COMPARATIVE GROWTH OF MULTIPURPOSE TREES AND THEIR INFLUENCE ON SOIL MOISTURE AND MAIZE PERFORMANCE IN SEMI-ARID CONDITIONS, CENTRAL KENYA

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Abstract
Maintaining trees in cropland can help reduce the levels of carbon dioxide in the atmosphere, increase agricultural productivity and achieve climate resilience. However, it is unclear how trees impact on soil moisture and crop performance in semi-arid conditions. A study was undertaken to evaluate the growth of an exotic tree (*Grevillea robusta*) and indigenous tree species (*Cordia africana*, *Vachellia xanthophlea*, *Vachellia seyal* and *Faidherbia albida*), and their influence on soil moisture content and growth performance of maize at a long-term experiment in Juja. Trees established in 2011 were monitored for growth by measuring diameter at breast height (DBH) and height over a period of one year. Basal diameter and biomass of maize crops established in the trial plots was monitored for one season. There was no significant difference in height and DBH of the trees. Nevertheless, *G. robusta* had the greatest height, followed by *V. seyal* and *V. xanthophlea* while *C. africana* had the lowest. Mean DBH was highest in *V. xanthophlea* followed by *G. robusta* while *F. albida* had the lowest. Soil moisture content was higher in plots with trees than those without trees. Maize plants grown in plots with trees were significantly taller and had more biomass ($P<0.05$) than those in plots without trees; no significant differences were observed in maize basal diameter. Given the ecological limitations of semi-arid areas in Juja, the growth and biomass accumulation observed in the tree species is promising, being able to positively influence soil moisture without negatively affecting biomass of maize.

Key words
Agroforestry, biomass, climate change, maize growth

1.0 Introduction

A central challenge to agriculture in sub-Saharan African is determining how to sustainably increase production in the face of limitations such as, small area (4%) of irrigated farm land, low soil fertility and inadequate rainfall, lack of farm inputs, (Sileshi *et al.*, 2014) and impacts of climate change (Dinesh *et al.*, 2015). A variety of climate smart technologies such as agroforestry, conservation tillage, rainwater harvesting, irrigation and crop insurance are being used by farmers to increase agricultural production under uncertain farming conditions in sub-Saharan African

(Khatri-Chhetri *et al.*,2017; Rosenstock *et al.*, 2014). Among these, agroforestry has potential to achieve the triple win of increased agricultural productivity, environmental stability and reduced impacts of climate in ways that benefit smallholder farmers (Jose, 2009; Ong *et al.*, 2006; Rosenstock *et al.*, 2014)

Planting trees in crop or pasture fields allows both mitigation and adaptation actions to be applied with benefits to both ecosystems and food security (Boko *et al.*, 2008). Trees in agroforestry bind carbon in tree biomass and can raise soil organic carbon levels more than monoculture crop and pasture fields (Kuyah *et al.*, 2016). Globally, agricultural landscapes with trees stock an average of 21.4 Mg C ha^{-1} in biomass (Zomer *et al.*, 2016). In western Kenya, agricultural landscapes are estimated to stock an average of 17 Mg C ha^{-1} in aboveground biomass (Kuyah *et al.*, 2012a)) and 5 Mg C ha^{-1} in belowground biomass (Kuyah *et al.*, 2012b). When practiced in degraded lands, agroforestry can restore the productivity of the land, for example by improving soil fertility, water retention and microclimate (Kuyah *et al.*, 2016).

Irregular rainfall and recurrent dry periods (in addition to inadequate inputs) are the leading causes of low production or crop failure in sub-Saharan Africa (Benin, 2016; Boko *et al.*, 2008). Lack of water can also decrease the ability of trees to effectively photosynthesize, reducing their capacity for carbon sequestration. The positive effects of trees on water occur when trees preserve soil moisture during the dry season or protect soils and crop from erosion during rainy seasons (Kuyah *et al.*, 2017). Mulch from litter and shading by tree canopy regulate this function, improving local water availability by controlling evapotranspiration from understory plants (Kho et al., 2001; Rhoades, 1995) and the soil, and by enhancing infiltration (Chirwa *et al.*, 2007; Chirwa *et al.*, 2004).The impact of agroforestry on water availability depends on climatic and edaphic conditions, tree or crop species planted, planting density and management activities such as pruning of roots or branches (Kuyah *et al.*, 2016, 2017). Typically, trees lose more water through transpiration than understory plants (Anderson *et al.*, 2009; McIntyre *et al.*, 2001) The negative effects are adverse when fast growing trees are mixed with crops (Kidanu *et al.*, 2004) during the dry season and in landscapes with infertile or shallow soils (Ong *et al.*, 2006; Rao *et al.*, 1998). Competition also occurs when trees with extensive roots near the surface are grown with crops (Rao *et al.*, 1998). In such cases, trees are significant consumers of water except when they are pruned (Muthuri *et al.*, 2005; Ndoli *et al.*, 2017).

A recent review by Kuyah *et al*, (2016) established that effects of trees on water regulation is context specific, and that combining trees and crops on the same piece of land can also lead to competition between the trees and crops. The results appear to differ in relation to soil, vegetation, climatic conditions, as well as sampling techniques used. In certain situations, trees maintained high soil moisture content and favourably modified microclimate with positive impact on crop performance

(Chirwa *et al.*, 2007; Chirwa *et al.,* 2004). In other situations, the presence of trees was associated with low soil moisture content and depressed yields (Livesley *et al.*, 2004; Ndoli *et al.*, 2017; Odhiambo *et al.*, 2001) effects of trees on soil moisture and crops are often reported in studies featuring fast growing trees. What is needed is a management strategy that can reduce trade-offs, especially water consequence of trees species deemed suitable for agroforestry.

