THE INFLUENCE OF TREE THINNING ON GRAIN YIELD AND BIOMASS OF MAIZE IN TREE INTERCROPPING SYSTEMS OF SEMI-ARID ETHIOPIA

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Abstract. This study evaluated adaptation of agroforestry trees and simultaneously studied the effect of thinning on maize yield and biomass. Treatments were *Faidherbia albida, Moringa stenopetala, Acacia nilotica, Cordia africana*, tree mix and sole crop planted in RCBD with four replications. Thinning was applied on *Acacia nilotica* and *Cordia africana* which were found fully stocked at six years. Maize (Zea mays L.) was intercropped to study if thinning influences maize yield and biomass. Grain yield was significantly ($\alpha<0.05$) affected by thinning and tree species. Thinning *Cordia africana* significantly influenced maize yield with 36.4% increase in yield. Maize yield and biomass under thinned *Cordia africana* was significantly higher ($\alpha<0.05$) compared to un-thinned plots. Maize grain yield and biomass under un-thinned *Acacia nilotica* was significantly lower than the yield under un-thinned *Cordia africana* and crop alone plots. Thinning *Acacia nilotica* brought no significant increase in grain yield and biomass. Significantly higher yield ($\alpha<0.05$) of maize was observed under plots of thinned *Cordia africana* compared to thinned *Acacia nilotica*. Crop alone plots produced higher yield though the difference was statistically non-significant compared to thinned *Cordia africana*. Thinning *Cordia africana* to 130 trees/ha (25% thinning intensity) is recommended to significantly increase maize yield and biomass.

Keywords: Harvest index; monocropping; stocking; thinning.

INTRODUCTION

Incorporation of appropriate trees in farming systems can build soil health, sustain crop yield improvement, livestock productivity and water use efficiency, as well as provide energy, food and materials. Perennials can gain access to more of the soil's nutrients and water, for a longer time than annual crops and hence integrating perennials in agroforestry systems is increasingly promoted as an important tool in addressing soil fertility issues in Africa (Glover et al. 2012). The roots of perennials often extend more than two meters deep (compared with less than a meter for most annuals), and their growing seasons are longer. These attributes make them more resilient to harsh environmental conditions and their production of more biomass, both above and below ground, reduces soil erosion, transferring organic inputs to soil microorganisms and increasing the amount of carbon stored in the soil — a key component of soil health. Trees planted on only 3-5% of agricultural lands can increase farm productivity, reduce vulnerability to climate change and greenhouse gas emissions (Possu et al., 2016). Agroforestry systems, containing mixtures of trees and crops, are often promoted because the net effect of interactions between woody and herbaceous components is thought to be positive if evaluated over the long term (Philip et al. 2017).

Agroforestry, where trees are integrated with crops and/or livestock is a promising land management system that can address many of the challenges farmers

are facing (Lundgren & Raintree 1982). It is promoted as a land use strategy to support climate change mitigation and climate change adaptation, biodiversity conservation, sustainable agriculture and other goals. Agroforestry has the potential to mitigate climate change, adapt resource poor smallholder farms to extreme and variable weather and increase tree-related essential ecosystem services, while increasing farm productivity without reliance on large amounts of external inputs such as inorganic fertilizers and chemicals for pest management (Agroforestry network, 2018). Agroforestry systems range from simple – such as one crop species and one tree species – to complex, with various crops species, tree species and livestock all meeting different needs (Gassner A and Dobie P. 2022). Agroforestry systems involve land management practices, perennial crops, long rotation systems for soil conservation including crop diversification, home gardens, boundary plantings, hedgerow intercropping, live fences, improved fallows, multistorey agroforestry etc. (Uthappa et al., 2017; Riyadh, Z.A., Rahman, M.A., Saha, S.R., Ahamed, T. and Current, D. 2021).

