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CONSERVATION AGRICULTURE WITH LEGUMINOUS SHRUBS AT DIFFERENT SPATIAL PATTERNS ENHANCES SMALLHOLDER PRODUCTIVITY OF MAIZE-LEGUME INTERCROPS IN DRY-LAND EASTERN KENYA

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ABSTRACT

Declines in soil fertility and water, prolonged dry-spells/droughts and erratic climatic patterns in general continue to undermine optimal agricultural productivity in Sub-Saharan Africa (SSA). Drier parts of Eastern Kenya already endure low/declining soil fertility, low soil water content, increased temperatures/atmospheric heat, and unpredictable rainfall and drought patterns. These have occasioned continued declines in smallholder farm productivity (below 1 Mg ha^{-1} against a potential of 6-8 Mg ha^{-1}) and resiliency. Optimizing on on-farm soil water and fertility management through conservation agriculture (CA) technologies such as sustained soil cover/residue retention, micro-dosing and minimum tillage, integrated with selected tree species (for soil fertility enhancement, fodder, firewood) may hold in upgrading and developing resiliency towards extreme climatic risks among smallholder farming systems. Redressing the problem of increased food insecurity and productivity challenges requires a farming system that maximizes on yield productivity per unit water/nutrient and/or land. This study evaluated the best integration of *Gliricidia sepium and Calliandra calothyrsus* in a maize inter-cropping system under conservation agriculture (CA) among smallholder farmers in dryland Eastern Kenya, using completely randomized block design trials, where CA (minimum tillage) and conventional agricultural (COA) systems were evaluated. *Gliricidia sepium and Calliandra calothyrsus* were integrated at inter-row spacings of 4.5m, 3.0m and 1.5m; and 1m intra-row in each system in plots of 12 by 12 m, set up at the Agricultural Research Station (ATC) in

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Machakos, Kenya. Yield data was analyzed with mixed model of analysis of variance, treating tree species, inter/intra row tree spacing and CA/COA as fixed effects, while maize, legume, tree yield and replication were treated as random effects. Accounting for heteroscedasticity utilized modeling the covariance structure with power-of-the-mean using Genstat 14. Standard error of difference of means (SED) test ($p < 0.05$) was used to evaluate how significant treatments differed from each other. Results showed that *Calliandra* spaced at 3 or 4.5 m yielded significantly ($p= 0.003$ and 0.01) higher maize yield when compared to spacing *Calliandra* at 1.5. Yields (Grain=5.31 and stover=5.66 Mg ha^{-1}) in *Gliricidia* spaced at 4.5 m were significantly ($p=0.01$) higher compared to yield in any other treatments tested. No significant ($p=0.136$) differences occurred in maize yields under CA or COA as sole and on integration with tree species. Yields at researcher managed trials were more than those at on farm trials, whereas in both, productivity of biomass; growth of canopy; heights and tree circumference were enhanced in CA than COA.

Keywords: Conservation agriculture, conventional farming, Gliricidia sepium, Calliandra calothyrsus, tree spacing

1.0 INTRODUCTION

A vast majority of smallholder farmers sustaining their livelihoods on rain-fed agriculture are found in tropical developing countries. This region is characteristic of declining soil fertility and water, unreliable rainfall, recurrent floods, prolonged droughts/dry-spells and growing population segments (Rockström, 2000). Yet, the small-holder sector is responsible for 80% agricultural productivity indicating its critical role in subsistence food supply and livelihood security (Rockström, 2000). UNDP (2012) noted drastic declines in per capita food productivity and widespread food insecurity in Sub-Saharan Africa (SSA) in the past decades besides a very low per capita income of USD 668 compared to the rest of the developing World which averages USD1717. Given the complex interaction amid soils, climate and socio-economic factors on agricultural production, the agricultural sector in SSA faces complex challenges. These entail sustainably producing ample food, while utilizing less water and optimal fertility enhancement per unit output. Additionally, there is need to develop novel productivity technologies that ensure environmental sustainability but contributing to both national and rural house-holds' socio-economic development (UNESCO 2006).

Like most smallholder farmers in Sub-Saharan Africa (SSA), farmers in Eastern Kenya practice intensive, mixed crop-livestock rain-fed farming system. According to Herrero *et al.,* (2010), this system provides for productivity diversification, besides enhancing households' food security. Conversely, the system enhances income generation and asset investment, provides for risk spreading, nutrient recycling as well as farm power. However, large ruminants and farmers in

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this system often rely on crop residues for feed, soil cover and firewood, especially during dry periods of the year (Lenné and Wood, 2004). Besides the system's capacity to self-sustenance, there is continued decline in per capita agricultural productivity in the region, for instance maize yields at less than 1Mg ha^{-1} while the potential is estimated at 6-8 Mg ha^{-1} (Mugwe *et al.*2006; Macharia, 2012). This can be attributed to declining soil fertility occasioned by continuous cultivation and shorter but unpredictable fallow periods with little or no inputs (Adesina *et al.*, 2000; Kwesiga *et al.*, 2003). The region further endures high atmospheric heat, prolonged dry spells/droughts, and erratic rainfall, rendering rain-fed farming almost unfeasible. Both drought and rainfall impact significantly on fertilizer and water use efficiencies and also determine the efficacy of risk-aversion strategies by smallholder farmers (Morris *et al.*, 2007). Soils in this area are predominantly Plinthic Cambisols and Ferralsols, characteristic of low water holding capacity, low Cation Exchange Capacity (CEC) and often with low organic matter (Jaetzold *et al.*, 2007). While base saturation for such soils may be high, amount of nutrient base is quite low owing to low CEC contributing to Nitrogen, Phosphorous and Potassium deficiencies (Akponikpè, 2008). Large and growing population segments in the region imply increased land fragmentation, overdependence on the natural environment for food and fuel thus further environmental degradation. Thus, there is need for technologies that can increase sustainable total farm productivity and reduce production risks under this intensive mixed-farming system. Generally, a focus on strategies that maximizes on rain-water retention within the soils' root zone, conserves soil nutrients status and provides sustainable alternatives for farm's fodder, feed, food and fuel requirements is required. Optimizing on on-farm soil water and fertility management through conservation agriculture (CA) technologies such as sustained soil cover (residue retention), micro-dosing and minimum or zero tillage, integrated with selected tree species (for soil fertility enhancement, fodder, firewood) may aid in upgrading and developing resiliency towards extreme climatic risks among smallholder farmers in Kenya.

The concept of conservation agriculture strives to optimize on sustainable natural resource utilization, management, productivity levels as well as profits while at the same time conserving the environment (FAO 2009; Bayala *et al.*, 2011). Conservation agriculture (CA) continues to gain acceptance among stakeholders as an alternative to both conventional and organic agriculture as a means of ensuring production and environment sustainability (FAO, 2009). This technology aims at maintaining adequate soil cover (often achieved through retention of crop residues on the soil surface after harvest) and minimum or zero tillage. In the latter though, yields often tend to be lower compared to yields of crops sown under conventional tillage (Wall, 1999; Sayre et al., 2001). However, Fowler and Rockstrom (2001) suggested that retaining at least 30% of soil surface cover with crop residue under fields with minimum or zero tillage at planting increased would increase crop yield production. Farage *et al.* (2007) further showed that CA with zero tillage could increase soil carbon content of about 0.1- 0.2 Mg $ha^{-1}yr^{-1}$. Despite its

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indubitable importance, effective promotion and adoption of CA systems under intensive mixed crop-livestock systems is quite intricate especially among smallholder farmers in SSA. For instance, crop residues are dependable sources of animal feeds; thus at a farmer's small-scale level, practicing CA would be undermined due to unavailability of sufficient crop residues for mulch (Bationo et al., 2007; Fowler and Rockstrom, 2001; Erenstein, 2003; Tursunov, 2009). In light of this observation, Giller *et al.* (2009) alleged that CA would not be apt among most smallholder farmers since its adoption would directly occasion competition towards an otherwise scarce resource, where crop (maize, sorghum and millet) residues are frequently used not only as animal feed but as a source of fuel energy due to scarcity of firewood or other forms of fuel. In more marginal environments, where CA confers even more ecological benefits, crop productivity is lower and therefore volumes of crop residues are lower making competition for them even greater. It has been suggested that farm productivity can be achieved by combining trees and crops in agroforestry systems, assuming that the trees can exploit resources currently under-utilized by crops (Cannell *et al.*, 1996).

Leguminous shrubs can naturally improve soil fertility. They enhance soil nutrient availability, nitrogen (N) supply, through biological N fixation, organic matter build-up, and recycling of N from deeper profile layers (Kang *et al.*, 1985; Kwesiga *et al.*, 1999). Leguminous shrubs equally play critical role in improving soil physical and biological conditions. Nonetheless, the choice of tree species for use in any intercropping system with arable crops is of utmost importance as it determines, to a large extent, the success or failure of the system (Rachie, 1983). *Calliandra Calothyrsus* has been shown to thrive in a wide range of environments and soil types. Its roots nodulate well under natural conditions and are easily infected with beneficial *Vesicular arbuscular* (VA)-mycorrhizal fungi making it easily adaptable to nutrient-deficient soils (NRC, 1983), has and it has also been reported to increase topsoil organic matter and cover, improve soil physical properties and reduce soil erosion (Palmer *et al* .,1994). *Calliandra Calothyrsus* does not develop dense leaves though when it grows too high can inhibit crop growth through shading which can be redressed through coppicing and pruning. The rooting system of Calliandra is extensive and deep .Its roots develop quickly and may reach 1.5 to 2 m in plants of 4 to 5 months old (Wiersum and Rika, 1992).This makes it particularly suitable for rejuvenating degraded soils besides erosion control on sloping lands. It has been also shown that *Calliandra Calothyrsus can* produce a herbage biomass of 45.9 $Mgha^{-1}$ yr^{-1} at a cutting frequency of four months and a crude protein content of 492.8g/kg dry matter within two months (Kabi and Bareeba, 2008).This makes its twigs good supplements for livestock feeds in terms of protein and mineral supply besides improving milk production. Tuwei *et al.* (2003) estimated that 3kg of fresh Calliandra has the same effect on the production of milk as 1 kg of commercial dairy concentrate when supplemented with elephant grass. Thus, *Calliandra Calothyrsus* can successfully be integrated in cropping fields to optimize on farm production. *Gliricidia sepium* is

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popular multipurpose tree known for its soil fertility enhancing qualities as both as green manure and nitrogen fixing (Akinnifesi *et al*., 2006). Its twigs as green manure and integration of the shrub into cropping fields have also been shown crop yields (Kaya and Nair, 2001). Makumba *et al*. (2006) in a study in Malawi found out that incorporation of *Gliricidia sepium* twig biomass into soils produced an average of 4–5 Mg DM ha^{-1} yr^{-1} of its leafy biomass, and a maize grain yield of 3.8 Mg ha^{-1} yr^{-1} without inorganic fertilizer amendment. Besides other similar management attributes as those of *Calliandra Calothyrsus*, it is evident that the two species offer apt alternatives in redressing problems of declining soil fertility, animal feed, fuel as well as soil cover.