Integration of trees in agricultural landscapes can have significant consequences on climate, food security, and resilience of farms. This is important in smallholder systems where intercropping with trees is a common practice. A recent study shows that over 30% of rural farmers in Sub-Saharan African have trees on their farms and about 17% of their annual household income from these trees (Miller *et al.*, 2017). The majority of these farmers grow maize, a staple crop in several countries in sub-Saharan Africa. In Kenya, maize is grown under rain-fed agriculture, exposing the crop to impacts of climate variability. Smallholder farmers in many parts of Kenya also turn to trees for livelihood, especially during periods of drought (Quandt *et al.*, 2017). Over the past years, a variety of tree species have been tested to determine their suitability for agroforestry. However, solutions to overcoming the challenge of competition between trees and crops are context specific. Successful integration of trees in cropland requires knowledge on their performance and their effects on factors that influence crop production. Information to support this understanding is lacking in semi-arid conditions of certain regions in Kenya, particularly for indigenous tree species.

2.0 Materials and Methods

2.1 Study site

The study was conducted at Jomo Kenyatta University of Agriculture and Technology (JKUAT) in Kiambu County, Central Kenya. JKUAT is located at latitude 1°06'S, longitude 37°01'E with an elevation ranging from 1519 m to 1533 m above sea level. The mean annual rainfall in Juja is 799 mm and is received twice a year; from May - July (long rains), and October - November (short rains). The temperatures in Juja average 19.6 °C. Monthly average for the warmest month (March) is about 21 °C and for the coolest month (July) is estimated at 17.3 °C. Soils in the area get waterlogged during the rainy season and crack during the dry season. The soils have low organic matter content (1.4%), low nitrogen (1.8%) and phosphorus below 0.4% (Muthuri *et al.*, 2005).

2.2 Experimental set up

The experiment was established in 2011 as a randomized complete block design containing four replicates. The experimental study units were plots with different types of tree species (*F. albida, C. africana*, *and G. robusta, V. seyal* and *V. xanthophlea)* and the control plots all replicated four times. Treatments 1 is a single stand of *Faidherbia albida*, treatment 2 is a single stand of *Cordia africana* while treatment 4 is a mixed stand *F. albida, C. africana*, *and G. robusta, V. seyal* and *V. xanthophlea*. The experimental site is a block of length and width of 355m by 100m respectively. The site is subdivided into 16 blocks of 50m and 40m leaving a pathway around each plots. Each plot has 7 rows of trees. Between the rows is a 2m space and between the trees also has 2m space.

2.3 Field measurements

Diameter at breast height (DBH) and height measurements were collected monthly to evaluate growth of 335 trees from June 2016 to April 2017. Dead bark, debris and other materials loosely attached to the stem were first removed prior to measurement. The circumference of tree was measured at 1.3 m from the ground using a regular tape measure held tight and horizontal to the tree axis. The measurements were converted to DBH by dividing circumference by pi (π). Multiple stems of trees fork below 1.3 m (e.g. *C. africana*) were measured as individual trees and the DBH determined as the square root of the sum of squares of individual stems. A diameter stick of 1.3 m length was used for quick location of 1.3 m point, and to minimize the human error when locating DBH for trees of different sizes. Total height of the trees (from the base of the main stem to the top of the leading leafy shoot) was measured using a calibrated height pole.

Gravimetric soil moisture was monitored fortnightly between February and June 2017, before, during and after rains. A total of 27 access tubes (PR2-UM-3.0. Delta-T Devices: Cambridge U.K.) were installed. Four access tubes were installed at each of three plots with *F. albida* and each of the three plots of *C. africana* (two access tubes at 1 m and two access tubes at 2 m away from the base of the tree); three access tubes for the control were installed at the middle of the plot. Access tubes were installed vertically in the soil using spiral auger (28 mm in diameter and 1.11 m in depth). The access tubes projected above the soil surface with 50 mm and were covered with a black plastic cork wrapped with an adhesive tape to exclude soil and rain water. The tubes were fitted tightly to avoid any vacuum beneath the tip of the tubes. Readings at 10, 20, 30, 40, 60 and 100 cm depths were obtained using a moisture meter type HH2 attached to the probe.

Maize crop (hybrid DH 04) was established in October 2016 at a spacing of 75 cm x 50 cm after ploughing. Three maize rows were planted with one seed in each hole. The first row was established 1 m from the tree trunk. The height and basal diameter of maize were measured 30 days after sowing, and monitored every 30 days until maturity when destructive measurements were done to determine biomass. Two plants per row and on each side of the tree were sampled randomly and labelled to facilitate repeated measurements. Maize plants in tree-less plots were sampled randomly. The two maize plants per row measured for diameter and height were harvested and the fresh weight of stover determined using a 5 kg scale. Sampled plants were oven dried to constant weight and the dry weight determined.

Stover biomass was estimated from the ratio of the sub-sample dry weight-to-fresh weight multiplied by the total fresh weight. Grain yield was not assessed in the experiment due to crop failure following a prolonged dry spell (Fig. 1).

2.4 Data analysis

The statistical results of DBH and height measurements were calculated for assessing growth of trees. Diameter and height measurements were converted to aboveground biomass (AGB) using allometric equations developed for agricultural landscapes (Kuyah *et al.*, 2012a). Three equations were used to estimate biomass from DBH alone ($AGB = 0.091*dbh^{2.472}$); DBH combined with wood density, ρ ($AGB = 0.225*dbh^{2.341}*\rho^{0.73}$), DBH combined with height ($AGB = 0.092*dbh^{2.488}*h^{-0.028}$), and DBH combined with height and wood density ($AGB = 0.221*dbh^{2.301}*h^{0.062}*\rho^{0.755}$). Biomass estimates was then converted into carbon stocks using default value of carbon fraction in wood (0.47) reported by the Intergovernmental Panel on Climate Change (IPCC, 2006). Estimates of biomass from individual tree species was up-scaled to plot level in tons per hectare (ha). Gravimetric water content was converted into volumetric soil water content and summary statistics calculated. Non-parametric tests (Kruskal-Wallis Test) was performed to test for statistically significant differences between treatments.

