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SUBSOIL NITROGEN DYNAMICS AS AFFECTED BY PLANTED COPPICING TREE LEGUME FALLOWS IN EASTERN ZAMBIA

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SUMMARY

Nitrogen (N) is a major nutrient that limits crop production in southern Africa. We hypothesized that coppicing tree legumes, which are integrated in cropping systems, would intercept leaching nutrients and could also increase topsoil N in nutrient-depleted soils. This hypothesis was verified in three ongoing experiments at Msekera (experiments 1 and 2) and Kagoro (experiment 3) in Zambia. Planted tree fallows of *Gliricidia sepium*, *Leucaena leucocephala*, *Acacia angustisma*, and *Sesbania sesban* were compared with natural fallows and with continuous maize cropping with or without fertilizer (no-tree) controls. Top and subsoil samples were taken in the tree treatments and in the no-tree controls to establish short and long-term tree effects on soil N dynamics. ^{15}N was introduced at various soil depths down to 2 m to determine the vertical root-reach of coppicing trees. Samples taken on two different dates showed that planted trees are capable of capturing subsoil N. The amounts retrieved by trees in experiment 2 did not vary with depth or dates except for *A. angustisma* which retrieved more N from the top 0.20 m than from the subsoil. *L. leucocephala* and *G. sepium* had similar characteristics in terms of coppice biomass production and N content, and both species rooted to at least 2 m. *G. sepium* in a mixture with *S. sesban*, retrieved more applied N than when planted alone, implying that mixed fallows may be effective in resource capture. There was more inorganic-N in the topsoil of coppiced fallows than in unfertilized maize plots. Subsoil N accumulation was evident under fertilized maize plots. There was less subsoil nitrate-N beneath planted trees than beneath mono-cropped maize plots indicating that trees probably retrieved subsoil N. Maize yields subsequent to coppicing tree fallows were at least 170 % higher than unfertilized controls indicating improved soil fertility status in the tree systems.

INTRODUCTION

The supply of nitrogen (N) is one of the crucial concerns in the management of soil fertility in most tropical cropping systems. Nitrogen deficiencies are widespread in most arable Zambian soils. However, many smallholders lack the financial resources to purchase sufficient fertilizers to correct low soil N levels to increase crop yields (Mafongoya *et al*., 1998). Farmers in eastern Zambia are increasingly adopting planted tree fallow systems using coppicing tree legumes such as *Gliricidia sepium* and *Leucaena leucocephala* as a cheaper means of soil fertility replenishment (Kwesiga and Coe, 1994). Tree legumes are known to improve soil fertility by increasing inorganic-N availability

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mainly through biological nitrogen fixation (BNF), deep capture of N from subsoil profiles and the addition of leaf litter (Mafongoya *et al*., 1998).

In a few cases, it is customary to replenish the dwindling soil N economy by applying commercial fertilizers such as urea (Jannsan and Persson, 1982). However, continuous N fertilization of shallow rooting crops may lead to N leaching and accumulation in the subsoil, which is not only a loss for crops but may also pose serious environmental problems. Coppicing tree legumes with deep roots can potentially intercept nutrients leaching down the soil profile, and also access the nutrients accumulated in the subsoils below the rooting zone of annual crops. Subsoil nutrients captured by planted trees in farming systems become inputs when transferred to the soil surface in the form of leaf litter and other tree residues (Jama *et al*., 1998). Although considerable knowledge is available on the contribution of trees to N supply through aboveground biomass in agroforestry systems, little is known about the role of tree roots in N cycling.

If water or nutrient stress occurs in the topsoil, the uptake of subsoil nutrients and water by deep-rooted trees is enhanced, particularly if the subsoil has accumulated nutrients and water (Buresh, 1995). Torquebiau and Kwesiga (1996) found that planted tree legumes rooted much deeper than annual crops at Msekera in eastern Zambia. Adequate knowledge about the rooting depth of coppicing tree legumes is critical in designing agroforestry systems. Integration of trees and annual crops with similar rooting depths in time and space might result in deleterious competition for water and nutrients, and suppress crop yields (Giller and Cadisch, 1995). Most work on improved tree fallows in southern Africa has centered on single species fallows. These may be inefficient in resource (subsoil water and nutrient) capture. Mixing tree species of varying growth characteristics, for instance coppicing tree legumes planted with non-coppicing ones, may lead to large and prolonged soil fertility fallow effects on subsequent crops (Gatumbi, 2000).

This study used the ^{15}N method to demonstrate the potential of tree legumes to capture subsoil N. The effects of coppicing trees on soil N and maize yields were also investigated.

