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On-Farm Tree Abundance and Biomass Carbon Stocks of *Grevillea robusta* and *Eucalyptus saligna* on Farms Around Kakamega Forest

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Abstract: The integration of trees on farmlands has recently received attention due to their contribution to livelihoods improvement and climate change mitigation. They provide ecosystem services (ESs) like climate change mitigation, improvement of soil fertility, provision of timber and fuelwood among others. The choice of trees to plant depends on the role the farmer intends to put them into and the size of the farm. The trees can either be indigenous or exotic andare mostly planted along farm boundaries, in home gardens, as woodlots orientation among others. This study was conducted in western part of Kenya on farmlands that mostly border the Kakamega Forest. The study soughtto determine abundance, distribution and biomass carbon stocks of *Grevillea robusta* and *Eucalyptus saligna* for enhanced climate change mitigation. A total of (N=3,468) trees were inventoried in 80 farms with a total of 27.5ha. The average size of farms where the survey was done was about 1.28±1.01 ha. *Eucalyptus saligna* had a tree abundance 1133 (33%) of the total trees sampled while *Grevillea robusta* had 2,335 (67%). Two sites were purposively selected (Lubao and Tea zone area). In the Lubao site, *Eucalyptus saligna* abundance was 627 (29%) while *Grevillea robusta* abundance was 1565 (71%) of the total trees sampled. In Tea Zone site, *Eucalyptus saligna* abundance was 506 (40%) while *Grevillea robusta* tree abundance was 770 (60%). Total biomass estimated in the study area was 3.86±0.21Mgha^{-1}(1.96Mg C ha^{-1}). This was distributed as aboveground biomass (2.8±0.12Mgha^{-1}) and belowground biomass (0.87±0.41Mgha^{-1}). There was no significant difference in biomass among farms in Lubao (F=43.12; p=0.34) and in Tea zone sites (F=53.12; p=0.23). Lubao site had an estimated biomass of 1.97±0.023Mgha^{-1} distributed as above ground biomass (1.31±0.043Mgha^{-1}) and below ground biomass (0.67±0.023Mgha^{-1}). Tea zone site had an estimated biomass of 1.99±0.38Mgha^{-1}. This was distributed as above ground biomass (1.58±0.023Mgha^{-1}) and below ground biomass (0.40±0.18Mgha^{-1}). Biomass was significantly different among the agroforestry practices in Lubao (F=13.1; p=0.002) and in Tea Zone (F=29.12; p=0.001). Hedgerow had the highest biomass among the agroforestry practices in Lubao (1.91±0.16Mgha^{-1}) and in Tea zone sites (1.7±0.23Mgha^{-1}). Alley cropping that was only practiced in Lubao had the least biomass (0.0044±0.009Mgha^{-1}). The twotree species provided benefits for household use and at the same time for monetarysale. Firewood and timber were the most mentioned (n=80). This was followed by construction material and fencing material. These functions/uses were most preferred by the *Eucalyptus grandis.*

Keywords: Biomass, Tree Abundance, Climate Change, Livelihoods

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1. Introduction

Trees on agricultural landscapes are every significant because playkey roles in the provision of essential ecosystem services (ESs) that support smallholder livelihoods [1, 2]. These services include, provision of timber, improvement ofsoil fertility, provision of fodder, carbon sequestration among others. These treeshave been estimated to cover around 45% of the agricultural lands globally which translates to 10% tree cover [3, 4]. Thistrend has been increasing annually dueto the efforts farmers are putting in place to increase tree cover on these landscapes and recent attention that trees in these landscapes have received. Farmers grow and maintain indigenous or exotic trees on their farmland [5] for various purposes depending on the needs. The presence of trees on farmland helps to offset pressure on natural forests in addition to contributing to the improvement of productivity of agricultural and forest landscapes [6]. The indigenous trees can either be planted or grow naturally based on the seed bank or proximity to a natural forest where seed dispersers like birds, simians frequently visit the adjacent farmlands. The trees are intergrated on the farmland as woodlots, windbreaks, intercropping, and homegardens among others. The integration of trees on farmland or along boundariesdepends on the size of the land and the use to which the trees planted will be put into [7]. Proper management of the intergrated trees on farmlands have shown greater potential to sequester carbon in addition to improving livelihoods of the rural communities [1]. Recent attention that has been drawnto these trees [3] has ledto more focus in the quantification ofthe amount of carbon stocks in these treeswhich is an important component in the implementation of the emerging carbon credit such as Reducing Emissions from Deforestation and Degradation (REDD+) [8]. The trees have been documented to store carbon biomassstocks of between 3-18Mg C ha^{-1} [9]. Despite these attributes, they have often been neglected in carbon accounting both nationally and internationally [10]. In Kenya, farmers have incorporated trees on their farmlands that include *Cordia abysinica, Eucalyptus spp, Grevillea robusta, Markhamia lutea, Croton macrostachyus* and *Leucaenia leucocephala* among others [11]. Most farmers in Kenya and more so the western part prefers *Grevillea robusta* and *Eucalyptus saligna* due to their faster growth and economic value. This studysought to establish the abundance of most preferred species, their distribution, carbon biomass stocks and their role in mitigating the effects of climate change in addition to improving livelihoods. The findings of this paper will help inform policy based on the value the trees are put into, will contribute to reduction of pressure on the existing natural forests.

