial allocation to farm forest increases carbon stocks at a coefficient of 0.560, significant at p≤0.01, while spatial allocation to open grazing negatively influenced carbon stocks at a coefficient of 0.459, significant at p≤0.05 (Table 6). Spatial allocation to other land uses had no

Table 6. Effects of relative land use allocations, diameter at breast height and tree age on carbon stocks (t/ha).

Carbon factor	Coefficients with outliers (n=30, CI=95%)	Coefficients without outliers (n=28, CI=95%)
Relative land use allocation		
Cash Crops	0.156	-0.83
Farm Forest	0.481***	0.560**
Fodder	-0.057	0.064
Food crops	-0.325**	-0.06
Grazing land	-0.075	-0.459**
Other factors		
Diameter at breast height	0.599***	0.245**
Tree age	0.459**	0.649***

Correlations *** significant at 0.01 level, **significant at 0.05 level, *significant at 0.1 level.

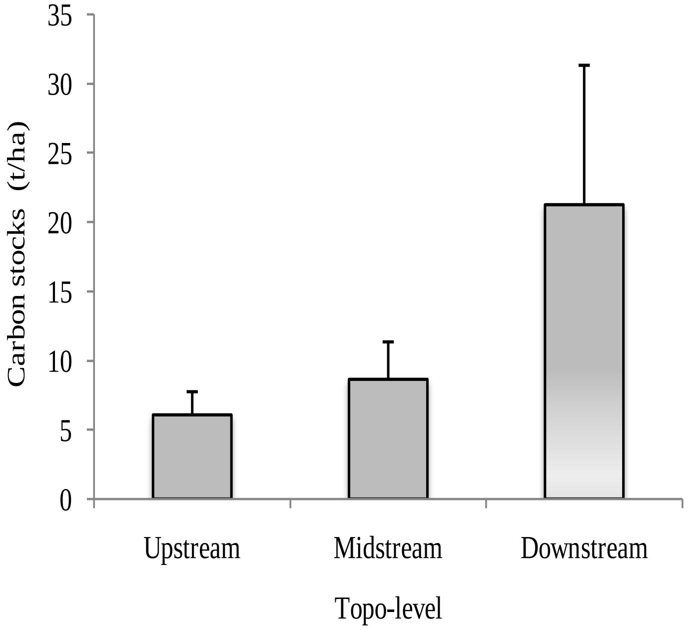

Figure 3. Average carbon stocks of farms in the downstream, midstream and upstream parts of Maasai Mau forest.

significant influence on carbon stocks. Age of trees also positively influenced carbon stocks at a coefficient of 0.649, significant at p≤0.01. In terms of the position of a farm in the catchment, upstream farms had the least carbon stock of 6.6 t/ha±1.6, on average while farms downstream had the most carbon stock at 22.4 t/ha ± 10.0 (Figure 3).

Carbon-land use model

To aid the projections, two linear models were first derived based on carbon measurements from a sample of 28 farms and the corresponding relative land use allocations.

Model 1 (General linear model)

$F_c = -5.914+0.814T_{ag}+0.130F_{cal}+0.043C_{cal}+0.448F_{fal}-0.173G_{lal}+0.083F_{dal}$

$R^2=0.68$; F_c = Farm level carbon stocks per ha; -5.914 = Constant; T_{ag} = Time (years); F_{cal} = Relative allocation to food crops; C_{cal} = Relative allocation to cash crop; F_{fal} = Relative allocation to farm forest; G_{lal} = Relative allocation