Diversification of existing farming systems by developing suitable agroforestry models seems to be the need of the day to cope up with ever increasing demand for diversified products (Chauhan et al. 2013). Mixed cultivation has been advocated as an alternative to traditional farming systems, with the potential to increase the productivity of land and to diversify products (Xiaoqing et al. 2017). Hence the issue of exploring tree crop interaction studies has recently grown in importance.

Fragmented studies dealing with the effects of trees in parkland agroforestry systems on yield and yield contributing parameters were conducted in the semi-arid areas of Ethiopia. However simultaneous evaluation of the effect of tree stocking changes of different tree species on biomass and crop yield is uncovered and is also lacking.

The study site for this tree inter cropping trial was under monocropping for several years and there is a need to evaluate the effect of tree stocking on the associated crop biomass and yield. Tree inter cropping could bring a lot of benefit to the site for this study which normally was under crop production alone without any integration of trees. Currently the notion that trees introduce competition to resources on farm lands and hence result in crop yield reduction is making most farmers reluctant to integrate trees on their farmlands. As perennials may introduce completion to environmental resources aappropriate management is needed to minimize tree crop trade-offs (Ong and Kho 2015; Tadesse et al 2021). Tree choice and planting arrangement in the farming system, as well as the total number of trees of that species that need to be planted is important to maximize the ecological and socioeconomic benefits from the tree itself and simultaneously to reduce the potential competition with other components of the system such as annual crops (Xu J, Mercado A, He J and Dawson I, 2013). The objective of this study is therefore to explore the effect of thinning *Cordia africana* and *Acacia nilotica* on maize biomass and yield at Melkassa tree intercropping trial site and simultaneously evaluate the adaptation and performances potential agroforestry trees at the site. The study is hoped to contribute to a better understanding of the effects of different tree cover (stocking) on biomass and yield of maize in tree inter cropping system and demonstrates to farmers the integration of trees with prescribed stockings on farmlands.

MATERIAL AND METHODS

Description of the experimental site

Melkassa long term trial site is located at 115 km South East of Addis Ababa at a geographical location 80 24' N & 390 21' E and at an altitude of 1550 m a.s.l. The area is characterized as semi-arid and it is part of the central rift valley of Ethiopia. Total annual rainfall varies between 512 mm to 1345 mm. Main season rainfall starts in June and reaches at its peak in August and terminates in early September. Mean annual temperature is 21.20C with a mean minimum temperature of 140C and mean maximum temperature of 28.40C .Soils in this area are of diverse type, generally low in organic matter, poor fertility, infiltration and water holding capacity and hence drought prone contributing to periodic crop moisture deficit, and they are classified as Andosols.

Experimental design

Melkassa long term trial is based on 4 Ha of land. Four different trees species including *Faidherbia albida, Moringa stenopetala, Acacia nilotica, Cordia africana* ,mix of tree species and crop alone plots were established as treatments for tree intercropping trial arranged in RCBD with four replications (Figure 1). A block comprises four 35m*35m plots of each tree species intercropped with maize, a mix of tree species intercropped with maize and a sole crop (maize) plot that would give six plots of treatment combinations per block. At the trial establishment spacing between trees was 5m with 64 trees per plot planted in 8 rows. At five years *Acacia nilotica* and *Cordia africana* were found at a relatively full stocking and with higher survival and adaptation. Thinning was then applied on plots of *Acacia nilotica* and *Cordia africana* to increase the spacing between trees from 5m to 10 m prior to inter cropping with maize (*Zea mays* L.) and the influence of thinning on inter cropped biomass and grain yield was studied. The original stocking of the trial was 522 trees/ha with 5 m spacing between trees. Thinning reduced the stocking to 130 trees/ha which refers to 25% thinning intensity. Plots of the remaining tree species were not found adapted to the site at five years and hence plots of *Acacia nilotica* and *Cordia africana* were selectively thinned out to study the effect of thinning on maize biomass and crop yield.