MATERIALS AND METHODS

Site characteristics

The study was done at Msekera Research Station (32° 34′ E 13° 39′S, alt. 1020 m asl) and on-farm, in Kagoro (32°00′E, 14°15′S, altitude 990 m asl) in eastern Zambia. The climate is sub-humid with a unimodal rainfall pattern. The wet season is from November to April followed by a dry season from May to October. Annual rainfall at Msekera generally ranges between 800 and 1000 mm, but rainfall at Kagoro is more variable, and the annual average is lower than 800 mm. The soils at Msekera are chromic–haplic Alisols (FAO, 1988), with the following properties in the top 0.20 m: pH in Ca Cl_2 (1: 2.5; soil to solution ratio) = 4.7, organic carbon = 1 %, sand = 52 %, and clay = 35 %. The Kagoro soils are classified as chromic-haplic Acrisols with the top 0.20 m layer having pH in $CaCl_2$ (1: 2.5; soil to solution ratio) = 5.2, less than 1 % organic C, sand = 44 % and clay = 50 %.

Experimental design, treatments and cropping history

Measurements of deep N capture by trees and subsoil N dynamics were made in the 1999/2000 season in two existing agroforestry field experiments at Msekera (experiment 1 established in November 1992 and experiment 2 established in 1997) and at Kagoro (experiment 3 established in 1997). Experiment 1 had 10 treatments but only *G. sepium* and *L. leucocephala* were selected for the study. Experiment 2 also had 10 treatments, but the following treatments only were selected: *Acacia angustisma, G. sepium, L. leucocephala, Sesbania sesban* and natural fallow. Experiment 3 had 12 treatments but only the *G. sepium* + *S. sesban* (mixture), *G. sepium* sole, *S. sesban* sole and the natural fallow were monitored. In all the experiments the continuous maize, with fertilizer and without fertilizer, were used as controls mainly to compare maize yields and soil inorganic-N against the planted fallow treatments. The experiments were rain-fed and the unimodal rainfall at both sites supports only one maize crop per year. The size of each experimental unit (gross plot) was 10 m × 10 m. The treatments were replicated three times in a randomized complete block design (RCBD). The spacing between trees was 1 m × 1 m. The planted fallow trees in experiment 1 had been clear felled in 1995 after three years of growth. When the study was carried out in 2000 the fallow treatments were under the fifth maize crop and the continuous maize cropping controls had their eighth crop (Chintu *et al*., 2004). The measurements in experiment 2 and 3 were made at the same time as in experiment 1 but this was during the second year of fallow, which was the second crop for the continuous maize cropping controls in both experiments.

Plant management

The foliar biomass of planted trees and from natural fallows, were respectively incorporated into the soil by hand hoeing in the post-fallow phase across all the experiments. The test crop, a hybrid maize variety (MM 604 taking 135–140 days from planting to reach physiological maturity and with a yield potential of 7–9 t ha^{-1}) was hand sown in continuous maize cropping and post-fallow plots, at a spacing of 0.25 m within the rows and 1.0 m between the rows across experiments. Fertilizer was applied only to the fertilized control plots at the rate of 20 kg N, 18 kg P, and 17 kg K ha^{-1} using Compound-D at sowing and 92 kg N ha^{-1} using urea, four weeks after sowing. All the experiments were cultivated manually by hand-hoe at establishment. Post-fallow resprouts of coppicing tree species in (experiment 1) were allowed to grow in the dry season. The resprouts were cut and incorporated at the time of maize sowing each season and again five weeks later. Experiments 2 and 3 were in the fallow phase until November 2000 and thus no management was needed except in the control plots of continuous maize, both with and without fertilizer. However, similar management to experiment 1 was applied in experiment 2 and 3 during the post-fallow phase.

Deep N capture

To determine the N sourcing depths of tree roots, ^{15}N labeled ammonium nitrate, with 3.0 atom percent ^{15}N excess, was placed at soil depths of 0.1, 1.1 and 2.0 m in experiment 1; 0.2 and 1.1 m in experiment 2; and 0.1, 0.5 and 1.0 m in experiment 3. Holes were drilled to the required depths at 0.5 m from the tree. Afterwards 20 mm diameter PVC tubes, 0.1 m longer than the depth of each particular hole, were installed with 0.1 m of each tube protruding above the soil surface. The tubes were designed to allow for the introduction of ^{15}N only to the required depth without contaminating any part of the soil profile above the placement point. In each plot, the ^{15}N tracer was applied as 10 cm^3 of ammonium nitrate solution at the rate of 30 kg N ha^{-1}, in eight tubes centred around two trees, per depth. The tubes were capped after the application of ^{15}N to avoid direct entry of rainwater.

Data collection and analysis

Sub-samples of leaves and wood of each tree species were collected on a plot basis at two months (first sampling, February, 2000) and three months (second sampling, March, 2000) after ^{15}N placement. Leaf and wood subsamples were oven dried at 65 and 105 °C respectively, to constant weight. The samples were finely ground, for total N and atom % ^{15}N excess analysis at the Seibersdorf laboratories in Vienna, Austria.

