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Combining Tree-Crop Farming: Mimicking Farmers' Mixed Cropping and Land Fallowing Practices in Developing Sustainable Farmland Management System

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Abstract: Growing population and climate changes exerts pressure on land productivity and forest resources. Emerging unsustainable practices such as shortened period of traditional smallholders' natural fallows, exploitative cultivation and extension of farms through opening new farmlands and harvesting of natural forests for fuel wood are threats to productivity and environment. This necessitates development of sustainable production and environmental management solutions. Tree and shrubs were grown for two seasons in association with maize to mimic traditional farmers' mixed cropping and land fallowing in south western Tanzania, which significantly increased soil fertility with concomitant doubling of maize yield and reducing households' drudgery through increasing accessibility to firewood. Trees, *Acacia mearnsii* and *Calliandra calothyrsus* provided on average 20t/ha and 10t/ha of fuel wood biomass sufficient for over 590 and 330 days requirement of a rural household, respectively. These trees were liked by households as fuel wood for their heating strength, smokiness, charcoal and smelling on burning. The results mean that scaling up and out in the local landscapes of trees-crops culture would substantially increase farmland productivity, while eliminating harvesting pressure on natural forests. Trees and shrubs wood biomass and crop residues are promising economic resources in development of small electric power plants in rural areas.

Keywords: Energy; Rural electrification; Land productivity; Natural forests; Wood biomass.

INTRODUCTION

Growth in human population stresses natural resources through exploitative utilization. Natural resources degradations caused by over exploitation have led to climate change and variability, water scarcity stress and rural energy for cooking and heating (Meridian Institute, 2013). Climate change and variability in turn causes low agricultural soil productivity. This is seen through the decline in the ability of the land to yield desired products at sufficient and economically profitable level to meet the basic needs of land users. It is traditionally measured in terms of yield per unit area and/or input (Brady, 1990; Pieri and Steiner, 1997). The soil in the cropped lands through over cultivation and poor management practices, while the natural forest are degraded due to extension of cultivation and wood requirements as rural households' wood biomass energy sources such as charcoal and fuel wood (Naustdalslid, 2011). The conversion of grassland, tropical rain forest or peat bogs into agricultural land will generally lead to a release of additional carbon dioxide over several years or even decades (Fargione *et al*., 2008). Land conversion to expand cultivation increases GHG emissions and impacts biodiversity and ecosystem services. Anthropogenic activities for livelihoods, contributes to environmental degradation and greenhouse gases (GHG) emission that causes climate change (Gregory *et al*., 2005; Naustdalslid, 2011). In Tanzania, impacts of such degradations and climate change and variability are evident in increasing water scarcity for agriculture, domestic use and energy generation (URT, 2007; Malley *et al*., 2009a; Malley, 2011), soil fertility/productivity decline (Malley *et al*., 2006; Malley *et al*., 2009b).

Integrated multiple land uses approaches represent the largest climate mitigation potential in many countries (Scherr et al., 2012). They assert that these approaches is planned to deliberately support food production, ecosystem conservation, and rural livelihoods across entire landscapes. These are known under various terms including eco-agriculture, landscape restoration, territorial development, model forests, satoyama, integrated watershed management, agro-forestry landscapes, and the ecosystem approach to managing agricultural systems, among many others (Scherr *et al*., 2012). Climate-smart discourse leading to conceptual integrated landscape management as an organizing framework for action and policy within the agricultural development and conservation communities is being fostered in different parts of the world (Scherr and McNeely, 2008; LPFN, 2012). According to Lal, (2004), land-based carbon sequestration efforts currently offer the possibility of large-scale removal of greenhouse gases (GHG) from the atmosphere, through photosynthesis and carbon sequestration in soils and perennial plants. He further argued that soil organic carbon (SOC) sequestration is one of the important strategies to improve soil quality, increase agricultural land productivity, and mitigate climate change. Agricultural soil carbon accounts for 89% of the technical sequestration potential, representing an estimated potential of between 5.5 and 6 gigatons of CO_2 emissions per year, which roughly equals agriculture's total yearly contribution to global emissions (Smith *et al*., 2007). The importance of soil as C sink is evident from the fact that, its C pool is 3.3 times the atmospheric, and 4.5 times the biological pools (Lal, 2004). The soil organic C (SOC) pool is highly dynamic, variable and greatly influenced by land use and soil/crop management practices (Rice *et al*., 2004).

