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**Title**

Root and Inorganic N Distribution in a Soil Profile: Cropped Versus Non-Cropped Fields

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## Introduction

The rapidly increasing population in developing countries and reduction in arable land in many parts of the tropics has resulted in decreased bush fallow period for natural regeneration of soil fertility. While a two year grass fallow phase in a Ferrasol increased N content in the top 0-15 cm (Jones, 1972), tree legumes were better at increasing soil fertility than natural weed regrowth (Dreschsel et al., 1991). A maize crop grown on land after 1, 2 and 3 years of sesbania fallow gave yields of 2.3, 5.6 and 6.0 tonnes ha<sup>-1</sup>, respectively, without N-fertilizer (Onim et al., 1990). This was much higher than the 1.6, 1.2, and 1.8 tonnes ha<sup>-1</sup> after 1, 2 and 3 years of continuous maize cropping (Kwesiga and Coe, 1991).

Mineralization of organic matter (OM) in absence of plant roots can result in build up of nutrient levels in the soil (Hartemink et al., 1995) that can potentially be leaching. Nitrate leaching of 40-84 kg N ha<sup>-1</sup> as been reported to occur between maize seasons (Weisler and Horst, 1993). Leaching of soil nutrients takes place when there is excessive downward movement of water as opposed to upward movement from plant uptake (Allison, 1973). In N fertilized coffee plantation in Kenya, up to 2200 kg NO<sub>3</sub>-N ha<sup>-1</sup> was observed to accumulate at 100 to 500 cm depth (Michori, 1993). While losses of up to 56 kg NO<sub>3</sub>-N ha<sup>-1</sup> have been observed in monocropped maize, only 1 kg NO<sub>3</sub>-N ha<sup>-1</sup> was lost in mixed perennial system (Seyfried and Rao, 1991). Loss of NO<sub>3</sub>-N reported during the first two months of growth in maize was attributed to low N requirement that reduced its uptake coupled with low quantity of roots (Cahn et al., 1993; Poss and Saragoni, 1992). Better root establishment and continued presence of roots in a perennial system is mostly likely responsible for reduced NO<sub>3</sub>-N losses. This study was carried out to determine effect of plant cover and cropping system on inorganic-N in the soil profile.

## Materials and methods

### Study site and project initiation

The study was carried out at the International Centre for Research in Agroforestry (ICRAF) Field Research site. The research site has two growing seasons annual each with rainfall ranging from 300-500 mm. Previously, the site was under unfertilized maize. The soil at the site is a fine mixed isothermic Kandic Paleustalf (USDA, 1992). Air dried soil in the top 15 cm had pH (1:2.5 soil/water suspension) = 5.7, organic carbon = 8g kg<sup>-1</sup>, bicarbonate – EDTA extractable P = 5 mg kg<sup>-1</sup>, KCL extractable Ca = 3.4 cmol<sub>c</sub>kg<sup>-1</sup>, clay = 29% and sand = 565. The experiment was laid down in a randomized complete block design with three replications and land uses systems (LUS): *Sesbania sesban* (Sesbania) fallow, unfertilized *Zea mays* (Maize), weed fallow, and bare fallow. At the start of first season, sesbania was established whereas weed and bare fallow was under maize. Natural weeds were left to grow in the fields during the second season.

Four-months-old sesbania seedling were planted at spacing of 100 cm by 100 cm. Maize was sown at spacing of 75 cm by 25 cm. At the end of every season, all above ground biomass from maize was removed from the plots. Root sampling of fourth maize crop was done at plant physiological maturity. Weeds were left undisturbed for three successive seasons, and root sampling done during the fourth season. Sampling sesbania roots was done eighteen months after establishment.