2. Materials and Methods

The study was conducted on smallholder farms in two sites that are adjacent to the northern part of Kakamega Forest (Figure 1). These were the Lubao site and Tea Zone site. Lubao village is 9 km from Kakamega town and less than 1km from Kakamega Forest. Tea Zone village is located 2km from Kakamega town and 1km from Kakamega Forest. The two villages were selected based on the fact that they are less than 1km from the forest and most people have their farms less than 50m from the forest. The forest ecosystem is made up of fragments of different size, structure and distances to each other [12]. Agriculture is the main economic activity in the area; land-use systems vary from mainly subsistence agriculture (maize, beans, bananas and sweet potatoes) to a few cash crop-oriented farms (tea and sugarcane). Farms to the South and West of the forest are bounded by a maize-growing belt and sugarcane growing belt to the North [13]. Woody vegetation forms part of the complex agricultural mosaic on smallholder farms, varying from individual free standing trees to pockets of stands that consist of indigenous and exotic species managed in different ways [14]. The study targeted communities living within 2km radius from the forest edge. According to KIFCON (1994), these are the communitiesthat have total dependency on the forest resources either directly or indirectly. Simple random sampling was used to select farmers to participate in the research. At each of the study site, 40 farmers were chosen making a total of 80 as the sample size.

In each farm, the nature of planting of the trees (agroforestry practices), tree abundance for the two species was determined and recorded. Circumference at Breast Height (CBH) was determined 1.3m from the ground using a tape measure. CBH was converted to Diameter at Breast Height (DBH) by multiplying pi (π=3.142) with circumference. Aboveground biomass (AGB) was determined by applying allometric equations to DBH measurements.$0.091\times(DBH)^{2.472}$ model was selected for estimation of biomass from tree measurements [7]. DBH measurements were applied to allometric equations to obtain biomass estimates for individual trees in kg per tree. Biomass estimates of trees were summed up to obtain plot level estimates in Megagrams per hectare (Mg ha^{-1}). Below ground biomass (BGB) was estimated by using a root-to-shoot ratio of 0.26 [15, 16]. Total biomass was calculated by adding the AGB with the BGB. Biomass estimates were converted to carbon using the IPCC default value 0.46 of the carbon fraction in wood. Closed and open-ended questionnaires were administered to farmers whose farms trees were being inventoried to determine the utilization of the tree species and how it improves household. The questionnaire captured farm size, number of trees on the farmland, economic values into which the trees give to them among others.

3. Statistical Analysis

Data entry was done in Microsoft excel 2016. This was then exported to Predictive Analytical Software (PASW). Differences in the abundance, biomass and use of the tree species were determined using ANOVA. Summaries of agroforestry practices, uses of the trees were made through tables and figures.