3.0 Results

3.1 Tree growth

The average rainfall during the study period (June 2016 – June 2017) ranged between 17 mm and 184.7 mm. The lowest precipitation was recorded in January 2017 and rainfall peak was in May 2017. Mean temperatures ranged between 22 ˚C and 25 ˚C (Fig. 1).
(Insert Figure 1)

All tree species increased in DBH and height during the period of measurement, from 3 cm and 2 m in June 2016 to between 7.2 cm and 5 m in April 2017 in DBH and heights, respectively (Fig. 2a and b). No significant difference was observed in the mean height increases among the five tree species during the growing season. However, differences in overall growth were observed when the final height of the six-year old trees was considered. *G. robusta* had significantly high growth throughout the growing season while *Vachellia* species had moderate and almost similar increase in height. *C. africana* and *F. albida* had comparable increase in height. There was greater increase in height during the periods coinciding with peak rainfall (August and April). A converse growth trend was observed with DBH, where *V. Xanthophlea* consistently had higher DBH while *F. albida* had the lowest initial and final DBH. Fig. 3a and b are box plots showing the measured plant DBH and height at the end of the study period (April 2017).
(Insert figure 2)

Similar to height, increase in DBH was highest around August and April and lowest (slowed growth) between October and December. In single stand system, *C. africana* had the largest average DBH (7.0 ± 0.3 cm) compared to 5.5 ± 0.2 cm of *F. albida*. A similar trend was observed in mixed stands, although the mean DBH was smaller than that of single stand system.
Insert table 1

Vachellia xanthophlea and *G. robusta* had the highest biomass estimate among the species (Fig. 3c). The average biomass of *V. Xanthophlea* and *G. robusta* at the end of the measurement period was about 50% higher than that of *V. seyal*, *C. Africana*, and about 75% higher than that of *F. albida*. Between the two planting patterns, the biomass from single stand was higher than that of mixed stand for *C. africana* while in *F. albida* higher biomass was in mixed stand; the difference was striking both between the species and the planting pattern. Application of equations that included height and wood density significantly varied the trend in biomass estimates among the five species (from that obtained using DBH as the only predictor variable). *C. africana* had the highest biomass estimates followed by *V. Xanthophlea*, *G. robusta*, *F.albida* and *V. seyal*. Variations between biomass estimates from the equation with DBH alone and the rest of the equations ranged between 0.11 and 0.30%. Biomass estimates of *V. seyal*, *V. Xanthophlea*, *C. africana* and *G. robusta* were underestimated relative to estimates by equation with DBH as the only predictor while the biomass of *F. albida* was overestimated (1.08%) relative to estimates by equation with DBH as the only predictor variable. The influence of height and wood density was moderate and comparable in *Vachellia* species but pronounced in *F.albida*.
(Insert Figure 3)

3.2 Effect of trees on soil moisture

Soil moisture content varied between treatments with trees and those without, and between plots with *F. albida* and those with *C. africana*. Plots with trees had consistently higher soil moisture content compared to those without (Fig. 4). Higher moisture content was recorded under *F. albida* plots than under *C. africana* (Fig. 4). The differences in soil moisture content between plots with and without trees increased after rainfall peaks in April through June. Variation in soil moisture in all treatments was consistent with rainfall patterns during the period of measurement, being highest in the months of April and May for control and treatment plots; and lowest in June and February for control and treatment plots, respectively (Fig 4).
(Insert Figure 4)

The temporal pattern of soil moisture content at different depths is shown in Figure. 5a -f. The effect of trees on volumetric soil water content at all depths was not significantly different. At all depths, control plots had the lowest soil moisture content compared to plots with *C. africana* or *F. albida* (Fig. 5 a-f). Soil moisture

content in the 0-10 cm depth in treatment with *C. africana* increased while that of *F. albida* decreased between April and May but it dropped for all the plots from May to June. Noticeable differences were only observed in the 0-10 cm depth; the rest were constant. A unique pattern of soil moisture pattern was observed at 40 cm depth in relation to other depths. However, all other depths from 20 to 100 cm profiles showed a drop from April to June while respective depths in control treatment had an increase in moisture content between April and May.
(Insert figure 5)

3.3 Effects of trees on maize plants

Growth of maize grown in plots with trees was better than that in plots without trees (Fig. 6). There was an overall significant difference ($P<0.05$) in the height of maize plants in association with trees to that in tree-less control plots (Fig. 6a and b). The influence of the trees on maize plants differed according to the distance of the row from the base of the tree. The average height of maize under tree-based system at 1 m away from the tree trunk was 11.3% higher (Fig. 6a) than in plots without trees; the height at 1.75 m was 45.5% higher than in plots without trees (Fig. 6b). At 1 m away, the height of maize in association with *F. albida* was 11.5% higher than height in sole crop, while maize grown with *C. africana* had height that was 9.9% higher than that in control. When the growing period was considered, increase in height was greatest within the first 60 days but slowed in the third month. However, there was no significant difference in the height of maize under the tree species at 30, 60 and 90 DAS.

Basal diameter of maize plants in all the tree species plots sampled increased with time (30, 60 and 90 DAS) but did not show any significant difference both at 1 m and 1.75 m away from the tree base (Fig. 6c and d). Maize in the control had the smallest basal diameter, the difference between plots with trees and those without being significant in the first two months (at 30 and 60 DAS) but not significant at 90 DAS (Fig. 6c and d). Basal diameter of maize in the mixed species and *F. albida* plots decreased with distance from the tree except in the 60 DAS where it was larger. At 1 m distance, mixed species and *C. africana* treatment had the largest basal diameter in the third month, although the difference was not significant compared to other treatments (Fig. 6). However, at 1.75 m, *C. africana* had the largest basal diameter, but still not significant. At 60 and 90 DAS, significant differences were observed in basal diameter of maize plants in all the treatments except those with *F. albida* at 1.75 m.
(Insert Figure 6)