The integration of the technologies described in the study has however not been adequately tested and studied in the Eastern Kenya. This is despite of its potential in maximizing on soil-water retention, soil nutrient regeneration, provision of sustainable alternatives for farm's fodder, feed, food and fuel and general increase in farm productivity. Indeed, farmers' attitudes towards, and rationales behind adoption of such technologies are influenced by, among others, the availability and access to the technology (Bationo *et al.*,1995). Additionally, their access to the information on optimal quantities and guidelines on how such technologies ought to be implemented under varying agro-climatic conditions is essential (Bationo *et al.*,1995; Mureithi *et al.*,1995 and Akponikpè *et al.*, 2008). In light of this background, the study broadly focused on enhancing understanding of the role of selected leguminous shrubs in CA systems in increasing total farm productivity in eastern Kenya. The study specifically evaluated the effects of CA combined with different tree species at different spacing on maize yield, legume yield and tree biomass production in three agro-ecological zones under researcher and farmer management trials in comparison to conventional farming practice.

2.0. MATERIALS AND METHODS

2.1. Study Area

The study was conducted in the dry land agro ecosystems of Machakos County in Eastern Kenya, covering three sub-counties namely, Machakos central, Mwala and Kangundo (Fig 1).

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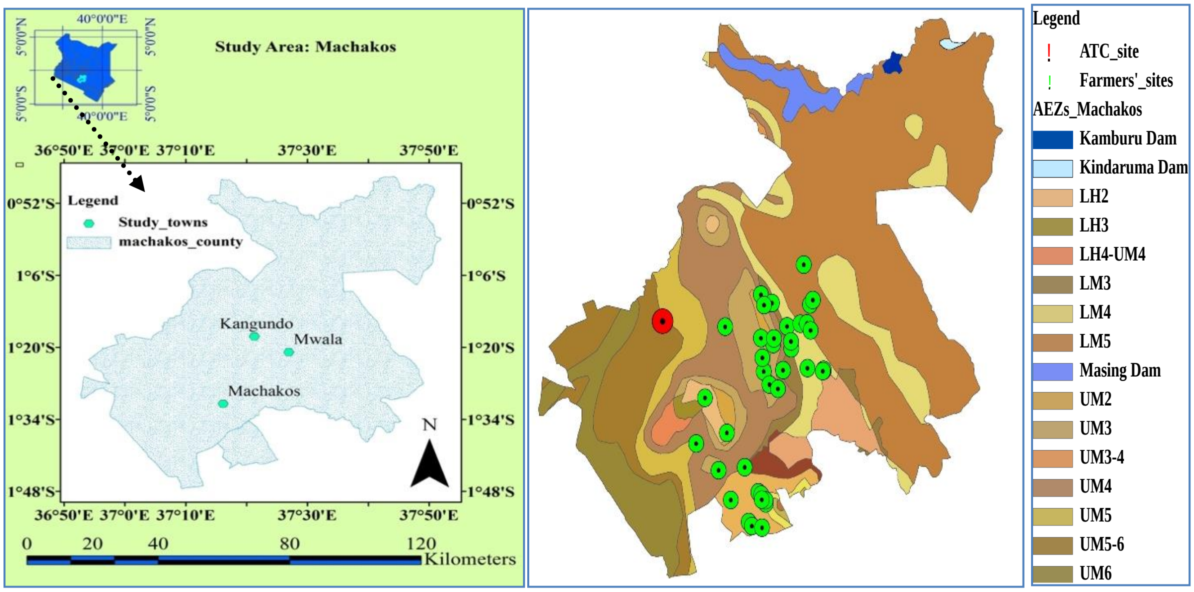

Figure 1: The study area showing distribution of demonstration sites in Machakos County.

Machakos is an administrative County in Kenya and lies in the sub-humid and semi-arid eastern, Kenya covering an area of about 6,281.4km^2 located 64 km southeast of Nairobi city. It stretches from latitudes 0^0 4´ to 1^0 31' South and longitudes 36° 45' to 37° 45' east, administratively, divided into 12 divisions, 62 locations and 225 sub locations (HSK, 2005). Covering close to 1,574 square kilometers, the region represents medium to high potential production area. The region lies within three agro-ecological zones clustered generally as, sub-humid, transitional and semi-arid (Jaetzold *et al*., 2006). Kangundo sub-county (stretching to Iveti) represents the high potential area with moderate temperature (17^{o}C to 24^{o}C) but highly erratic rainfall averaging 1250mm per annum. Conversely, Mwala sub-county is emblematic of low and erratic rainfall (600 mm p.a.) representing low potential agricultural production region. Machakos sub-county represents medium transition region with rainfall ranging from 800 mm to 1000mm p.a. (Jaetzold *et al.*, 2007). Specifically, the region falls within the lower midland (Mwala, LM4), Upper midland, (Kangundo and Machakos; UM4) agro-ecological zones (Jaetzold *et al.*2006) at an altitude of approximately 700 m to 1600 m above sea level (a.s.l) and predominantly hilly. The region experiences annual mean temperature and rainfall range of 17.7 to 24.5^o C and 700 to 1300 mm respectively. The rainfall is bimodal with long rains (LR) from mid-March to June and short rains (SR) from late October to December hence potential of two annual cropping seasons. Average seasonal average rainfall range is 250mm and 400mm, but highly variable (coefficient of variation range of 45% to 58 %), characterized by prolonged dry-spells, frequent crop failure and high food insecurity (KARI, 1995). The soils are predominantly Luvisols, Ferralsols and Acrisols (FAO .2009). These soils are characteristic of low water holding capacity, shallow and

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sandy, high deficiency in phosphorus and nitrogen and low organic carbon contents (0.5 – 1.0%) (Gicheru and Ita, 1987; Siderius and Muchena, 1977) explaining the predominant crop failures (Jaetzold et al., 2007). Various agricultural-based studies have been carried out in the region hence the rationale behind its selection. It has a population density of 82 persons per km^2 with an average farm size of 5.0 ha per household. Nonetheless, there is a general secure tenure system on land ownership but underscore in food productivity. The predominant cropping system is maize intercropped with beans/cowpea though livestock keeping is equally dominant. Maize, beans and cowpeas are dominant crops in the semi-humid and transitional zone while sorghum and millets are grown in semi-arid areas. The region is a strategic production hub for food, fruit and livestock products not only for Nairobi city but to the adjacent regions and entire country's food cover.

Table 1: Selected agro-climatic and meta-data characteristics of the study sites

Station	**Lat***	**Long***	**Alt* (m)**	**Rainfall (mm)**	**AEZ**	**Climate**
Machakos	1˚31ˈ8.09''	37˚16ˈ 7.44''	1138	800-1000	UM4	Semi-arid
Kangundo	1˚17ˈ39.7''	37˚20ˈ22.52''	1544	1250	UM4	Semi-arid
Mwala	1˚21ˈ4.91''	37˚27ˈ2.63''	1400	600	LM4	Semi-arid

* Lat=Latitude, Long=Longitude, Alt=Altitude, Record_

Source: Jaetzold *et al*., (2007)

2.2. Experimental Design

The experiment ran from Long rains 2013 (LR2013) to Short rain 2014 (SR2014). At the inception of the project, researcher managed trials on integration of selected leguminous shrubs (*Grilicidia sepium, Calliandra calothyrsus and Cajanas cajan* (Pigeon pea*))* into a maize-legume intercropping system under CA and Conventional agriculture (henceforth referred to as COA) were set-up at the agricultural training centre (ATC) in Machakos. The trials adopted a split plot design with two main blocks on CA and COA, each with 10 treatments (Table 2) replicated thrice. Thus, a total of 30 demonstration plots measuring 12 by 12 m in a randomized complete block design (RCBD) were established on each of the main block, summing up to 60 demonstration plots. *Gliricidia sepium* , *Calliandra calothyrsus and Cajanas cajan* were integrated at different inter-row spacing of 4.5m, 3.0m or 1.5m; and an intra-row spacing of 1m between individual trees. The tree treatments are summarized in table 2 below.