Among important strategies to increase the SOC pool are: soil restoration and woodland regeneration, no-till(NT) farming, cover cropping, nutrient management, manure and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agro-forestry, and growing energy crops on spare lands (Lal, 2004). Scherr *et al*., (2012) observed that agro-forestry, the use of live fences or intermingled crops and trees, is important strategy to achieve climate-smart objectives at landscape level. Agro-forestry and tree crops increase resilience of local communities by providing a diversity of fruits, nuts, medicines, fuel, timber, nitrogen-fixation services, fodder, and habitat. These economically useful trees and shrubs can reduce soil erosion and maintain higher levels of biomass than annually tilled crops (through extended growth periods and root systems), also storing more carbon (Milder et al., 2011). Other significant ways of emissions reductions include improved feed systems and manure management, more efficient fertilizer use, reducing deforestation and wetland conversion, and restoring degraded lands (Gustavsson, *et al*., 2006). Changes in land management and land use may also moderate local and regional climate through changes in albedo, evapo-transpiration, soil moisture and temperature (IPCC, 2007). Moreover, within agriculture, many adaptation measures have significant mitigation co-benefits such as increasing soil organic matter, which improves adaptive capacity by increasing soil water holding capacity and soil fertility, while also sequestering carbon (Schlamadinger, *et al*., 1997). In addition, increased forest biomass can be used as a substitute for fossil fuels and carbon intensive materials to reduce carbon emissions (Schlamadinger, *et al*., 1997). Using wood biomass to substitute for fossil fuels directly avoids fossil carbon emissions, except to the extent those fossil fuels are used to operate the wood biomass system (Hall, *et al*., 1994). Use of wood biomass to substitute for carbon-intensive materials may reduce carbon emissions by lowering fossil energy use during the manufacture of products, by avoiding industrial processes emissions, by increasing carbon stocks in wood materials, by using biomass residues to replace fossil fuels, and possibly by carbon sequestration or emissions from wood products deposited in landfills (Gustavsson, *et al*., 2006). The substitution potential depends on the amount and type of forest biomass harvested, which means, larger biomass harvests create greater substitution potential. The best alternative to conventional fossil fuels should have high calorific value, availability, easy production, transport and use. However, these present limitations, requires social and environmental policies that can open the possibilities to find quick and satisfactory solutions (Cherubini *et al*., 2009; Kaditi, 2009).

Growing of trees and shrubs that are compatible with food-crops seemingly opens new economic and development opportunities in rural areas. The harvested crop residue and trees wood biomass could be substitute to conventional fuels in order to avoid environmental and social adverse effects derived from fossil fuels non-renewability (Larson, 2006; Davis *et al*., 2009; Hoefnagels, *et al*., 2010; Cherubini *et al*., 2009).

Challenges of environmental degradations, climate change, food insecurity and poverty in rural areas of Tanzania, called for necessity to find integrated rural environmental management and energy solution for farming households. Testing of combination of mixed crop-trees with subsequent fallowing system was conceptualized as one of the solutions to manage the rural environment and finding an alternative to dependence on the distant natural forests for cooking and heating energy. This work therefore reports results of evaluations of crop-trees and shrubs combination with subsequent fallowing for land quality restoration in crop production and to increase households' access to fuel wood biomass at farm level. In addition, we discussed implications of the results in the face of climate change for rural landscape environmental management and electric and thermal energy development.

MATERIALS AND METHODS

Research locations and area

Research locations were Mbinga District, Ruvuma region and Mbozi Districts, Mbeya region in the southern highlands of Tanzania. The villages of study were Kitanda and Mtama in Mbinga District; Ivwanga and songwe in Mbozi District. The area has sub-humid tropical climate, receiving mono-modal rainfall of 700 mm to 1100 mm per year. Rains starts in November and ends in April/May of the following year. Altitudes of the area are between 1000 to 1800 meters above sea level (masl). Soils of the study villages are: Acrisols in Mbinga District which are deeply weathered, well drained, red sandy clays with massive red subsoil. In Mbozi District the Songwe village is characterized by shallow and gravely soils with ironstone overlying weathering rock classified as *orthic ferralsols*. Ivwanga village is dominated by deep red clay soils classified as *Ferralic cambisols.*

Research approach

Two types of on-farm experimental approaches were used for this research. Type-1 (researcher designed and managed) and type-2 (researcher designed farmer managed). For type-1 the village governments provided communally owned plots for the experiments. For type-2 trial, nineteen volunteer farmer experimenters tested trees/shrubs species they have selected on their private plots.