### **Deep soil sampling**

Deep sampling was done using a corer at the top horizons and Edelman auger in lower layers. Samples were collected from eight layers unless restricted by a rocky layer: 0-15 cm, 15-30 cm, 30-50 cm, 50-100 cm, 100-150 cm, 150-200 cm, 200-250 cm, and 250-300 cm. In sesbania, the diagonal distance between two trees (140 cm) was divided into two strata (0-50 cm and 50-65 cm) from the tree. Samples from the each stratum were compost before  $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$  was determined. Soil layer  $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$  content was calculated as weighted mean. Bulk density of each layer established using a corer on the dug pit was used to N content in  $\text{kg ha}^{-1}$ .

### **Plant and root sampling**

In sesbania, depth of sampling was up to the bedrock, while it was up to 150 cm in maize and weed. Weed material was obtained from a 150 x 10 cm area, the length of which coincided with the surface edge of dug soil profile. In maize plot, profile was dug across two rows and two plant 5 cm from the profile wall were harvested at physiological maturity. Maize plant separated into grains, cores and stover. In sesbania plots, profiles were dug diagonally and one plant 5 cm from the profile wall were harvested. Harvested sesbania was separated into pods and seeds, leaves and young immature flowers, twigs (< 2 cm diameter) and stems (> 2 cm diameter). All plant material was dried to obtain dry weight. Soil for root extraction was obtained by driving a metallic box (15 cm by 15 cm by 10) perpendicularly into the profile. On a 15 cm soil layer, ten samples were obtained in maize and weed and nine samples in sesbania. A subsample was obtained from each sample for inorganic N determination and the rest washed to extract roots. In sesbania, inorganic N and root measurement for a given layer was calculated as weighted mean to account for surface area round the tree.

### **Root scanning, soil extraction, soil and plant tissue analysis**

Roots length and average diameter were obtained using Delta-T-scan (Kirchhof, 1992). Soil sample water content was obtained at the time of extraction and soil extracted with potassium chloride (2 N KCL). Complete oxidation of plant material was achieved by Kjeldahl digestion (Parkinson and Allen, 1975). Soil  $\text{NH}_4\text{-N}$  concentration was determined colorimetrically (Anderson and Ingram, 1993). Extractable soil  $\text{NO}_3\text{-N}$  and plant N concentration was determined by calorimetric method (Hilsheimer and Harwigs, 1976). Phosphorous was determined by the molybdenum blue colorimetric method (ICRAF Lab Manual, 1995).

Statistical analysis of data was done using Generalized Linear Model Procedures in SAS (SAS Institute, 1989).

## **Results**

### **Shoot biomass and nutrient content**

Total above-ground biomass was approximately 12, 28, and 5.3 tonnes  $\text{ha}^{-1}$  for maize, sesbania, and weeds respectively (Table 1). The materials contained 86  $\text{kg N ha}^{-1}$  and 7  $\text{kg P ha}^{-1}$  in maize, 238  $\text{kg N ha}^{-1}$  and 12  $\text{kg P ha}^{-1}$  in sesbania and 50  $\text{kg N ha}^{-1}$  and 0.6  $\text{kg P ha}^{-1}$  in weeds (Table 1).

Table 1. Shoot N and P content, shoot and root biomass, and shoot:root ratio of different LUS.

Variable	Maize	Weed	Sesbania
	Kg ha <sup>-1</sup>		
Shoot N	86.5 (34.1)	50.1 (30.7)	248.1 (51.0)
Shoot P	7.1 (1.6)	5.8 (4.1)	11.3 (3.7)
Shoot weight	12230 (4109)	5318 (2540)	28603 (8792)
Root weight	776 (227)	914 (172)	11635 (1824)
Shoot: root ratio	16	5.8	2.5