P-19	**P-20**	**P-21**	**P-22**	**P-23**	**P-24**	**B-I**
P-18	**P-17**	**P-16**	**P-15**	**P-14**	**P-13**	**B-II**
P-7	**P-8**	**P-9**	**P-10**	**P-11**	**P-12**	**B-III**
P-6	**P-5**	**P-4**	**P-3**	**P-2**	**P-1**	**B-IV**

P= plots **B=** Blocks
Plots 1, 11, 18 and 23 are planted with ***Cordia africana***
Plots 2,7,13 and 20 are planted with ***Moringa stenopetala***
Plots 3,8,17 and 24 are crop alone ***(Control plots)***
Plots 4, 10, 15 and 22 are planted with ***Acacia nilotica***
Plots 5,9,14 and 21 are planted with ***Faidherbia albida***
Plots 6, 12, 16 and 19 are planted with **mix of tree species**

Figure 1. Field layout of Melkassa long term intercropping trial

Maize (*Zea mays* L.) hybrid variety- Melkassa II was intercropped in 2018 G.C before thinning and in 2020 G.C after thinning. Between the two maize cropping years

the site was rotated with Tef (*Eragrostis tef*) in 2019 G.C. Maize was planted at a spacing of 50 cm between rows and 30 cm between plants. The experiment was carried out for two seasons (2018 and 2020) under rain fed conditions during the main cropping season. Data on biomass and crop yield was collected from four subplots of dimension 2m*2m randomly laid out with in 35m*35m plots of each tree species and converted to hectares. Tree DBH and collar diameter data was collected using calliper and tree height was measured with hypsometer. Tree growth and survival data to compare across the year scenarios was also collected and analyzed using Ex-cell and SPSS statistical software (Figures 1-3).

Figure 2. Maize under *A. nilotica* before thinning

Figure 3. Maize under *C. africana* before thinning

RESULTS AND DISCUSSIONS

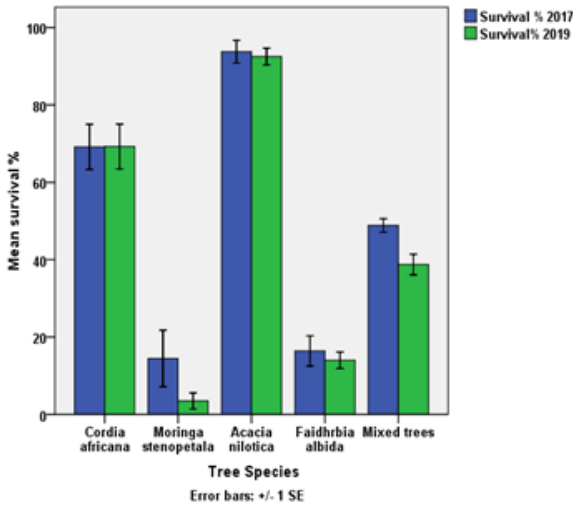

Figure 4. Survival of trees across the years

Tree growth and survival

Analysis results indicate that there is significant difference in survival and adaption of tree species tried out in the trial at α=0.05. Growth of trees planted also revealed marked differences between species and across the years. Accordingly *Acacia nilotica* revealed significantly higher survival percentage (90%) followed by *Cordia*

africana (70%). These survival percentages however did not show significant differences across the years in 2018 (before thinning) and 2020 (after thinning) for *Acacia nilotica* and *Cordia africana*. Mixed tree species showed moderate survival percentages (40-50%).The survival of trees in mixed trees significantly declined as the years went by (Figure 4).The survival of *Moringa stenopetala* declined significantly across the years. *Faidherbia albida* resulted in the lowest tree survival percentage (15%) in 2017 that is statistically comparable to that of *Moringa stenopetala* (Figure 4).