Experimental layout, design and treatments

In researchers designed and managed, and farmer managed private farmer fields, plots sizes of 10m x 10m separated with 1m paths were laid out. In type-2, single rows of 5-6 selected trees/shrubs treatments were replicated over the private separate farmers' plots. The researcher designed and managed experimental plots, 7-8 selected treatments were replicated three times on the same site. On the plots of both design types treatments were randomly imposed. The trees/shrubs species used are shown in Table 1.

Table1. Trees/shrubs inter-planted with maize and subsequently left fallows over 18 months in farmer and researcher managed plots.

District	Village	Trees/shrubs treatments	
		Type-1 experiments	**Type-2 experiments**
Mbozi	Songwe	1. Natural fallow	1. Natural fallow
		2. Sesbania sesban	*2. Sesbania sesban*
		3. Crotalaria ochroleuca	*3. Crotalaria ochroleuca*
		4. Tephrosia vogelii	*4. Tephrosia vogelii*
		5. Cajanus cajan	*5. Cajanus cajan*
		6. Calliandra calothyrsus	
		7. Tithonia diversifolia	
Mbozi	Ivwanga	1. Natural fallow	1Natural fallow
		2. Sesbania sesban	*2. Sesbania sesban*
		3. Crotalaria ochroleuca	*3. Crotalaria ochroleuca*
		4. Tephrosia vogelii	*4. Tephrosia vogelii*
		5. Cajanus cajan	*5. Cajanus cajan*
		6. Acacia mearnsii	
		7. Calliandra calothyrsus	
		8. Tithonia diversifolia	
Mbinga	Mtama	1. Natural fallow	1. Natural fallow
		2. Sesbania sesban	*2. Sesbania sesban*
		3. Crotalaria ochroleuca	*3. Crotalaria ochroleuca*
		4. Tephrosia vogelii	*4. Tephrosia vogelii*
		5. Cajanus cajan	*5. Cajanus cajan*
		6. Acacia mearnsii	*6. Acacia mearnsii*
		7. Calliandra calothyrsus	
		8. Tithonia diversifolia	
Mbinga	Kitanda	1. Natural fallow	1. Natural fallow
		2. Sesbania sesban	*2. Sesbania sesban*
		3. Crotalaria ochroleuca	*3. Crotalaria ochroleuca*
		4. Tephrosia vogelii	*4. Tephrosia vogelii*
		5. Cajanus cajan	*5. Cajanus cajan*
		6. Acacia mearnsii	
		7. Calliandra calothyrsus	
		8. Tithonia diversifolia	

Implementation of the experiments

Land preparation and soil sampling

Land was cleared and cultivated by hand hoe, plots and planting holes were marked in both farmers and researchers managed experimental plots. Soils were sampled at 0-20 cm depth by using zig-zag sampling pattern on each plot. The sampling at beginning of experiment, before treatment application and was repeated again after 18 months of trees and shrubs stayed in the field as fallows. Composite samples were made by each plot for soil analysis.

Soil analysis

Soil samples were air dried, grounded and sieved to pass 2-mm sieve. The samples were analyzed for texture, pH-H_2O, total nitrogen, available phosphorus and organic carbon and cat-ion exchange capacity (CEC) using the standard appropriate method as follows: texture, by the hydrometer method (Gee and Bauder, 1986), pH in 1:2.5 soil to water suspension, using a pH meter (Maclean, 1982), total nitrogen, by the semi-microKjedahl method (Bremner and Mulvaney, 1982), available phosphorus, by the Bray-1 method (Bray and Kurtz, 1945), and organic carbon, by the Walkley and Black method (Nelson and Sommers, 1982). Bases and the cation exchange capacity (CEC) were determined, by neutral ammonium acetate saturation, followed by distillation of ammonia and titration with dilute H_2SO_4 method (Thomas, 1982).

