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Salim Maliondo

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Growth and yield of maize alley cropped with *Leucaena leucocephala* and *Faidherbia albida* in Morogoro, Tanzania

S. A. O. CHAMSHAMA [1], A. G. MUGASHA [1,*], A. KLØVSTAD[2], O. HAVERAAEN[2] and S. M. S. MALIONDO[1]
[1] *Department of Forest Biology, Faculty of Forestry, Sokoine University of Agriculture, P.O. Box 3010, Morogoro, Tanzania;* [2] *Department of Forest Sciences, Agricultural University of Norway, P.O. Box 5044, N-1432 Ås, Norway (*Author for correspondence)*

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Abstract. This study examined the effect of alley cropping of *Leucaena leucocephala* and *Faidherbia albida* on wood biomass, maize grain yield and soil nitrogen status. The treatments were: trees planted alone at 1 × 5 m spacing; trees intercropped with maize and a sole maize crop. Mulch biomass averaged 6.18 and 0.97 t ha^{-1} for *L. leucocephala* and *F. albida*, respectively. Corresponding wood production was 1.71 and 1.11 t ha^{-1}. Both total N and inorganic N (NO_3^-–N plus NH_4^+–N) were higher under *F. albida* and lowest under *L. leucocephala*. Similarly, foliar N concentration in maize was higher in plots intercropped with *F. albida* and least in *L. leucocephala* intercropping. Maize grain yield was little affected by the tree intercrop as competition for resources was reduced through periodic pruning and clean weeding. There was no gain in maize grain yield due to the presence of *L. leucocephala* and *F. albida*. These results suggest that alley cropping in Gario is justified for wood production but not for increasing maize grain yield.

Introduction

Almost twenty years ago, Tanzania started a village afforestation programme focusing chiefly on community woodlots producing fuelwood and poles (Forest Division, 1984). There is an increasing realization that progress has been hampered by lack of integration between forestry operations and agriculture. To solve this, an agroforestry approach has been proposed as an alternative. However, there is a lack of information about potential tree species, the optimal agroforestry systems, appropriate management techniques and the reactions of villagers. While some exotic tree species have been integrated in land use, the use of nitrogen fixing tree species has been limited. To partially fill this gap, *Leucaena leucocephala* (Lam.) de Wit and *Faidherbia albida* (Del.) A. Chev (syn. *Acacia albida* Del.) were used in alley cropping at Gairo, a semi-arid area in central Tanzania with a severe fuelwood shortage and declining food crop yields. *Faidherbia albida* which is an indigenous tree species in Tanzania was included in this study to compare its results with those of *L. leucocephala* (exotic leguminous tree species).

Alleying cropping is one of the agroforestry technologies that has generated a lot of interest since it may increase crop yields, maintain soil fertility, and provide a sustainable alternative to shifting cultivation (Ssekabembe, 1985; Kang et al., 1985; Kang et al., 1986; Vergara, 1987). In alley cropping, shrubs or trees are periodically pruned during the crop growing season to minimize the adverse effects of shading and to reduce competition with food crops (Kang et al., 1985). It has now been realised that alley cropping does not work in areas experiencing soil moisture deficit during the cropping season (Kang, 1993; Ong, 1994). In these areas, food crop yields from the alley cropping system tend to decline with time due to competition for soil moisture and nutrients. Soil moisture availability is one of the important factors limiting food crop productivity in semi-arid areas of Tanzania.

Since the effect of trees or shrubs on soil fertility and crop yields in alley cropping systems vary from one part of the world to another due to crop genotypes, soil factors, rhizobial strains and often due to different nitrogen determination procedures, it is important that such investigations are carried out in the areas where the results are needed. Against this background, two alley cropping experiments were established at Gairo. The objective of the study was to evaluate the effect of alley cropping of *L. leucocephala* and *F. albida* on biomass and maize grain yield and soil nitrogen.

Materials and methods

Site

The study was carried out at Gairo (36°45′ E, 6°30′ S; 1200 m a.s.l.) located on the main road between Morogoro and Dodoma, about 130 km from Morogoro. Rainfall is unevenly distributed, and varies from year to year, with the rainy season starting from November and ending in May. For the period 1982 to 1987, the mean annual rainfall was 499 mm (Chamshama et al., 1994) with a range of 388–656 mm.

