Chapter 3

Nitrogen release and immobilization following combined applications of legume tree prunings and maize stover

Abstract

An experiment was conducted to examine the N mineralization of low and high quality organic materials under controlled conditions, using the double-pot technique and maize as test crop. The specific aims of the experiment were to assess (1) N mineralization and substitution values of high quality organic materials, (2) N immobilization by low quality maize stover, and the subsequent remineralization of immobilized N, and (3) N mineralization of mixtures of high and low quality organic materials. The experiment was setup as an 8 x 3 factorial comprising combinations of easily and poorly available N sources. The 8 levels of easily available N were 0, 50, 100 and 150 mg N per pot in the form of NH_4NO_3-N, and about 34 and 136 mg organic N per pot with *Gliricidia sepium* (1.25 and 5 g) and *Sesbania sesban* prunings (1 and 4 g per pot). The 3 levels of poorly available N were 0, 2.5 and 5.0 g per pot of maize stover. The various materials were mixed thoroughly with 2000 g of quartz sand and potted in 2.5 L pots. Maize dry-matter yield and N in shoot and roots were determined at 28, 42 and 49 days after sowing (DAS). Maize biomass yields in gliricidia treatments were lower than the control yields. Gliricidia prunings had an inhibitory effect on maize root development. From the results of N uptake, it was inferred that the substitution value, *i.e*. the ratio of the fraction of legume-N that was recovered in the maize crop to the fraction of NH_4NO_3-N that was recovered, was between 0.16 and 0.36 for gliricidia, and between 0.23 and 0.41 for sesbania. Application of 2.5 and 5 g maize stover resulted in yield reductions of 4 and 16%, and N immobilization between 18 and 24% of added equivalent fertilizer N at 28 DAS, and to 14 and 22% at 42 and to 10 and 22% at 49 DAS. The decline of immobilized N at 42 and 49 DAS for the 2.5 g stover was ascribed to remineralization of earlier immobilized N. There were no distinct indications found of an interaction between the low and high quality organic materials. Their effects were just additional.

3.1 Introduction

Leguminous tree prunings are capable of releasing substantial amounts of N that can support crop growth. The use of N-rich tree prunings as a substitute to inorganic fertilizers has been recommended for low input farming systems in N deficient tropical soils (*e.g.* Akinnifesi *et al.*, 1997; Ikerra *et al.*, 1999; and Kang and Shanon, 2001). Decomposition studies of various leguminous tree prunings have shown that the rates of N release from various organic materials is dependent on the quality of the material (Mafongoya *et al.*, 1998; Seneviratne *et al.*, 1998). This has led to a distinction between high quality materials with low C:N ratio, and low polyphenol and lignin contents, and low quality materials with high C:N ratio, and/or high polyphenol and lignin contents. High quality organic materials decompose very fast releasing N initially in excess of plant needs (Handayanto *et al.*, 1994; Mafongoya *et al.*, 1998). In a field experiment conducted in the sub-humid highlands of Kenya, high quality agroforestry prunings released up to 107 kg N ha^{-1} in excess of the plant demand within 4 weeks after application (Mugendi *et al.*, 1999). The excess N was lost through leaching and other natural processes, resulting in N deficits a few weeks after peak mineralization.

Good management implies synchronizing N release from the organic materials with the crop's N demand. It has been suggested that such a synchrony can be achieved by optimum timing of the application of organic materials, and by combining high and low quality organic materials (Swift, 1987). Field studies at Domboshawa in Zimbabwe (Mafongoya *et al.*, 1997) and at IITA, Ibadan in Nigeria (Mulongoy *et al.*, 1993) have demonstrated that application of prunings at the time of planting resulted in significantly higher maize N uptake than application 4 weeks before or after planting. However, correct timing of application of organic materials relative to the crop planting is difficult in the tropics because of unpredictable rainfall patterns (Vanlauwe *et al.*, 1995).

The N content or the C:N ratio of organic material is one of the main determinants of the rate of mineralization (*e.g.* Frankenberger and Abdelmagid, 1985; Constantinides and Fownes, 1993). According to Palm *et al.* (1997), the critical value for the transition from net immobilization to net mineralization is found at N mass fractions of the organic material between 18 to 22 mg g^{-1}. These critical values refer to the initial pattern of immobilization and release of N. During decomposition the C:N ratio decreases and after some time also substrates with initial C:N higher than the critical values start releasing N. Other studies have demonstrated that N release in legume prunings is also governed by lignin and polyphenol contents in the plants (Fox *et al.*, 1990; Palm and Sanchez, 1991; Oglesby and Fownes, 1992; Tian *et al.*, 1993). Lignin contents >150 mg g^{-1} slow down N release considerably, and polyphenol contents between 30 and 40 mg g^{-1} can result in net immobilization (Palm, 1995). In a study with high-quality gliricidia, low-quality *Peltophorum dasyrrachis* and (50:50 w/w) mixtures of these prunings, Handayanto *et al.* (1994) demonstrated that the decomposition rates declined in the order gliricidia > mixtures > peltophorum. The contents of N, lignin and polyphenol have been combined into a so-called resistance index (Janssen 1996).