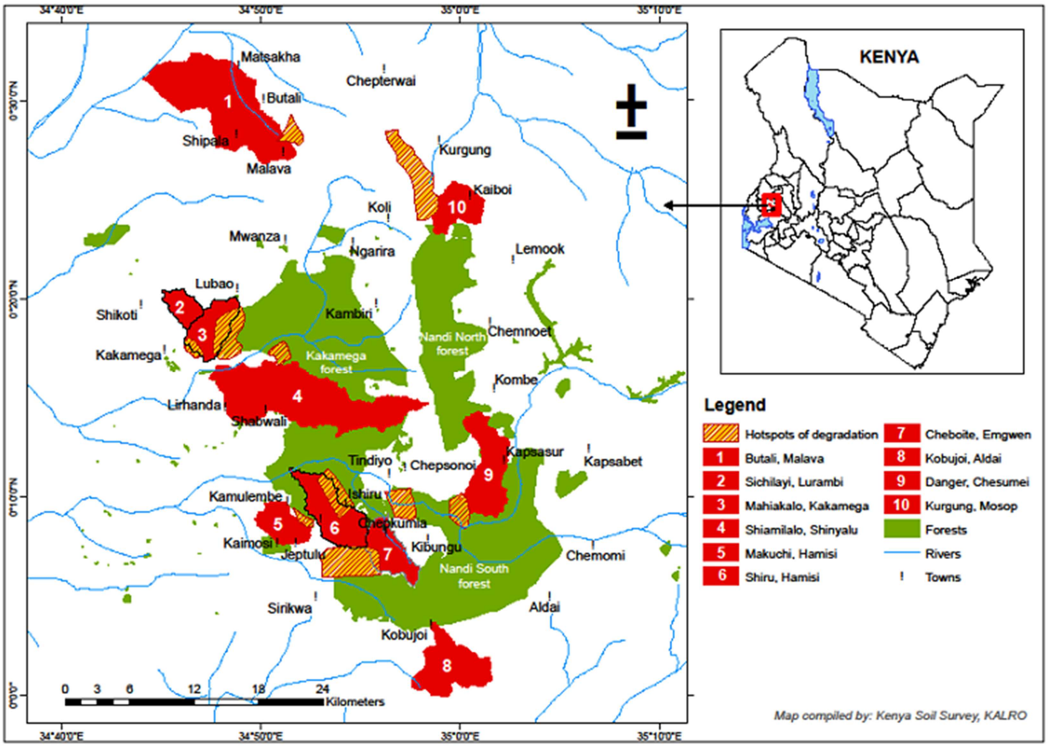

Figure 1. *Map showing Extend of Kakamega Forest with surrounding some of the villages where the study was done (Source: Geological, 2019).*

4. Results and Discussions

4.1. Tree Abundance and Agroforestry Practices

A total of (N=3,468) trees were inventoried in 80 farms covering some27.5ha. The average size of farms where the survey was done was about 1.28±1.01 ha (table 1). *Eucalyptus saligna* had a tree abundance 1133 (33%) of the total trees sampled while *Grevillea robusta* had 2,335 (67%). In Lubao site, *Eucalyptus saligna* abundance was 627 (29%) while *Grevillea robusta* abundance was 1565 (71%) of the total trees sampled. In Tea Zone site, *Eucalyptus saligna* abundance was 506 (40%) while *Grevillea robusta* tree abundance was 770 (60%) (table 1). Trees were distributed between homegardens, boundary planting, alley cropping and woodlots. Boundary planting had the highest abundance of trees in the two study sites. This was followed by home gardens, woodlotsand finally alley cropping. Boundary planting had the highest abundance of the *Grevillea robusta* sampled in Lubao (56%) and in Tea Zone (46%) of the total trees sampled. This was followed by woodlots in Lubao (8%) and in Tea Zone (13%). *Eucalyptus saligna* was mostly planted as woodlot at Lubao (17%) and Tea Zone (28%) of the total trees in the two studysites. Lubao tree abundance under homegarden was (9%) while Tea Zone had (12%). Alley cropping was only practiced in Lubao by using *Grevillea robusta* and comprised 1% of the total treeabundance in the site (figure 2).

Table 1. *Summmary of tree abundance for the two study sites.*

Site	Agroforestry practice	Abundance	DBH (cm)			Biomass (Mg/ha)			Total Carbon (Mg/ha)
			mean	min	max	Above	Below	Total	
Lubao	Hedgerow	1,420	16.59	0.13	40.7	1.12±0.05	1.8±0.13	1.96±0.16	1.472±0.12
	Home garden	196	13.8	1.27	41.0	1.2±0.01	0.96±0.011	2.16±0.005	0.66±0.01
	Woodlot	552	18.49	0.63	74.47	2.7±0.21	1.2±0.02	3.9±0.24	1.7±0.004
	Alley cropping	24	2.96	2.9	11.6	0.035±0.007	0.0088±0.018	0.0044±0.009	0.002±0.001
	Sub-total	2,192	12.96	1.23	41.94	1.3±0.43	0.67±0.16	1.97±0.28	0.96±0.015
Tea Zone	Hedgerow	656	16.87	0.31	61.74	1.4±0.23	0.3±0.05	1.7±0.23	1.4±0.21
	Home garden	150	14.67	1.27	33.73	0.2±0.09	0.05±0.03	0.25±0.01	0.7±0.03
	Woodlot	470	17.21	0.63	35.96	0.2±0.21	0.25±0.06	0.5±0.19	0.9±0.3
	Sub-total	1,276				1.58±0.23	0.72±0.06	1.99±0.01	1.00±0.00
Total	(Tea Zone +Lubao)					2.8±0.03	0.87±0.08	3.86±0.38	1.96±0.12

