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Soil nutrients and maize yields responses to indigenous agroforestry tree post-fallows management in Tanzania

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ABSTRACT

Agriculture is characterized by low production and expansion into forests and woodlands rather than increased productivity leading to deforestation and land degradation in sub-Saharan Africa. Use of appropriate low input agricultural and other land management technologies may increase production and benefit smallholder farmers through increased productivity in already degraded land. A field experiment was established to assess tree fallows and tree coppice intercropping of indigenous agroforestry tree species (*Albizia harveyi* and *Albizia versicolor)* for soil fertility and maize yield improvements in Morogoro, Tanzania. *A. versicolor* tree fallows recorded significantly ($p < 0.05$) highest amounts of soil total nitrogen, extractable phosphorus, calcium, magnesium and potassium in 0 - 15 cm soil depth compared to the *A. harveyi* tree fallows and continuous cropping. *A. harveyi* tree fallow recorded significantly ($p < 0.05$) higher amounts of organic carbon and calcium than the continuous cropping system. In comparison with continuous cropping, amount of organic carbon was higher by 41% and 56% in *A. harveyi* and *A. versicolor* tree fallows, respectively. During the first cropping season, yields of grains (1.26 Mg ha^{-1}), cobs (0.3 Mg ha^{-1}) and stovers (2.43 Mg ha^{-1}) in maize intercropped with *A. versicolor* coppices were significantly ($p < 0.05$) higher than those of maize intercropped with *A. harveyi* coppices (0.74 Mg ha^{-1}, 0.2 Mg ha^{-1}, 1.49 Mg ha^{-1}) and maize in continuous cropping system (0.29 Mg ha^{-1}, 0.06 Mg ha^{-1} and 1.06 Mg ha^{-1}). During the second cropping season, yields of maize stovers, height and diameter growth were lower in intercropped maize relative to continuous cropping by 98% to 98.7%, 14.8% to 15.3% and 46.4% to 81.0% respectively; due to increasing competition imposed by growing coppices. The studied indigenous agroforestry tree species are recommended for rotational woodlots and short rotation coppice systems to enhance agricultural productivity and safeguard the environment.

1. Introduction

Agriculture employs about 75% of the workforce and forms a backbone of many developing economies of countries in sub-Sahara Africa (SSA) (Nziguheba et al., 2010). It has therefore the potential to contribute greatly to achieving Sustainable Development Goals (SDGs) particularly poverty eradication, attaining zero hunger and ensuring responsible consumption and production. Adopted unanimously by all UN member states in 2015, SDGs is a collection of global goals set to ensure a better and sustainable future for all citizens by 2030 (UN General Assembly, 2015). Food production in SSA has increased during the last few decades as a result of expansion of area cultivated into forests and woodlands rather than increased productivity leading to deforestation and land degradation (Kopittke et al., 2019). Another concern is the fact that population growth estimated at 2.7% in 2017 has already outpaced the increase in food production. Thus, there has been a parallel decline in per capita food production by about 2% per year (World Economic Forum, 2017). Available records (e.g. Rakotoarisoa et al., 2012) show that since the 1970s, Africa has been a net exporter of food but in recent times around $ 35 billion was spent for annual food imports (African Development Bank, 2016). More also, currently, two-thirds of African countries are net food importers (Morsy et al., 2021).

Increasing human population coupled with use of inappropriate agricultural and other land management technologies are among the root causes of the problems of declining per capita food production in

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the SSA (Mafongoya et al., 2006) with negative consequence on SDGs. The escalating population has constrained traditional shifting cultivation that used to be successful in sustaining crop yields. As a result, smallholder farmers have resorted to short fallow or continuous cropping with no external inputs such as fertilizers due to high farm gate prices (Mafongoya et al., 2006; ten Berge et al., 2019). This has resulted in declining soil fertility and crop yields as well as household incomes due to soil nutrient depletion through repeated crop harvest and soil erosion (Njoroge et al., 2017).

Soil fertility depletion is the major cause of declining per capita food production and the concomitant widespread food shortage, low income and perpetual poverty in Africa (Sanchez and Jama, 2002; African Development Bank, 2016). This is a consequence of breakdown of traditional shifting cultivation or bush fallow system that was used successfully in the past to replenish and maintain soil fertility (Hauser et al., 2006). Shifting cultivation is currently not feasible for most farmers due to dwindling landholdings as a result of increasing population. Farmers are forced to intensify land use by either reducing fallow periods to a level that is below the minimum required to maintain soil fertility or practice continuous cropping (Asadu et al., 2008). As a result, nutrients are being depleted through nutrient mining via repeated harvesting. In such a situation, the only viable options for replenishment and sustaining soil fertility appear to be application of mineral fertilizers and green manuring (Sanchez, 2015) but these are constrained too. Most of the farmers lack the required capital to use adequate and appropriate specification of mineral fertilizers that can counter the effect of short or no fallow on soils (Asadu et al., 2008; Njoroge et al., 2017). While organic manuring could be an option, but the practice is limited by bulky nature of the organic matter (OM) and unavailability (Asadu et al., 2008).

Agroforestry (AF) practices have been identified as one of appropriate sustainable solutions to the problems of soil fertility depletion, low crop productivity and woodfuel scarcity (Kimaro 2009; Kuyah et al., 2020) and can reduce wood harvesting pressure on natural forests and woodlands thereby reducing the rate of deforestation. However, despite the potential of AF practices to fix Nitrogen (N), utilization of indigenous tree species in AF has received little attention (Chamshama et al., 2000; Kimaro et al., 2008; Vyamana et al., 2021) due to low growth rate and inadequate silvicultural knowledge. Where woodfuel scarcity is acute, crop residues and livestock manure are used as supplementary energy sources (Neupane and Thapa, 2001), which means little or no OM is available to be returned to the soil in farms. This aggravates the vicious cycle of low agricultural productivity, food shortage, low income and perpetual poverty. Therefore, alternative land use strategies to improve soil fertility and woodfuel supplies are urgently needed to sustain agricultural productivity, conserve the remaining forests and woodlands and ensure achievement of the SDGs.

With few exceptions, most AF studies on evaluation and selection of AF trees/shrubs in Tanzania have focused on exotic multipurpose tree/shrub species (Chamshama et al., 1998; Kimaro, 2009). This is notwithstanding the fact that the indigenous tree/shrub species are more adapted to local environmental conditions and can meet local requirements better than exotics (Vyamana et al., 2021). In addition, there is increasing realization that indigenous tree species can be more efficient in improving soil fertility and less competitive to the companion crops, especially for soil moisture (Nyadzi, 2004). This study was therefore initiated with the overall objective of assessing the potential for utilizing indigenous AF tree species with contrasting crown shading characteristics (*Albizia harveyi* with a narrow rounded crown and *Albizia versicolor* with a spreading rounded crown) through management of their fallows and coppice intercropping for increasing soil nutrients and yield of maize (*Zea mays*). These tree species have a wide range of geographical distribution, fast growth, adapted to dry areas and soils with poor nutrient contents and efficient for nutrient cycling as they are nitrogen fixers and form mycorrhizae association with fungi (Högberg, 1990). Maize was used in the study because it is the most widely cultivated cereal of great importance to food security and livelihoods in SSA.