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Table 2: Tree treatments (species at spacing) set-up at the ATC during the experimentation period

CA		COA	
PLOT ID	**Treatment (species at spacing)**	**PLOT ID**	**treatment(species at spacing)**
1	Maize-legume (No Trees)*	2	Maize-legume (No Trees)*
3	Gliricidia at 1 m by 1.5 m	4	Gliricidia at 1 m by 1.5 m
5	Gliricidia at 1 m by 3 m	6	Gliricidia at 1 m by 3 m
7	Gliricidia at 1 m by 4.5 m	8	Gliricidia at 1 m by 4.5 m
9	Calliandra at 1 m by 1.5 m	10	Calliandra at 1 m by 1.5 m
11	Calliandra at 1 m by 3 m	12	Calliandra at 1 m by 3 m
13	Calliandra at 1 m by 4.5 m	14	Calliandra at 1 m by 4.5 m
15	Cajanus at 1 m by 1.5 m	16	Cajanus at 1 m by 1.5 m
17	Cajanus at 1 m by 3 m	18	Cajanus at 1 m by 3 m
19	Cajanus at 1 m by 4.5 m	20	Cajanus at 1 m by 4.5 m

CA=Conservation Agriculture, COA=Conventional Agriculture, Maize-legume (No Trees)* was treated as control

The test crops were maize-legume intercrop with legumes (often seasonal herbaceous cover-crop) as follows: *Dolichos lablab* (LR2013) and *Vigna unguiculata (*cow pea) (SR2013) at both farmer and researcher managed trials, and Beans (*Phaseolus vulgaris*) in LR14 at the researcher managed trials. Three maize seeds per hill were planted with a spacing of 0.25 m by 0.75 m between the plants and within the rows respectively. Leguminous cover crops were intercropped between maize rows and an intra-spacing of 0.07 m. Mineral fertilizer was spot-applied as NPK 23:23:0 and Di-Ammonium Phosphate (DAP) to the recommended N rate of 60 kg ha^{-1} and total P of 90 kg P ha^{-1} respectively. Trees were harvested (by coppicing to a height of 0.3 m) at planting where samples (twigs/leaves, stalks/wood) were collected for lab analyses. The remaining twigs and stalks were left within the CA plots at the ATC and totally removed from the COA plots. At the same time, 40 farmer groups were s within three sub-counties: Machakos, Kangundo and Mwala to host the duplicate plots at the ATC, but under farmer managed approach, as described in section 2.1. For each group, a voluntary farmer was identified in regard to availability of land and willingness to host a replica of the experimental trials on their farms within the three sub-counties. Similar to trials at the ATC, after two season of establishment, trees were harvested (by coppicing) just before planting the crops for each of the subsequent seasons and samples (twigs/leaves and wood/stem) were collected for lab analyses while farmers retained stalks for firewood, leaves for fodder and cover residue. In all sites, weed control in CA plots utilized weed scraper and occasional application of herbicides. All other standard agronomic practices were followed for optimal productivity. Yields and tree measurements of height, canopy and root collar diameter were recorded consistently in two seasons SR13 and LR 13 while biomass productivity was measured in three seasons LR13, SR13 and LR14.

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2.3. Data Analysis

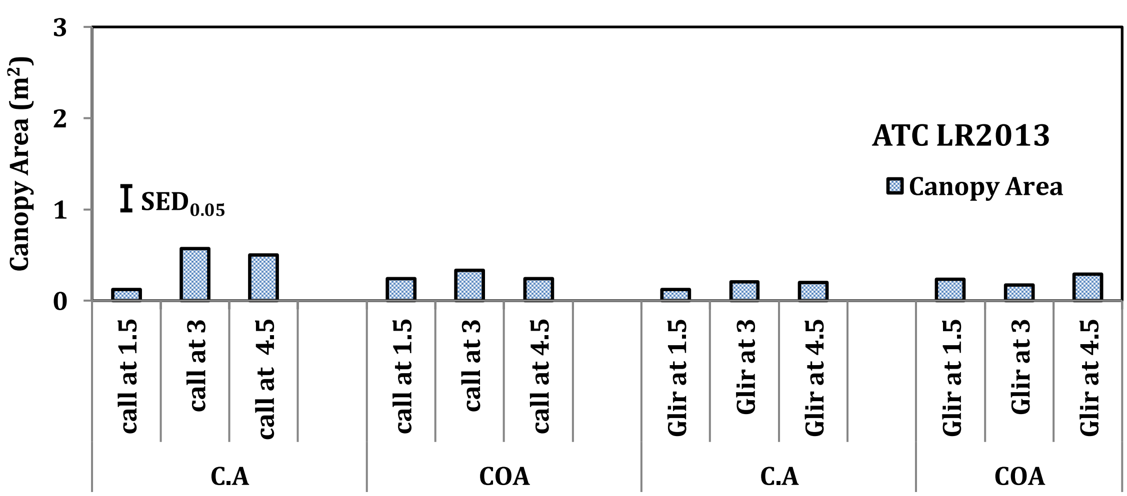
The data was captured and managed in MS-excel for preliminary analyses on tree growth (Height, Canopy cover, canopy height and root collar diameter). Yield and biomass data were subjected to two-way ANOVA using Genstat 14. Standard error of difference (SED) at ($p < 0.05$) was used to compare the mean differences between the treatments. Differences in tree growth between replicates are shown by standard errors (S.E.).

3.0. RESULTS AND DISCUSSION

3.1. Tree Growth and Production

3.1.1.Canopy Growth

Results showed that growth of canopy area was faster in Calliandra when compared to that of Grilicidia. The average canopy area for Calliandra (inter-row spacing of 3 m) reached 0.6 m^2 compared to that of Grilicidia (0.29 m^2) during LR2013 season (Fig 2). Generally, results showed that regrowth of canopy area was fater in Calliandra (Call at 4.5 m with canopy area of 1.8 m) than that of Grilicidia (1.49 m for Gril at 3). In terms of inter-row spacing, trees spaced far apart (at 3 m and 4.5 m) appeared to record higher canopy area values than when spaced closer (at 1m) for instance as follows: call at 3 m (0.6 m^2), Glir at 4.5 (0.18 m^2) during LR2013 and Call at 4.5 (1.8 m^2) and Gril at 3 m (1.48 m^2) during SR 2013 (Figure 2). Evidently, faster canopy growth was under CA during first season then COA during second season.



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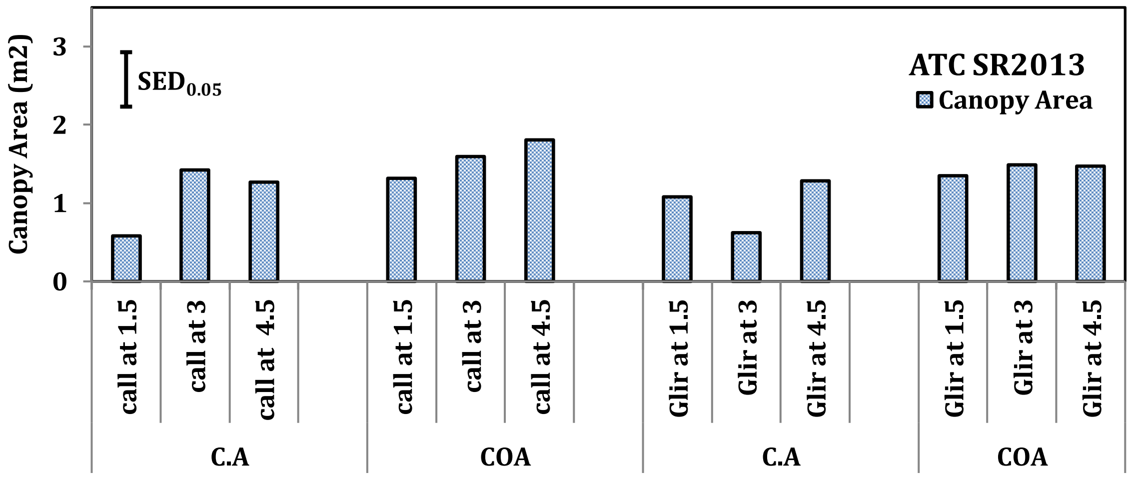
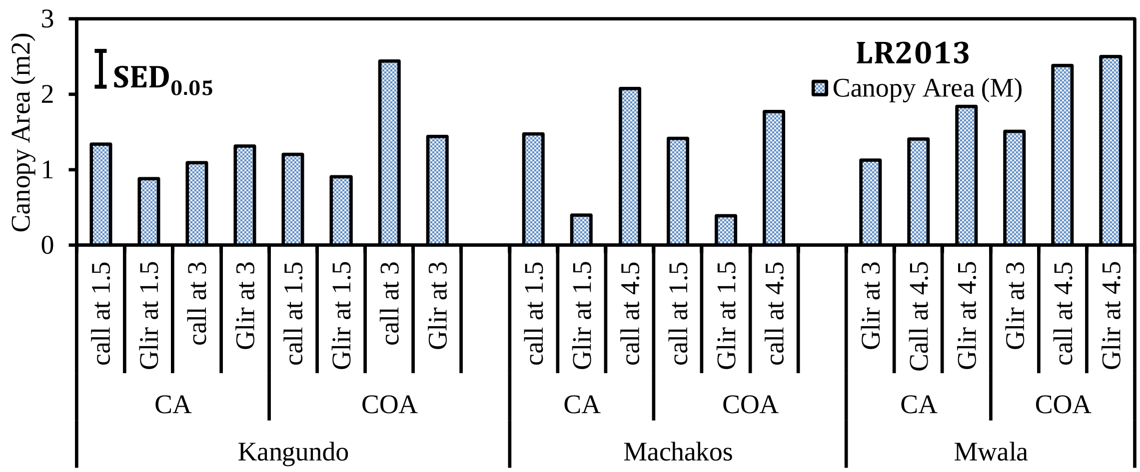


Figure 2: Canopy growth at the ATC

Canopy growth and regeneration was equally faster and denser under farmer managed trials. Calliandra spaced at 3 m and Gliricidia spaced at 4.5 recorded the highest (averaging 2.4 m and 2.5 m) canopy area values during test seasons (Figure 3). Besides Mwala representing a low potential area in terms of agricultural production, canopy area of both tree species was found to be equally high, for insttnace, 2.6 m for Glir at 4.5 and 2.3 m for Call at 3 (Figure 3).