Value in parenthesis is standard deviation

### **Soil Inorganic N content**

Nitrate contents as determined by deep sampling were similar in all LUS in the top 30 cm layer (Figure 1). However, in bare fallow, the NO<sub>3</sub>-N increased significantly (p=0.05) to 16 kg ha<sup>-1</sup> in the 30-50 and 86 kg ha<sup>-1</sup> in the 50-100 cm soil layer was higher (P=0.05) compared to LUS. At 50-100 cm layer, bare fallow and continuous maize had higher NO<sub>3</sub>-N either weed or sesbania fallow. At deeper layers greater than 200 cm, continuous maize had high NO<sub>3</sub>-N compared to bare fallow. In general, below 30 cm depth, bare fallow and continuous maize had the highest total NO<sub>3</sub>-N. At 30-200 cm layer, the NO<sub>3</sub>-N contents reached 129 and 207 kg ha<sup>-1</sup> in maize and bare fallow, respectively. In the same layer, only 50 and 47 kg ha<sup>-1</sup> were observed in sesbania and weed fallow, respectively. Ammonium in the soil profile was low at the top 25 cm for all LUS (Figure 1). The NH<sub>4</sub>-N content in the bare fallow was the lower of all LUS at all depths. In general, the NH<sub>4</sub>-N content increased in all LUS and peaked at 50-100 cm layer. However, but unlike NO<sub>3</sub>-N in same depth, the NH<sub>4</sub>-N levels were in the range 5-10 kg N ha<sup>-1</sup>.

Compared to deep sampling, comparable soil layer in profile sampling had similar NO<sub>3</sub>-N and NH<sub>4</sub>-N (Table 2).

### **Root length density and biomass**

At soil depth 0-15 cm, root length density of 4.0 x 10<sup>4</sup> m m<sup>-3</sup> (60,000 km ha<sup>-1</sup>) was higher (P=0.05) than 2.5 x 10<sup>4</sup> m m<sup>-3</sup> (38,000 km ha<sup>-1</sup>) and 7.0 x 10<sup>3</sup> m m<sup>-3</sup> (11,000 km ha<sup>-1</sup>) in sesbania and maize, respectively (Figure 2). Root length density at 30-45 cm dropped by 80 % (Sesbania), 58% (Weed) and 50% (Maize) to 6.7 x 10<sup>3</sup>, 4.0 x 10<sup>3</sup> and 3.5 x 10<sup>3</sup> m m<sup>-3</sup>, respectively. Between 50 cm and 135 cm depth, the change in root length density was small and sesbania showed an almost uniform distribution to below 250 cm depth.

Below-ground biomass for roots with a diameter ≤ 2 mm diameter was highest for all LUS at 0-15 cm than other layers (Figure 2). Sesbania had higher root biomass at the top 15 cm than maize and weed. Root weight of 528 g m<sup>-3</sup> (792 kg ha<sup>-1</sup>) in sesbania, 193 g m<sup>-3</sup> (289 kg ha<sup>-1</sup>) in maize, and 310 g m<sup>-3</sup> (464 kg ha<sup>-1</sup>) in weed, were observed. Root weight declined by more than 50 % at 45-60 cm depth to 120 g m<sup>-3</sup>, 54 g m<sup>-3</sup>, and 37 g m<sup>-3</sup> for sesbania, maize, weeds, respectively. At 135-150 cm, 45 g m<sup>-3</sup> in sesbania fallow was significantly higher (P=0.05) than 11 g m<sup>-3</sup> in weed fallow and 8 g m<sup>-3</sup> in maize. Sesbania fallow had additional biomass of 67 g m<sup>-3</sup> (100 kg ha<sup>-1</sup>) at 255-270 cm.