2. Materials and methods

2.1. Study area

The study area (i.e. Maseyu) is located about 50 km east of Morogoro and 150 km west of Dar es Salaam, Tanzania (Fig. 1). The area experiences tropical and sub-humid climate (Kielland-Lund, 1990). It has a bimodal rainfall pattern with annual mean of 900 mm and seasonally distributed on wet (November to May) and dry (June to October) seasons. The mean annual temperature is 24.3 °C while the minimum and maximum annual temperatures are 18.6 and 28.8 °C, respectively. Because of favourable rainfall and temperature small holder farmers practice rain-fed agriculture where maize (*Zea mays* L.), sorghum (*Sorghum bicolour* L. Moench) and garden peas (*Pisum sativum* L.) are mainly grown. Recently a small portion of local community members have started keeping domestic animals including cattle, sheep and goats. Charcoal production outside agricultural area takes place and contributes significantly to the household income.

The area is surrounded by miombo woodland dominated by trees of *Julbernardia globiflora* (Benth.) Troupin, and *Combretum* spp. On the northern side there is Kitulanghalo Forest Reserve, while on the southern side there is a General Land. Precambrian Usagaran metasedimentory rocks consisting of garnet biotite gneiss dominate the area. Thus, mixed alluvial and colluvial deposits tend to occur in low-lying areas (Msanya et al., 1995). The soils of the area are well drained, red, acid-neutral, sandy clay loams with brown friable top soil and are generally nutrient poor.

2.2. Experimental design and establishment

A 2 × 2 × 4 × 2 factorial experiment with three replications was established in a randomized arrangement to assess tree coppice intercropping of *Albizia harveyi* (Ah) and *Albizia versicolor* (*Av*) for soil fertility and maize yield improvements (Table 1). The experiment was established in March 2007 using four-years plantations of Ah and *Av* planted separately on the same site. The plantations were planted in March 2003 at a spacing of 2 m x 2 m. Prior to establishment of the plantations, the site was prepared by clearing all vegetation followed by plowing by a farm tractor and pitting using hand hoe where the pit size was 20 cm x 30 cm x 30 cm. The plantations were kept clean weeded all the time for four years prior to establishment of the present experiment.

Plots were rectangular (10 m x 6 m) and plots and blocks were separated by 2.5 and 3 m-unplanted buffer strips, respectively. For each study species, there were three block each with 9 plots including one continuous maize cropping (control) plot .

Establishment of cropping experiment involved cutting trees at respective heights as per cutting height treatments two weeks before maize planting (Table 1). All leaves and twigs were spread and left to decompose naturally in each plot whereas stems and big branches were removed prior land preparation for maize sowing. Land was prepared using a hand hoe, and maize seeds of TMV-1 variety were sown for two consecutive cropping seasons at a spacing of 30 cm within row and 75 cm between rows giving a population of 44,444 maize plants per ha. Thinning was applied when coppices reached 10 cm height, which was achieved four months after tree cutting. Subsequent coppice thinning was maintained at the same interval of four months. At every thinning occasion, all thinned coppices were spread in the respective plots and left to decompose naturally. During the first coppice thinning occasion, the two tallest coppices were left per thinned stump and any coppices that sprouted were subsequently removed.

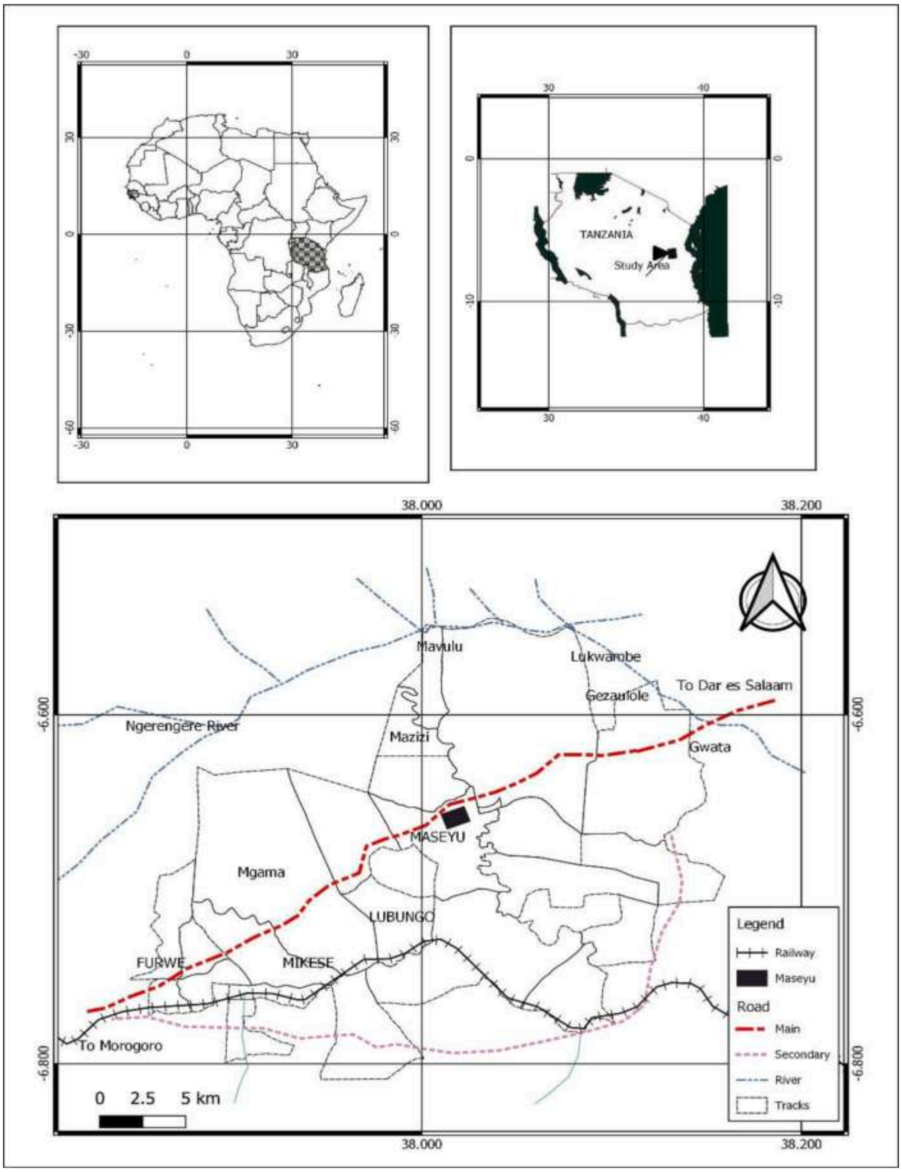

Fig. 1. A map showing location of study site, Morogoro, Tanzania.

Table 1
A factorial experimental design for testing the effects of Albizia harveyi and Albizia versicolor and management of their fallows on maize yield and soil nutrients in Morogoro, Tanzania.