Biomass of maize grown under trees was higher than that from plots without trees (Fig. 7a and b), although the effect of tree species on biomass was not significant. Aboveground crop biomass between the two distances from the base of the tree stalk did not differ significantly. The largest biomass produced was 0.558 t ha^{-1} under

C. africana plots at 1.75 m distance (Fig. 7b.). A narrow margin was observed between maize grown under *F. albida* and mixed species plots (Fig. 7a and b). Biomass production in the tree species plots at 1 m away from the tree base was not significantly different from that produced at 1.75 m away.
(Insert figure 7)

4.0 Discussion

4.1 Tree growth

Grevillea robusta and *V. xanthophlea* were the best performing tree species evidenced by greater height and larger DBH compared to *C. africana*, *F. albida* and *V. seyal*. *G. robusta* has been shown to grow faster in semi-arid conditions compared to indigenous tree species (e.g. *C. africana*) during the juvenile stage (Takaoka, 2008). The average height attained by the 6-year old trees in this study is slightly below height values (about 6 m) reported for 2-year old trees at Kiroka in Tanzania (Maliondo *et al.*, 1998) at Kachwekano and Bushenyi in Uganda (Okorio *et al.*, 1994) and in Rwanda (Kalinganire, 1996). Better growth of *G. robusta* reported by (Kalinganire, 1996; Maliondo *et al.*, 1998; Okorio *et al.*, 1994) could be attributed to higher amounts of rainfall and more fertile soils in respective sites compared to the semi-arid conditions of Juja, Kenya. The increment of 1.2 m in height and 1.9 cm in diameter attained by *G. robusta* over 12 months in this study is lower than (in the case of height), but closer to (in the case of diameter) the annual growth rates of 2.0 m in height and 2.0 cm in diameter over the first 5 years of establishment (Kamweti, 1996). Growth rates of above 2.0 m in height and 2.0 cm in diameter for *G. robusta* can be achieved where climate and soils are suitable. *V. xanthophlea* and *V. seyal* also grew well in diameter attaining an increment of 2.0 cm but had a smaller (1.0 m) increment in height. Height increment determined for *V. xanthophlea* in this study was within the annual growth rate range (1.0-1.5 m per year) for the species in southern Africa (Orwa *et al.*, 2009). The increment in DBH determined in this study (1 cm) is higher than the mean annual diameter increment (0.5 cm) determined for *V. seyal* in growing in semi-arid region in Ethiopia (Gebrekirstos *et al.*,2008).Variations between values from this study and Gebrekirstos *et al.*, (2008) could be attributed to extreme dry conditions in Ethiopia, mature trees considered in that study, and methodological differences for estimating growth rate. Greater increase in height by *V. Xanthophlea* occurred during the rainy season suggesting better adaptation of the species in the harsh environment (often water-logged soils) at Juja.

Cordia africana and *F. albida* performed better when grown in single stands than in mixed stands, corresponding to findings by (Lott *et al.*, 2000a) that tree size is generally greater in sole *Grevillea* than in the dispersed agroforestry system. Studies have also shown that *C. africana* trees planted at wider spacing grew faster than those grown at narrow spacing, suggesting that competition in mixed stand limits growth of *Cordia* trees (Mehari, 2005). Water deficit and below-ground competition from intercrops can slow the growth of juvenile trees in semi-arid conditions (Lott *et al.*, 2000a). The low diameter and height attained by *F. albida* corresponds to reports that it grows slowly; though the species is drought tolerant and has a high rate of survival in water stressed areas. Although the species occurs widely in dry zones of Africa, it may not be well adapted to the conditions in Juja. Much of the growth of *F. albida* occurred during the dry season contrary to other tree species which exhibited greater growth during the rainy season, a phenomenon that is also associated with reverse phenology (Kho *et al.*, 2001; Roupsard *et al.*, 1999). *C. africana* is widespread in central Kenya, mainly introduced and retained in farms for food, fodder, fuel, timber and other environmental services (Takaoka, 2008). The high growth rate of *C. africana* in Juja (dry) and other parts of central (wet) Kenya suggest the adaptability of the tree species to different conditions. The low height of *C. africana* trees in this study could be attributed to the high tendency of the tree species to have more branching and rapid growth of diameter growth at the expense of height (Mehari, 2005).

4.2 Effect of tree species on soil moisture

The amount of water determined in the plots with trees was greater than that in plots without trees. This is consistent with findings of a recent review evaluating effects of trees on soil moisture in sub-Saharan Africa (Kuyah *et al.*, 2016), where 51% of the studies show positive effects of trees, although there are situations when the effect is negative (35%) or neutral (14% studies). Higher water content in the plots with trees compared to those without trees is attributed to reduced loss of soil moisture from evapotranspiration and improved infiltration (Chirwa *et al.*, 2007; Chirwa *et al.*, 2004; Kho *et al.*, 2001; Rhoades, 1995). Supporting the idea of higher soil moisture in agroforestry, studies report differences in water content among species, radial distance from the stem and different depths in the soil profile (Anderson *et al.*, 2009; Kidanu *et al.*, 2004; Livesley *et al.*, 2004)

The differences in soil water content under *F. albida* and *C. africana* plots suggest varied potential of the species to influence availability of soil water. Plots with *F. albida* maintained higher moisture content in lower soil profiles. *F. albida* has an open canopy that permits sunlight, which could have allowed loss of water through evaporation. Observations at the site revealed that litter from *F. albida* does not effectively cover the soil to prevent soil evaporation. Contrary to findings in this study, experiments with *F. albida* in Malawi shows that soil moisture in the upper 0-15 cm is higher under the influence of tree canopies (Rhoades, 1995b). Younger trees (such as in this study) do not exhibit the beneficial effects of *F. albida* on soil moisture (Kho *et al.*, 2001; Rhoades, 1995b; Roupsard *et al.*, 1999). Plots with *C. africana* had higher soil moisture content at shallow depths (0-30 cm), attributed to large quantities of leaf mulch from *C. africana* and shade cast by the canopy. Trees that produce large quantities of litter or that have dense canopies, cover the soil and shade the crops beneath, reducing evapotranspiration. Changing soil water content throughout the measurement period in all plots including controls is attributed to the rainfall pattern which peaks in the month of November and May. The higher water content in plots with trees at greater depths after rainfall can be attributed to recharge following improved infiltration. During the dry season, rainfall does not replenish water depleted via uptake and evapotranspiration (Jackson *et al*., 2000; Livesley *et al*., 2004; Odhiambo *et al*., 2001). and therefore trees should be pruned to control water uptake and transpiration (Muthuri *et al.*, 2005; Ong *et al*., 2006).

