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Agroforestry Trees as Source of N for Sustainable Alley Cropped Maize (*Zea Mays* L.) Yield on Depleted Loamy Soils

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Research Article

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ABSTRACT

The effects of leguminous agroforestry trees as sources of N for sustainable performance of alley cropped maize on depleted loamy soils were investigated under field conditions. The hedgerow species studied were *Leucaena leucocephala*, *Senna siamea* and *Flemingia macrophylla*. This study was superimposed on an existing ICRAF alley cropping trial at Chalimbana, Zambia. In this experiment, maize (variety MM 603), was the companion crop and the leguminous species comprised the alley hedgerows. Supplementary low levels of N (0 kg ha⁻¹, 34 kg ha⁻¹, 68 kg ha⁻¹ and 112 kg ha⁻¹) were applied. Tree litter was incorporated at 5 t ha⁻¹ for all species. There was no significant species effect on maize yields. A significant N fertiliser effect on yield was obtained at 68 kg N ha⁻¹. This result probably indicates the need for moderate fertiliser N addition to incorporated residues so as to sustain maize yields in alley cropping.

Keywords: leguminous agroforestry trees, alley cropping, hedgerows, companion crop, depleted loamy soils, sustainable yield.

INTRODUCTION

Sustainable farming systems requiring low external inputs are being developed in many parts of the tropics where declining soil fertility is a major constraint to crop production. The need for alternative systems is especially great for small scale farmers with limited access to artificial fertilisers (SPRP, 1989). One alternative approach to sustainable soil fertility management is alley cropping or hedgerow intercropping system (Chirwa *et al.*, 1994).

Handayanto *et al.* (1994) defined alley cropping/hedgerow intercropping as an agroforestry system where food crops are grown between rows of trees, preferably leguminous trees. The trees are periodically pruned to prevent shading of the companion crop and to reduce competition. The prunings are utilised as green manures, particularly as source of N and mulching material. The objectives of agroforestry technologies are to increase soil fertility, conserve moisture, conserve biodiversity and in some cases suppress insect pests and weeds (Kang *et al.*, 1984; Sileshi & Mafongoya, 2006a). Ladd *et al.* (1981) reported that the main value of leaves from N-fixing agroforestry trees was the accumulation of soil organic matter from the litterfall, which eventually is made available to companion crops in the alley after mineralisation of the litter.

Results of various alley cropping experiments in Sub-Saharan Africa have indicated that sustained food crop production is feasible using a combination of legume residues and judicious amounts of inorganic nutrient input (Kamara *et al.*, 1994;). Xu *et al.* (1993), working on N cycling in semi-arid tropics, established that the N supply by the hedgerow legumes was more sustainable but not sufficient to achieve optimum companion crop yield. In general, Kumar *et al.* (2007) recommends a judicious combination of organic and chemical fertilisers so as to maintain soil and crop productivity.

Information on optimum amounts of inorganic N needed to be applied in conjunction with incorporated leaf litter from multipurpose tree hedgerows for sustainable companion crop (maize) yields is limited. The study provides guidelines on the three leguminous tree litter and inorganic N combinations for sustainable maize production in alley cropping for smallholder farmers.

The objective of this research was to assess the effect of three leguminous agroforestry tree leaf biomass on sustainable alley cropped maize production on a depleted loamy soil.

MATERIALS AND METHODS

Experimental site

The study was carried out at the SADC/ICRAF Zonal Agroforestry Research Project at Chalimbana Research Station in Lusaka, Zambia (Figure 1.). The site is situated 28°29'56" E, 15°21'32" S, and its elevation is 1280 m above sea level. Rainfall for this study season was 520 mm and the mean minimum and mean maximum temperatures were 18°C and 31°C, respectively. The soil is derived from quartz muscovite schist with surface soil being acidic, pH – CaCl₂ (4.8), while subsoil is neutral to alkaline. Chemical composition of major nutrients shows 1.3 mg kg⁻¹N, 0.13%N 1.97 mg kg⁻¹ P and 0.66 cmol K kg⁻¹ soil. The soils have been classified as plinthic lixisols or in soil taxonomy as loamy, mixed iso-hyperthermic plinthic kandistalf (Chirwa *et al.*, 1994). The experiment was superimposed on an alley cropping experiment established in 1987. The hedgerow species were *Leucaena leucocephala*, *Senna siamea* and *Flemingia macrophylla*. The companion crop has been maize since establishment of the alleys. This experiment was conducted on those plots which had not received fertiliser treatments since establishment of the alley cropping experiment.