Factor one	Factor two	Factor three	Factor four
Two levels of study species	Two levels of cropping systems	Four levels of tree cutting heights	Two levels of coppice thinning
Ah = *A. harveyi* *Av* = *A. versicolor*	i) IC0 = Continuous maize cropping (control) ii) IC1= maize intercropped with coppices	i) C0 = Trees not cut (tree fallows) ii) C1 = 5 cm (ground level iii) C2 = 30 cm above the ground iv) C3 = 90 cm above the ground	i) TH0 = All coppice shoots left (no thinning)- control ii) TH1 = Coppices thinned to leave two coppice shoots per stump

2.3. Soil fertility, maize growth and yield assessments

Just before maize sowing in each season, soil samples were taken from 4 randomly selected points in each intercropped plot at a depth of 0–15 cm using soil auger leaving 1 m border strip on both sides of each plot. These samples were mixed thoroughly and sub-sampled to get a composite sample. The composite soil samples for each plot were transported to the laboratory for soil organic matter (SOM) and soil fertility analysis. All soil sub-samples were air dried prior chemical analysis. The dried samples were then ground to pass through a 1 mm sieve and analysed for Total N (TN), extractable Phosphorus (P), Potassium (K), Magnesium (Mg), Calcium (Ca), Sodium (Na) and total soil organic Carbon (OC). Extractable P, K, Ca, Na and Mg were determined by simultaneous Inductive Coupled Plasma (ICP) Emission Spectroscopy technique in acid digested samples while Total N was determined by the Kjeldahl procedure. Soil OC was determined by wet calorimetric method (Anderson and Ingram, 1993).

Maize plants were measured for diameter at 10 cm above ground (D10) and height at maturity. Height was measured to the nearest 0.01 m using a graduated pole while D10 was measured to the nearest 0.01 cm using a veneer caliper. At maturity, a total of 20 maize plants in the middle two rows were harvested, stems cut at ground level, weighed fresh and sub-sampled for dry weight determination. Also, maize cobs were harvested, shelled and both shaft and grain weighed fresh and sub-sampled for dry weight determination. Assessment of coppice growth was done at the ages of 6, 12, 18 and 24 months. During each assessment, all surviving coppices were measured for D10 and total height. The tally of height and D10 provided the number of coppice stems per stump.

2.4. Statistical analyses

Visual inspection and significance test were used to test for standard parametric statistical assumptions of normality and constant variance of residuals. Visual inspection was done by plotting the residuals against normal scores and predicted values while significance test was executed using Shapiro-Wilks's test (SAS Institute, 2020). Sodium (Na) content, maize plant survival, coppice mortality and stump survival data sets violated the requirements for normality and homoscedasticity. Thus, soil Na content data were square-root transformed; and maize plant survival, coppice mortality, and stump survival data sets were arcsine transformed to correct for deviations from parametric statistical assumptions. However, only non-transformed data are presented for clarity (Wallin et al., 2008). Plot means were subjected to Analysis of Variance (ANOVA) using the General Linear Model procedure in Statistical Analysis System (SAS) at 5% level of statistical significance. In the study, block and block-by-treatment interactions were error terms in the model. The ANOVA for maize, biomass and soil data tested the effects of two study tree species, two cropping systems, four tree cutting heights and two coppice thinning regimes (a $2 \times 2 \times 4 \times 2$ factorial experiment) replicated three times in a RCBD (Table 1). All statistical analyses were done by using SAS version 8 (SAS Institute, 1999).

3. Results

3.1. Effects of tree fallows on soils

Table 2 and Fig. 2 show results for soil chemical properties from tree fallows of *A. harveyi* and *A. versicolor* at four years old just before cutting to establish the experiment to test the effects of *A. harveyi* and *A. versicolor* fallows on soil nutrients.

At that age of four years of *A. versicolor* fallows, TN of top soil at a depth of 0–15 cm differed significantly ($p < 0.05$) from that recorded in continuous cropping plots (Fig. 2-a). There was no significant difference ($p > 0.05$) in TN between *A. harveyi* fallows and continuous cropping (Fig. 2-a). TN ranged from 0.073% in *A. harveyi* to 0.11% in *A. versicolor* tree fallows compared to 0.06% in the continuous cropping system. The values of TN recorded in tree fallows were higher by 21.7% (although not significant) to 83.3% compared to continuous cropping plots for *A. harveyi* and *A. versicolor*, respectively. This indicates a superior ability of *A. versicolor* fallow to increase TN as compared to *A. harveyi*.

Organic Carbon was significantly higher ($p < 0.05$) under the tree fallows compared to continuous cropping plots. In comparison with continuous cropping plots, amount of OC was higher by 41% and 56% in *A. harveyi* and *A. versicolor* tree fallows respectively (Fig. 2-b). OC ranged from 0.96% in *A. harveyi* to 1.06% in *A. versicolor* tree fallows. This was in contrast to 0.68% OC recorded in continuous cropping plots. *A. versicolor* tree fallows had significantly higher extractable P than *A. harveyi* tree fallows and continuous cropping system (Fig. 2-c).

Effects of tree fallow on ECEC were not significant ($p > 0.05$) but it was highest (22.04 Cmol kg^{-1}), intermediate (18.37 Cmol kg^{-1}) and lowest (17.38 Cmol kg^{-1}) under *A. versicolor* fallow, *A. harveyi* fallow and continuous cropping plots, respectively (Fig. 2-d). This corresponds to improvement in ECEC by 5.7% to 26.8% as a result of tree fallow management. With the exception of Na, *A. versicolor* tree fallow recorded significantly ($p < 0.05$) highest amounts of soil cations (TN, Ca, Mg and K) in 0 - 15 cm soil depth compared to the continuous cropping (Figs. 2-a, e, f and g).

3.2. Effects of tree coppices on soils after tree cutting

For the effects of tree coppices on soil properties, statistical analysis showed further that there was no significant interaction ($p > 0.05$) of the factors for all soil chemical properties assessed except for ECEC, which showed significant interaction between tree species and cutting height (Table 3). However, there were no significant 3-way interactions among factors. There were significant effects ($p < 0.05$) of tree species, stump cutting height and coppice thinning on the assessed soil chemical properties (Tables 3 and 4).

Significant effects of tree species on soil chemical properties were detected for TN, OC and soil cations (Ca, Mg and Na). On the other hand, coppice thinning had significant effects on TN, OC, ECEC as well as cations (Mg, K and Na). The overlaps of the effects of these two factors are revealing but it is worth to emphasize that there were no any significant interactions between these two factors.

Results showed no significant differences ($p > 0.05$) between the two levels of coppice thinning for TN and OC but both recorded similar and significantly lower amounts of TN and OC compared to continuous cropping as well as tree fallows. The same pattern was observed for effects of thinning on amounts of Mg, K and Na. However, the pattern was reversed for ECEC, which was significantly highest ($p < 0.05$) in thinned and unthinned coppices compared to tree fallow and continuous maize cropping. The superiority of the tree fallows over both thinned and not thinned coppice plots with regard to soil TN and OC amounts is conceivable but that of continuous cropping calls for further elaboration.