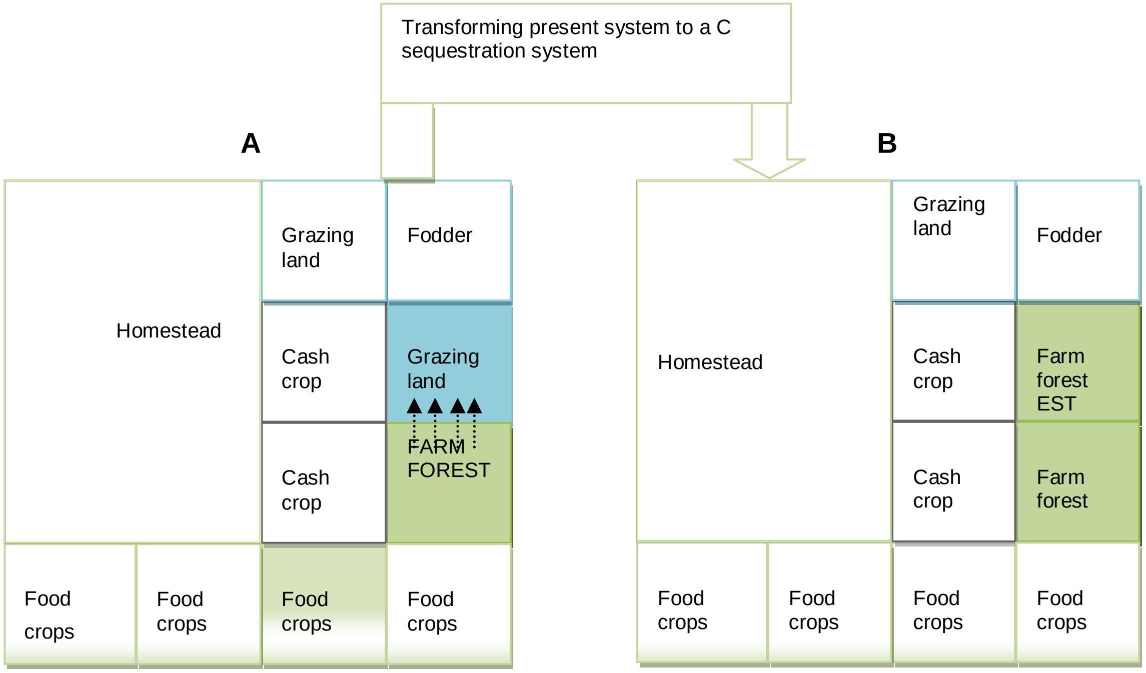

Figure 4. (A) Business as usual land use design with farm forest occupying 10% of land. (B) Carbon project land use design entails a tradeoff between farm forest and grazing land by increasing land allocation to farm forest by 10% and reducing land allocation to grazing land by a similar percentage.

to open grazing; F_{dal} = Relative allocation to fodder.

Model 2 (Stepwise regression model)

$$F_c = 4.155+0.806T_{ag} +0.30F_{fal}-0.280G_{lal}$$

$$R^2=0.65$$

where; F_c = Farm-level carbon stocks (t/ha); 4.155= Constant; T_{ag} = Time (years); F_{fal} = Land allocation to farm forest (%); G_{lal} = Land allocation to open grazing (%).

The models show how carbon stock is likely to respond to any change in the predictor variables. Model 1 incorporates all the five land use types identified in the sample farms while model 2 excludes land use types which are not significant to carbon. Model 2 was deemed appropriate for the objective of this study because it incorporates significant variables influencing carbon stocks. On average, farm forest and grazing land contribute the highest and lowest carbon stock respectively. Also, unlike food crops, fodder and cash crops which have a seasonal harvest cycle with unstable carbon fluxes, farm forest and grazing land are relatively long term land uses.

Based on model 2 therefore, land use tradeoff between farm forest and open grazing was the most efficient. For instance, converting 10% of the current land allocated to open grazing to a farm forest, after 8 years would yield 14.633 t/ha of carbon stock almost twice the business as usual land use situation. The 10% tradeoff is a hypothetical example based on researchers‘ judgment and understanding of the study area but the model is flexible and can use any figures to develop scenarios. A figure beyond 10% would mean significant shifts in land use which farmers may become suspicious of in the first instance. A figure below 10% for the ease of calculations would be rounded off with more implications on carbon stocks. The implication is that a hectare of every small farm designed with 20% farm forest, 8% open grazing, 38% food crops, 20% cash crops and 13% fodder after eight years would stock 14.4 t/ha of carbon. The tradeoff is schematically presented in Figure 4.

DISCUSSION

From the initial land use mapping; food crops, cash crops, open grazing land and scattered trees were common in most farms. Such land use trends were expected as most smallholders in the study area depend on food produced from their own farms all year round and additionally supply the produce, in some seasons, to other parts of the country. On the other hand, farm forests recommended by most agro-ecologists/ agroforesters as the land use option that stabilizes the natural resource base at farm-level, were present in fewer farms. According to Morton (2007), smallholders in the tropics are responsible for high proportions of food and cash crop production with equal proportion of natural resource depletion.

Ideally, achieving sustainable land use requires a balance between the needs of all prospective land demands while ensuring the sustainability of natural resource base (World Commission on Environment and Development; WCED, 1987). In this context, the major challenge to smallholders is how to make careful tradeoffs between usually conflicting land use demands (Mwasi, 2001). For instance, the significant correlations between land allocations to; cash crop and food crops as well as farm forest and food crops depict existing tradeoffs between environmental (farm forest), social (food security) and economic (cash crops) land demands in small farms (Bekele and Stein, 2005). Despite such tradeoffs, results of this study showed that smallholders, regardless of their geographical locations, give priority to subsistence land uses mainly in growing food crops. Expectedly, growing food crops is allocated a larger share of land in smaller farms compared to bigger farms which have more allocation to cash crops (wheat). The subsistence and income dependency on farm size in smallholder systems is indicative of the role farm sizes play in determining land use practices (IFPRI, 2002). Field observations further revealed that most large farms around Maasai Mau forest are leased to private investors for commercial wheat farming. IFPRI (2002) observes that increasing farm sizes diversifies land use rights tailored mainly towards income generation and such use rights are closely hinged on the existing land tenure system.