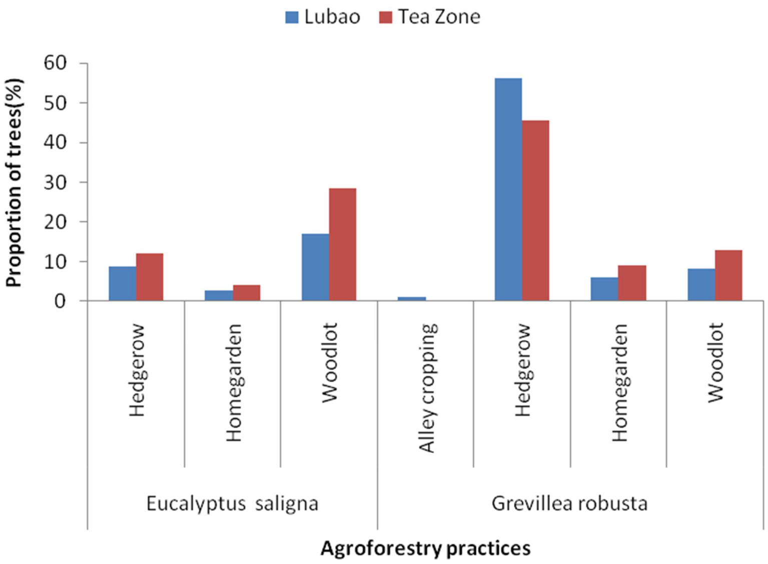

Figure 2. *Proportion of Eucalyptus saligna and Grevellia robusta among the agroforestry practices.*

4.2. Tree Biomass in the Grevillea robusta and Eucalyptus saligna Sampled

Total biomass estimated in the study area was 3.86±0.21Mgha^{-1}(1.96Mg C ha^{-1}). This is the amount ofcarbon that can be lost if trees sampled were removed/cut in these farms. This could in turn contribute to carbon emissions. This was distributed as aboveground biomass (2.8±0.12Mgha^{-1}) and belowground biomass (0.87±0.41Mgha^{-1}). There was no significant difference in biomass among farms in Lubao (F=43.12; p=0.34) and in Tea zone sites (F=53.12; p=0.23). However, total biomass significantly differed between the two sites (F=22.15; p=0.001). Lubao site had an estimated biomass of 1.97±0.023Mgha^{-1} distributed as above ground biomass (1.31±0.043Mgha^{-1}) and below ground biomass (0.67±0.023Mgha^{-1}). Tea zone site had an estimated biomass of 1.99±0.38Mgha^{-1}. This was distributed as above ground biomass (1.58±0.023Mgha^{-1}) and below ground biomass (0.40±0.18Mgha^{-1}). Biomass was significantly different among the agroforestry practices in Lubao (F=13.1; p=0.002) and in Tea Zone (F=29.12; p=0.001). Hedgerow had the highest biomass among the agroforestry practices in Lubao (1.91±0.16Mgha^{-1}) and in Tea zone sites (1.7±0.23Mgha^{-1}). Alley cropping that was only practiced in Lubao had the least biomass (0.0044±0.009Mgha^{-1}). There was a significant difference in the total biomass held by the two tree species (F=22.1; p=0.001) and held by *Grevillea robusta* (17.04; p=0.0001) in the two study sites. Total biomass estimated in the two sites for *Eucalyptus saligna* was 1.53±0.12Mgha^{-1} while that in *Grevillea robusta* was 2.27±0.15Mgha^{-1}. In site Lubao, *Grevillea robusta* had a total biomass estimate of 1.9±0.32Mgha^{-1} while site Tea zone had 1.17±0.39Mgha^{-1}. There was no significance difference in the biomass estimate held by *Eucalyptus saligna* in the two study sites (F=29; p=0.62). Trees planted as hedgerow had the highest abundance and hence the highest biomass held in them. Mean biomass had a strong significant relationship with farm size in Lubao (p=0.02; r=0.99) and Tea Zone (p=0.023; r=0.98).