4.3 Effect of tree species on crop performance

The growth of maize was better in plots with trees compared to tree-less plots, evidenced by higher biomass and greater diameters and heights of maize in plots with trees. This is consistent to findings from a recent review evaluating effect of trees on crop yield (Kuyah *et al*., 2016). In the review, crop yields increased under tree-based systems compared to systems without trees in 68% of the studies, decreased in 18% and were unaffected in 14% of the studies (Kuyah *et al.*, 2016). Better growth of crops could be attributed to improved microclimate, nutrient cycling and soil fertility under plots with trees (Rao *et al.,* 1998). In monoculture crop fields, the amount of soil moisture lost to the atmosphere is high, and the scorching of the plants slows growth of plants.

The effects of trees on crop growth depends on the species and distance from the stem. Biomass of maize plants was higher in plots with *C. africana*, consistent with reports in Ethiopia that the shading effect of *C. africana* can significantly improve crop yields during adverse weather conditions. The lower biomass determined for maize under *F. albida* compared to *C. africana* and other findings this study is attributed to the young trees (6-year old) that do not yet exhibit the "Faidherbia effect", which is pronounced in mature trees (Kho *et al.*, 2001; Rhoades, 1995; Roupsard *et al.,* 1999) Results of height and diameter of maize in the middle of the canopy (at 1.75 m) and close to the tree (1 m) was consistent with findings that performance of crops increases with increasing distance from the base of the tree. In the case of *F. albida,* the tree has less foliage and therefore soil moisture is mainly preserved near the base of the trees where many roots are found (Hadgu & Kooistra, 2009). Findings that growth of maize was better in mixed stand than in single stand are similar to those reported by Nyaga *et al* (2017), where maize in plots with different tree species achieved greater height. This was attributed to complementary effects of different trees planted together with crops. For example, leguminous trees in this study (*V. Xanthophlea* and *V. seyal*) have potential to improve growth of crops by improving soil nitrogen, while litter and shading by *C. africana* and *G. robusta* canopies improve microclimate and reduce water loss. Generally, lower yields close to the stem could be attributed too much shading, allelopathic effects and competition for water and nutrients (Muthuri *et al*., 2005; Ndoli *et al*., 2017). This suggest that maize stover biomass can be compromised when crops are grown together with trees without proper arrangement or management (Jackson *et al*., 2000; Lott *et al*., 2000b; Ong *et al*., 2006)

5.0 Conclusion

The results show that exotic tree *G. robusta* had the highest growth rate, and a comparable growth rate was attained by the native *V. xanthophlea*. This suggests that adapted native species grow as fast as exotic *G. robusta* in semi-arid conditions, while *V. seyal* may not withstand harsh conditions at the study site (e.g. flooding and prolonged dry season). The prolific branching of *C. africana* and associated large canopy and foliage had the advantage of improving microclimate and soil properties. However, much branching is detrimental to crops because excessive shading limits light intensity reaching the crops underneath. Farmers integrating *C. africana* in crop fields should prune the trees or plant them at a wider spacing to allow formation of straight poles and to minimize competition with crops. *F. albida and C. africana* variedly maintained higher soil moisture compared to tree-less plots, underscoring the importance of trees in water regulation and the different mechanisms by which trees regulate local water availability. Prolonged dry season led to crop failure. Nevertheless, trees positively influenced growth of maize stover. This is important because maize stover is increasingly used for livestock feed during the dry season. It is important to investigate the contribution of the trees to soil carbon in the area. Investigation on maize yield could also be followed up through repeated experiments.

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FIGURES

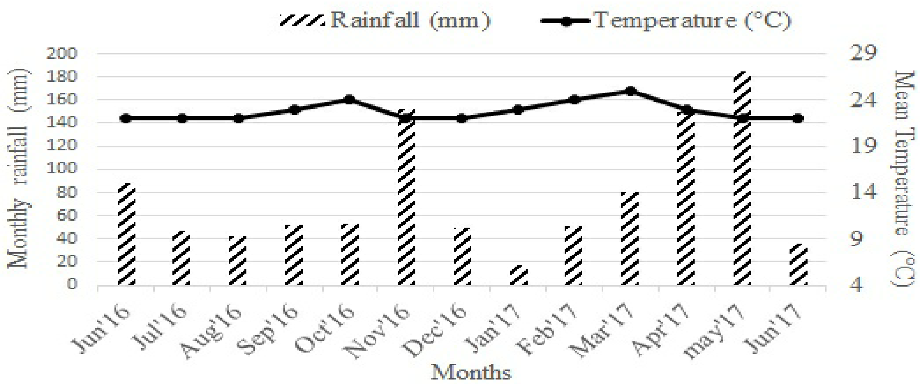


Figure 1: Monthly rainfall (mm) and mean monthly temperatures (˚C) in Juja during the study period (June 2016 – June 2017).