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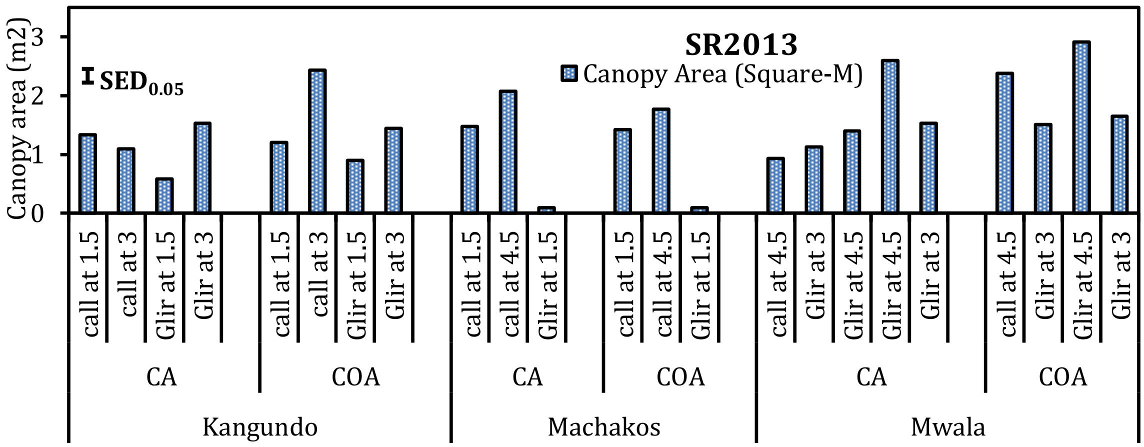
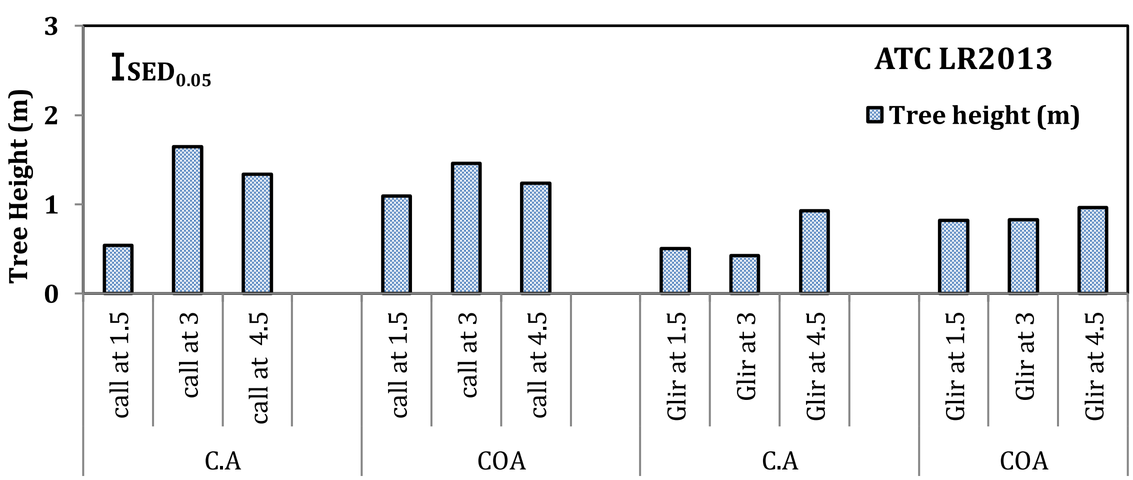


Figure 3: Canopy growth under farmer managed trials in LR2013 and SR 2013

3.1.2. Height growth

Tree height was found to be high in Calliandra spaced at 3 m both in CA (1.6 m) and COA (1.5 m) during LR2013 but could reach 1.9 m (CA) and 2 m (CoA) during SR2013 when calliandra was spaced at 4.5 m at the ATC (Figure 4). Results further showed that increasing spacing in Grilicidia translated to an increase in tree height growth, for instance Gril at 1.5 m reached a height of 0.5 m and 1 m while Gril at 4.5 m reached a height of 1 m and 1.5 m during LR2013 and SR2013 seasons respectively. Tree height growth was found to be high in treatments under CA as compared to the same treatments under CoA (Figure 4). At the farmer managed trials, height growth and regrowth was found to be faster in Kangundo (high potential area) to as high as 2 m (Figure 5).



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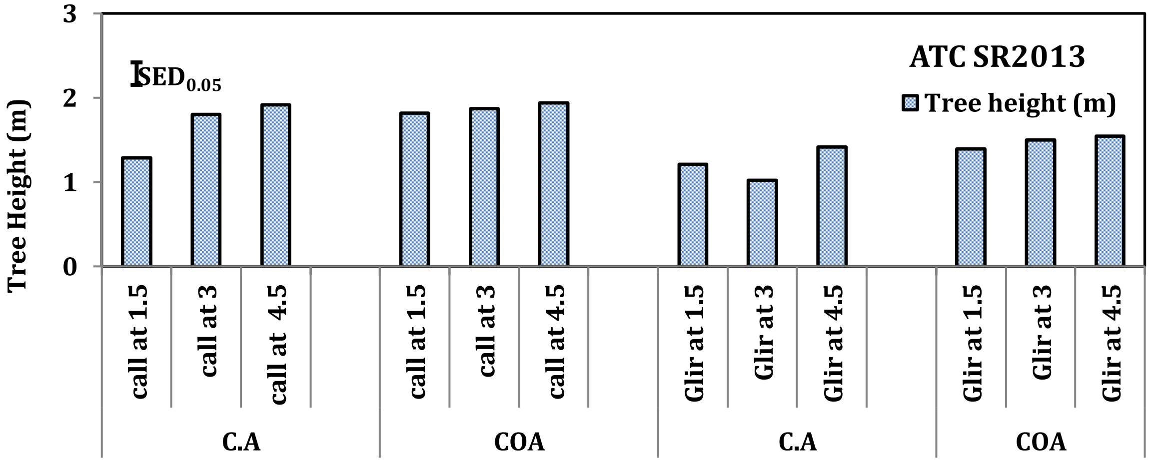
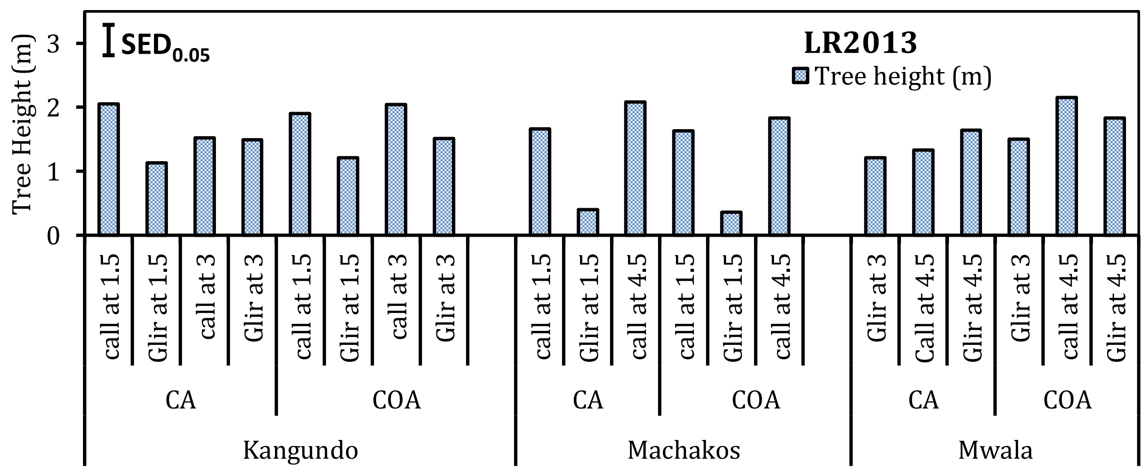


Figure 4: Height of trees at the ATC researcher managed trials



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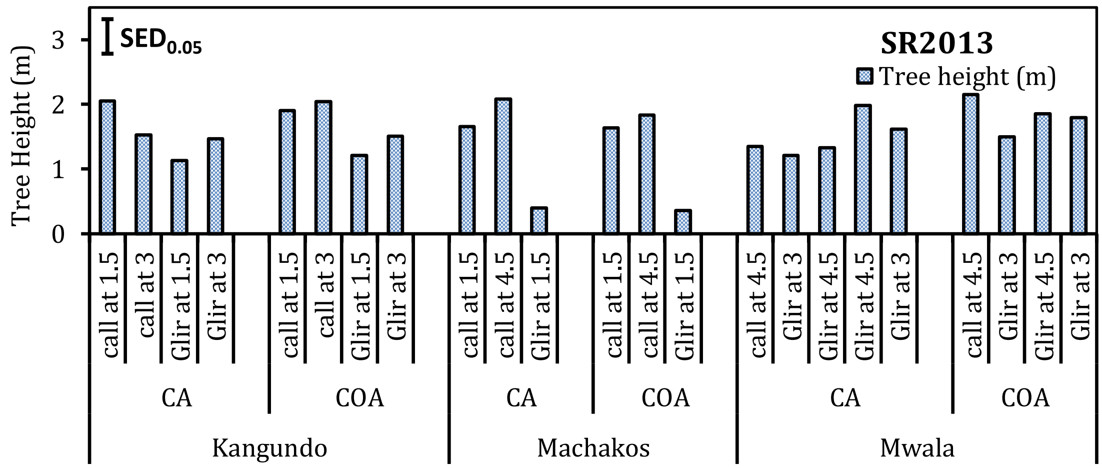
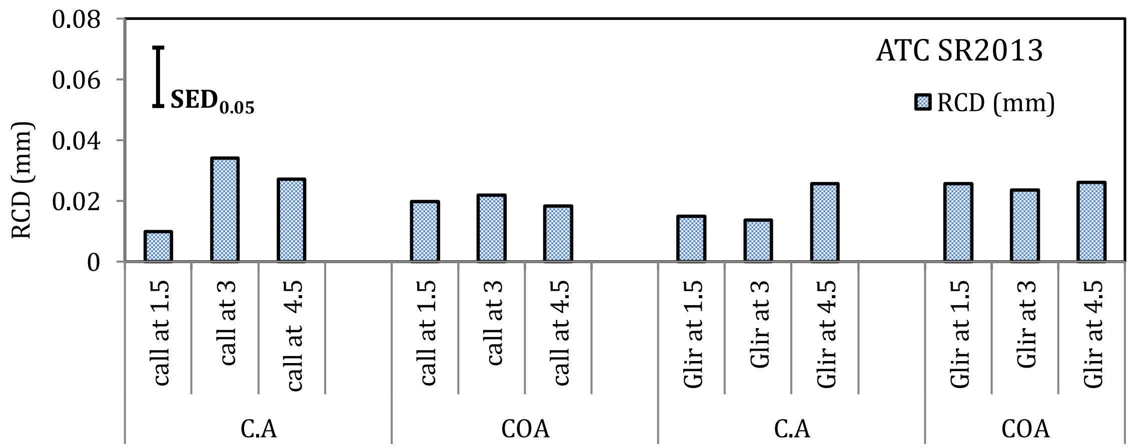