3.3. Effects on tree coppices on maize growth and yield

For the first cropping season i.e. 2008, results showed significant 2-way interaction between stump cutting height and coppice thinning on maize plant diameter growth ($p = 0.0443$, Table 5), and 3-way interaction between coppice tree species, coppice stump cutting height and coppice thinning ($p = 0.0075$, Table 5) but they were not significant for yields of maize grains, cobs and stovers (Table 6). More or so, during the second cropping season i.e. 2009, effects of interactions between the factors on maize growth and yield were no longer significant (Table 6).

During the first cropping season, ANOVA revealed significant main effects ($p < 0.05$) of coppice tree species on all of the assessed maize

Table 2
Summary of one-way ANOVA ($p > F$) testing the effects of fallow tree species on soil chemical properties just before planting first maize crop in 2008 cropping season at Maseyu in Morogoro, Tanzania.

Source of variation	df[1]	TN	OC	P	ECEC	Ca	Mg	K	Na[2]
Block(Blk)	2	0.5233	0.8808	0.3317	0.5715	0.8475	0.5790	0.9116	0.2958
Tree species(Spp)	2	0.0905	0.0328	0.0378	0.0626	0.0007	0.0055	0.0019	0.3487
Residual error	4	–	–	–	–	–	–	–	–
Corrected total	8	–	–	–	–	–	–	–	–

[1] df = numerator degree of freedom.
[2] ANOVA for soil Na content used square root transformed data to induce normality.

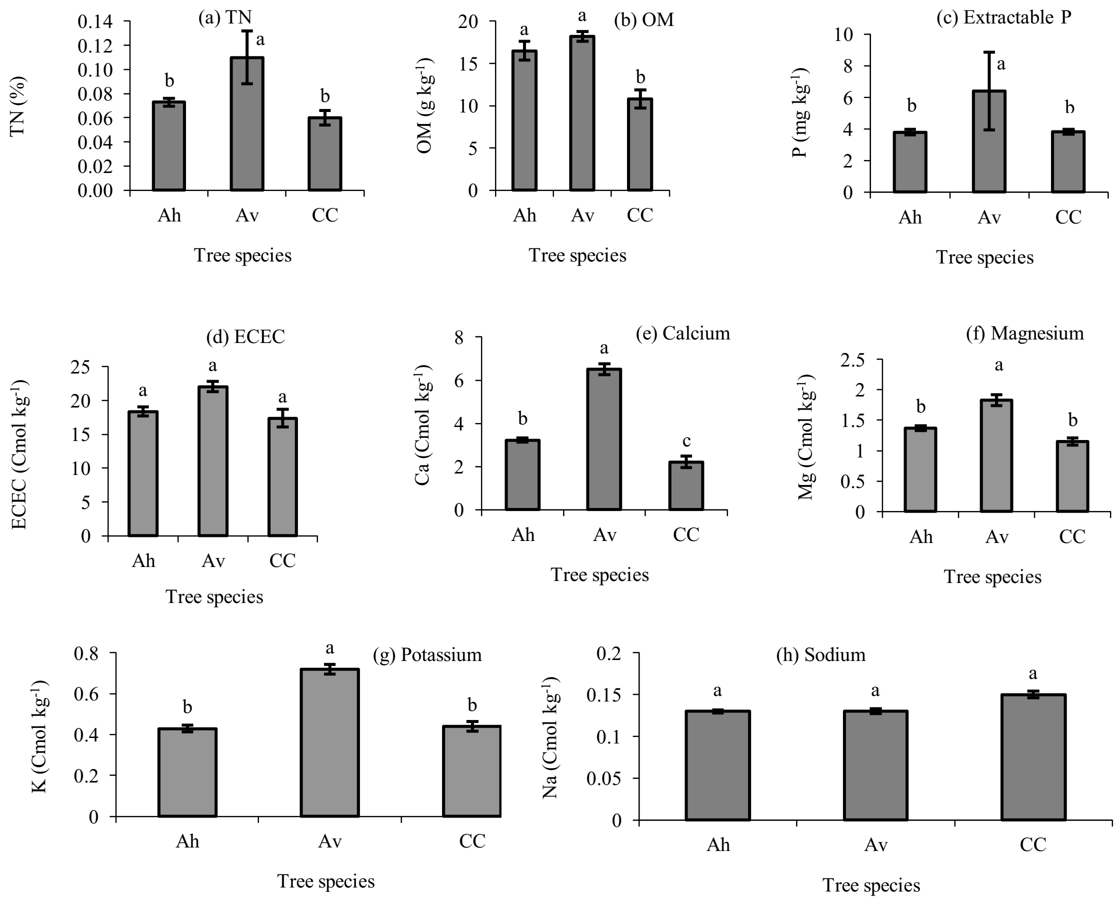

Fig. 2. Effects of three-year tree fallow on soil total Nitrogen (a) soil organic Carbon (b), soil extractable Phosphorus (c), effective cation exchange capacity (ECEC) (d), exchangeable Calcium (e), exchangeable Magnesium (f), exchangeable Potassium (g) and exchangeable Sodium (h) assessed just before planting first maize crop in 2008 at Maseyu, Morogoro, Tanzania. Ah = Albizia harveyi, *Av* = Albizia versicolor and CC = Continuous cropping. For each figure, means marked by the same letter indicate means that are not statistically different at $p < 0.05$ according to DMRT. Vertical bars indicate standard errors of means ($n = 3$).

Table 3
Summary of ANOVA ($p > F$) testing the effects of tree species, coppice cutting height and coppice thinning on soil chemical properties for the second cropping season (2009) at Maseyu, Morogoro, Tanzania.

Source of variation	[1]df	TN%	OC%	P	ECEC	Ca	Mg	K	Na
Block (Blk)[2]	2								
Tree species (Spp)	1	<0.0001	<0.0001	0.8415	0.4756	0.0045	0.0397	0.0562	0.0007
Blk x Spp	2								
Cutting height (Cut)	2	0.6768	0.3577	0.6279	0.2948	0.9864	0.2873	0.5441	0.7240
Blk x Cut	4								
Spp x Cut	2	0.4209	0.6450	0.1252	0.0238	0.6703	0.8297	0.3415	0.7626
Blk x Spp x Cut	4								
Coppice thinning (Copthin)	1	<0.0001	<0.0001	0.4864	0.0209	0.4013	<0.0001	<0.0001	<0.0001
Blk x Copthin	2								
Spp x Copthin	1	0.5622	0.0524	0.9537	0.8167	0.0965	0.1853	0.2797	0.2511
Blk x Spp x Cut	4								
Cut x Copthin	2	0.7373	0.3511	0.7135	0.3037	0.9196	0.3378	0.3344	0.4849
Blk x Cut x Copthin	4								
Spp*Cut* Copthin	4	0.7764	0.5586	0.5790	0.3522	0.3099	0.2053	0.3764	0.9521
Blk*Spp*Cut* Copthin	4	–	–	–	–	–	–	–	–
Residual error	6	–	–	–	–	–	–	–	–
Corrected total	45	–	–	–	–	–	–	–	–

[1] df = numerator degree of freedom.
[2] No test statistics (i.e., F-ratios and probabilities) for replication and replication-by-treatment interactions because these were specified in the error terms of the General Linear Model of SAS for testing main and interaction effects of tree species, coppice cutting height and coppice thinning.