Planting of trees/shrubs and maize sowing

Trees/shrubs were planted at 1 m between rows and 0.8 m between holes except *Crotalaria ochroleuca*, was drilled in furrows spaced 1m apart at rate of 20kg/ ha. No fertilizers were applied to any of the plots. At beginning of rainy season maize was planted in each plot at a spacing of 45 cm between hills and 100 cm between rows with two plants per hill. In first season as tree-maize intercrops. The second season was a tree/shrubs fallow on the plot to allow land cover and trees/shrubs develop adequate woody biomass. During the maize-trees/shrubs phase, first and second weeding was undertaken 17-21 and 34-42 days after maize planting, respectively. Fallowed plots of trees and shrubs after intercrop season were not weeded. After eighteen months of tree/shrubs fallow were harvest and green manure were soil incorporated, maize was planted again using the same spacing as during the intercrop phase.

Maize crop harvesting and yield assessments

Maize grain yield was assessed from harvests under maize-trees/shrubs intercrops as well as after trees/shrubs fallow green manures were soil incorporated. Each time researchers, extension workers and farmers hand harvested all the plots. Maize grain was threshed from the cobs, harvest weight recoded and grain moisture content was determined by using the moisture meter. Then grain yield from each plot was calculated and expressed in kilogram per hectare at 130g kg^{-1} moisture content.

Wood biomass production assessments

With exception of *Crotalaria ochroleuca*, the planted woody trees and shrubs were harvested using cutlass at soil surface, woody parts were removed for fuel wood and the rest of organic materials from trees and shrubs were soil incorporated as manure. After removing leaves and small branches the fresh woody parts were cut into lots of 50 cm length. From each plot several lots were made and tight tied with sisal twines and weighed by a weighing balance to the nearest grams. The weight for each tree or shrub wood biomass was recorded. A fresh sample of five kilograms were taken for sun-drying and weighed again after samples were dry and ready for use as fuel wood. The samples weights were used to calibrate fresh weight into dry weight of the total firewood harvested from each tree or shrub.

Wood biomass farmer quality assessments

Farmers listed the attributes for good quality firewood. The attributes important to farmers were: heating strength, smokiness, charcoal quality and unpleasant smell. The attributes were scored by farmers in a matrix against each tree and shrub wood biomass tested.

Wood biomass accessibility assessment

Record keeping forms were prepared and demonstrated to the women of each experimenting households, who are most affected by backbreaking firewood fetching work in the households. In type-1 experiment three households were chosen by their fellows among experimenting households to use firewood from different trees and shrubs and keep the records of number of days each type was used. In type-2 experiment each farmer recorded number of days for use of firewood produced from his/her plot. The number of days and firewood dry weights were used to calculate households' accessibility to firewood per hectare from each tree and/or shrub used in the experiment.

Data analysis

Analysis of variance between trees/shrubs treatments as compared to natural fallow was performed for maize yield data and compared to baseline data from research site. Averages of villagers' scores for firewood quality attributes of trees and shrub species were calculated. Data of firewood production in mixed trees/shrubs-crops farming were extrapolated into hectare. Averages and standard deviations were computed for replications on potential of firewood production and accessibility to the households from their tree-crop farming.

RESULTS

Change in soil fertility

Results of change in key soil fertility parameters are in Table 2.

Table 2 Changes in some soil quality parameters on incorporating residues of 18 months of fallows