Plant residue management

Prunings of three leguminous woody species of *L. leucocephala*, *S. siamea* and *F. macrophylla* were used in this study. The prunings were sun-dried and incorporated 10-15 cm into the soil at the rate of 5 t ha⁻¹ in the alleys of each species at the time of planting.

Field layout and plot management

A split plot in a randomised complete block design (RCBD) replicated three times was used. Plant residues made up the main plot factor while N levels were the subplot factor. The experiment was carried out in the outer three rows of the hedgerows. Each of the three species in a block delineated an alley 4.5m wide and 10m long with 6 rows of maize in the main alley and 3 rows on either side of the hedgerows. The outer rows were divided into two, measuring 2.25m wide x 4.5m long to give four subplots of each species per block. Subplots received 0, 34, 68, and 112 kgNha⁻¹ plus 5 t ha⁻¹ dry prunings of the tested tree species. One- third of the N fertiliser treatments was applied as D compound (10N:20P:10K) at planting. The balance was applied as urea (46%N) four weeks later. The 0 kgNha⁻¹ plots did not receive any fertiliser at all because soil analysis results revealed that Potassium, Phosphorous and Sulphur were above critical levels and hence the 0 kg N ha⁻¹ were not compensated with other sources. The rate of 5 t ha⁻¹ was used since it was the expected average pruning yield from the trees.

Figure 1: Location of Chalimbana Research Station, Zambia.

Source: This study

Companion maize crop

Plant height

Maize plant height was measured at 45 and 90 days after planting (DAP) from the harvest area and their heights were measured in centimetres from the ground to the top of the last leaf (45 DAP) and to the apex of the tassel (90 DAP). The respective mean values were considered to be the plant heights of the periods.

Leaf area index

An automatic portable leaf area metre was used to measure the leaf area (cm^2) of five randomly selected middle row maize plants at 90 DAP. The mean value was then divided by the area covered by the maize plant (1875 cm^2).

Grain yield

Cobs from five randomly selected plants in the harvest area (3.375 m^2) were harvested, threshed and the grain dried in an oven (105°C) to a constant weight (assumed to be 0% moisture content). The yield was adjusted to a hectare basis. All yield figures were corrected to 12.5 % moisture content at the time of weighing.

Harvest Index (HI)

Harvest index was determined at harvest, and it was expressed as a percentage of the ratio of grain yield to the total biological yield or dry matter (DM). Only the above ground portion of the crop, dried to constant weight at 105°C was considered after harvest. The mathematical relationship between grain yield and dry matter yield is described by Stoskopf (1981) and Milthorpe & Moorby (1979);

$$\text{HI} = (\text{EY}/\text{BY})100$$

Where HI is the harvest index value as a percentage, EY is the grain yield in kg ha^{-1} and BY is the total biological yield in kg ha^{-1} .

Statistical analysis

Data was analysed using the MSTAT computer package. The Duncan's Multiple Range test was used to separate means where significant treatment effects were obtained from the analysis of variance.

RESULTS AND DISCUSSION

Alley cropped maize

Maize growth and yield parameters were evaluated as a measure of response to the N release from incorporated tree litter and fertiliser rate. Maize grain yields increased with increasing fertiliser rate irrespective of litter type (Table 1). Separation of means revealed significant differences in yield among the N levels (Table 2). There was no species effect (Table 3). The 112 kg N ha^{-1} fertiliser rate gave the highest yield which was significantly different from the rest (Table 2). The interaction of species and fertiliser rate was not significant at 5% level. The maize yields were comparable to the previous year's results at the same site at least for the 0 and 68 kg N ha^{-1} rates.