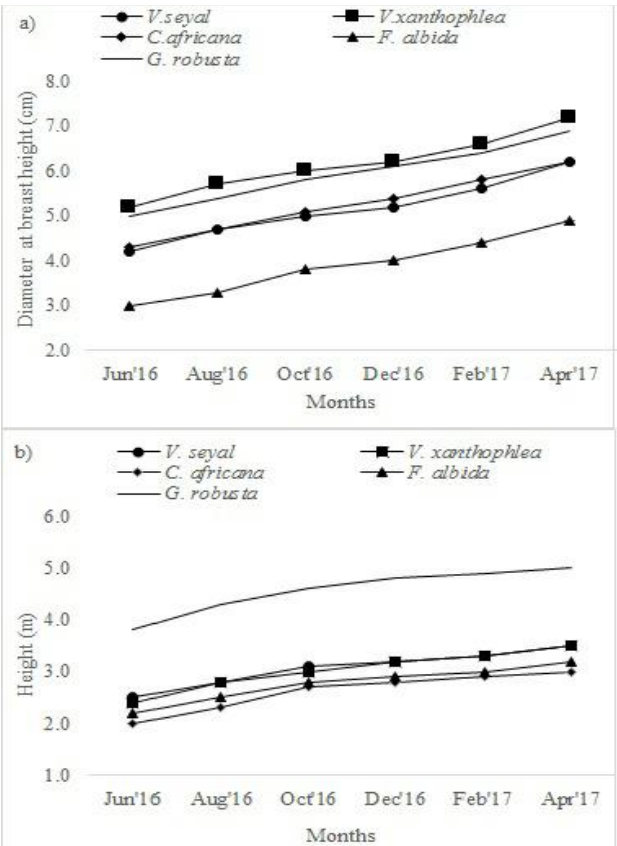
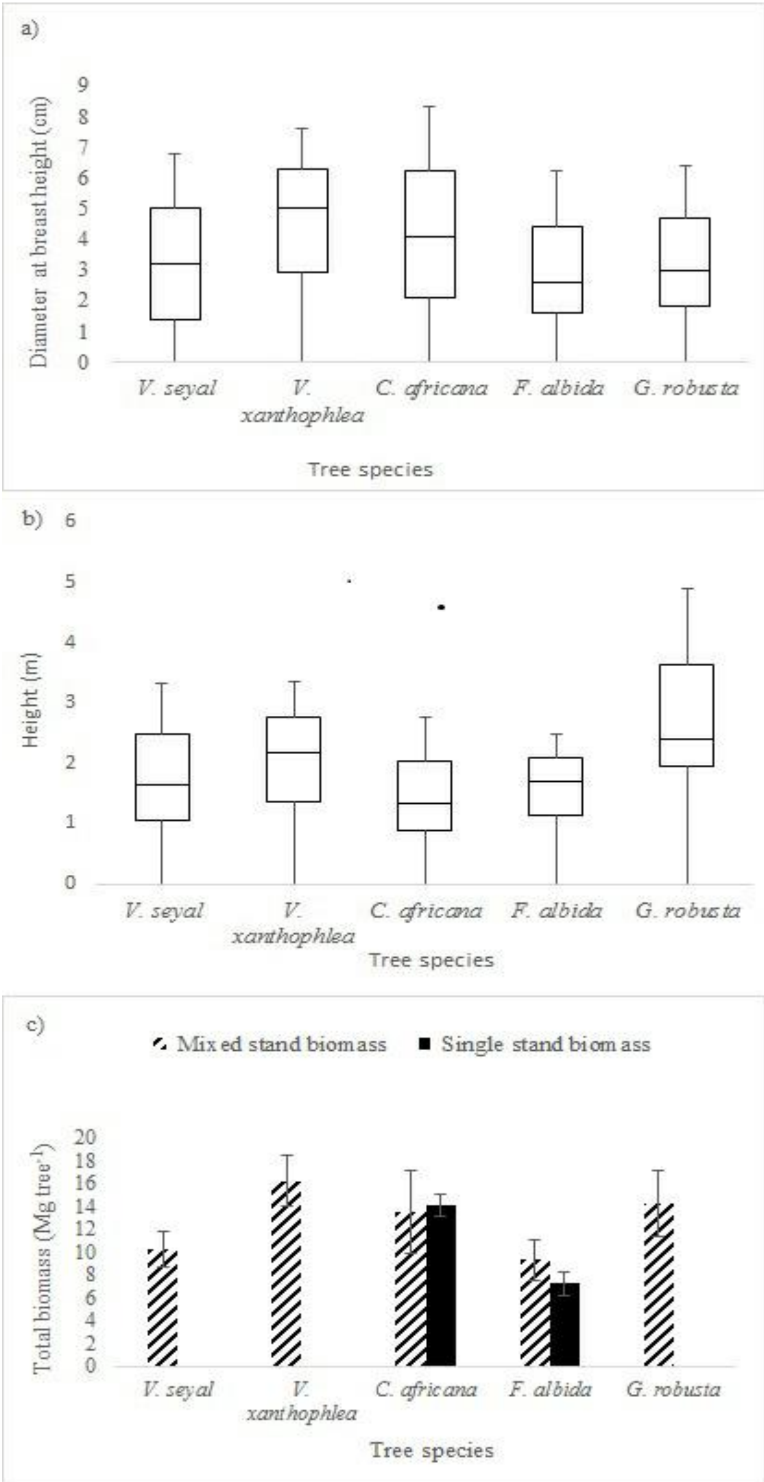


Figure 2a and b: Time courses of (a) mean tree height and (b) mean diameter at breast height of Vachellia seyal, Vachellia xanthophlea, Cordia africana, Faidherbia albida and Grevillea robusta in Juja between June 2016 and April 2017.


a)
Diameter at breast height (cm)
0
1
2
3
4
5
6
7
8
9
V. seyal
V. xanthophlea
C. africana
F. albida
G. robusta
Tree species
b)
Height (m)
0
1
2
3
4
5
6
V. seyal
V. xanthophlea
C. africana
F. albida
G. robusta
Tree species
c)
Mixed stand biomass
Single stand biomass
Total biomass (Mg tree-1)
0
2
4
6
8
10
12
14
16
18
20
V. seyal
V. xanthophlea
C. africana
F. albida
G. robusta
Tree species