Plant-N content derived from the applied ^{15}N tracer (Ndff %) was calculated by the following equation reported by FAO/IAEA (2001):

$$Ndff\% = \frac{atom\%\,^{15}N\ excess\ of\ plant\ sample}{atom\%\,^{15}N\ excess\ of\ the\,^{15}N\ tracer\ applied} \times 100 \tag{1}$$

The N derived from the atmosphere and the soil (soil ATM %) was calculated as follows:

$$SoilATM = 100 - Ndff(\%) \tag{2}$$

To determine tree biomass production, the above ground biomass of trees was separated into foliage and wood at fallow clearing and the fresh weight of each component was recorded. The wood (>5 mm diameter) biomass was taken away for use as fuel wood. Weed and litter biomass was estimated only in the natural fallow plots, although substantial amounts were also present in planted fallows, at clearing. These data were used to estimate the dry weights. Maize plants were harvested from each plot at physiological maturity (140 days after sowing). Maize grain yields were determined on an oven dry weight basis.

Soil sampling for N (ammonium-N and nitrate-N) dynamics across all these experiments was conducted in the wet and dry seasons (preseason) using a metal sampler (42 mm diameter G. I. pipe). Samples were collected from 0 to 0.2, 0.2 to 0.4, 0.4 to 0.6, 0.6 to 1.0, 1.0 to 1.5 and 1.5 to 2.0 m depths in each treatment at Msekera. Experiment 3 in Kagoro was sampled only down to 1 m because below 1 m there was a large proportion of gravel which was difficult to sample. A soil sample from each depth was collected from the 8 × 8 m treatment subplot at eight points in a systematic diagonal pattern. These were combined into a composite sample of 250 g for each depth. Ammonium was determined by a colorimetric method

Table 1. Atom ^{15}N excess (%) in the foliage, and nitrogen derived from foliage (Ndff%) two (February, 2000) and three (March, 2000) months after label (^{15}N) placement at 0.2 m and 1.1 m respectively in experiment 2 at Msekera, Zambia.

		^{15}N excess (%)†				Ndff (%)			
Sampling date	Fallow species	0.20 m	1.10 m	*t*-value	*p*-value	0.20 m	1.10 m	*t*-value	*p*-value
9 February, 2000	*A. angustisma*	0.18	0.05	3.116	0.036	6.3	1.7	3.11	0.04
	Natural fallow	0.36	0.60	1.122	0.344	12.3	19.9	1.12	0.34
	G. sepium	0.28	0.07	1.350	0.270	9.5	2.5	1.35	0.27
	L. leucocephala	0.29	0.06	1.709	0.163	9.8	1.9	1.70	0.16
	S. sesban	0.13	0.08	1.408	0.200	4.3	2.6	1.41	0.20
	sed	0.197	0.115			6.63	12.3		
	p	0.66	0.05			0.66	0.05		
14 March, 2000	*A. angustisma*	0.11	0.10	0.254	0.812	3.7	3.4	0.25	0.82
	Natural fallow	0.42	0.32	1.064	0.347	13.9	10.7	1.06	0.35
	G. sepium	0.14	0.15	0.164	0.880	4.5	5.0	0.16	0.88
	L. leucocephala	0.12	0.05	1.488	0.211	4.0	1.6	1.49	0.21
	S. sesban	0.03	0.06	0.449	0.697	1.2	1.9	0.45	0.70
	sed	0.056	0.065			2.90	2.16		
	p	0.05	0.05			0.05	0.05		
Comparing Dates	February	0.21				6.9			
	March	0.16				5.3			
	t-value	1.028				1.03			
	p	0.31				0.31			

† Percentage of ^{15}N above the natural abundance of 0.366 %.

(Anderson and Ingram, 1993). Nitrate concentration was determined by the cadmium reduction method (Dorich and Nelson, 1984). The sum of inorganic ammonium-N and inorganic-Nitrate-N is collectively referred to as the 'inorganic-N'.

All data that did not follow a normal distribution were log transformed (Gomez and Gomez, 1984) before being subjected to analysis of variance (ANOVA) using the GLM procedure of the SAS system (SAS Institute, 1996). The *sed* or *t*-test, where appropriate, was used to separate treatment means in case of a significant *F*-test at $p \leq 0.05$.

RESULTS

Plant ^{15}N enrichment and deep soil N capture

Both the planted and natural fallows were able to acquire N from as deep as 1.0 m at Kagoro, 1.1 m in experiment 2 and 2.0 m in experiment 1 at Msekera (Tables 1, 2 and 3). However, there was no significant difference in the ^{15}N enrichment between *L. leucocephala* and *G. sepium* in experiment 1 at both sampling dates and at all three depths (Table 3), implying similar rooting patterns for the two tree species in the top 2.0 m. The ^{15}N concentration in the natural fallow in experiment 2 was consistently high at both sampling times but in the planted tree species the first samples from

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Table 2. Leaf-nitrogen derived from the N label (Ndff%) at two and three months respectively after placement at 1 m soil depth at Kagoro, Zambia.

	Ndff (%)			
Fallow systems	9 February, 2000	14 March, 2000	*t*-value	*p*
G. sepium Sole	4.0	2.2	1.71	0.117
S. sesban Sole	3.9	1.1	3.23	0.014
S. *sesban*† + *G. sepium*	5.0	2.6	2.33	0.040
S. sesban + *G. sepium*†	11.0	5.5	1.59	0.136
Natural fallow	5.3	11.2	1.95	0.050
sed	2.40	2.15		
p	0.05	0.01		

† The species in mixture treatment to which the mean values in the row belong.