Fallow treatments	**Songwe**				
	pH (H_2O)	**P (mg/kg)**	**N (g/kg)**	**OC (g/kg)**	**CEC (Cmol/kg)**
Tephrosia vogelii	6.82	16.10	2.8	19.3	18.00
Cajanus cajan	6.46	9.80	2.8	17.3	19.00
Crotolaria ochroleuca	6.76	12.60	4.2	11.9	18.00
Calliandra calothyrsus	6.46	14.00	2.8	19.1	20.00
Sesbania sesban	5.59	9.00	2.8	19.4	22.00
Tithonia diversifolia	6.48	11.90	2.0	12.2	20.00
Natural grass fallow	6.49	10.90	1.8	18.8	18.90
Baseline status	**6.43**	**5.95**	**1.4**	**11.7**	**17.83**
	Ivwanga/Mbimba				
Tephrosia vogelii	5.46	12.60	4.2	19.8	21.00
Cajanus cajan	5.96	25.90	3.5	21.9	22.00
Crotolaria ochroleuca	5.42	15.40	4.2	19.9	19.00
Calliandra calothyrsus	5.69	11.90	4.2	23.4	20.90
Sesbania sesban	5.64	14.70	3.2	21.8	19.95
Acacia mearnsii	5.67	14.00	4.2	19.4	18.00
Tithonia diversifolia	5.66	17.50	2.8	24.2	21.50
Natural grass fallow	5.60	15.40	2.8	24.2	20.60
Baseline status	**5.54**	**7.00**	**2.0**	**19.4**	**20.38**
	Mtama				
Tephrosia vogelii	5.46	21.35	4.9	35.2	21.00
Cajanus cajan	5.56	21.70	4.2	33.4	20.00
Crotolaria ochroleuca	5.43	24.50	4.9	31.1	19.00
Calliandra calothyrsus	5.73	20.30	3.5	28.0	19.00
Sesbania sesban	5.52	21.70	4.9	32.2	22.00
Acacia mearnsii	5.53	23.10	4.9	30.7	20.00
Tithonia diversifolia	5.76	26.25	3.5	25.1	17.00
Natural grass fallow	5.35	14.70	2.5	31.6	20.00
Baseline status	**5.58**	**14.00**	**2.0**	**24.1**	**11.52**
	Kitanda				
Tephrosia vogelii	6.06	25.55	3.5	33.1	16.00
Cajanus cajan	5.94	25.20	4.2	31.6	18.00
Crotolaria ochroleuca	5.80	25.94	3.5	27.6	11.00
Calliandra calothyrsus	5.93	32.87	3.5	25.0	15.00
Sesbania sesban	5.86	25.60	4.2	39.7	18.00
Acacia mearnsii	6.10	31.85	2.8	39.2	15.00
Tithonia diversifolia	5.88	27.95	3.5	30.9	18.00
Natural grass fallow	6.08	20.30	2.8	36.2	19.00
Baseline status	**5.88**	**14.00**	**2.0**	**29.7**	**12.48**

Generally, there are no notable consistent changes in soil reactions. Available soil-P, total soil nitrogen and CEC were consistently increased by manures of the soil incorporated leaves and twigs of trees on plots upon trees/shrubs harvesting. Increase in total available phosphorus and nitrogen due to trees and shrubs were higher than natural grass fallows and baseline data, while increases in OC and CEC are similar. Total nitrogen increases for legumes tress and shrubs were double the baseline values in most cases.

Maize yield in tree-crop intercrops

Maize yields from the inter-planted maize in combination with trees and shrubs are in Table 3. The results show that most of the trees have small positive impact on maize yield in intercropping on the first season. In researcher managed trials interplant of *Cajanus cajan* with maize has increased maize yield across all locations. However the significant (p ≤0.05) increases were found from the control and baseline in Mbinga District. The increases realized were small in Mbozi soils as compared those in Mbinga soils. Inter-planting of *Calliandra calothyrsus* with maize had positive effects on maize yield comparable to that of *Cajanus cajan* in Mbinga District. Other trees/shrubs effects on companion maize though were positive but small in in Mbozi District soils as compared to Mbinga.

The results from farmer managed trials, further indicated the same patterns as in researcher managed trials, though not significantly (P≤0.05) different from the control and baseline values in all villages except Kitanda village in Mbinga District (Table 4). The trees/shrubs which gave significant effects from control are *Cajanus cajan*, *Sebania sesban* and *Tephrosia vogelii* at Kitanda village.

Maize yield after incorporating trees/shrubs manure

Maize yield results from researcher managed trials from that followed trees/shrubs fallow period of the eighteen months were significantly (P≤0.05) higher compared to control and baseline in researchers managed plots except for *Tithonia deversifolia* (Table

3). Fallowing with trees/shrubs and incorporating their green residues in most cases doubled maize yield when compared to control and baseline data. This was particularly the case for trees/shrubs that are legumes species. This implies contribution of the supply of soil-N to crop nutrition have increased substantially as evident in Table 2. In farmer managed plots, similar patterns of change in yield as in researcher managed plots were observed, though yields increases were generally not to the extent of doubling except at Songwe and Kitanda villages (Table 4).

Table 3 Effect of trees/shrubs-maize pre-fallow intercrops and after 18 months subsequent fallow on maize yields in researcher-managed plots (type-1) in the four research villages.