Results of alley cropped maize performance are varied and diverse. Kang *et al.* (1981b) found that addition of 10 t ha^{-1} fresh weights of prunings of *L. leucocephala*, containing about 100 kg N ha^{-1} produced similar maize yields as that fertilised with 100 kg N ha^{-1} . Similar promising results were also reported by Kang *et al.* (1984) and Isaac *et al.* (2004). Others have reported less promising results with alley cropping (Yamoah *et al.*, 1986b; Kass & Diaz-Romeu, 1985). These varied results are due to several factors and must not necessarily be interpreted as explicit failures of alley cropping in maintaining crop production. Some of these factors include tree/crop competition, amount and quality of residues, placement method, climatic and soil conditions. Yamoah *et al.* (1986b), found little differences in maize yields between plots with prunings of *Gliricidium sepium*, *Flemingia congesta* or *Cassia siamea*.

This study did not establish significant effects of species treatment (Table 2). Mean yields averaged over N rate decreased in the following order; *Leucaena* > Sole > *Senna* > *Flemingia*, though the differences were not significant despite differences in chemical composition (Table 4). This was probably due to complexing of N by

lignins and polyphenols which might have limited N release for crop uptake. The other reason could be the low pruning rates of 5 t ha⁻¹ which were incorporated in this study. Another reason could be that only a small proportion of the N added as part of plant residues was taken up by the maize crop following incorporation. Xu *et al.* (1993), working on N cycling in Leucaena alley cropping in semi-arid tropics found that the recovery of ¹⁵N by maize was less than 9% in the first cropping season. This view was also shared by Chirwa *et al.* (1994), who reported that the effect of prunings as a source of N was not even evident when prunings were considered as an N source in the absence of inorganic fertiliser during one season. Kang *et al.* (1981b) observed that although prunings from leguminous trees can supply N for crop production, N utilisation efficiencies are reportedly low as compared to inorganic N sources. Possible reasons for the inefficiency include NH₃ volatilisation due to surface incorporation, inappropriate timing of pruning applications, delayed release of N and competition with hedgerow trees. Palm (1988) observed that efficiency of N utilisation by crop plants might be improved if release of N from the prunings was synchronised with crop demands. The same researcher suggests that this synchrony will depend on the timing of application of the prunings relative to crop uptake patterns. In this study, the material was incorporated into the soil meaning that loss by N volatilisation was therefore considered to be minimal.

The significant increase in yield in response to inorganic fertiliser in combination with leguminous plant residues has been reported by many researchers (XU *et al.*, 1993; SADC/ICRAF, 1994; Chirwa *et al.*, 1994; Yamoah *et al.*, 1986b; Kang *et al.*, 1984). Where inorganic fertiliser was applied in combination with prunings, the readily available inorganic N may have been a more effective source of N compared to prunings which may take some time before they are decomposed and subsequently mineralised. For example, in this study, 5 t ha⁻¹ of *L. leucocephala* residues (3.50%N) and *S. siamea* and *F. macrophylla* (2.31%N) could have supplied 175 kgNha⁻¹ and 115.5 kgNha⁻¹ respectively in the unfertilised plots and the maize yields could have increased accordingly. This strongly suggests that N availability and crop uptake were apparently affected by factors other than just the N supplying potential by the legumes. The significant increase in maize yields with increasing fertiliser N rates (Table 3) suggests that the nutrient was limiting performance even in the presence of prunings. This is probably because N from residues was not readily available in the short term.

Alley cropped maize height and leaf area index (LAI)

Maize plant height at anthesis were significantly taller ($P \leq 0.05$) in *L. leucocephala* alleys than in the other species although this was not translated into yield (Table 2). Overall, the 68 and 112 kgNha⁻¹ rates had taller plants averaged over species than 0 and 34 kgNha⁻¹. This implies that increased N supply affected growth rate in terms of height.

Leaf area index was significantly affected by N rate ($P \leq 0.01$) (Table 2), which generally increased with increasing N fertiliser rate, but not affected by species. Species by N rate interaction was also insignificant. The 112 kgNha⁻¹ rate gave significantly ($P \leq 0.05$) greater LAI than the other N levels, although there were no significant differences between 34 and 68 kgNha⁻¹ rates (Table 2). Generally LAI increased with increasing N-fertiliser rate.

Increased LAI implies increased photosynthetic surface area which was probably responsible for the corresponding yield increase as the N levels increased.