Figure 5: Height of trees under farmer managed trials

3.1.3.Tree circumference

Growth of the root collar diametor (RCD) was established to replicate similar effects observed under tree height growth. For instance, development of RCD was found to high in calliandra especially when spaced at 3 and 4.5 m under CoA. SED comparisons of its RCD growth showed lesser significance difference between the growth of RCD in Calliandra and Grilicidia, otherwise pronounced in tree canopy area and heights under both researcher (ATC) and farmer managed trials (Figure 6 and 7 respectively).



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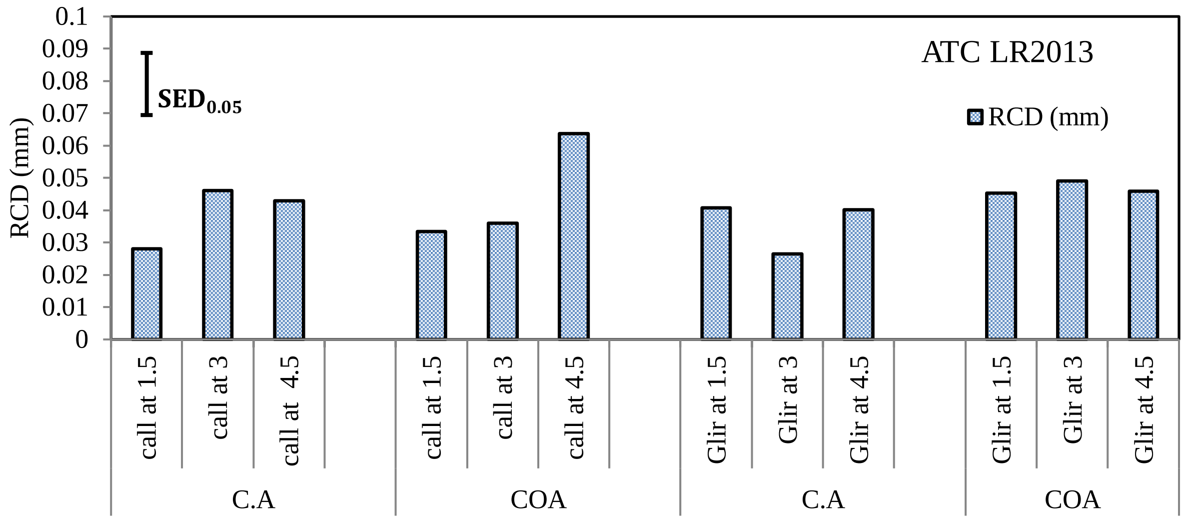
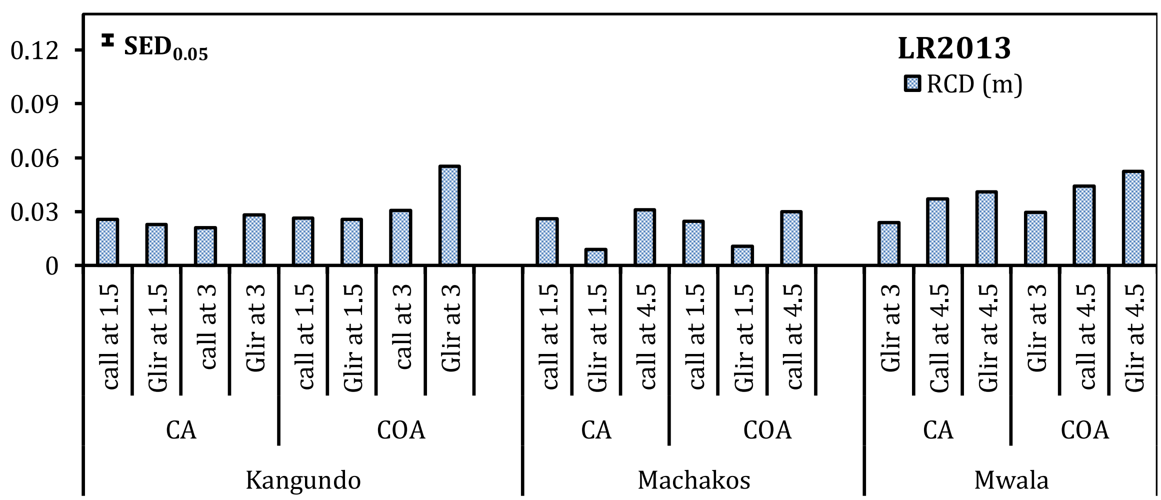


Figure 6: Growth of root collar diameter under researcher managed trials



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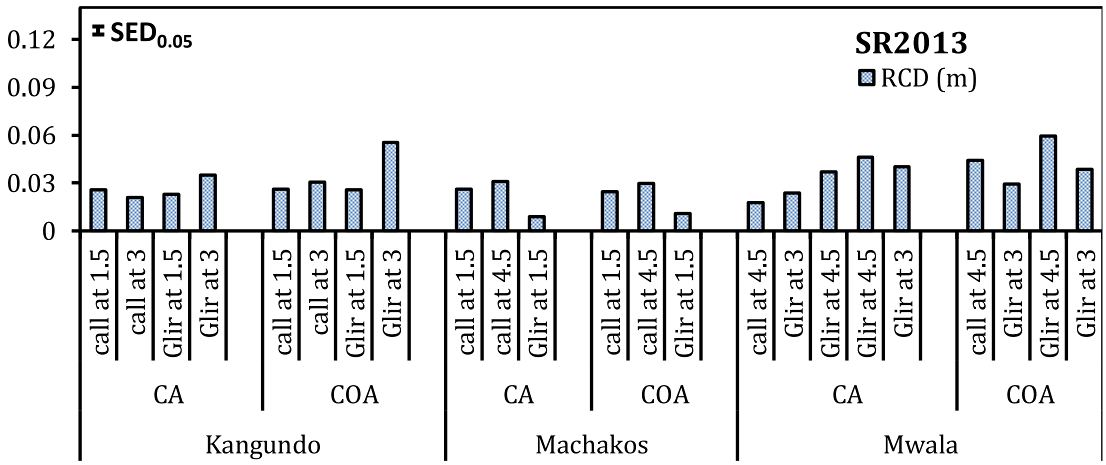

Figure 7: Growth of root collar diameter under farmer managed trials

Generally, results showed that tree growth both under researcher managed and farmer managed trials was slower during the first season as compared to the second test season. Like most other legumes, *Calliandra calothyrsus* has been shown to display slow early growth (Evans, 1984). Jama *et al.* (1989) attributed this to poor and ineffective mycorrhizal (Vesicular arbuscular) associations. Faster regeneration and growth of Calliandra, as observed during this study, has been reported in cases with vigorous mycorrhizal growth to a height of 3.5 m in 6 months (Wiersum and Rika, 1992). Additionally, rapid seasonal growth of Calliandra can be attributed to its capacity to thrive under a wide range of environments and soil types. Growth rate of Gliricidia was however observed to be low. It has been shown that *Gliricidia sepium* is a tolerable species suited to moderate altitudes (0-1,200 m). Its rainfall range is 600-1,500 mm and although it grows best where rainfall is well distributed throughout the year it can still tolerate a protracted dry season of 3-6 months.