Table 3. *G. sepium* and *L. leucocephala* foliage nitrogen derived from the label (Ndff%) at two and three months after placement at 0.1, 1.1 and 2 m respectively in experiment 1 at Msekera, Zambia.

	Ndff (%)					
	February, 2000			March, 2000		
Fallow species	0.10 m	1.10 m	2.0 m	0.10 m	1.10 m	2.0 m
G. sepium	3.25	0.20	0.15 (1.503)†	2.82	1.05	0.93 (1.211)†
L. leucocephala	4.15	0.32	0.27 (2.151)†	5.00	3.55	3.30 (4.450)†
t-value	0.977	0.569	1.857	0.898	2.177	1.093
p	0.384	0.599	0.204	0.420	0.095	0.336

† Value in parenthesis is *sed* comparing differences across depths for each sampling date and species at $p = 0.05$.

subplots with ^{15}N placed at 0.2 m had relatively more ^{15}N than the second samples from the same trees.

The trend of decreasing ^{15}N content with time was also observed for planted fallow trees in experiment 3 at Kagoro (Table 2). Similarly, the trend of increasing ^{15}N in the natural fallow at Msekera was consistent even for Kagoro at 1.0 m depth (5.3 Ndff% at first sampling compared to 11.2 Ndff% at second sampling, Table 2). An opposite trend was observed in the case of the planted fallows. For instance; 3.9 Ndff% at first sampling compared to 1.1 Ndff% for *S. sesban* at second sampling at Kagoro (Table 2). Natural fallow had the highest Ndff% at second sampling in Kagoro and at both samplings in experiment 2 at Msekera (Table 1). As at first sampling, the *G. sepium* planted in mixture with *S. sesban* at Kagoro had retrieved significantly more of the ^{15}N label than the sole *G. sepium* and all the other treatments (Table 2).

Tree nitrogen yield

Significant treatment differences were observed in the plant biomass N variables at Kagoro at the end of three years (Table 4). *G. sepium* sole was higher in all variables measured (i. e. total biomass N derived from the soil and atmosphere, Ndff%, total leaf

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Table 4. Tree nitrogen yield derived from the atmosphere (soil ATM), fertilizer (Ndff) and total leaf-N at the end of three-years of fallow in experiment 3 at Kagoro, Zambia.

	Tree nitrogen yield (kg ha^{-1})			
Fallow systems	Soil ATM	Ndff	Total leaf-N	Total N yield
G. sepium sole	140.9	4.69	38.9	145.6
S. sesban sole	17.8	0.50	5.0	18.3
S. sesban† + *G. sepium*	24.3	0.89	2.1	25.3
S. sesban + *G. sepium*†	70.1	5.75	15.0	75.9
Natural fallow	0.06	0.01	¶	0.07
sed	8.24	1.780	3.04	8.60
p	0.01	0.01	0.01	0.01

¶ = Not determined.
Soil ATM = Total biomass nitrogen derived from the soil and the atmosphere.
† = The species in mixture treatment to which the mean values in the row belong.

Table 5. Total nitrogen concentration in the foliage of different planted and natural fallow species in experiment 2 at Msekera, Zambia.

Fallow systems	N concentration (%)
A. angustisma	3.48
Natural fallow	1.01
G. sepium	3.81
L. leucocephala	3.16
S. sesban	3.12
sed	0.450
p	0.05

N and total N yield). Planted tree legumes in experiment 2 had similar high nitrogen concentrations ranging from 3.1 to 3.8 % (Table 5). However, the natural fallow species (mostly grasses) had significantly lower N concentrations (1 %) than planted trees. Tree N yield for experiment 1 resprouts, indicated that both *L. leucocephala* and *G. sepium* had similar yield characteristics (Table 6). However *L. leucocephala*, unlike *G. sepium*, yielded more total biomass N derived from the soil and the atmosphere (soilATM) at the first compared with the second sampling (Table 6).

Soil N

Wet season soil N-experiment 2 (January, 2000). Wet season nitrate-N and total inorganic-N in the top 0.20 m were higher in fertilized maize plots (Figure 1) than in planted fallows. *L. leucocephala* and *A. angustisma* had the lowest top and subsoil inorganic-N (Figure 1b). However, soil nitrate-N levels beyond 0.6 m depth did not vary among treatments although the fertilized maize still had the highest nitrate levels.

Dry or preseason soil N-experiment 2 (October, 2000). Compared to the wet season soil N trend (Figure 1), there was marked nitrogen depletion in the top 0.40 m under the fertilized maize, in the dry season, while the soil N levels in planted fallow remained

Table 6. Biomass yield and nitrogen derived from the atmosphere and the soil by foliage of post fallow *G. sepium* and *L. leucocephala* coppices in experiment 1 at Msekera, Zambia.