The soil texture is sandy clay loam with a pH in the upper 20 cm varying from 5.9–6.5 (Kløvstad, 1991). Other soil properties are as follows: organic carbon content 0.15%, total nitrogen 0.069%, Bray I available P 5.5 mg kg^{-1}, cation exchange capacity 13.3 cmol(+)kg^{-1}. The soils are classified as Haplic Lixisols (Msanya and Msaky, 1994). The vegetation cover of Gairo is scarce, and consists mostly of shrubs and a few scattered trees (Chamshama et al., 1994).

The *Faidherbia albida* experiment was established about 50 m (up the slope) away from the *L. leucocephala* experiment. These differences in positions of the experiments along the soil catena might have resulted in slight differences in soil properties.

Experimental design and treatments

Two experiments were established in January 1989, i.e. one for each *L. leucocephala* and *F. albida*. Each experiment consisted of three treatments in a randomized complete block design with four replications. The treatments assigned were:

A – Trees alone at 1 × 5 m spacing
B – Trees at 1 × 5 m spacing plus maize
C – Maize alone

The individual plots were 20 × 20 m square, separated from each other by 4 m interval. There were 3 m gaps between blocks. To minimize interference of tree roots invading control plots, the following was done. Near the onset of each cropping season, control plots were isolated by trenching at mid-distance (i.e. 1.5 m) between plots and at mid-distance (i.e. 2 m) between blocks. These trenches were dug to a depth of 50 cm followed by immediate backfilling.

Cultural treatments

At each experimental site, all vegetation was cleared and destumped; this was followed by ploughing and harrowing using a farm tractor. Hand hoes were used for pitting. Five-month-old container-grown tree seedlings of similar height were collected from Sokoine University of Agriculture, Mafiga Nursery, Morogoro and planted on 9 January, 1989. Trees were planted with 1 m spacing within rows and 5 m between rows. Maize was planted with spacings of 90 × 30 cm in treatments B and C in January, 1989, 1991 and 1992, and February, 1990. In treatment B maize was planted in rows parallel to the tree rows and both maize and tree rows lay in a north-south direction at a right angle to the slope.

All experimental plots were clean weeded twice using a hoe each cropping season and once during the dry seasons. In both experiments, hedgerows of *L. leucocephala* and *F. albida* were cut back to 1 m height once per year, e.g. just before planting maize to minimize the adverse effects of shading and to reduce competition for soil growth resources, especially moisture and nutrients. Prunings were left on the site to enhance soil fertility.

Assessment of tree attributes and maize yield

For assessment of tree biomass production, all trees were measured for root collar diameter 10 cm above the ground using a small calliper, to the nearest 0.01 cm. For each plot, average root collar diameter per row was then determined. Within each row of each plot, one tree of average root collar diameter was clipped 1 m above the ground followed by determination of dry weight of leaves and woody components. Mean fresh weight of each component on a per ha basis was determined as follows. For each plot, mean fresh weight of each component was multiplied by the number of surviving trees to obtain component fresh weight per plot. Sub-samples of each component were sent to the laboratory where they were oven-dried (80 °C) to constant weight. The moisture content of each component was used to obtain the dry weight of each component. Plot mulch and wood components were then converted into kg ha^{-1}.

Maize crops were harvested in July/August 1989, 1990, 1991 and 1992, sun-dried, thrashed and weighed for grain weight. Plot grain yields were converted into kg ha^{-1}. Additionally, in May 1991 there was an assessment of height and biomass of maize plants in treatments B and C. This was done as follows: For each plot, an inner plot measuring 10 × 10 m was demarcated. Each inner plot was then divided into four equal sub-plots, each 5 × 5 m. Two sub-plots were randomly chosen in each plot. The height of all maize plants was measured using a steel tape to the nearest 1 cm. Maize plants were then harvested from two sub-plots in each plot as follows: From each row of maize in these sub-plots, two plants were dug up with a hoe, taken to the laboratory, separated into leaves, stem, cobs and roots, oven-dried at 70 °C to constant weight and weighed. Dry weights were averaged for each plot, multiplied by number of maize plants to get plot totals which were later converted into kg ha^{-1}.