Trees/ shrubs	**Yield (t/ha) in intercrops pre-fallows**				**Yield (t/ha) after 18 months trees fallow**			
	Songwe	**Mbimba**	**Mtama**	**Kitanda**	**Songwe**	**Mbimba**	**Mtama**	**Kitanda**
Control	0.64	0.56	1.29	1.08	0.71	1.01	1.23	1.40
Sesbania-maize	0.75	0.70	1.67	1.77	3.95	3.93	2.91	3.34
Calliandra-maize	1.22	1.40	2.04	2.02	1.91	3.00	2.23	2.68
Acassia-maize	-	0.48	1.48	1.48	-	3.75	2.40	2.60
Tithonia-maize	0.79	0.68	1.56	1.82	0.91	3.41	1.76	3.29
Crotalaria-maize	0.83	0.88	1.48	1.02	1.56	3.84	2.07	2.54
Cajanus-maize	1.73	1.66	2.06	1.96	1.89	3.81	2.07	2.33
Tephrosia-maize	0.61	0.81	1.74	1.64	2.09	4.23	2.44	2.70
Baseline data	**0.75**	**0.70**	**0.90**	**0.85**	**0.75**	**0.70**	**0.90**	**0.85**
LSD (0.05)	**0.12**	**0.17**	**0.26**	**0.27**	**0.75**	**1.25**	**0.77**	**0.87**
CV (%)	**22.00**	**21.19**	**9.04**	**9.81**	**23.27**	**19.36**	**20.05**	**18.88**

Table 4 Effect of trees/shrubs-maize pre-fallow intercrops and after 18 months subsequent fallow on maize yields in farmer-managed plots (type-2) in the four research villages.

	Yield (t/ha) in pre-fallow period intercrops				**Yield (t/ha) after 18 months trees fallow**			
Trees/ shrubs	**Songwe** (n=7)	**Ivwanga** (n=11)	**Mtama** (n=11)	**Kitanda** (n=10)	**Songwe** (n=7)	**Ivwanga** (n=11)	**Mtama** (n=11)	**Kitanda** (n=10)
Natural fallow	0.82	0.66	1.27	1.12	1.11	0.54	1.04	1.18
Sesbania-fallow	0.95	0.44	1.48	2.10	2.72	0.96	1.97	3.23
Acassia-fallow	-	-	1.80	-	-	-	1.64	-
Crotalaria-fallow	0.83	0.88	1.72	1.28	2.06	0.79	1.74	2.83
Cajanus-fallow	0.76	0.68	1.74	2.13	2.56	1.11	1.92	2.82
Tephrosia-fallow	0.69	0.81	1.84	1.77	2.54	1.10	1.75	3.02
Baseline data	**0.75**	**0.70**	**0.90**	**0.85**	**0.75**	**0.70**	**0.90**	**0.85**
LSD (0.05)	**NS**	**NS**	**NS**	**0.42**	**0.63**	**0.44**	**0.44**	**0.45**
CV (%)	**30.83**	**47.92**	**26.03**	**26.74**	**29.93**	**57.06**	**26.62**	**17.66**

Firewood production

Trees/shrubs biomass harvested for firewood is presented in Table 5. Highest biomass producer among the trees/shrubs tested were *Acacia mearnsii*, (20 t/ha) followed by *Calliandra calothyrsus* (11 t/ha) and *Sesbania sesban* (6 t/ha) and *Tithonia diversifolia* (6 t/ha) after two years of growth on the farm plots. The first three are legume tree species, which fixes atmospheric nitrogen to enrich the soil-N. In addition, *Acacia mearnsii* and *Calliandra calothyrsus* have multiple uses. The *Acacia* tree provides good building poles, the bark extract are used in commercial shoe polish production, while the *Calliandra* is used in feeding dairy cattle as a concentrate formulation. The *Tithonia diversifolia* is not a legume, it is known for its ability to accumulate the soil-P in its leaves biomass, which is released upon incorporating the leaves and small branches as fertilizer in the soil. Its leaves extracts are locally used in de-worming the livestock such as goats and pigs, particularly in Mbinga District.

Table 5 Trees/shrubs firewood production (t/ha) attained after two years in the four villages

Tree/shrub	VILLAGES (SITES)				
	Ivwanga	Songwe	Kitanda	Mtama	Average
Sesbania sesban	6.37±1.80	7.97±0.77	6.03±0.88	4.32±2.04	**6.17±1.37**
Tephrosia vogelii	10.30±0.33	0.71±0.19	1.18±0.05	1.60±0.18	**3.45±0.19**
Cajanus cajan	4.30±0.53	5.68±1.78	2.95±0.55	2.38±1.02	**3.83±0.97**
Acacia mearnsii	30.78±7.23	-	19.13±1.43	10.75± 0.17	**20.22±2.90**
Calliandra calothyrsus	13.51±3.12	6.94±4.20	10.91±1.70	11.71±1.62	**10.77±2.66**
Tithonia diversifolia	11.49±1.96	3.40±0.14	5.87±0.75	4.40±1.65	**6.29±1.13**