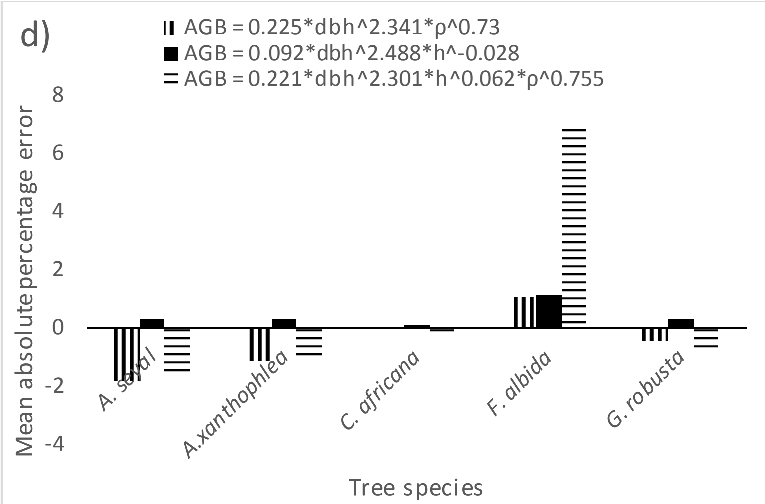


*Figure 3a, b, c and d: Box plots showing distribution of (a) dbh (cm), (b) height (m) (c) total above ground biomass and (d) mean absolute percentage error of the models applied to each of the tree species of V. seyal, V. xanthophlea, C.africana, F.albida and G. robusta in Juja in April 2017. Error bars in **a** and **b** represents the minimum and maximum values; Vertical bars in **c** shows the standard errors of the mean.*

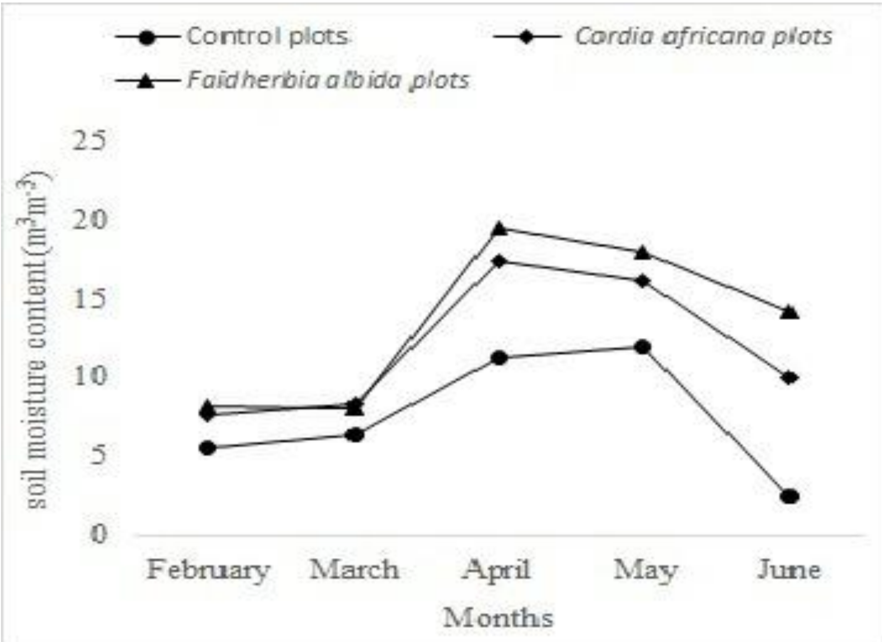


Figure 4: Effects of C. Africana and F. albida on volumetric soil water content (m^3m^{-3}) compared to control in Juja between February 2017 and June 2017.