Alley cropped maize harvest index (HI)

Harvest index (HI) is the ratio of economic yield to the total above ground dry matter yield and is an important indicator of the efficiency of photosynthate partitioning between source and sink (van Averbek & Marais, 1994). Maize in *L. leucocephala* alleys had larger HI though not significantly different from *S. siamea* alleys and the sole crop (Table 3). This suggests that growth and biomass production under Leucaena alleys were more pronounced. In fact, *L. leucocephala* residues decomposed faster, though not significantly different from *S. siamea*, thus suggesting better synchrony with crop demand. Combination of residue and fertiliser N produced higher HI due to improved N nutrition and hence biomass production in favour of the sink.

Table 1: Mean maize grain yield at Chalimbana as influenced by N rates and hedgerows of *L. leucocephala*, *S. siamea* and *F. macrophylla* pruned at 50 cm height

N rate	Maize grain yield under.....			
	Sole crop	Leucaena (kg ha ⁻¹)	Senna	Flemingia
0	3007	2806	1788	2222
34	3650	3602	3885	2952
68	4204	5186	4365	3192
112	6406	6500	5752	5359

Analysis of variance

Species = ns¶; N-level = **; Species x N-level = ns

cv(%)=18

¶** and ns= significant and not significant at 1 and 5% levels, respectively.

Table 2: The effect of fertiliser N rate on maize parameters

N-rate (kg ha ⁻¹)	Yield	Height (cm)		HI	LAI
		45DAP	90DAP		
0	2455.67d	60.53b	189.53c	0.37b	1.64c
34	3521.75c	72.33ab	205.38b	0.41ab	2.10b
68	4236.58b	70.48ab	214.44ab	0.42a	2.20b
112	6004.08a	79.95a	222.31a	0.43a	2.68a
*cv(%)	17.55	18.97	5.40	10.49	18.50
LSD _(0.05)	599.48	11.32	9.46	0.04	0.39

DAP- Days After Planting; HI- Harvest Index; LAI-Leaf Area Index

Table 3: The effect of species on maize yield parameters

Species	Yield ...(kg ha ⁻¹)....	Height (cm)		HI	LAI
		45DAP	90DAP		
<i>L. leucocephala</i>	4523.42a	75.60a	220.25a	0.44a	2.18a
<i>S. siamea</i>	3946.92a	72.15a	212.13a	0.42ab	2.19a
<i>F. macrophylla</i>	3431.08a	64.53a	201.43b	0.37b	2.09a
Sole crop	4316.67a	71.02a	197.84b	0.40ab	2.16a
*cv(%)	17.55	18.97	5.40	10.49	
18.5					

DAP- Days After Planting; HI- Harvest Index; LAI-Leaf Area Index

Table 4: Initial chemical composition of litter from the three leguminous plants

Component	<i>L. leucocephala</i>	<i>S. seamea</i>	<i>F. macrophylla</i>	Mean	SD±
% water	6.92	5.53	9.18	7.21	1.80
% Ash	7.22	5.28	5.82	6.11	1.46
% Carbon	62.03	68.70	57.61	62.78	5.57
% N	3.50	2.31	2.31	2.71	0.69
% Lignin	29.94	28.29	35.43	31.22	3.74
% Polyphenol	4.60	1.60	3.50	3.20	1.52
% cellulose	8.43	13.57	40.29	20.73	17.10
C: N Ratio	17.72	29.74	24.94	24.13	6.05
Lignin: N Ratio	8.55	12.25	15.33	12.04	3.39
Polyphenol: N ratio	1.31	0.69	1.51	1.17	0.43
Polyphenol+lignin: N	9.87	12.94	16.85	13.22	3.50

SD-Standard Deviation

CONCLUSIONS

Results obtained in this study provide guidelines for the selection and sustainable management of alley cropping systems. From this study it has been observed that there were no species effects on companion crop yield. Combination of pruning residues and inorganic N fertiliser is recommended for sustainable annual crop production. Also nutrient contribution from residue has been seen to be very minimal in the short term. The 68 kgNha⁻¹ in combination with prunings has proved to be attractive in terms of effect on decomposition and on the yields of the alley cropped maize. *L. leucocephala* and *S. siamea* had more positive attributes in terms of quality (save for the high polyphenol content for *Leucaena*), and greater influence on sustainable companion crop performance than *F. macrophylla*.

However, further research for more than one season with higher rates of incorporated residues and including some non leguminous residues for comparison is needed.

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