Table 4
Effects of tree species, coppice stump cutting height and coppice thinning on soil chemical properties during the second season (2009) of intercropping with maize at Maseyu, Morogoro, Tanzania.

Treatment (Unit)†	% TN	% OC	mg kg^{-1} Extrac. P	g kg^{-1} OM	ECEC and bases (Cmole (+) kg^{-1}) ECEC	Ca	Mg	K	Na
Tree species									
A. harveyi	§0.07c (0.01)	0.66b (0.02)	5.43a (0.07)	12.41a (0.09)	17.37a (0.08)	2.77b (0.06)	1.15b (0.03)	0.45b (0.01)	0.20b (0.01)
A. versicolor	0.38a (0.02)	1.27a (0.03)	4.84a (0.07)	11.31a (0.10)	17.66a (0.08)	4.24a (0.05)	1.46b (0.03)	0.56b (0.02)	0.16c (0.01)
Continuous cropping	0.11b (0.24)	0.85b (0.41)	3.13a (0.31)	6.6a (0.44)	10.35a (1.00)	2.64b (0.46)	3.98a (0.69)	1.37a (0.40)	5.09a (0.97)
Coppice stump cutting height									
5 cm	0.07a (0.01)	0.67a (0.04)	4.67a (0.13)	11.57a (0.15)	18.36a (0.14)	3.78a (0.11)	1.42a (0.04)	0.51a (0.03)	0.18a (0.01)
30 cm	0.53a (0.01)	0.71a (0.06)	5.38a (0.13)	12.27a (0.19)	18.02a (0.14)	3.73a (0.10)	1.16a (0.06)	0.48a (0.04)	0.18a (0.02)
90 cm	0.07a (0.01)	0.80a (0.10)	5.55a (0.08)	13.79a (0.11)	16.70a (0.25)	3.68a (0.12)	1.38a (0.17)	0.56a (0.10)	0.19a (0.24)
Tree fallow	0.07a (0.02)	1.7a (0.07)	5.39a (0.30)	9.661a (0.26)	16.43a (0.29)	2.14a (0.19)	3.94a (0.09)	1.38a (0.06)	0.18a (0.03)
Continuous cropping	0.07a (0.18)	0.54a (0.31)	2.60a (0.28)	5.198a (0.44)	10.35a (0.75)	2.64a (0.35)	1.22a (0.51)	0.46a (0.30)	5.09a (0.73)
Coppice thinning									
Thinned	0.07c (0.01)	0.72b (0.02)	4.736a (0.09)	12.43a (0.10)	17.42ab (0.10)	3.52a (0.07)	1.31b (0.03)	0.52b (0.02)	0.19b (0.01)
Not thinned	0.07c (0.01)	0.73b (0.04)	5.67a (0.09)	12.66a (0.12)	17.97a (0.10)	3.95a (0.06)	1.32b (0.04)	0.50b (0.03)	0.19b (0.01)
Tree fallow	0.30a (0.10)	1.08a (0.20)	5.34a (0.15)	8.95a (0.22)	14.67c (0.50)	2.67a (0.23)	2.51a (0.34)	0.90a (0.20)	0.21b (0.48)
Continuous maize cropping	0.22b (0.23)	0.95ab (0.38)	2.66a (0.39)	6.27a (0.64)	14.27c (0.45)	2.13a (0.46)	1.33b (0.18)	0.49b (0.15)	2.62a (0.04)

†Means for each individual factor are averaged over all other treatments; §Mean of three replicates with standard error in parentheses; within each category means in the same column followed by the same letters are not statistically different at $p < 0.05$ according to DMRT.

Table 5
Summary of ANOVA ($p > F$) testing the effects of tree species, coppice cutting height and coppice thinning on maize plant growth and survival for the first and second cropping seasons at Maseyu, Morogoro, Tanzania.

Source of variation	[1]df	2008 Height	Diameter at 10cm	Arcsine transformed survival	2009 Height	Diameter at 10cm	Arcsine transformed survival
Block (Blk)[2]	2	–	–	–	–	–	–
Tree species (Spp)	1	0.0003	0.0513	0.0052	0.7218	0.9961	0.2064
Blk x Spp	2						
Cutting height (Cut)	2	0.8318	0.7973	0.7960	0.0258	<0.0001	0.3856
Blk x Cut	4	–	–	–	–	–	–
Spp x Cut	2	0.1451	0.5077	0.7448	0.8196	0.3967	0.8168
Blk x Spp x Cut	4	–	–	–	–	–	–
Coppice thinning (Copthin)	1	0.6189	0.0453	0.4533	0.0141	<0.0001	0.4791
Blk x Copthin	2	–	–	–	–	–	–
Spp x Copthin	1	0.7613	0.6056	0.4533	0.8743	0.4550	0.6068
Blk x Spp x Cut	4	–	–	–	–	–	–
Cut x Copth	2	0.7613	0.0443	0.1386	0.6791	0.7773	0.0528
Blk x Cut x Copthin	4	–	–	–	–	–	–
Spp*Cut*Copthin	4	0.8258	0.6461	0.0075	0.8151	0.8954	0.4756
Blk*Spp*Cut*Copthin	4	–	–	–	–	–	–
Residual error	5	–	–	–	–	–	–
Corrected total	44	–	–	–	–	–	–

[1] df = Degree of freedom.
[2] No test statistics (i.e. F-ratios and probabilities) for replication and replication-by-treatment interactions because these were specified in the error terms of the General Linear Model of SAS for testing main and interaction effects of tree species, coppice cutting height and coppice thinning.

growth and yield variables with the exception of maize plant diameter but this trend was reversed in the second cropping season (Tables 5 and 6). Fig. 3 shows the main effects of coppice tree species on maize growth and yield variables for the first and second cropping seasons.

During the first cropping season, yields of grains (1.26 Mg ha^{-1}), cobs (0.3 Mg ha^{-1}) and stovers (2.43 Mg ha^{-1}) in maize intercropped with *A. versicolor* were significantly ($p < 0.05$) higher than those of maize intercropped with *A. harveyi* (0.74 Mg ha^{-1}, 0.2 Mg ha^{-1}, 1.49 Mg ha^{-1}) (Fig. 3). Corresponding values for continuous cropping treatment were 0.29 Mg ha^{-1}, 0.06 Mg ha^{-1} and 1.06 Mg $ha^{-1}$for yield of maize grains, cobs and stovers respectively. This is equivalent to yield gain in maize grains, cobs and stovers by 334.5%, 129.2% and 400% relative to continuous cropping treatment as a result of first season intercropping with *A. versicolor* coppices respectively. The analogous increase in yield, relative to continuous cropping treatment, due to intercropping with *A. harveyi* coppices were 155.2%, 40.6% and 233%. The results indicate superiority of *A. versicolor* coppices over that of *A. harveyi* in improving yields of the intercropped maize. However, this trend was reversed in the second cropping season (Fig. 3) where, though not statistically significant, intercropping with coppices of any of the studied tree species

Table 6
Summary of ANOVA ($p > F$) testing the effects of tree species, coppice cutting height and coppice thinning on maize grains, stovers and cobs yields in Mg ha^{-1}for the first and second cropping seasons at Maseyu, Morogoro, Tanzania.