	Biomass and N yields					
	9 February, 2000			14 March, 2000		
Fallow species	Biomass ($t\ ha^{-1}$)	N ($kg\ ha^{-1}$)	SoilATM ($kg\ ha^{-1}$)	Biomass ($t\ ha^{-1}$)†	N ($kg\ ha^{-1}$)†	SoilATM ($kg\ ha^{-1}$)†
G. sepium	1.07	53.5	44.5	1.06 (0.024, 0.98)	43.9 (1.67, 0.115)	43.1 (1.64, 0.121)
L. leucocephala	1.16	66.6	63.6	0.93 (1.252, 0.264)	37.1 (2.41, 0.071)	35.9 (2.47, 0.006)
t-value	0.253	1.16	1.06	0.770	1.04	1.04
p	0.817	0.33	0.37	0.484	0.39	0.39

† Value in parentheses is *t*-value with *p*-value after comma, comparing differences between sampling dates.
Treatment means of the two species were not significantly different at both sampling dates by *t*-test at $p = 0.05$.
SoilATM = Total biomass nitrogen derived from the soil and the atmosphere.

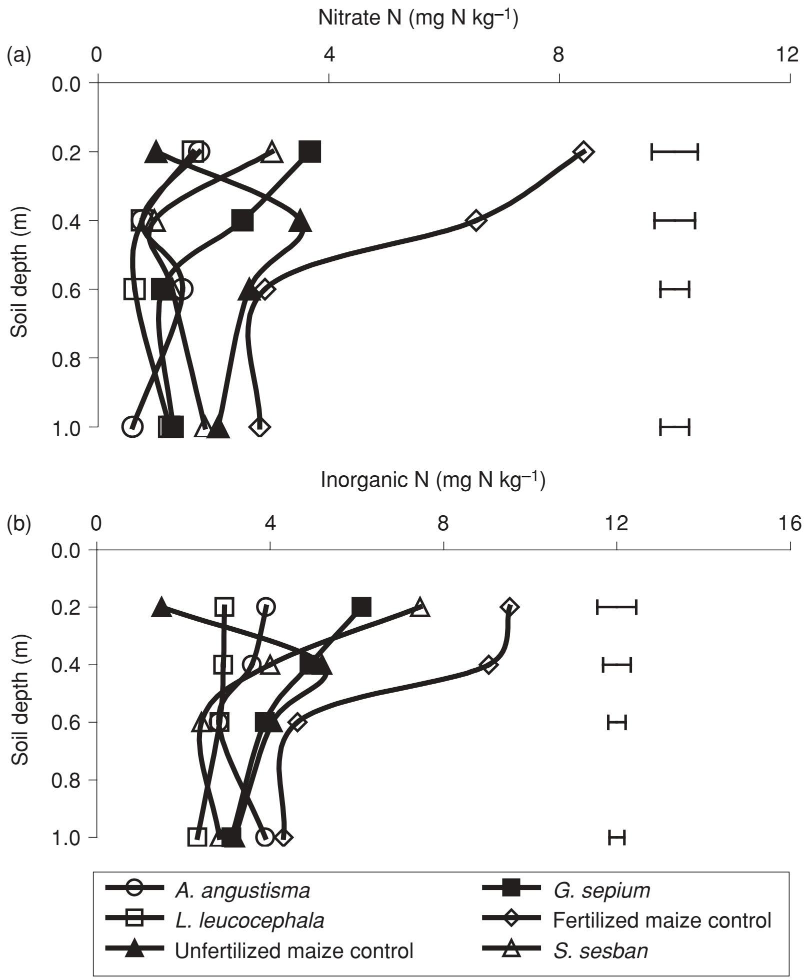

Figure 1. Wet season soil nitrate (a) and inorganic N (b) as affected by treatments and soil depths in experiment 2 at Msekera, Zambia, January 2000. Horizontal bars represent *sed*.