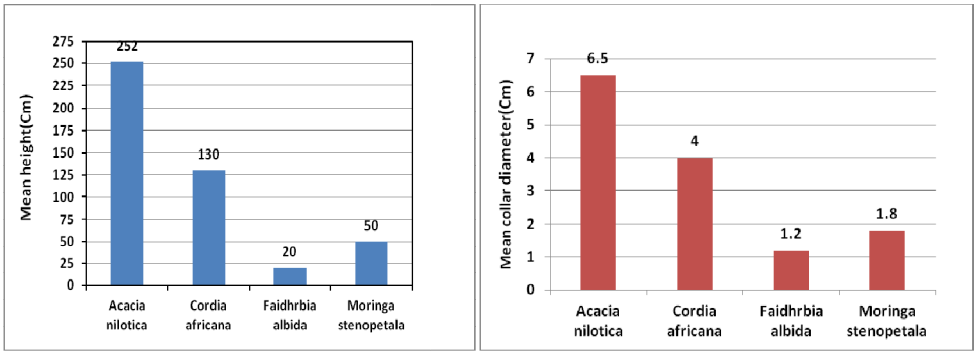

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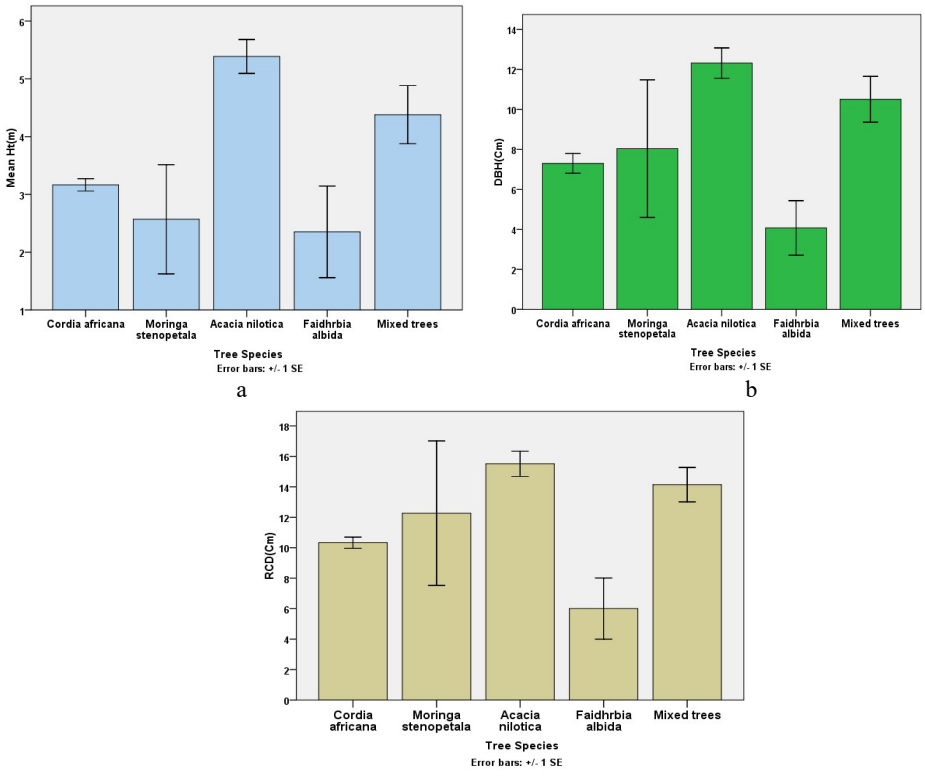
Figure 5. Comparison of tree growth between species :(a) Height growth at 3 years after planting (before thinning); (b) Collar diameter at 3 years after planting(before thinning)



a b

c

Figure 6. Performances of different tree species: (a) Mean Height; (b) Mean DBH; (c) Mean RCD at 6 years (after thinning)

The height growth of highly surviving and fully stocked tree species i.e *Acacia nilotica* and *Cordia africana* was not markedly different before thinning (Figure.5a). Analysis of tree growth data after thinning in 2019 indicated that *Acacia nilotica* had a significantly higher growth (α=0.05) in height, DBH (diameter at breast height) and RCD (root collar diameter) with 4.55 m, 12.6 cm and 16 cm respectively as compared to the remaining tree species and tree mixes at six years after planting (Figures.6a-c).Tree growth under mixed tree plots was second in performance. *Faidherbia albida* revealed the least growth in height, DBH and RCD.