4.3. Household Use of Trees

The twotree species provided benefits for household use and at the same time for sale. Firewood and timber were the most mentioned (n=80). This was followed by construction material and fencing material. These functions/uses were most preferred by the *Eucalyptus grandis* (figure 3). The farmers' alluded that the trees present on their farms were planted by them for the mentioned functions. *Grevillea robusta* was preferred as a shade tree, boundary fencing and asfirewood. Farmers also believed that *Grevillea robusta* added nutrients to the soils. *Grevillea robusta* can also grow naturally which in most cases could be as a result of the seeds had been dispersed by wind on the farm. Such trees did not have an orientation of its growth to either type of agroforestry. There was a positive correlation owed to the presence of the two species trees on the farm and its use as timber (r=0.473; p<0.05). The choice of the two species by the farmers was as a result of their multiple benefits to the farmers which they mentioned in addition to their faster growth rates.

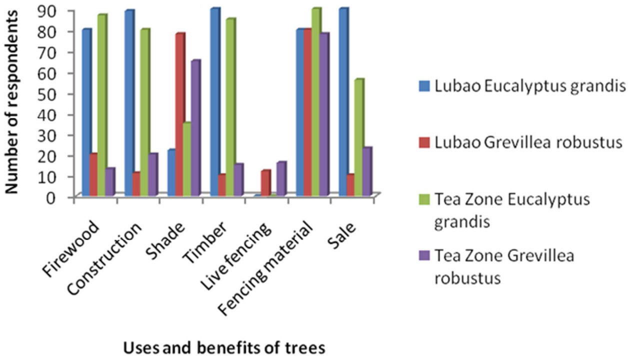

Figure 3. *Common uses and benefits of the two tree species (Eucalyptus spp and Grevillea robusta).*

5. Discussions

Grevillea robusta and *Eucalyptus saligna* dominated most homesteads in the study areas. Similar studies especially by [17] confirm the same. Thus, tree species with higher economic value were widely spread across farms adjacent to Kakamega Forest. The preference thatthe two species were given was based on the faster growth rates which give farmers economic value thatimproves livelihoods of these communities. In addition, these two tree specieshave been proven to be resistant to pests and diseases. *Grevillea robusta* has been proven to improve soil fertility [18]. *Grevillea robusta* was highly abundant which is considered as a trade-off for climate change mitigation on small farms. In addition it also helps reduce pressure on the existingforest as it reduces deforestation rates greatly. According to [19] self-sufficiency in firewood supply also can prevent the danger of deforestation of off-farm land or nearby forests. The total biomass carbon stocks estimated for the twotree species in the study area was 3.86 Mg ha^{-1}. These estimates are in the range of aboveground carbon stocks of tropical agroforestry systems in Africa1.0–18 Mg C ha^{-1} [9], for the humid tropical Africa for agrisilvicultural agroforestry System stores 29-53 Mg C ha^{-1} [20]. They were however less than those recorded by [14] in Vihiga among the small holder farms. This could be attributed to differences in the methods used in quantification, size of pool selected for quantification, differences in the values of DBH that reflects the age of the trees among other factors. *Grevillea robusta* with highest abundance held most of the biomass/carbon stocks. It was the preferred trees farmers planted along boundaries. Most of thebiomass estimatedwashence held in trees along boundaries followed by those scattered on homesteads and then woodlots forms of agroforestry. Woodlot type of agroforestry did not hold more biomass as compared to the other twotypes of agroforestry due to a few householdsthat practiced it and in addition they sold most of the mature trees for a number of reasons which ended up releasing carbon into the atmosphere than storingit. Based on the findings, farmers with large farm size could manage woodlot type of agroforestry. Thisis in agreementwith studies by [21, 18] among others. This is an indication that farm size is a determinant in carbon storage capacity as a result of trees density on the same farmland. Alley cropping was least practised by farmers in this area which suggested most have not been informed on its benefits or could be attributed to small land sizes. Most farmers preferred planting the trees for firewood which ranked highly in all the sites sampled. This was followed by timber and third most ranked was for sale which helped improve their livelihoods.

6. Conclusions

Farmers have been planting trees on their farms based on the findings of this study. Tree abundance was evident in the two sites on smallholder farms in western Kenya. The most preferred trees were *Grevillea robusta* and *Eucalyptus saligna*. Number of trees was dependent on farm size and purpose for planting the trees which included provision of timber, fuelwood, soil stabilisation and mostly *Grevillea robusta*. The trees held quite some biomass in them which greatly contributes to climate change mitigation. The biomass held in the trees varied per tree species, site and size of trees that was attributable from the DBH measurements. Farmers preferred the two tree species based on the return value they got from the sale of these trees. This in turn has contributed to improvement in smallholder livelihoods. This study forms a basis for other similar studies in other areas of the country and the rest of the world to help in informing on the greater role farmers play towards climate change mitigation.

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