Soil and maize foliage sampling and analysis

Maize plant foliage and soil samples were taken in May 1991 as follows. Maize leaf samples were taken from two randomly selected sub-plots in each plot. All leaf samples were dried, packed in plastic bags and sent to Norway for chemical analysis.

For each treatment, soil samples were taken from one sub-plot in all plots. They were taken with an auger to a depth of 0–20 cm. For each treatment A (‘trees alone’) plot, two samples were taken: one within the rows of trees and one between. For each treatment B (‘trees plus maize’) plot, seven samples were taken, i.e. one in each row of maize and one in each row of trees. For each treatment C (‘maize alone’) plot, one sample between two rows of maize was taken. For treatments A and B, soil samples from each category were bulked, mixed thoroughly and subsampled. A total of 20 soil samples were packed in polythene bags and kept in a freezer until they were sent to Norway four weeks later for analysis.

In the laboratory, maize foliage samples were ground to pass through a 1 mm sieve. Phosphorus, potassium, calcium, magnesium and sulphur were determined by simultaneous ICP (Inductive coupled plasma emission spectroscopy) technique in acid digested samples. For both plant and soil samples, total nitrogen was determined by the Kjeldahl procedure. For soil samples, ammonium-nitrogen and nitrate-nitrogen were extracted with 2 M KCl and their concentrations in extracts were measured calorimetrically at 566 and 540 nm, respectively.

Data analysis

Analysis of variance for the randomized complete block design was performed on plot means of tree root collar diameter, and production of mulch and wood biomass; maize plant height, biomass, foliar nutrient concentration and grain yield, and soil nitrogen (total N, ammonium-nitrogen and nitrate-nitrogen). For statistically significant treatments, means were separated by LSD.

Results

Tree root collar diameter, and production of mulch and wood biomass

Alley cropping of *L. leucocephala* with maize resulted in significantly ($P <$ 0.05) higher mean root collar diameter as compared to 'tree alone' treatment (Table 1). Alley cropping of *F. albida* and *L. leucocephala* with maize had no significant ($P > 0.05$) effect on mulch and wood biomass production four years after planting. Mulch biomass averaged 6.18 t ha^{-1} for *L. leucocehala* and 0.97 t ha^{-1} for *F. albida*. Wood production ranged from 1.71 t ha^{-1} for *L. leucocehala* and 1.11 t ha^{-1} for *F. albida* (Table 1).

Soil nitrogen status

The amount of total and mineral N in the upper 0–20 cm depth of the soil is shown in Table 2. The amount of total N in *F. albida* 'trees alone' and 'tree plus maize' plots were significantly higher than in 'maize alone' plots (Table 2) suggesting that *F. albida* had a stronger influence on soil total N. For 'trees alone' and 'trees plus maize' plots, amounts of ammonium-nitrogen and

Table 1. Effect of alley cropping of *Leucaena leucocephala* and *Faidherbia albida* with maize on tree root collar diameter at 2.5 years, and production of mulch and wood biomass four years after planting at Gairo, Morogoro, Tanzania.

Treatment	Root collar diameter (cm)	Biomass production (kg.ha^{-1})	
		Mulch	Wood
Trees alone	3.42[a] (0.09)	5272 (400)	1733 (300)
Maize grown with *Leucaena*	3.61 (0.09)	7080 (800)	1689 (225)
Trees alone	2.88 (0.53)	978 (176)	1113 (200)
Maize grown with *Faidherbia*	2.24 (0.44)	969 (158)	1102 (178)

[a] Means of 4 observations with standard error in parentheses.

Table 2. Effect of alley cropping of *Leucaena leucocephala* and *Faidherbia albida* with maize on soil nitrogen status at a depth of 0–20 cm, 2.5 years after planting at Gairo, Morogoro, Tanzania.