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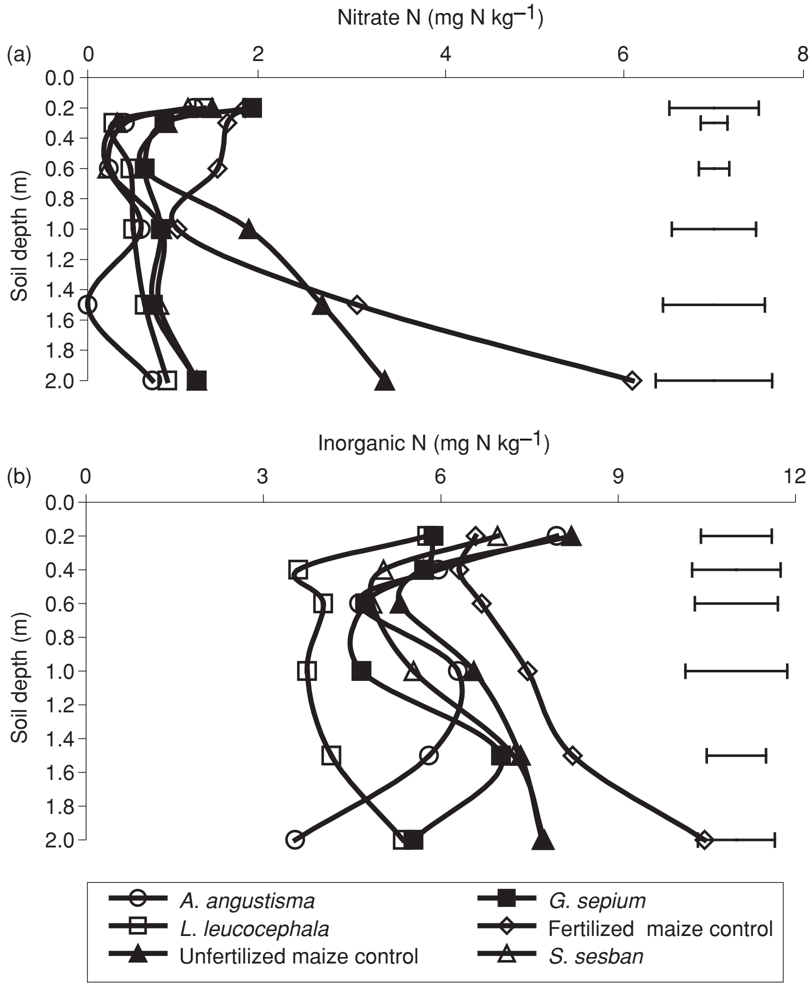

Figure 2. Preseason soil nitrate (a) and inorganic N (b) as affected by treatments and soil depths in experiment 2 at Msekera, Zambia, October 2000. Horizontal bars represent *sed*.

stable throughout the profile (Figure 2). Significant subsoil nitrate accumulation was evident under the unfertilized maize and even more under fertilized maize at 2.0 m (Figure 2a).

Preseason soil N-experiment 1 (November, 1999). Topsoil N was higher under the planted fallow systems than under the unfertilized maize control. Both planted fallow systems (*L. leucocephala* and *G. sepium*) had very similar soil N trends, and N concentrations between them did not differ significantly over all the profiles studied (Figure 3). Topsoil N was higher in the tree fallows (top 0.20 m) than in the no tree unfertilized control, whereas subsoil N concentrations were similar from 0.40 m to 1.5 m. However, N levels at 2 m were higher under the control treatment than in the planted fallow systems (Figure 3). In short, N concentrations were high in the top 0.20 m under the planted fallows systems but consistently low below 0.20 m.