Potential accessibility of households to firewood through mixed trees-crop farming

Trees/shrubs biomass harvested after two years and used as fuel wood biomass showed that all of them except *Tephrosia vogelii* on average would provide rural household with adequate firewood from a hectare plot for over a year (Table 6). *Acasia mearnsii* would be the best tree for this purpose, followed by *Calliandra calothyrsus.* Albeit, *Tithonia diversifolia* having comparable production as *Sesbania sesban* in evident in Table 5, its potential for firewood is low by about a half of that of *Sesbania* (Table 6).

Table 6 Potential accessibility of firewood to household (days/household) for a hectare of trees / shrubs planted two year fallows

Tree/shrub species	**LOCATIONS**				**Mean**
	Mtama	**Kitanda**	**Ivwanga**	**Songwe**	
Sesbania sesban	383±239	592±187	542±307	1056±069	**643±201**
Cajanus cajan	367±131	505±181	613±236	767±082	**563±138**
Tephrosia vogelii	240±157	183±095	321±163	367±205	**278±155**
Calliandra calothyrsus	800±163	333±125	1033±309	589±431	**689±229**
Tithonia diversifolia	367±085	300±041	500±245	383±083	**388±114**
Acacia mearnsii	591±239	1000±327	1533±249	-	**1041±272**

Wood biomass quality for firewood

Assessments of quality attributes of the wood biomass used for firewood by the experimenting households are summarized in Table 7. The *Acacia mearnsii* tree had highest scores for all the four attributes of suitability established by the farm households. Pooled scores across the villages it has 98% of the total highest score expected.

Table 7 Household average scores of wood biomass quality for use as fuel wood

Village/trees or shrub specie	***Quality attributes scored (1-4 scale)[1]**					
	LS	**FC**	**NIS**	**HS**	**Total**	**Rank**
Sesbania sesban	2.75	2.00	3.25	2.25	10.25	**3**
Tithonia diversifolia	1.25	1.25	2.25	1.50	6.25	**6**
Calliandra calothyrsus	3.00	2.25	3.25	2.75	11.50	**2**
Tephrosia vogelii	2.75	1.75	3.50	2.00	10.00	**4**
Cajanus cajan	2.00	2.00	2.25	2.50	8.75	**5**
Acacia mearnsii	3.67	4.00	4.00	4.00	15.67	**1**

* LS= less smoky, FC= forms charcoal, NIS= not smelly, HS= heating strength; [1]Scores: 1= low, 2= average, 3= high, 4=very high

The *Calliandra calothyrsus* and *Sesbania sesban* followed with 72% and 64% of the total highest score expected, respectively (Table 7). This means, for firewood production on farm, household would prefer the trees/shrubs species with those quality attributes.

DISCUSSIONS

Land quality restoration in crop production

The results of soil fertility parameters assessed in Table 2, revealed that trees/shrubs had positive impacts on soil-N, P, OC and CEC. These are important indicators for soil fertility to increases crop productivity and production. Trees/shrubs mimicked natural fallow processes of soil fertility restoration, used by smallholder farmers in most of the tropical climates to restore soil productivity on their farms (Pieri and Steiner, 1997). However, the natural grass fallows requires longer period to adequately restore natural fertility as the process is naturally slow. Use of fast growing trees/shrubs seems to accelerate the process of natural restoration in the soil productive quality in a shorter time. This is evident from concomitant doubling of maize yield after 18 months fallows of trees/shrubs (Table 3 & 4). This implies that, fertilizers application particularly nitrogen could be halved (Yang, *et al*, 2015) and attain desired yield. Under organic soil fertility amendments yield increments are gradual processes (Yang, *et al*, 2015) over time as the soil fertility build up through trees-crop manures incorporated. It is evident from soil analytical data (Table 2), that the use of mixed trees/shrubs- crops farming, potentially restores the natural soil fertility and would act as sink for GHGs and sequester atmospheric carbon. Adopting this approach in smallholder farming has short-term benefits in climate change adaptation in agricultural production and long-term benefits in mitigation in the face of climate change.