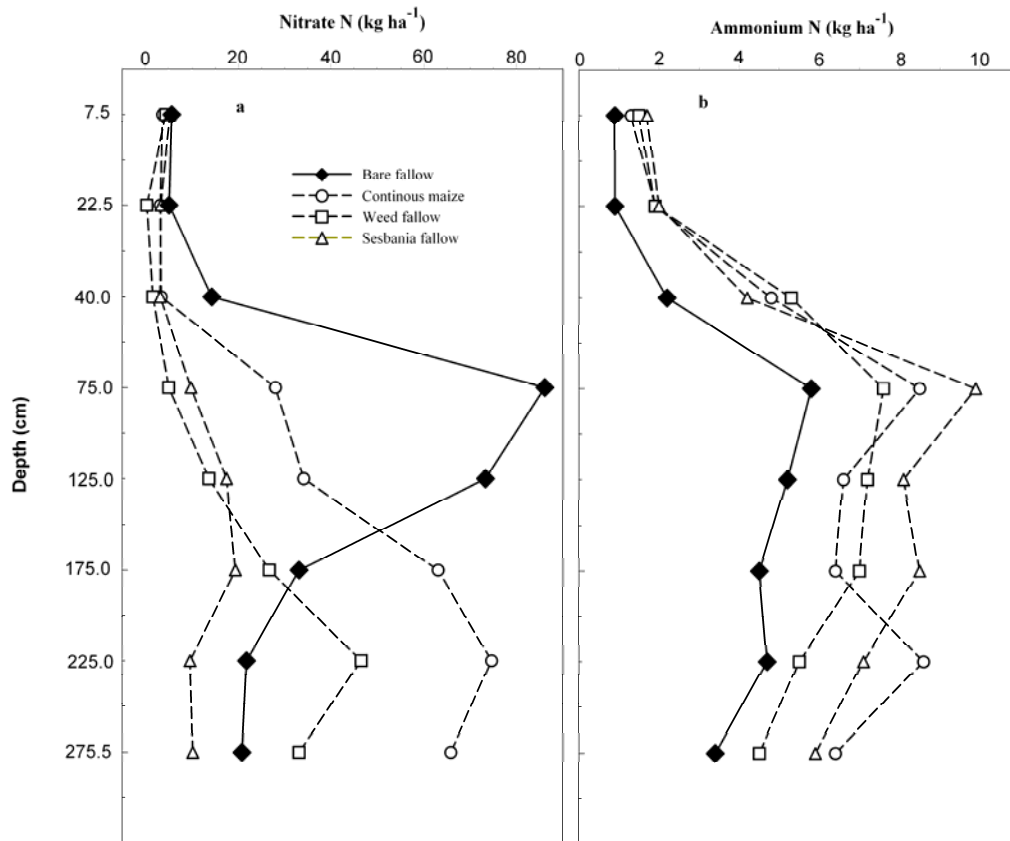


Figure 1. Soil NO<sub>3</sub>-N (a) and NH<sub>4</sub>-N (b) contents at varying depths for different LUS obtained from deep soil sampling. Values are Means (n=3).

Table 2. Soil NO<sub>3</sub>-N and NH<sub>4</sub>-N contents for the different LUS obtained from profile sampling.

Soil depth	NO <sub>3</sub> -N			kg ha <sup>-1</sup>	NH <sub>4</sub> -N		
	Maize	Weed	Sesbania		Maize	Weed	Sesbania
0-15	5.8	8.0	5.9		0.7	8.0	5.9
15-30	1.2	1.8	3.6		1.2	1.8	3.6
30-60	2.3	2.2	4.3		3.3	4.6	4.2
60-105	11	6.8	4.2		5.2	6.8	4.5
105-150	34.0	25.0	7.0		3.4	6.7	4.1
150-195			15.3				5.1
195-255			5.5				4.1
255-270			0.7				2.1