Source of variation	df[1]	2008			2009*		
		Grain	Stover	Cobs	Grain	Stover	Cobs
Block (Blk)[2]	2	–	–	–	–	–	–
Tree species (Spp)	1	0.0008	0.0070	0.0163	–	0.7211	–
Blk x Spp	2	–	–	–	–	–	–
Cutting height (Cut)	2	0.2943	0.5423	0.1283	–	<0.0001	–
Blk x Cut	4	–	–	–	–	–	–
Spp x Cut	2	0.2649	0.8089	0.6408	–	0.3908	–
Blk x Spp x Cut	4	–	–	–	–	–	–
Coppice thinning (Copth)	1	0.2414	0.8733	0.4827	–	<0.0001	–
Blk x Copth	2	–	–	–	–	–	–
Spp x Copth	1	0.6832	0.4421	0.7777	–	0.4651	–
Blk x Spp x Cut	4						
Cut x Copth	2	0.3975	0.2044	0.8817	–	0.7513	–
Blk x Cut x Copth	4	–	–	–	–	–	–
Spp*Cut*Copth	4	0.0919	0.4070	0.5921	–	0.9417	–
Blk*Spp*Cut*Copth	4	–	–	–	–	–	–
Residual error	5	–	–	–	–	–	–
Corrected total	44	–	–	–	–	–	–

[1] df = Degree of freedom.
[2] No test statistics (i.e., F-ratios and probabilities) for replication and replication-by-treatment interactions because these were specified in the error terms of the General Linear Model of SAS for testing main and interaction effects of tree species, coppice cutting height and coppice thinning. *Grain and cobs were not produced in the second cropping season (i.e. 2009).

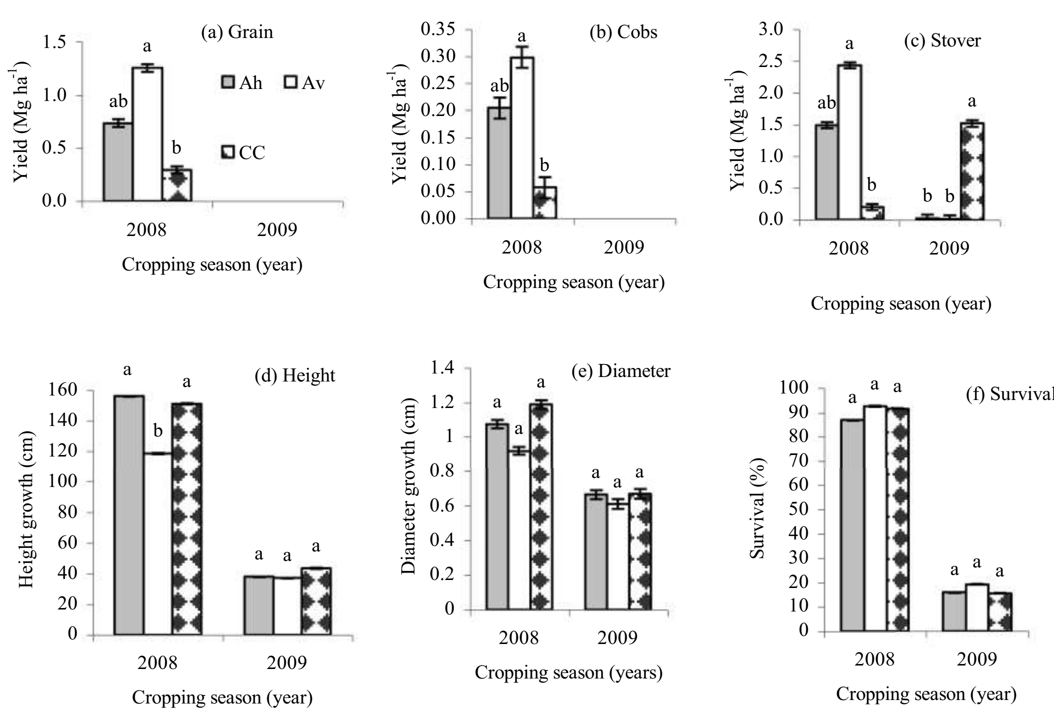

Fig. 3. The effects of coppice tree species on intercropped maize grain (a), cobs (b), stovers (c), Height (d), diameter growth (e) and survival (f) for the first and second cropping seasons at Maseyu, Morogoro, Tanzania. Treatments were coppice tree species Ah = *Albizia harveyi, Av* = *Albizia versicolor*; and CC = continuous cropping. For each figure and within each cropping season, means marked by the same letter are not statistically different at $p < 0.05$ according to DMRT. Vertical bars indicate standard errors of means ($n = 21$ for tree species and $n = 6$ for continuous cropping).

tended to suppress maize growth and yield.

During the second cropping season, there was no maize grain in any of the treatments due to sporadic rainfall. Despite the fact that there were no statistically significant differences, coppices of both tree species tended to suppress maize growth and yield in the second cropping season and the effect was similar for both tree species. Yields of maize stovers, height and diameter growth were lower in intercropped maize relative to continuous cropping by 98% to 98.7%, 14.8% to 15.3% and 46.4% to 81.0%, respectively.

Coppice stump cutting height and coppice thinning had no significant effects ($p > 0.5$) on growth and yield of intercropped maize during the first cropping season, whereas their effects became significant ($p < 0.05$) in the second cropping season (Table 6). Effects of coppice stump cutting height on growth and yield of intercropped maize for two consecutive cropping seasons are presented (Fig. 4).