Implications for rural landscape management

Removal of land cover for cultivation exposes the land to degradation by various erosive agents. Changing native vegetation into agricultural land by clearing and tillage disrupts the soil structure, and depletes soil organic carbon (OC) pool (Tivet *et al.,* 2013). They found that soil OC fractions were negatively impacted by the conversion of native vegetation to conventional tillage, and those losses of OC fractions were restored by the adoption of no-tillage systems. However, the magnitude of recovery in OC fractions depends of the input of biomass. This implies that crop production without restitution of nutrients losses and uptake by plants and loss in soil organic matter causes soil degradation. As population grows resource poor smallholder farmers tend to excessively mine the soils as a source of revenue (Pieri and Steiner 1997). For example van der Pol (1992) found that in southern Mali 40% of the farm income are generated from soil mining. Smallholder farmers in Tanzania practice this extractive form of farming due to inability to purchase industrial fertilizers and shortage of land for practicing long natural fallows. This practice destroys the future productive capacity of the land; soil becomes vulnerable to degradation due to structural breakdown (Malley *et al.*, 2002; Tivet *et al.,* 2013). Use of trees/shrubs in combination with crops increase soil organic matter, which is needed to create favorable soil conditions for crop growth, prevention of land degradation processes such as erosion and nutrient losses.

Results showed that trees-crops combination practices provide firewood and maintain soil productivity per unit area. Scaling up-and-out of mixed trees-crop farming mimicking natural process of nutrients restitution has implications for reduced pressure on deforestation of land vegetative cover for expansion of cultivation. In Tanzania, rural households are natural forests resources dependent for wood biomass firewood in cooking and heating (URT, 2007). The results of number of days of households' access to firewood from the combination of crops-trees/ shrubs farming suggest that, there is great potential in eliminating dependence on natural forests for firewood. This implies the significance in developing a smallholder farming systems in a sustainable manner, which would supply firewood to rural households as part of their farming. This could have significant impact on the back-breaking labour for firewood fetching to rural women (Malley *et al.*, 2002).

Implications for rural electric energy development

Rural areas of Tanzania is characterized with no/or very low access to electric power for lighting, heating and cooking. A clean source of power is hydro-electric power which its supply is being heavily affected by climate change and variability in Tanzania (Malley, 2011). Alternative sources of energy in Tanzania include fossil fuel such as natural coal and gas which have recently being discovered. Developments of these electric sources have been given high importance and are underway, however are contributors to high GHGs emissions. Harvesting of standing natural forests for electricity and heating is subtraction of carbon, leading to debit in the process as the stored carbon stock is emitted (Johnson, 2011). Incorporating planting of forest trees into the crop farming, creates additional cost effective alternative, which is carbon neutral or negative source of electricity and thermal energy, since more carbon is returned to the soil and in the vegetation (Johnson, 2011). Scaling up and out of trees/shrubs biomass and crop residues produced could be both important source of income through wood biomass sales, electric power and thermal energy for rural people, instead of depending on natural sources such as coal, gases and forests.

CONCLUSIONS AND RECOMMENDATION

Mixed forest-crop combination farming restored land productive quality in short time than long natural grass fallows regeneration practices used by farmers to sequester the SOC and to recycle the plant nutrients. Maize yield doubled over two seasons by trees/shrubs subsequent fallows after an intercrop season. Production of wood biomass varied widely between trees and shrubs ranging from 3t/ha to over 20t/ha depending on the observed wood density of tree/shrub. There were correlations between number of days the households could have access to firewood for cooking and heating at farm level and scores of their suitability for the purpose. The best producers are the same as trees/shrubs give longer access time and high preference scores for wood biomass quality such as *Acacia mearnsii*, *Calliandra calothyrsus* and *Sesbania sesban.* Results suggest that, mixed forest-crop farming would substantially contribute to rural environment management through increased land cover as well as soil productive quality on the cropped land.

Evaluation of additional trees/shrubs species under different farming, socio-cultural and physical environment is recommended in developing forest-crop combination farming. It is pertinent that, scaling up and out of the forest-crop farming, would mitigate climate change, while generating adequate wood biomass for rural energy generation. Wood biomass could be periodically harvested in rotational manner and become an economic development opportunity for smallholder farmers. In addition, provide and avenue of attracting investments in small bio-energy plants to generate electric and thermal energy in rural areas, should be encouraged by Rural Electrification Agency in Tanzania.

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