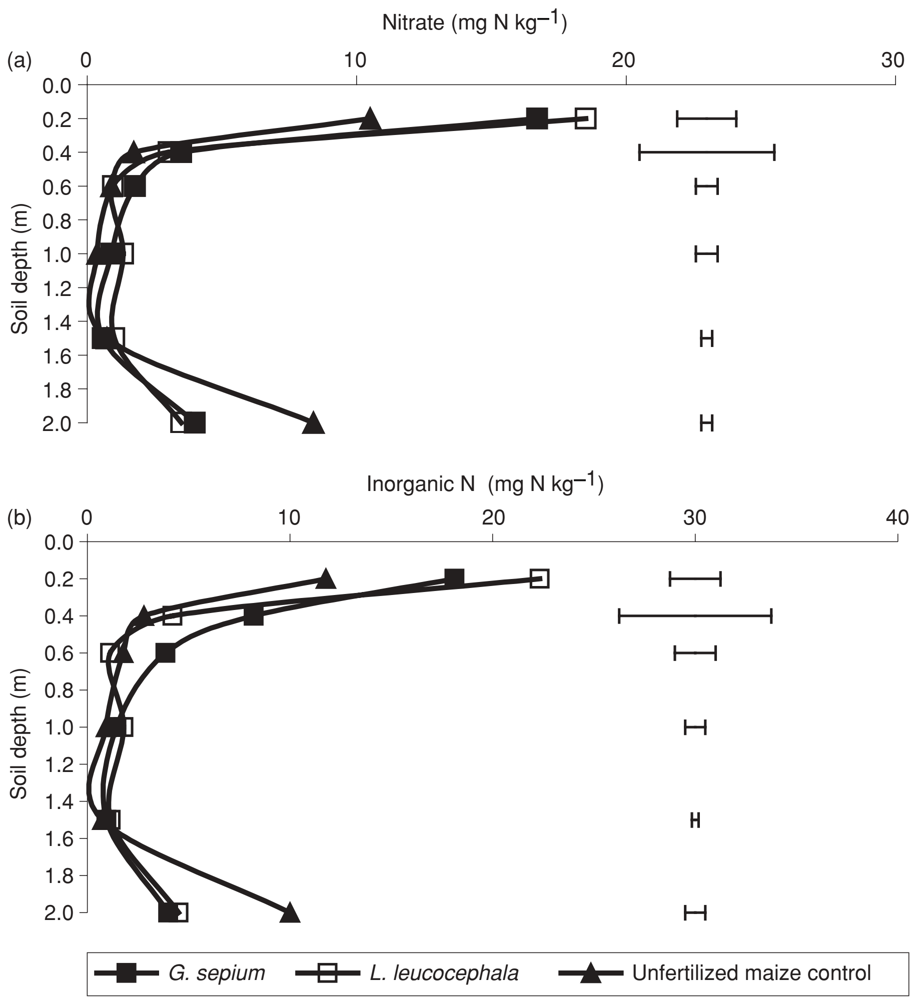

Figure 3. Preseason soil nitrate (a) and inorganic N (b) as affected by treatments and soil depths in experiment 1 at Msekera, Zambia, November 1999. Horizontal bars represent *sed*.

Wet season soil N-experiment 1 (February, 2000). Soil nitrate-N levels in the planted coppicing fallows were higher than the control in the topsoil but they were lower at 2.0 m depth. Soil nitrate-N concentrations in the unfertilized maize control increased with depth (Figure 4).

Maize grain yield

There were significant differences in grain yields between the treatments (fertilized maize, *G. sepium* and *L. leucocephala)* and the controls (natural fallow and unfertilized maize) in experiment 1 at Msekera. The highest grain yield of 5.1 t ha^{-1} was obtained from the fertilized plots. This was followed by *G. sepium* and *L. leucocephala* which had

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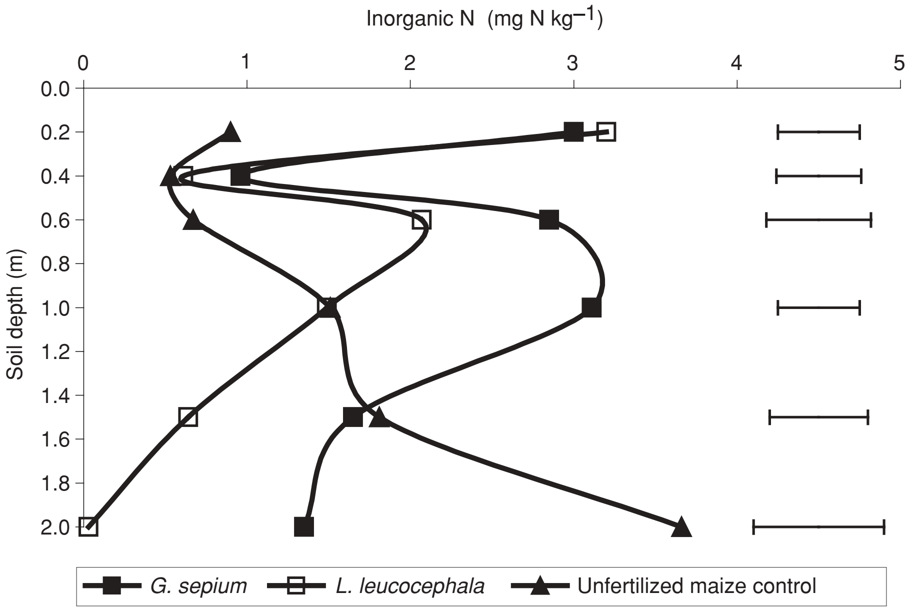

Figure 4. Wet season soil inorganic-nitrate as affected by treatments and soil depths in experiment 1 at Msekera, Zambia, February 2000. Horizontal bars represent *sed*.

Table 7. Maize grain yield (eight successive crop) following planted trees fallows and natural fallow compared with continuous maize with and without fertilizer in experiment 1 in 2000 at Msekera, Zambia.

Cropping system	Grain yield (t ha^{-1})
Continuous maize with fertilizer	5.11
Gliricidia sepium	3.23
Leucaena leucocephala	3.34
Natural fallow	1.20
Continuous maize without fertilizer	0.90
sed	0.831
p	0.05

similar yields of 3.2–3.3 t ha^{-1}, respectively. The planted fallow yielded 170–220 % more maize grain than the natural fallow and unfertilized maize controls (Table 7).

DISCUSSION AND CONCLUSION

The higher ^{15}N concentration in the natural fallow can be attributed to low dilution of the applied ^{15}N as a result of its low plant total N concentration compared to tree legumes. Furthermore, the natural fallow consisted mostly of non-nodulating grasses, implying that ^{15}N dilution due to atmospheric N-fixation was absent. Rowe and Cadisch (2002) treated *Peltophorum*, a non-N-fixing legume, and *G. sepium*, a