Tree species	Nitrogen (kg ha^{-1})	Treatments[a]		
		Trees alone	Trees + maize	Maize alone
L. leucocephala	Total N	1831.2 a (167.4)	1406.4 b (242.7)	1696.8 ab (218.1)
	NH_4–N	10.8 a (3.9)	8.4 a (2.7)	12.8 a (3.5)
	NO_3–N	8.1 b (2.0)	10.0 b (2.5)	25.5 a (1.9)
F. albida	Total N	1814.4 a (127.1)	1905.6 a (200.9)	1377.6 b (132.3)
	NH_4–N	14.8 a (2.1)	12.7 a (2.0)	10.8 a (2.2)
	NO_3–N	28.6 a (3.4)	12.3 b (2.6)	24.5 a (2.9)

[a] Means of 4 observations with standard error in parentheses. For each species, means followed by the same letter within the same row are not significantly different ($P > 0.05$).

nitrate-nitrogen were significantly higher under *F. albida* as compared to *L. leucocephala*. While amounts of ammonium-nitrogen and nitrate-nitrogen were similar under *Leucaena*, the amount of nitrate-nitrogen was significantly higher (×2) than NH_4–N under ‘tree alone’ plots of *F. albida* and all ‘maize alone’ plots.

Maize plant height, biomass and foliar nutrient concentration

Mean height, biomass and foliar nutrient concentration are shown in Table 3. *Leucaena leucocephala* depressed average height and biomass production in maize plants. The average height of maize plants interplanted with *L. leucocephala* trees decreased by 42.9% as compared to the height of maize plants grown alone. Corresponding decrease in maize plant biomass was 74.6%. In contrast, *F. albida* improved maize plant biomass production by 94.7%, and increased maize plant height by 19.7% as compared to maize alone (Table 3). In both cases, there were statistically significant differences ($P < 0.05$) in maize plant height and biomass production between ‘maize alone’ and ‘tree plus maize’ treatments.

Maize grain yield

For *F. albida*, in the first year of cropping, maize grain yield was significantly higher in the ‘maize plus tree’ plots, but in subsequent years the maize alone

Table 3. Effect of alley cropping of *Leucaena leucocephala* and *Faidherbia albida* with maize on height, biomass and foliar nutrient content of maize plants in 1991 at Gairo, Morogoro, Tanzania.

Treatment	Mean height (m)	Mean weight (g/plant)	Foliar macro-nutrients[a] ($g\ kg^{-1}$ dwt)				
			N	P	K	Ca	Mg
Maize grown with *Leucaena*	0.64[b] (0.11)	22.0 (0.32)	11.52	0.81	24.25	4.50	4.37
Maize alone	1.12 (0.09)	86.6 (5.8)	13.99	1.11	20.78	5.60	5.82
Maize grown with *Faidherbia*	1.40 (0.22)	155.0 (10.1)	6.85	1.48	18.86	5.55	5.25
Maize alone	1.17 (0.25)	79.6 (5.9)	4.37	1.32	21.91	5.58	5.75

[a] Not tested statistically since samples from different plots were bulked before analysis.
[b] Means of 4 observations with standard error in parentheses.

plots out-produced the intercropped plots; these differences were not, however statistically significant (Table 4). For *L. leucocephala*, during the first two years maize grain yield was higher in the 'tree-maize' plots, but this trend was reversed in the third and fourth cropping seasons (Table 4). In general, maize grain yield in subsequent years was only a fraction of the initial yield obtained following bush clearing.

Table 4. Effect of alley cropping of *Faidherbia albida* and *Leucaena leucocephala* with maize on maize grain yield at Gairo, Morogoro, Tanzania.

Treatment	Cropping season			
	1989	1990	1991	1992
	Maize grain yield ($kg\ ha^{-1}$)			
Maize grown with *Faidherbia*	2056[a] (200)	506 (109)	88 (27)	666 (111)
Maize alone	1656 (156)	669 (89)	113 (25)	706 (123)
Maize grown with *leucaena*	1938 (218)	375 (58)	180 (38)	293 (29)
Maize alone	1744 (185)	206 (26)	563 (41)	313 (33)

[a] Means of 4 observations with standard error in parentheses.

Discussion

The results from this study support the findings of other workers that *L. leucocephala* has high biomass production (Juo and Kang, 1987; Lulandala and Hall, 1987; Kang, 1993). Mulch biomass production at Gairo was 6.2 t ha^{-1} (Table 1) which compares very well with production figures for humid and subhumid zones (Juo and Kang, 1987; Lulandala et al., 1995). On the other hand, mulch production by *F. albida* was much lower (0.97 t ha^{-1}). Because of the low foliage productivity, *F. albida* is not suitable for use in alley cropping. Wood production was also higher for *Leucaena* (1.7 t ha^{-1}) than for *F. albida* (1.1 t ha^{-1}). Interestingly tree biomass production was not affected by the presence of maize. If the purpose of establishing agroforestry is mulch/fodder production, then *L. leucocephala* should be preferred over *F. albida*, although the threat of *Leucaena pysillid* may limit the establishment of *Leucaena*.