Grain Yield

Analysis results of 2018 yield data under plots of different treatment conditions revealed that yield of maize under un-thinned *Acacia nilotica* was significantly lower compared to the yield under un-thinned *Cordia africana* and crop alone plots (α<0.05). Maize yields in 2018 from un-thinned *Cordia africana* and crop alone plots were found higher and their difference was found statistically non-significant.

A significantly higher yield (α<0.05) of maize was observed under plots of thinned *Cordia africana* compared to *Acacia nilotica* in 2020. However maize yield from crop alone plots was found higher but statistically comparable with the yield from thinned *Cordia africana* plots in 2020. Maize yield under thinned *Acacia nilotica* was found out to be the least in 2020 (Figure.7)

The data analysis showed that maize grain yield was significantly (α=0.05) affected by both of the examined factors, i.e., thinning and tree species. Thinning *Cordia africana* has significantly influenced maize intercropped yield in 2020 accompanied by 36.4% increase in grain yield. Maize yield was found out to be significantly higher (α=0.05) under thinned plots of *Cordia africana* in 2020 as compared to un-thinned plots in 2018. Thinning *Acacia nilotica* resulted in no significant difference with the yield of maize. Maize yield from crop alone plots in 2020 was significantly higher than the crop yield in 2018.

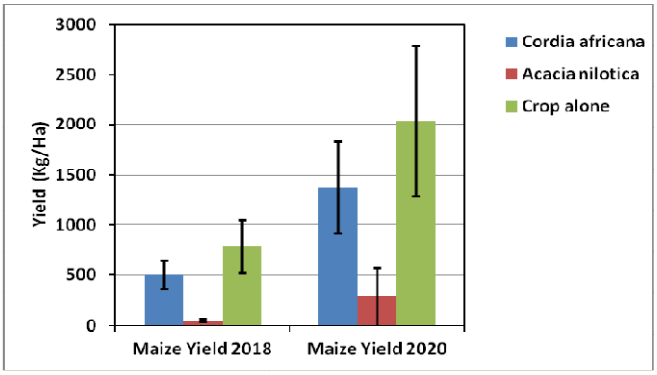


Figure 7. Maize yield under un-thinned and thinned conditions

Maize Aboveground Biomass

Analysis results of 2018 biomass data under plots of different treatment conditions revealed that above ground biomass of maize under un-thinned *Acacia nilotica* was significantly lower (α=0.05)compared to the biomass under *Cordia africana* and crop alone plots in the same year. Maize biomass in 2018 from un-

thinned *Cordia africana* and crop alone plots were found higher but their difference was found statistically non-significant.

A significantly higher (α=0.05) maize biomass was observed under crop alone plots as compared to *Acacia nilotica* in 2020. However maize biomass from crop alone plots were found statistically comparable with the biomass from thinned *Cordia africana* plots in 2020. Maize biomass under thinned *Acacia nilotica* was found out to be the least in 2020 (Figure 8).

Thinning *Cordia africana* has significantly influenced maize biomass in 2020. Maize biomass was found out to be significantly higher (α=0.05) under thinned plots of *Cordia africana* in 2020 as compared to un-thinned plots in 2018.Thinning *Acacia nilotica* in 2020 resulted in no significant difference with the biomass of maize. Maize biomass from crop alone plots in 2020 was significantly higher than maize biomass in 2018 (Figure 8).