N-fixing legume, with the same levels of ^{15}N. *Peltophorum* had a higher background ^{15}N abundance than *G. sepium* since it was reliant on soil N (Rowe and Cadisch, 2002). The dilution effects on the fertilizer-derived ^{15}N in a non-fixing plant come only from the indigenous soil N. However, despite the planted trees being prone to dilution of ^{15}N the *G. sepium* planted in a mixture with *S. sesban* in Kagoro had significantly more Ndff % at first sampling than the natural fallow and *G. sepium* sole treatment. This is an indirect indication that *G. sepium* may have retrieved more subsoil N when planted in a mixture than as a single species. The enhanced N capturing potential of *G. sepium* in a mixture over the *G. sepium* in sole establishment may be a response to inter-specific competition for nutrients with the *S. sesban*, unlike in pure stands. The competition could have caused the *G. sepium* to develop a profuse rooting system to meet its water and nutrient demands. Thus, mixed fallows could be more efficient than single species fallows in nutrient capture (Gathumbi, 2000). This study did not distinguish between N derived from the atmosphere and the soil because an appropriate non-fixing reference plant was not included. However, the ^{15}N results indicated that, the natural fallow vegetation and the two-year-old planted fallow trees in experiment 2 at Msekera and experiment 3 at Kagoro rooted to at least 1 m deep. *G. sepium* and *L. leucocephala* coppices in experiment 1 had a vertical root-reach of at least 2 m. Torquebiau and Kwesiga (1996) reported a 7 m vertical root-reach for two-year-old *S. sesban* at Msekera, although 85 % of the roots occurred in the top 1 m. The rooting depth of annual crops like maize under differing treatments may also vary. Torquebiau and Kwesiga (1996) found 85 % and 97 % of maize roots in the top 1 m of soil following two years and one year of *S. sesban* fallow respectively. Data on both the vertical and lateral soil N capture by trees, will be critical in designing compatible agroforestry systems of planted perennial tree legumes and annual crops under N limiting conditions (Giller and Cadisch, 1995). Superficially-rooted coppicing trees that source nutrients from the same soil depth as annual crops may not be compatible in simultaneous tree-crop agroforestry systems. In this context, efficient nutrient cycling in fallows calls for deep rooted trees to access deep subsoil nutrients, and to avoid mining the topsoils on which shallow rooted annual crops depend.

The high ^{15}N dilution and low subsoil N associated with planted coppicing tree fallows, indirectly imply that the trees have the potential to reduce N leaching or subsoil N. The no-tree systems such as the continuously fertilized and unfertilized maize plots are very leaky as they allow large losses of water and nutrients into the subsoil profiles due to scarcity of deep roots. The situation is likely to be worse in such systems during the dry season when no crops are present to utilize mobile residual water and nutrients in the subsoil. The ^{15}N results show that planted tree legumes can intercept or capture N from sub-soils and convert it into tree biomass N, part of which could potentially be recycled to crops upon leaf biomass application in cropping systems (Jama *et al.*, 1998). The high soil N in the top 0.2 m in the planted fallows of experiment 1 could be a result of leaf biomass application in November, 1999 and may be directly responsible for the increase in maize grain yield over non-fertilized maize and natural fallow. The presence of high nitrate-N in the top 0–0.2 m soil profile in the tree based cropping systems is a good indicator of high soil fertility. Nitrate has been widely used as a measure of N availability in temperate soils because it is highly influenced by soil management, has good reproducibility in laboratory analysis and correlates highly with subsequent crop yields (Barios *et al*., 1997). The fact that natural fallow grasses had a higher ^{15}N enrichment does not imply that they are much more efficient than the planted tree legumes in retrieving subsoil N. The high enrichment may have resulted from low ^{15}N dilution due to the inherently low total N, 1 % as compared to 3–3.8 % in tree legumes. The low N content of grasses coupled with low biomass production implies that grasses in natural fallows would be incapable of making a substantial contribution to increasing N availability to crops after fallow.

G. sepium sole at Kagoro had the highest total above ground biomass N (146 kg N ha^{-1}) yield after three years of growth. However, a substantial quantity of N was taken out as wood for home use and only 39 kg N ha^{-1} from the leaf biomass was applied. Thus, the soil fertility effects experienced following a tree fallow can be attributed to various other factors such as root and leaf litter, BNF and improvements in soil physical properties. The leaf-N in pure stands of planted trees was always 100 % higher than that of the same species grown in a mixture. The leaf-N yield of *S. sesban* (5.0 kg N ha^{-1}) was much lower than the value (95 kg N ha^{-1}) estimated by Torquebiau and Kwesiga (1996) for two-year-old *S. sesban*. However, the disparity is due to the fact that our estimates were made in the three-year *S. sesban* fallow. *S. sesban* fallows are known to experience high mortality after two years of growth (Torquebiau and Kwesiga 1996) and the mortality in this study was over 80 %. The high soil ATM in the *L. leucocephala* treatment at the first sampling was a direct result of advanced leaf shedding in March (as only standing tree biomass, and not fallen tree litter, was measured).

In conclusion, our results show that, planted trees are indeed deep-rooted and have the potential to retrieve subsoil nutrient although how much remains unknown. Results also hint that mixed fallows would be more effective than single species fallows in nutrient capture. Further, planted trees can potentially increase topsoil N through plant residue additions and these may translate into significant improvements in subsequent maize grain yield. Studies need to be undertaken to establish the potential of a range of agroforestry planted trees to intercept, retrieve and recycle subsoil N.

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