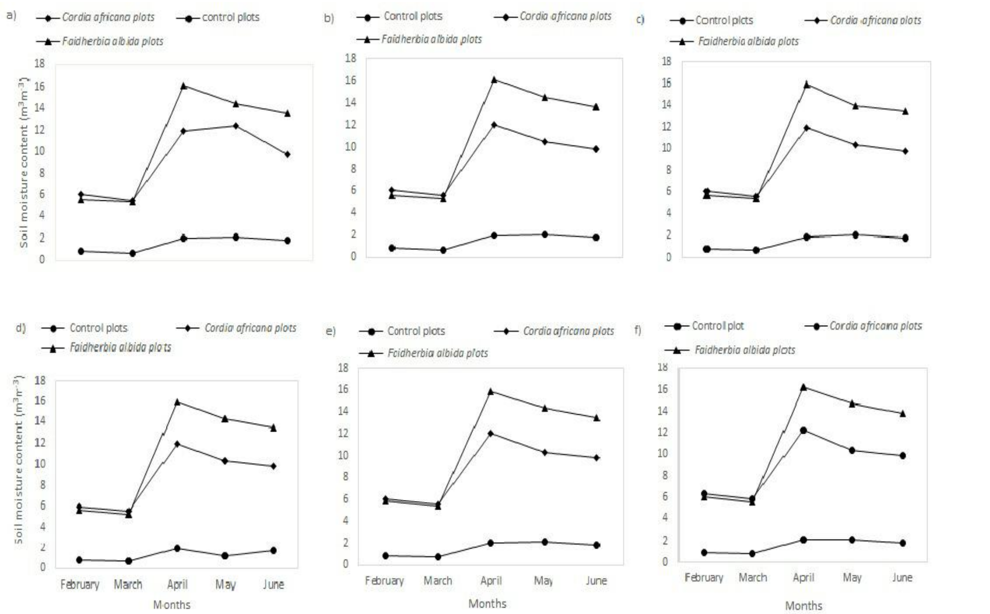
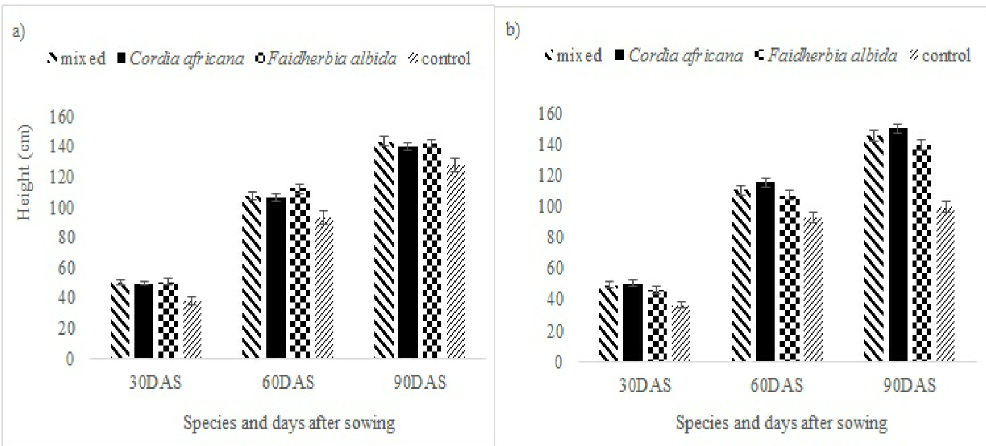
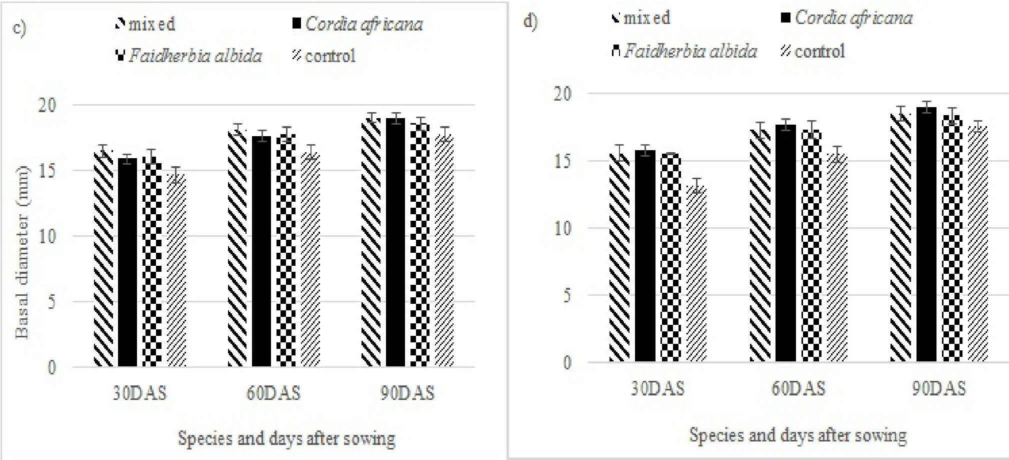


Figure 5a, b, c, d, e and f: Effects of the tree species and sampling depths on volumetric soil water content (m^{3}m^{-3}) compared to control in Juja between February 2017 and June 2017.

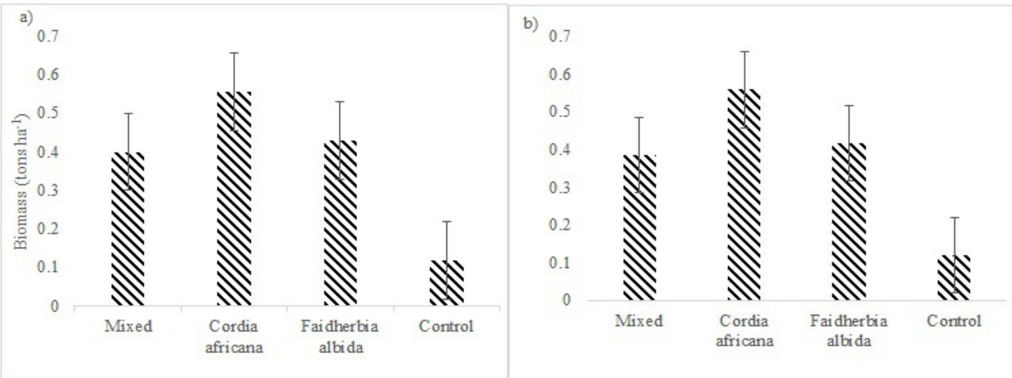


(a) (b)



(c) (d)

*Figure 6a, b, c, d: Mean maize plant height in centimetres at 1 m **a** and1.75 m **b** distance from the tree trunk and mean plant basal stem diameter in millimetres at 1 m **c** and 1.75 m **d** from the tree trunk for the measurements made between 30 and 90 DAS under tree-less, or mixed tree species (V. seyal, V. xanthophlea, C. africana, F. albida and G. robusta), C. africana and F. albida plots in Juja during the 2016-2017 short cropping season. Vertical bars in each bar shows the standard error of the mean.*



(a) (b)

Figure 7a and b: Average maize stover biomass (tonnes per hectare) under control, mixed (V. seyal, V. xanthophlea, C. africana, F. albida and G. robusta), C.africana and F. albida treatments at (a) 1 m (b) 1.75 m away from the tree trunk in Juja during the 2016-2017 short cropping season. Vertical bars in each bar shows the standard error of the mean.

Table 1. Table showing Minimum, maximum, mean values of diameter at breast height (DBH cm) and height (m); Standard errors of C. africana and F. albida grown in mixed species and single alone stand in Juja in April 2017.

Tree species	Pattern	DBH (cm)				Height (m)			
		Mean	Min	Max	SE	Mean	Min	Max	SE
Cordia africana	Single stand	7.0	2.6	14.4	0.3	3.1	1.73	5.34	0.1
Cordia africana	Mixed stand	6.6	3.2	17	0.6	3.3	1.67	5.81	0.2
Faidherbia albida	Single stand	5.5	2.6	9.8	0.2	3.4	2.1	5.28	0.1
Faidherbia albida	Mixed stand	6.2	3.7	8.8	0.5	3.5	1.7	5.76	0.3