Although not statistically significant, the general trend was highest

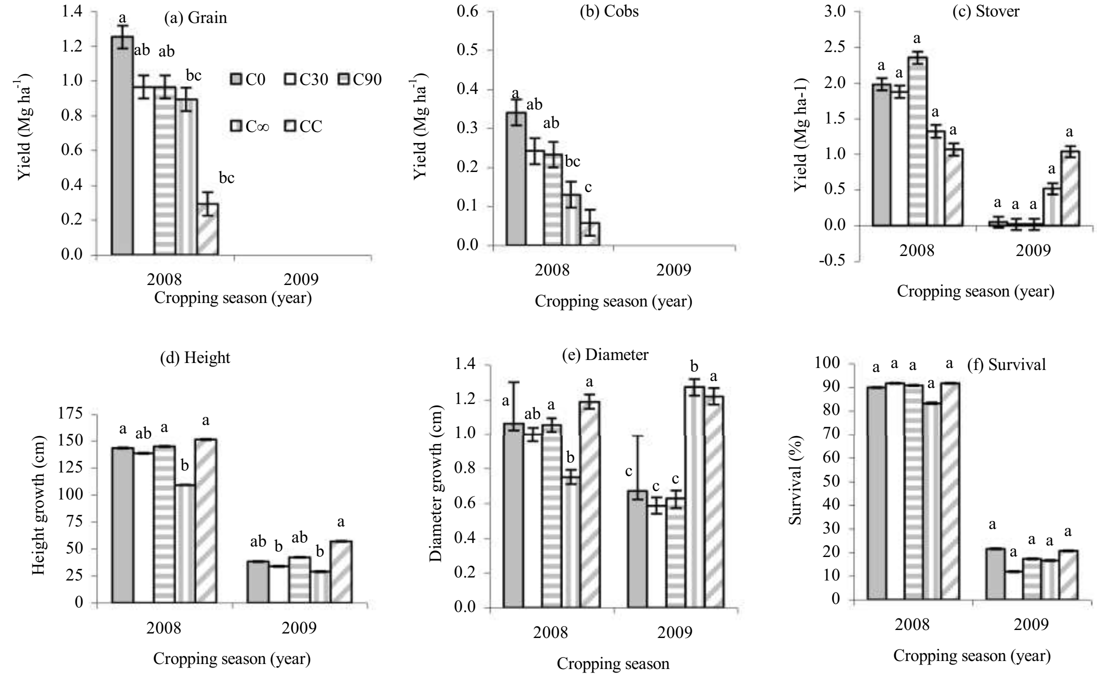

Fig. 4. The effects of coppice stump heights on yields of maize grain (a), stover (b), cob (c), maize plant height growth (d), diameter growth (e) and survival for the first and second cropping seasons at Maseyu, Morogoro, Tanzania. Treatments were C0 = coppice stumps cut at the ground level, C30 = coppice stumps cut at 30 cm from the ground level, C90 = coppice stumps cut at 90 cm from the ground level, C∞ = Tree fallow and CC = continuous cropping. For each figure and within each cropping season, means marked by the same letter are not statistically different at $p < 0.05$ according to DMRT. Vertical bars indicate standard errors of means ($n = 7$ for tree species and $n = 3$ for continuous cropping).

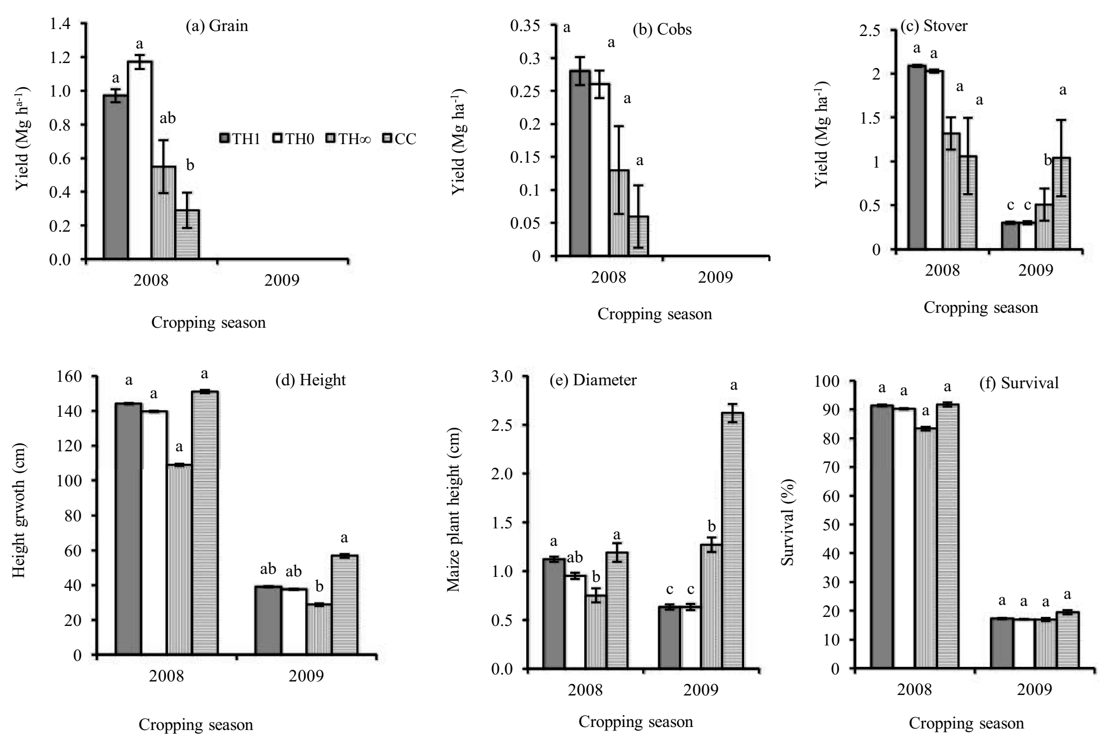

Fig. 5. The effects of coppice thinning on yields of maize grains (a), stovers (b), cobs (c), maize plant height (d), diameter (e) and survival for the first and second cropping seasons at Maseyu, Morogoro, Tanzania. Treatments were TH0 = no coppice thinning, TH1 = coppice thinned to leave two coppice stems per stump, TH∞ = Tree fallow and CC = continuous cropping. For each figure and within each cropping season, means marked by the same letter are not statistically different at $p < 0.05$ according to DMRT. Vertical bars indicate standard errors of means ($n = 7$ for tree species and $n = 3$ for continuous cropping).

maize grain yields in coppices grown from stumps cut at the ground level. A similar pattern was observed for maize cob yields, whereas the pattern for stover yields was not clearly defined being highest in stumps cut at 90 cm above the ground, intermediate in stumps cut at the ground level and lowest in sumps cut at 30 cm from the ground level. During the first cropping season, maize grain yield ranged from 0.98 Mg ha^{-1} for coppice stumps cut at 90 cm from the ground to 1.26 Mg ha^{-1} for stumps cut at the ground level. This is in contrast to maize grain yield of 0.29 Mg ha^{-1} recorded in continuous cropping treatment. These results translate into an increase of maize grain yields ranging from 237.9% for maize intercropped with coppices from stumps cut at 90 cm from the ground to 331% for stumps cut at the ground level.

During the second cropping season, growth and yield of intercropped maize were reduced compared to the first cropping season but similar for all coppice stump height treatments; whereas they become significantly ($p < 0.05$) lower compared to continuous cropping treatment (Fig. 4). In that season, stover yields ranged from 0.02 Mg ha^{-1} for both stumps cut at 30 cm and 90 cm from the ground to 0.04 Mg ha^{-1} for stumps cut at the ground level. This was in comparison to stover yield of 1.04 Mg ha^{-1} in continuous cropping treatment.

Fig. 5 shows effects of coppice thinning on growth and yield of intercropped maize for two successive cropping seasons. During the first cropping season, maize grain yield for maize intercropped with thinned coppice treatment (0.97 Mg ha^{-1}) was slightly lower than that from no coppice thinning treatment (1.17 Mg ha^{-1}) but about twice as much as grain yield of 0.29 Mg ha^{-1} from continuous cropping treatment (Fig. 5). A similar pattern was observed for cobs and stover yields as well as maize plant growth. The similarities in maize growth and yield between coppice thinning and no thinning treatments continued during the second cropping season but became significantly ($p < 0.05$) lower than continuous cropping treatment (Table 6; Fig. 5). In the second cropping season, maize stover yield was reduced to about 0.3 Mg ha^{-1} compared to 2.03 - 2.09 Mg ha^{-1} in first cropping season. This was significantly ($p < 0.05$) lower than 1.04 Mg ha^{-1} recorded in continuous cropping.