3.2 Yield Productivity

Maize and legume yields

3.2.1. Effects of CA and COA under assorted tree spacing on Maize and Legume yield (Farmer Managed)

There were generally lower yields observed under farmer managed plots compared to the researcher managed plots. For instance, in Kangundo and Mwala, mean averages showed crop failure (variance at zero mark) under COA treatment, indicating high chances of crop failure (Figure 8)

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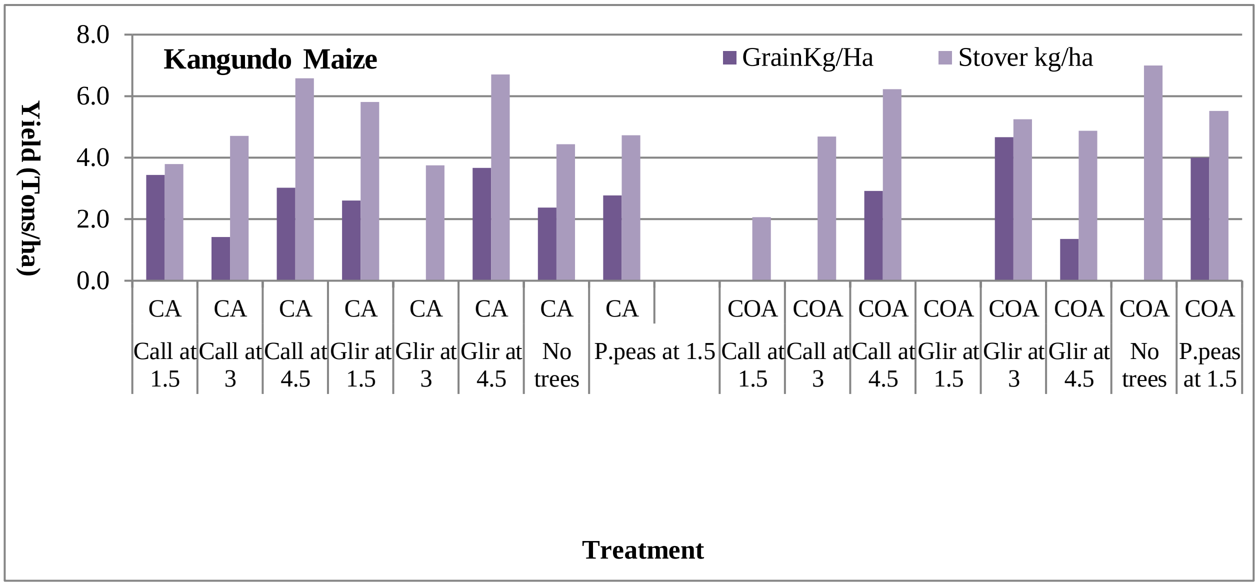

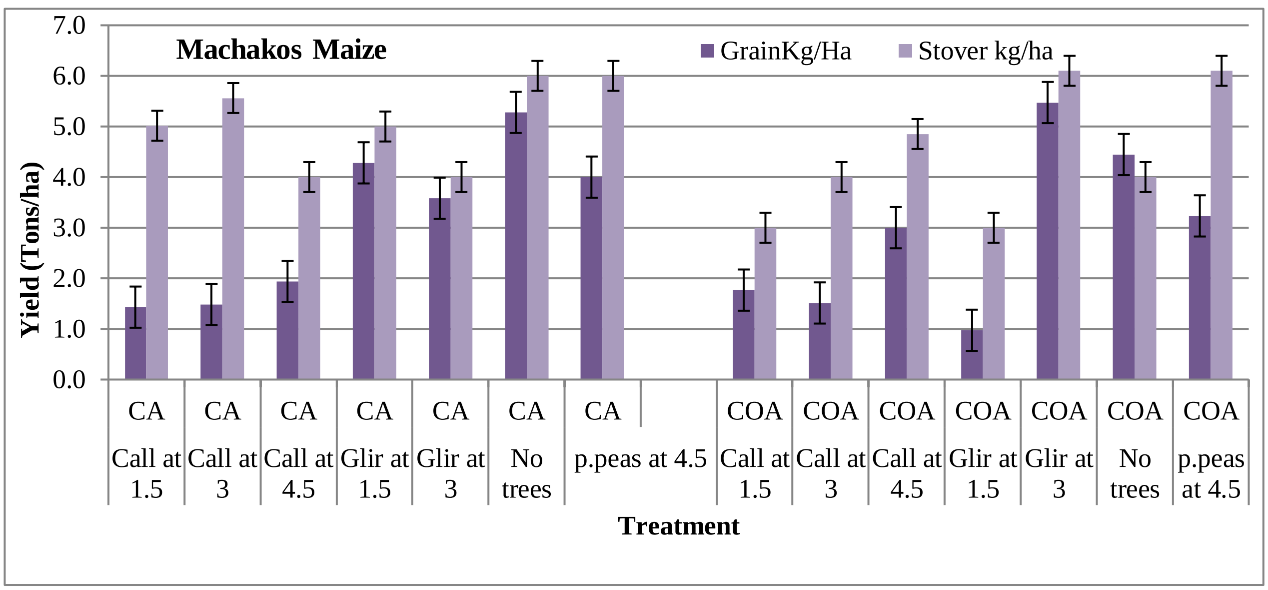

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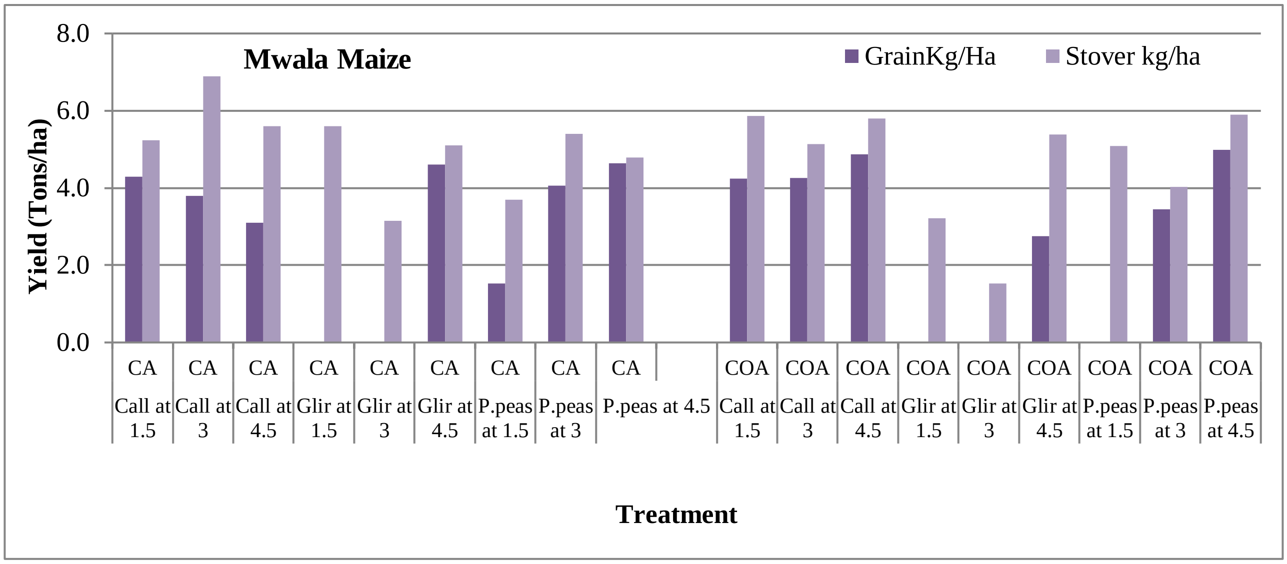

Figure 8: On-farm maize yield productivity in Machakos, Kangundo and Mwala on- farm trials

Table 3: Legume yields under farmer managed trials

Treatment		Dolichos ((Mg ha^{-1}) LR2013					
		Kangundo		Machakos		Mwala	
		Grain	Biomass	Grain	Biomass	Grain	Biomass
Call at 1.5	CA	2.13	4.63	2.63	5.23	0.43	1.53
Glir at 1.5		2.63	4.83	1.63	4.53	0.00	1.10
Glir at 3		2.33	6.33	1.83	3.93	2.60	1.20
No trees		1.23	3.23	4.23	4.23	2.53	4.63
Call at 1.5	COA	2.33	4.53	1.83	4.33	1.63	2.43
Glir at 1.5		2.93	5.13	1.23	3.93	0.00	0.00
Glir at 3		2.53	2.53	1.83	2.83	0.43	2.43
No trees		2.53	5.93	2.23	5.23	2.14	1.11
Mean		**2.33**	**4.6425**	**2.18**	**4.28**	**1.2025**	**1.79**
SED		**0.330**	**0.272**	**0.074**	**3.693**	**1.798**	**1.278**
P		**0.062**	**0.032**	**0.101**	**0.516**	**0.042**	**0.032**

Treatment		Cow pea (Mg ha^{-1}) SR2013					
		Kangundo		Machakos		Mwala	
		Grain	Biomass	Grain	Biomass	Grain	Biomass
Call at 1.5	**CA**	3.4	5.9	3.9	6.5	1.70	2.8
Glir at 1.5		3.9	6.1	2.9	5.8	0.00	0.00
Glir at 3		3.6	7.6	3.1	5.2	0.00	0.00

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No trees		2.5	4.5	5.5	5.5	3.80	5.90
Call at 1.5	**COA**	3.6	5.8	3.1	5.6	2.90	3.70
Glir at 1.5		4.2	6.4	2.5	5.2	0.00	0.00
Glir at 3		3.8	3.8	3.1	4.1	1.70	3.70
No trees		3.8	7.2	3.5	6.5	0.00	0.00
Mean		**3.6**	**5.9125**	**3.45**	**5.55**	**1.2625**	**2.0125**
SED		**0.433**	**0.375**	**0.177**	**3.796**	**1.901**	**1.381**
P		**0.234**	**0.001***	**0.0022***	**0.266**	**0.041**	**0.005**

Variations in on farm cowpea yields are summarized in Table 3 above. Total grain productivity was observed to be generally significantly (p=0.001 and p=0.002) higher Kangundo and Machakos as compared to yields in Mwala. This is however not a deviation from the norm owing to the fact that Machakos and Kangundo are Upper midland areas receiving much rainfall of 800-1000 and 1250 millimeters annually respectively, denoting high productivity potential, whereas Mwala is a lower midland area with limiting erratic patterns of rainfall to 600mm per annum, meaning there are higher chances of low productivity and crop failure. This explanation arises from the agro ecological zoning classification by Jaetzold *et al*. (2007)

3.2.2. At Researcher managed trials

Maize yields at the researcher managed trials were found to be significant among seasons ($p<0.001$) with LR14 registering the highest yield of 4.89Mgha^{-1} and the lowest being realized in the first season LR13 (2.35 Mgha^{-1}).The trends show that the yields increased after every test season for each test season for each treatment as shown in Table 4.Moreover, intervention with trees at close spacing of 1.5 m yielded less compared to trees spaced distantly at 3.0 and 4.5m with Gliricidia at 4.5 m for example recording a mean yield of 4.622Mgha^{-1},which was significantly different from other treatment yields. Planting sole maize with no tree intervention recorded the lowest yields on average over the test seasons (3.502 Mgha^{-1}). Even though conservation agriculture led to more yields compared to conventional agriculture in most of the treatments, the differences in yields among the two farming systems were not statistically different (p=0.92)

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Table 4: Maize yields at researcher managed trials at the Machakos Agricultural training Centre.