Another important objective of using N-fixing legume trees in agroforestry is soil fertility amelioration. In the current study, total soil N (Table 2) was similar under sole *L. leucocephala* and *F. albida* plots (1831 vs 1814 kg ha^{-1}). However, in the maize-tree plots higher total soil N was recorded under *F. albida* than under *L. leucocephala*, further supporting the ameliorative effect of the former species (Poschen, 1986). The beneficial effects of alley cropping on soil fertility maintenance as well as the differential effects of hedgerow species on soil fertility parameters has been reported in several other studies (Kang et al., 1985; Yamoah et al., 1986; Lal, 1989; Balasubramanian and Sekayange, 1990; Matthews et al. 1992; Dalland et al. 1993).

Total soil N is not a very useful indicator of soil N availability as only a small fraction of this can be mineralized per year. The amount of mineral N (ammonium-nitrogen and nitrate-nitrogen) in the soil is a more useful indicator of soil available N. The slightly higher mineral N under sole *F. albida* (43.4 kg ha^{-1}) than under sole maize (averaging 36.8 kg ha^{-1}) also suggests soil fertility enhancement under *F. albida*. The lowest amount was recorded under *L. leucocephala* (18.9 kg ha^{-1}) and was not influenced by maize intercropping (18.4 kg ha^{-1}). This result is surprising for a prolific N-fixing species estimated to fix 197 kg N ha^{-1} annually (Lulandala, 1985). Since *Leucaena* has high biomass production, this result can be explained by assuming that most of the mineral N was sequestered by trees to sustain the higher wood biomass.

Soil fertility status may also be gauged from plant nutrient uptake, a product of plant biomass and nutrient concentrations. Maize growth and foliar nutrient contents during the third year displayed in Table 3 showed that while maize growth was reduced by *Leucaena*, it was significantly increased by *Faidherbia*. Maize foliar N and P were reduced by the presence of *Leucaena* suggesting competition, but enhanced by *Faidheribia* implying fertility amelioration. These results are in agreement with enhanced mineral N under *Faidherbia* as noted above.

Maize grain yield in subsequent cropping seasons were substantially lower as compared to the first cropping season. This may be related to low rainfall in subsequent years. Maize grain yield, as expected, in the year of establishment was little affected by the presence of tree seedlings of either species (Table 4). However, while maize grain yield was little affected by *F. albida* trees in the subsequent three years, it was significantly affected though inconsistently by *L. leucocephala*. At 5 m interrow spacing used in the study, the decline in maize yield may be attributed to competition for soil water (Akonde' et al., 1996) as at that spacing and with frequent back pruning, shading plays a minor role in competition (Lawson and Kang, 1990; Leihner et al., 1996). Alley cropping in the semi-arid tropics induces competition for moisture (Singh et al., 1989) and nutrients (Fernandes et al., 1990) between trees and crops which may severely reduce crop yield, though root pruning of the hedgerows can partially reduce the competition. Nair (1993) concludes that alley cropping using such species as *Leucaena leucocephala* is unlikely to be a promising technology in the semi-arid tropics and recommends that more efforts are needed to identify hedgerow species that are appropriate for alley cropping in such dry areas.

While there was not any fertilization in the present study, studies in semi-arid and humid/sub-humid areas show that though shrub/tree prunings may sustain crop yields at a reasonable level, high yields require fertilizer supplementation (Kang et al., 1985, 1990; Yomoah et al., 1986; Danso and Morgan, 1993; Dalland et al., 1993; Chirwa et al., 1994; Shannon et al., 1994).

Conclusion

Although mulch production was especially high for *L. leucocephala* (6.18 t ha^{-1}) there was no increase in maize grain yield. Despite low mulch production, there was a tendency of soil fertility improvement under *F. albida* but this had no effect on maize yield. These results suggest that under the semi-arid conditions of Gairo, the benefits of alley cropping using *L. leucocephala* and *F. albida* on maize grain yield are not apparent. Further work is needed to identify other suitable species for alley cropping in the area and also to test other agroforestry technologies such as improved fallows and relay cropping.

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