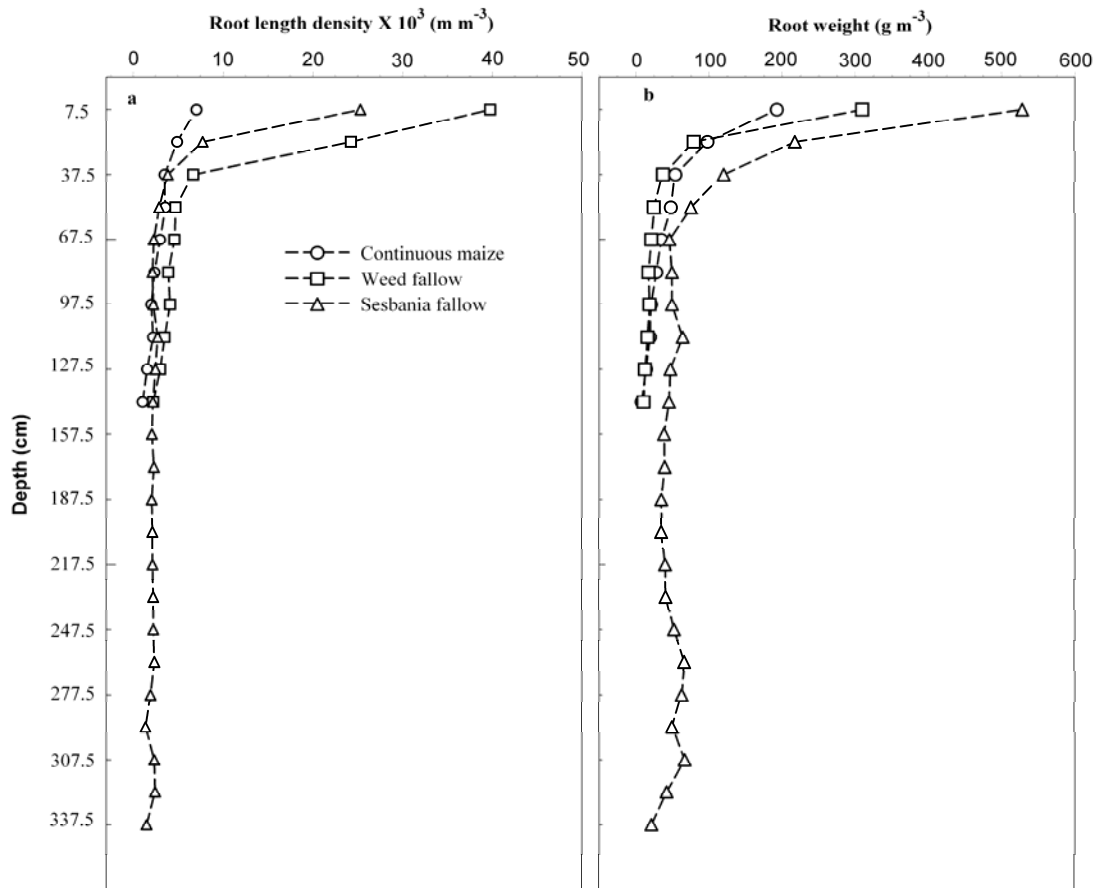


Figure 2. Root length density (a) and dry weight (b) of all roots less than 2 mm in diameter at varying depths for the different systems. Values are means (n=3).

## Discussion

Microbial mineralization of soil OM is the source of the soil inorganic N because no N fertilizer had been applied at the experimental site for 3 year prior to study initiation. Because mineralization occur mainly in the upper horizons, leaching is responsible for  $\text{NO}_3\text{-N}$  accumulation at lower depths. Low  $\text{NH}_4\text{-N}$  at top horizon is probably a result of aerobic condition that facilitates nitrification. At lower depths low oxygen, reduced nitrification, and low OM is responsible for high  $\text{NH}_4\text{-N}$ . Low  $\text{NH}_4\text{-N}$  content in bare fallow compared to other LUS at depth may be a result of low OM from lack of plant cover. In bare plot, released  $\text{NO}_3\text{-N}$  from mineralized OM was leached and accumulates at depth due to lack of plant uptake. Leaching losses of up to  $171 \text{ kg N ha}^{-1}$  during two years of bare fallow have been reported elsewhere (Simpson, 1961). Low OM, reduced infiltration and percolation due to possible surface sealing could explain low  $\text{NO}_3\text{-N}$  at depth below 150 cm. Surface sealing from aggregate breakdown in bare soil is reported to

increase runoff and reduce infiltration (Leutenegger, 1956; Le Bissonnais and Singer, 1993).