Maize yield at researcher managed trials at Machakos ATC (Mgha^{-1})						
	season				Yield by block	
Treatment	**LR13**	**LR14**	**SR13**	**Mean treatment yield**	**CA**	**COA**
Call at 1.5	2.12	5.3	4.16	3.863 ^{ab}	4.02	3.71
Call at 4.5	1.97	4.39	4.27	3.547 ^{a}	3.56	3.53
Call at3	2.23	5.05	5.32	4.198 ^{ab}	4.31	4.09
No trees	2.12	4.2	4.18	3.502^{a}	3.9	3.1
Glir at 1.5	1.84	5.16	3.94	3.647 ^{a}	3.6	3.69
Glir at 3	2.12	5.02	4.83	3.993 ^{ab}	4.16	3.83
Glir at 4.5	3.01	5.13	5.72	4.622 ^{b}	4.78	4.46
P.peas at 1.5	2.61	5.17	3.48	3.753 ^{ab}	3.07	4.44
P.peas at 4.5	3.11	4.62	4.22	3.988 ^{ab}	3.46	4.52
P.peas at 3	2.38	4.82	4.93	4.047 ^{ab}	4.11	3.99
Mean	**2.35**	**4.89**	**4.59**	**3.92**	**3.9**	**3.94**
p	**<.001***	**<.001***	**<.001***	**0.458**	**0.92**	**0.92**

Means without common superscript are significantly different (p<0.005)

Similar trends as in maize were also observed with legume yields. The yields were statistically significant among seasons (p<0.001), with sole legume plots yielding among the lowest in the test seasons. The legume yields however fluctuated among the two farming systems CA and COA and were also not statistically different. Lowest yields are observed for cow pea in the season LR13 while the highest are recorded for Dolichos in the season SR13.Iin general, legume yields superseded maize yields. This is not unusual since Legume cover crops (LCC) are able to grow faster and utilize the available nutrients and moisture before limiting conditions set in, even improving soil conditions further (Cheer *et al.*,2006). That Dolichos recorded the highest yields is an indication that it is most suited for the arid and semi arid lands and farmers should therefore look into venturing into such drought tolerant crops which ensure higher productivity.

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Table 5: Legume yield at researcher managed trials

Legume yield ($Mgha^{-1}$) at researcher managed trials						
	Yield by season				Yield by block	
Treatment	LR13 (cowpea)	LR14 (beans)	SR13 (Dolichos)	Mean treatment yield	CA	COA
Call at 1.5	3.42	4.485	5.18	4.362^{ab}	4.76	3.96
Call at 4.5	4.41	5.92	6.17	5.500^{b}	4.94	6.06
Call at3	3.31	4.375	5.07	4.252^{a}	4.49	4.01
No trees	3.69	4.755	5.26	4.568^{a}	4.77	4.36
Glir at 1.5	3.25	4.755	5.01	4.338^{ab}	4.51	4.17
Glir at 3	3.35	4.315	5.11	4.258^{a}	4.26	4.25
Glir at 4.5	3.765	4.415	5.525	4.568^{ab}	4.26	4.88
P.peas at 1.5	3.11	4.83	4.87	4.270^{a}	4.29	4.25
P.peas at 4.5	3.69	4.085	5.45	4.408^{ab}	4.46	4.36
P.peas at 3	3.02	4.175	4.78	3.992^{a}	3.38	4.6
Mean	**3.501**	**4.611**	**5.242**	**4.452**	**4.41**	**4.49**
p	**<.001***	**<.001***	**<.001***	**0.065**	**0.768**	**0.768**

Means bearing same superscript don't significantly differ from each other;*imply significance at 0.05 alpha level

Yields always do vary between conventional and conservation farming. Researchers have found yields under minimum or zero tillage often tending be lower compared to yields of crops sown under conventional tillage (Wall, 1999; Sayre et al., 2001). This could be due to a number of factors. Blevins and Frye (1993) for instance show that practicing no tillage can cause soil compaction and that although this may not inhibit growth, reduced yields can be realized due to the physical restrictions of the root zones alongside lower water infiltration at the top soil. Giller et al. (2009) argued that the benefits of CA should not be expected immediately but rather such benefits will only be realized in the long term. However, Fowler and Rockstrom (2001) suggested that retaining at least 30% of soil surface cover with crop residue at planting increased chances of realizing the expected effects (yields) in CA systems. The same has also been tabled by Kronen (1994) and Erenstein (2002). Ngwira et al. (2012) on the other hand reported significant differences in maize yields with CA plots having significantly greater yields than conventional practice.

3.3. Tree biomass production

3.3.1. At Researcher managed trials

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At the researcher managed trials at the ATC, closely spaced trees produced the highest biomass with Calliandra at 1.5m inter-row spacing producing the highest leaf biomass of 6.37 $Mgha^{-1}$ compared to Gliricidia at 1.5m which only produced 4.06 $Mgha^{-1}$ of leaf biomass in LR 2013. The lowest biomass production was realized on Gliricidia at 4.5m treatments under COA for season LR2013.Productivity however increased after each test season and this can be attributed to the fact that the trees were coppiced at the end of every season thus there was more shoot development and growth leading to increased biomass both leaf and wood.On average,the season LR14 recorded the highest overall biomass productivity above ground(6.47 Mg ha^{-1}) compared to other seasons(4.32 and 4.40 $Mgha^{-1}$ in SR13 and LR13 respectively). The biomass productivity was noted to be statistically different among the seasons and treatments ($p<0.001$). Nolte *et al*.(2003) in their study to compare the effects of spatial patterrns of calliandra trees on production of biomass found that planting in closely spaced clusters of 0.4m × 0.4m yielded more biomass than equidistant pattern.This observation is in agreement with the findings of this study where closely spaced trees at 1.5m inter row spacing registered more biomass production(Calliandra at 1.5m= 12.9$Mgha^{-1}$) (in comparison to distant spaced trees (Cal at 3m =12.52 and Cal at 4.5=8.83 $Mgha^{-1}$). Figure 9 below presents the results of biomass production at the ATC

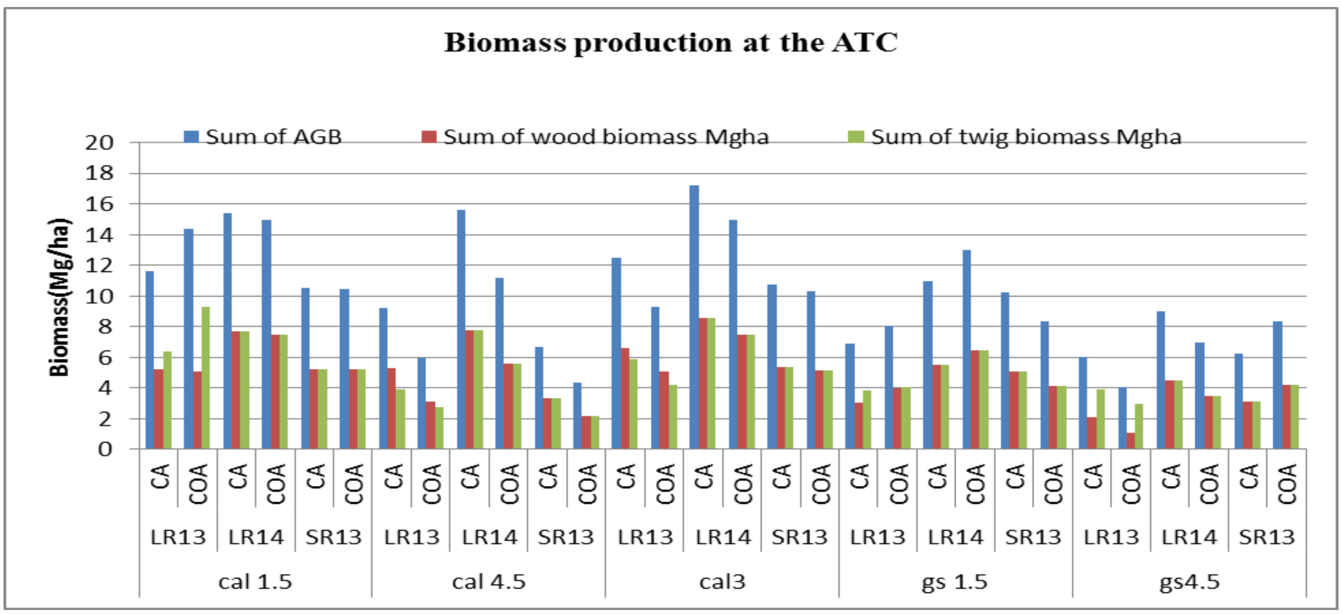

Figure 9: Production of biomass at researcher managed trials at the Machakos ATC

(Cal=calliandra, gs=Gliricidia, AGB=Above ground biomass)

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3.3.2. At Farmer managed trials

Different trends are observed in farmer managed trials where distantly spaced trees appeared to have produced more biomass compared to closely spaced trees. In Kangundo (Figure 10), highest AGB is recorded for calliandra at 4.5m (16 $Mgha^{-1}$) under CA in LR14 while lowest is recorded for calliandra at 1.5m spacing still under CA in LR13(4.5 Mg/ha).Similar trends as in Kangundo are also seen in Mwala (Figure 12) .In Machakos Central (Figure 11) however, calliandra at 1.5 m had the highest production of over 20 Mg/ha followed closely by the same species at 4.5m (19Mg/ha).