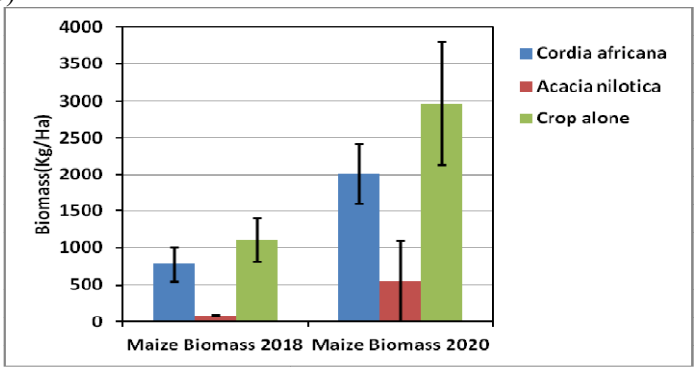


Figure 8. Maize Biomass under un-thinned and thinned conditions

Harvest Index (HI)

Harvest index is the physiological efficiency of a plant for changing the total dry matter into economic yield. It is the ability of the plant to effectively utilize environmental resources like moisture, light, nutrients, and growing space. This would result in high photosynthesis activity and higher allocation of photosynthate into grain yield. Harvest index is the ratio of grain yield to total above ground dry biomass yield multiplied by 100. Harvest index of maize under un-thinned and sole crop plots did not reveal significant differences in 2018.In contrast the harvest index of maize under un-thinned *Acacia nilotica* (53%) declined significantly (α<0.05) to 13% under thinned conditions (Figure 9). This might be attributed to the significantly lower maize yield (282kg/ha) that was attained after thinning of *Acacia nilotica*. This indicates that *Acacia nilotica* is not a good match to maize in tree- maize intercropping system and even the thinning management given to it could not facilitate positive interaction that could be explained by complementarities in the system and increase in grain and biomass yield of maize.

The harvest index of maize under un-thinned *Acacia nilotica* was found statistically non-significant with that of *Cordia africana* and sole crops. This is because it resulted from division of the grain yield to a comparatively very low maize biomass (87.7Kg/ha) under *Acacia nilotica* in 2018.The harvest indices of maize under *Cordia africana* and sole crop conditions were found to have no significant differences both under thinned and un-thinned conditions.

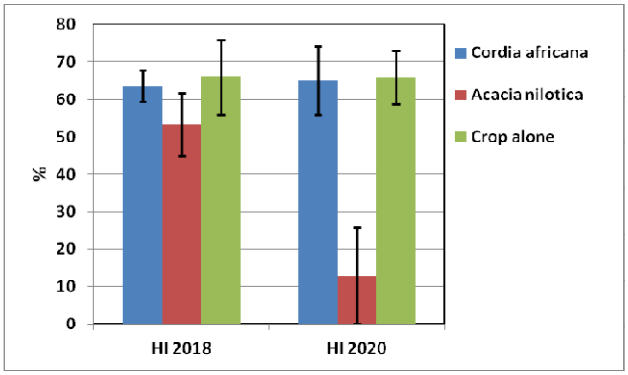


Figure 9. Harvest index of maize before and after thinning.

Discussion

It is disclosed in this study that thinning *Cordia africana* in agroforestry systems would result in a significant increase in inter cropped maize biomass and grain yield. Thinning *Cordia africana* at 25% thinning intensity to 130 trees/Ha brought a significant increase in maize biomass and grain yield without causing any significant yield reduction as compared to crop alone (control) plots. This is an expression of complementarities in tree intercropping systems. This finding agrees with (Bargali, K. and Bargali S.S, 2009) which explain that agroforestry systems with trees planted at wide spacing will result in higher crop yields, because of reduced tree-crop competition, reduced tree establishment and management costs and in larger tree diameter growth. It is also concluded by the study findings of [10] that maize yield is considerably influenced by tree density: a density of 800 trees ha-^{1} results in only 1/3 of the total yield that could be harvested on a maize monoculture scenario whereas a density of 100 trees ha-^{1}still provides close to 90% of the monoculture crop yield. It is also disclosed from this study that yield of maize under un thinned *Cordia africana* was 63.9 % of the total yield that could be harvested on maize monoculture while thinned *Cordia africana* to 130 trees/Ha (25% thinning intensity) resulted in close to 67.5% of the crop alone (control plot) yield. This is an indication that thinning *Cordia africana* positively influences tree intercropping systems and increases maize yield and biomass to a level comparable with the yield from crop alone systems while diversifying products from the same unit of land (a peculiarity of agroforestry systems). The significantly higher survival and growth of *Cordia africana* indicated its adaptiveness to the site also. This would have an implication that if planted with the recommended stocking *Cordia africana* is a potential candidate for tree intercropping system in the study area.