4. Discussion

4.1. Effects of tree fallows and tree coppices on soils

The OC content in 0 - 15 cm soil depth found in this study is within the range of 0.41–3.14% reported by Msanya et al. (1995) in the same area and 0.1 to 3.8% for the general miombo ecoregion (Frost, 1996). Soil assessment prior to establishment of coppice experiments demonstrated the potential of AF utilizing the tested indigenous tree species to increase OC and OM within a short period of four years. These results corroborate well with results reported by Kimaro (2009) for rotational woodlots in Tanzania. Other studies elsewhere found no significant increase in OC and OM within three to five years of AF due to the fact that processes to increase soil OC, OM and soil fertility in general occurred slowly taking several years to detect (Neupane and Thapa, 2001). The plausible explanation for the lack of significant AF trees effects on OC, OM and soil fertility in some studies could be nutrient removals associated with intensive fodder, fuel wood and poles extraction during tree fallow phase (Garcia and Gerrits, 1995). In contrast, in this study and studies by Kimaro (2009) and Nyadzi (2004), AF trees were not harvested until the canopy closure. Interim intensive harvesting of fodder and fuel wood from AF systems are likely to influence OC and OM build-up since they tend to expose the soils to high temperature leading to loss of C through oxidation (Grigal and Berguson, 1998) as well as limiting foliar mass deposits on the ground surface.

The low base (Ca, Mg, Na and K) content found in this study is a characteristic of highly weathered soils (Msanya et al., 2003) typical of miombo woodlands (Frost, 1996). Frost (1996) found a significant relationship between ECEC of the soil and the amounts of clay and OC in the top soils. Thus, the low ECEC recorded in this study corresponds well to the low amounts of OM in the area. However, this study has shown the potential of the tested tree fallows in improving both OC and OM. After one cropping season, the amount of TN and OC recorded in coppice plots were significantly lower compared to continuous cropping plots. The most plausible explanation for this phenomenon is C loss to the atmosphere from the coppice plots. The magnitude of changes of SOM depends on the quantity and quality of prunings, soil type, system management, climate and duration of practice of the system (Makumba et al., 2006; Nyirenda and Balaka, 2021). Although the quantity of prunings added in coppice plots was higher than the continuous cropping plots, it is possible that the studied tree species produce prunings that are of high quality, in terms of low carbon - to - nitrogen (C: N) and lignin-to-nitrogen (L: N) ratios. Materials of this nature are likely to have negligible or little effects on soil C build up because C is returned to atmosphere via C evolution process. This proposition is supported by Andrén and Kätterer (2001) who found that addition of plant materials of high quality to soil led to C loss rather than accumulation. This was probably aggravated by soil exposure to high temperatures when coppices were still young leading to oxidation (Grigal and Berguson, 1998) and hence loss of C to the atmosphere. This can also serve to explain the high amounts of TN and OC in the tree fallow plots associated with differences in microclimate compared to coppiced plots. However, it is important to note that the quality of prunings from the studied tree species was not assessed due to unforeseen budget constraint, thus this aspect calls for further investigation.

Lack of significant effects of tree coppice cutting height and coppice thinning treatments on soil chemical properties is probably due to the fact that variations in foliar biomass as a result of these treatments were on the lower side. Improvement in soil nutrient status in AF is mainly through nutrients released from mineralization of prunings (Rao et al., 1998; Kuyah et al., 2020). According to Sanchez and Jama (2002), nutrient contributions from AF systems are positively correlated to the amount of prunings added to the soil. In this study, foliar biomass ranged from 2.18 Mg ha^{-1} in *A. versicolor* to 2.86 Mg ha^{-1} in *A. harveyi*, which is lower compared to other AF studies that reported improved soil chemical properties. Nyadzi (2004) reported improved soil chemical properties in AF system in which foliage yield ranged from 6.3 to 20.2 Mg ha^{-1}. Besides yields of prunings, the effects of AF system on soil chemical properties can be influenced by nutrient contents and overall quality of the prunings such as C: N ratio that affects mineralization of nutrients (Vanlauwe et al., 2011; Njoroge et al., 2017). This study did not assess these factors thus they require further investigation.

4.2. Effects of tree coppices on maize growth and yield

This study has demonstrated an increase in maize grain yield of intercropped maize of up to 100% during the first cropping season as compared to continuous cropping. This could be attributed to fertility improvement as a result of AF tree coppices related to various mechanisms such as biological N fixation, pumping up or retrieval of nutrients from lower soil horizons and interception of nutrients that would otherwise be lost through leaching and surface runoff and release of nutrients during litter and root decomposition (Rao et al., 1998; ten Berge et al., 2019; Nyirenda and Balaka, 2021). Probably the increased maize yield in intercropped maize could be attributed to these mechanisms.

Significant reduction in maize stover yields for maize intercropped with coppices could be attributed to combination of competition for light as result of shading, and competition for water resulting from developed tree root system (Nyadzi, 2004). These results are consistent with other simultaneous AF system studies (Chamshama et al., 1998; Kimaro 2009; Kuyah et al., 2020). In a semiarid area of Tanzania, Nyadzi (2004) reported progressive reduction of yields of maize intercropped with Australian Acacias despite the fact that trees improved soil chemical properties. In Kenya, Ong et al. (2000) reported decreased yield of maize intercropped with *Grevillea robusta* after three years of intercropping. Similar results have also been reported by Lott et al.

(2000) in Kenya. It is important to note that the pattern of the effects of tree age on the nature and magnitude of competitiveness of AF trees varies with planting density (widely spaced trees taking longer to reduce crop yields) and is influenced by climate and species of crop involved (Yin and He, 1997; Muthuri et al., 2005; Nyirenda and Balaka, 2021). These aspects were not investigated in the present study, thus require further investigation.

5. Conclusion

Intercropping coppices of the studied tree species with maize increased maize grain yield by 100% compared to continuous cropping in the first cropping season suggesting soil amelioration effects of these tree species and the potential to boost livelihoods and achieve SDGs. However, in the second-year reduction in yields, growth (height and diameter) in maize intercropped with coppices of the studied tree species was observed indicating increasing competitive effects of the coppices of these tree species with age. Based on their positive effects on soil fertility, the studied tree species are recommended for on-farm planting for soil improvement. Planting these tree species in sequential AF systems such as improved fallow, intensive pruning of coppices or wider spacing in intercropping systems may reduce their competitive effects on the companion crops. However, more studies on these species are still needed regarding these aspects. Furthermore, the effects of AF system on soil chemical properties can be influenced by nutrient contents and overall quality of the prunings such as C: N ratio that affects mineralization of nutrients. Thus, these aspects require further investigation too.

Declaration of Competing Interest

There are no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' contributions

VGV and SAOC conceptualized and designed the study; VGV investigated, curated and analysed data under the supervision of SAOC; SMA did additional data analysis and prepared the initial draft of the manuscript; VGV and SAOC improved the draft. All authors read and approved the final manuscript.

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