According to Ndungu Land Commission (Republic of Kenya, 2004), land tenure system largely influenced the historical land use changes in the Maasai Mau forest especially in the downstream areas where the greatest direct expansion of private farms into forest land occurred. Such expansions were unplanned and in most cases illegal. Farms in this area have unclear land use boundaries coupled with scattered indigenous trees and expansive grazing land left from the initial forest cover. On the other hand, the upstream area was demarcated and cleared off forest by the government to settle the current inhabitants who were issued with valid title deeds. In these upper part, land use intensification is inherently evident with clearly demarcated farm boundaries, agro-silvicultural systems, use of fertilizers and shift from subsistence to commercial farming practices. According to IFPRI's (2002) multivariate analysis of land use tradeoffs in the tropics, there is marginally greater incentive to intensify land use on initially cleared areas with secure land tenure. Secure land tenure promotes access to extension services and input-oriented agriculture in the light of declining land holdings (Schuck et al., 2002). Studies also show that secure property rights enhances resource conservation at farm-level that collectively answers to the land use problems at a larger scale (Swallow, 2002).

scale (Swallow, 2002).

Therefore, the current debate on land rights and tenure reforms in Africa and Kenya in particular, envisages transferable property rights that would improv smallholder farmers' productivity and investment on land (Deininger and Jin, 2006; Smith, 2004).

Given the ensuing land use competition in small farms, incorporating less farmer-prioritized land use like farm forestry for carbon sequestration to mitigate climate change and earn income in the long run; require careful consideration of the most optimum land use tradeoffs (Noordwijk, 2008). Land use types and allocations determine carbon stocks that reflect smallholders' contribution to climate change mitigation and environmental conservation. The aboveground carbon pool considered in this study is the most important pool in carbon accounting for payments in the existing carbon markets (IPCC, 2007). Aboveground carbon fluxes at farm-level are a function of multiple factors but in this study, we discuss the effects of four attributes namely farm size, relative land use allocations, age of trees in the farm and the farm's position in the catchment.

Even though there is no clear evidence on the influence of farm size on carbon stocks, land use types in a farm considerably influenced carbon stocks. Trees in the farms contributed about 60% of the total carbon stocks an aspect further reflected in the significant positive correlation between carbon stocks and land allocation to farm forest. Results of land use tradeoff analysis in reference to carbon by Kirbi and Potvin (2007) show that conversion of forest to pasture and food crops[1] would have the greatest negative impact on carbon stocks at farm or landscape level. Sanchez (2007) asserts that on-farm forests sequester three times more carbon than herbaceous vegetation such as food crops and open grazing land s. Trees, preferably in woodlot system, are therefore the most important carbon pool for farm-level carbon payments. However, within the farm forests, carbon stock depends more on intrinsic attributes such as tree age. Older trees have accumulated more biomass over time, further explaining the difference in carbon stocks for farm forests under equal spatial cover. Alexandrov (2007) notes that doubling the length of harvest cycle for a forest, increases tree biomass by 40% translating into an annual sink 1 to 2% of the baseline carbon stocks. Alexandrov (2007) concludes that tree age is the most important indicator of ecosystem services from forests.

Additionally, the increase in carbon stocks downstream can be explained by the concept of mass flow (water and sediments). Studies indicate that spatial variability and neighborhood effects within the landscape, influence environmental service functions such as biodiversity and biomass (Noordwijk, 2002). Field observations revealed that upstream farms are characterized by input oriented

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[1] A negative tradeoff always exists between farmers' interest in crop productivity per unit area, and environmental interests in carbon stock (Noordwijk, 2002).

farming techniques and intense land use. According to Noordwijk (2002), if land use intensity increases beyond a critical point, due to soil erosion, land degrades from a farmer's and environmental perspective resulting erosion of nutrients and subsequent biomass accumulation downstream.

Increasing carbon stocks in a small farm, therefore, requires empirical and optimal land use tradeoffs. Such tradeoffs should be in harmony with traditional values that smallholders directly or indirectly attach to their land. Further, modifications derived from such projections become more practical if they are based on farmer’s conditions. Denich et al. (2005) assert that land use improvements developed off-farm fail to address the true concerns of the farmer. In the regression model we developed, a smallholder would considerably increase carbon stocks by converting open grazing area into farm forest while unchanging the initial land allocation to food crops, fodder and cash crops. For instance, converting 10% of the current land under open grazing to a farm forest almost doubles the carbon stocks per hectare of a small farm. The sequestered carbon, if added for a group of farmers, is substantive to enable the establishment of a carbon project.

Study limitations

Even though land use allocations and tradeoffs are based on primary data collected directly from smallholders fields, certain social variables especially land tenure system that are supposedly important in carbon fluxes have not been included in the model. Additionally, the economic evaluation of the smallholder land use tradeoff could inform, into detail, the benefits of changing land uses. This will however be covered in the next part of the project.

CONCLUSIONS AND RECOMMENDATIONS

Smallholder land use systems are characterized by complex interactions that largely evolve around social motivations of food security and economic motivation of income. Incorporating environmental motivations such as carbon sequestration, require careful readjustments of the land uses in a manner that minimize conflicts between environmental, social and economic land use demands in these small farms.

Overall, the results seem to point out the need to shift focus from the challenges of land use and changing climatic conditions to opportunities that the changes bring with them for smallholders. In this context, actualizing international policies such as carbon trade in specific localities is likely to harmonise forest conservation objectives with livelihood and income needs of small scale farmers around the forests.

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