The study results indicated that thinning *Acacia nilotica* improved growth and performance of the species. Maize biomass and grain yield under thinned *Acacia nilotica* was found significantly lower than the yield under thinned *Cordia africana* and monocropping (Control) plots. Maize biomass and grain yield under *Acacia nilotica* before thinning was also significantly lower than the yield under un-thinned *Cordia africana* and monocropping (control) plots. This could evidence that the interaction between *Acacia nilotica* and the associated maize crop was not a complementary type and the provision of thinning management could not influence it

positively. In spite of its prime adaptiveness to the site expressed by significantly higher survival and growth results, *Acacia nilotica* is not a potential species for tree-maize system in the study area. Phenotypically *Acacia nilotica* has extensive branches and dense canopy that could causes attenuation of photo synthetically active radiation that is highly demanded by a C-4 plant like maize in the understory. This could result in retarded growth of maize and decline in biomass and grain yield. (Pandey, C B, Pandya K. S., Pandey, D. and Sharma, R.B., 1999; Bargali, K. and Bargali S.S, 2009) reported that *Acacia nilotica* generally reduced crop yield under its canopy and this reduction varies with distance from the tree trunk. It is further disclosed that reduction in grain yield was maximum (30%) under the large tree canopy and lowest (12%) under the small tree canopy due to decreased availability of light by 44 to 62% under the canopy that resulted in slow photosynthetic rates and growth (Pandey, C B, Pandya K. S., Pandey, D. and Sharma, R.B.,1999) . It is also reported that the leaf leachates of *Acacia nilotica* inhibited the germination and growth of Zea mays (Bertomeu M, 2011; El-Khawas, S.A. and Shehata, M.M., 2005). (Bargali, K. and Bargali S.S, 2009) related that the inhibitory effect of *Acacia nilotica* on seed germination and seedling growth is due to the presence of allelochemicals including tannins, flavonoids and phenolic acids.

CONCLUSIONS

Tree stocking and appropriate tree - crop matching are crucial in tree inter cropping systems to enhance complementarities and increase crop biomass and yield. Thinning of *Cordia africana* influenced tree inter cropping systems positively and increased maize yield and biomass to a level comparable to the yield from crop alone systems. Therefore it is justifiable to conclude that *Cordia africana* is adaptive to the study site and if planted with the recommended stocking (about130 trees/Ha) the species is ideal for a tree- maize system in the study area. Maize biomass and grain yield under thinned *Acacia nilotica* was found significantly lower than the yield under thinned *Cordia africana* and mono cropping (Control) plots. Maize yield under crop alone plot was significantly higher than the same under thinned *Acacia nilotica*. Maize biomass and grain yield under un-thinned *Acacia nilotica* was also significantly lower than the yield under un-thinned *Cordia africana* and monocropping (control) plots. Considerable reduction in grain yield and biomass observed under the canopies of *Acacia nilotica* both before and after thinning would lead us to conclude that the species though highly adaptive to the site it is not well suited for tree - maize systems in the study area. Further studies may need to be carried out on variable stocking levels of *Cordia africana* in tree- maize systems to explore if maize yield from tree based systems could significantly increase over that from mono cropping systems.

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