In unfertilized maize, shallow roots, low root density, and low plant nutrient demand early in the season allowed  $\text{NO}_3\text{-N}$  loss from top horizons and accumulation at depth as reported elsewhere (Cahn et al., 1993). Maize root penetration may lag behind  $\text{NO}_3\text{-N}$  leaching front each season leading to cumulative  $\text{NO}_3\text{-N}$  accumulation. At physiological maturity when maize roots reach lower depth, nutrient demand is low and  $\text{NO}_3\text{-N}$  recovery from depth is minimal. Continuous uptake of water and nutrients in sesbania and weed fallows throughout the year could explain the low  $\text{NO}_3\text{-N}$  at depths below 100 cm. Dead of annual weeds between seasons may have allowed leaching of  $\text{NO}_3\text{-N}$  in weed compared to sesbania. Deep rooting nature of perennial crops and continuous presence of root is reportedly responsible for uptake of leached nutrients (Hartemink et al., 1995; Mekonnen et al., 1997). Sesbania is reported to recover up to  $54 \text{ kg N ha}^{-1}$  of leached  $\text{NO}_3\text{-N}$  from an oxisol in western Kenya (Gathumbi et al., 2002). The high length density in weed at the 0-30 may be attributed to dominance of annual grasses with fibrous roots. The high root density at the topsoil is a result of ideal growth conditions and reduction with depth in all LUS is in agreement with other research findings (Yan et al., 1995). Despite high root length density, low average diameter in weed roots resulted in dry weight similar to that of maize and lower than that of sesbania.

Sesbania shoot biomass of  $28 \text{ tonnes ha}^{-1}$  was higher than  $16.6 \text{ tonnes ha}^{-1}$  found for one year old trees in Western Kenya (Onim et al., 1990) and similar to  $30 \text{ tonnes ha}^{-1}$  of one year old sesbania fuel wood (Nair, 1993). The high shoot N content in sesbania could be attributed to N-fixation since planted seedlings were inoculated. Similarity in P content could be due to low mobility of P released by mineralization. Phosphorus is not subject to leaching, therefore, deep rooting sesbania has no advantages over other LUS in P uptake. Root biomass of  $10 \text{ tonnes ha}^{-1}$  in sesbania to a depth of 90 cm is higher than  $2.2 \text{ tonnes ha}^{-1}$  for a 1-year old forest regrowth found in Costa Rica (Berish, 1982) and the  $3 \text{ tonnes ha}^{-1}$  found in sesbania in western Kenya (Turquebiau and Kwesiga, 1996). This root biomass may significantly contribute as nutrient source to future crops, as shown in other studies were sesbania roots contributed up to  $25 \text{ kg N ha}^{-1}$  in western Kenya (Turquebiau and Kwesiga, 1996). Also mineralization of OM from tree legume roots was found not to immobilize N (Lehman et al., 1995). High sesbania shoot and root biomass may be due to sampling above average sized tree, the longer growth period (18 months) or a better root recovery method.

## Conclusions

Incorporating N-fixing leguminous trees in fallow rotation will capture leached  $\text{NO}_3\text{-N}$  and recycling it to the tops. Additional benefit will also come from inherent N-fixation capacity and the high N return from mineralized foliage. Substantial amount of inorganic N is released by mineralized underground organic material. This study complements other findings were incorporating tree legumes reduce subsoil  $\text{NO}_3\text{-N}$  losses. The cumulative N addition from continuous shedding and decomposition of sesbania leaves could be high. Improved soil physical and chemical characteristic may also be possible under sesbania due to high OM from the large root biomass. The research highlights the

potential for loss of NO<sub>3</sub>-N between maize cropping seasons and a need for a cover crop between seasons.

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