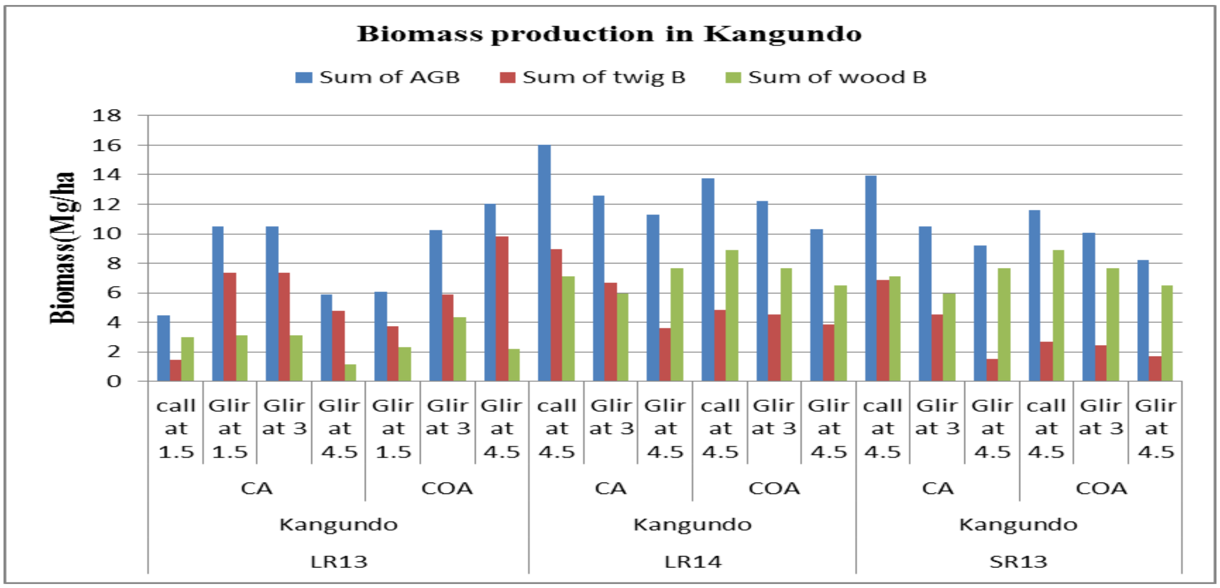

Figure 10: Biomass production in Kangundo

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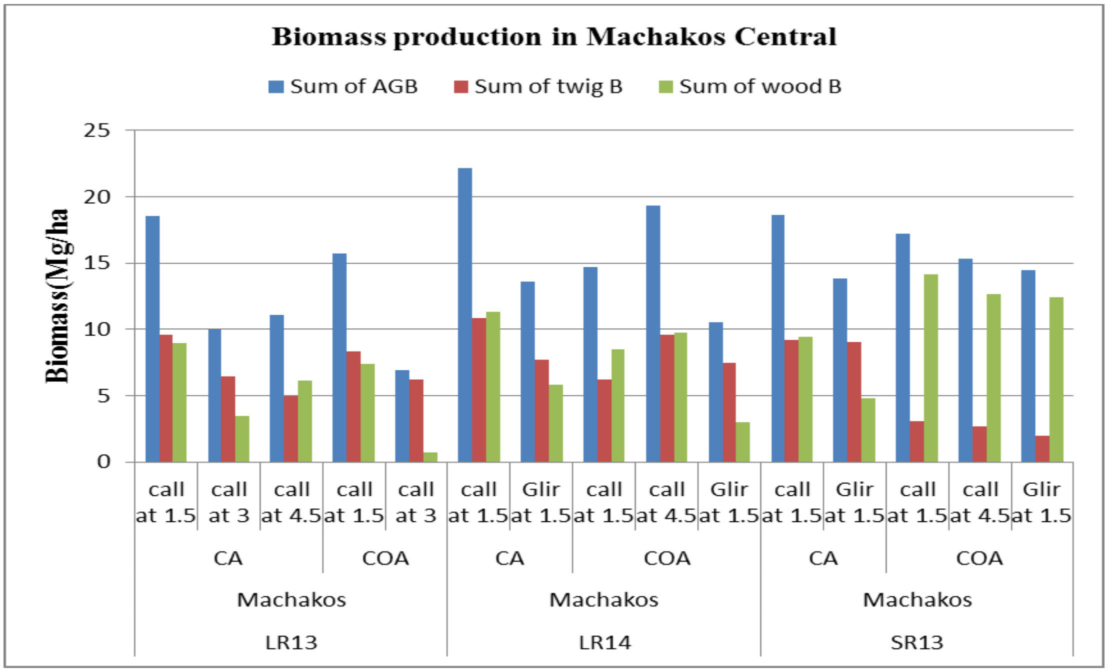

Figure 11: Biomass production in Machakos Central

The productivity of biomass at the on-farm trials was significantly influenced by the treatments ($p<0.001$) in the three sub counties. In other words, tree spacing had a great influence on the biomass production with closely spaced species observed to yield more biomass. Above ground biomass was also significant among seasons ($p<0.001$) with LR 14 recording highest grand mean of 14.08 followed by 12.96 Mgha^{-1} in SR13 and 9.22 Mg/ha in LR 13 .However, blocking by tillage i.e CA and COA did not have a significant effect on the production of biomass. The production was 11.95 Mgha^{-1} under CA and 11.5 Mgha^{-1} under COA ($p=0.803$), although COA led to production of more biomass compared to CA in the season LR13 (9.54 versus 8.89 Mg/ha)

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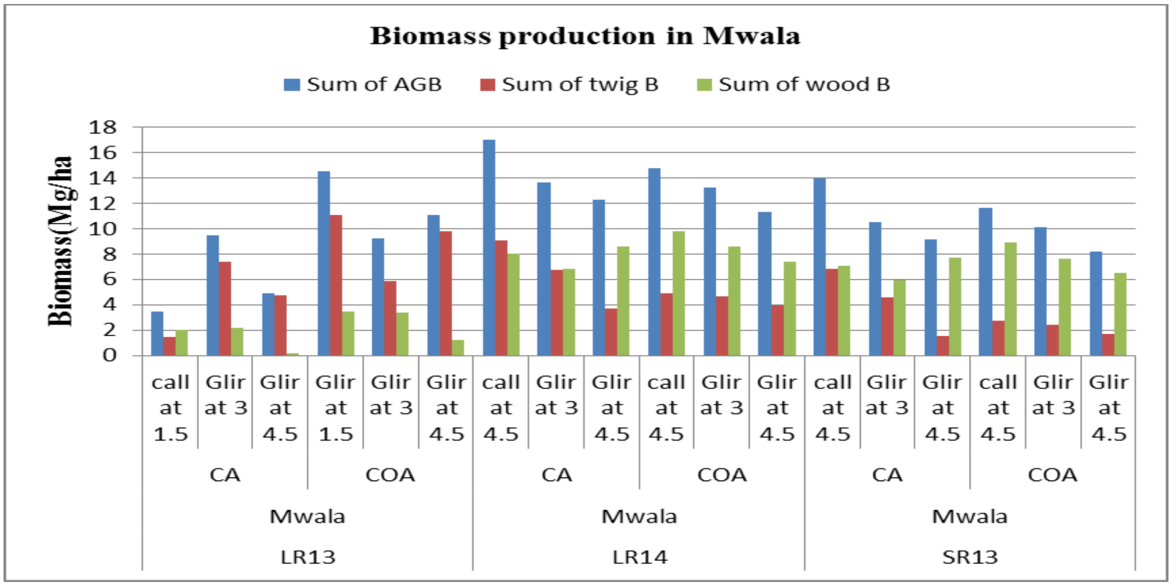

Figure 12: Biomass production in Mwala

Calliandra has been found to produce a herbage biomass of 45.9 t/ ha/ yr at a cutting frequency of four months (Kabi and Bareeba, 2008), which is equivalent to one season in this study. This means a three fold projection increment in the biomass production in a year. The amount of biomass produced by the tree moreover depends on the cutting frequencies of the regrowth. Frequent cuttings have been known to reduce the dry matter yields of forages as was noted by Karim et al (1991)

CONCLUSIONS

The study finds trees with larger canopies in Calliandra than in Gliricidia, with far apart trees spaced at 3 and 4.5m proving to have elaborate enlargement and elongation both at farmer managed and researcher managed trials. Calliandra has shown low earlier growth in first season due to poor mycorrhizal associations but later in the succeeding season exhibits faster growth. Yield productivity both in legumes and maize are more in researcher managed trials than farmer managed, and increasing after every experimental test season. *Dolichos lablab* as a leguminous cover crop is best suited for the arid and semi arid lands as was evident by the highest recorded yields, even when the maize yields in the particular season were a bit drastic. The practice of CA while also increasing trees has been shown to improve yields compared to sole legume and maize plantations. Yields also increase considerably when trees are integrated within farms at distant spacing as has been observed in the study where distant inter-row spacings of 3.0 m and 4.5 m had high yield productivity of both maize and legume than the closely spaced trees at

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inter-row spacings of 1m.It is therefore from the perspective of this study that farmers are advised to practice conservation agriculture while at the same time integrating trees within farms since the benefits are overwhelmingly high compared to the conventional practice. The notion that trees do destroy farms is therefore a myth and such can be overcome since it only happens at poor spacings and with wrong trees. The indubitable importance of CA with trees in enhancing total farm productivity is therefore proven not to be in doubt.

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