Though many studies have been carried out to assess the ‘mineralizability’ of organic materials, assessing and predicting the N release pattern of organic materials rapidly and accurately is still a major challenge. Various methods have been developed, which all have their pros and cons, but there are as yet little or no easily and rapidly to apply methods for all sorts of environmental conditions. Most common methods are the assessment of N release and immobilization by repeated measurements of mineral N during incubation in soil, or in a more indirect way via the uptake of N by crops. Both methods are rather laborious and time-consuming.

In the present study, high quality leguminous tree prunings, low quality maize stover, and their combinations were examined in a greenhouse experiment, with maize as test crop.

When organic materials are compared via the uptake by plants, precautions must be taken that the supplies of nutrients other than N are non-limiting and equal for all materials. For organic materials this is difficult, because it is not known beforehand which fractions of their nutrients will become available to the plant during the uptake period. Such problems can be overcome with the so-called double-pot technique.

The main premise of the study was that addition of maize stover would increase soluble organic compounds in the mixtures and by that stimulate the immobilization of N from chemical fertilizers or released from high quality legume tree prunings. The objectives of the current study were to assess (1) N mineralization from high quality organic materials (2) N immobilization by low quality maize stover and the subsequent remineralization of immobilized N, and (3) interactive effects on N mineralization or immobilization when high and low quality organic materials are applied in mixtures.

3.2 Materials and Methods

3.2.1 Experimental design of the greenhouse study

The greenhouse experiment was conducted at the Department of Soil Quality, Wageningen University, The Netherlands. It comprised 24 treatments, in a sort of 8*3 factorial. Eight levels of high-quality N sources were combined with three levels of a low-quality N source. The high-quality sources were NH_4NO_3, *Gliricidia sepium* (Jacq.) Walp ex Reltahaleu, Guatemala and *Sesbania sesban* (L.) from Zalewa provenance, Malawi. The low-quality material was maize stover, for which the hybrid LG 11 was used.

The experimental crop was maize, hybrid LG 11. Initially four harvest dates had been foreseen, each with two replicates. In view of the poor maize growth after 40 days, it was decided to reduce the number of harvest dates to three and to increase the number of replicates to three for the second and third harvest dates.

To get the required quantities of the organic materials, gliricidia, sesbania and maize were raised in pots in the greenhouse during a preceding period of 50 days. The maize stover was cut into two parts, *i.e.* a lower part below the ear leaf and an upper part above the ear leaf. Samples of the organic materials were dried in an oven at 75 ^{o}C for 48 hours and were finely ground for total N, P, K and C analyses, prior to the start of the main experiment (Table 3.1). The N contents of the high quality sesbania and gliricidia prunings were about 6-7 times higher and the C:N ratio about 6 times lower than those of the low quality maize stover. The upper part of the maize stover had a C:N ratio of 38, about 2-3 times higher than the high quality gliricidia and sesbania prunings. The lower part of maize, with the lower N content and wider C:N ratio (80), was used in this experiment.

3.2.2 Outline of the double-pot technique

The double-pot technique is a method where plants can take up nutrients simultaneously from two compartments (Fig. 3.1). An upper pot contains the substrate to be tested and a container underneath is filled with nutrient solution. The roots of the plants growing in the upper pot pass through a mesh that forms the bottom of the pot and reach the nutrient solution in the container. When a nutrient is omitted from the solution, plants can take it up only from the substrate in the upper pot (Janssen, 1990). In this way, the nutrients are supplied to the plants without mixing them with the soil, and the effect of the missing nutrient can be tested. Raijmakers and Janssen (1993) have modified the method for the study of organic substrates. Instead of individual lower pots, a 150 L tank is used for the nutrient solution. It is covered with a board with 28 (7*4) holes in which the upper pots fit. Under each pot a perforated bucket is used to keep the roots separated.

3.2.3 Experimental treatments

The eight levels of high-quality N sources were a control (zero N), 50, 100, and 150 mg N per pot applied with NH_4NO_3, 35 and 139 mg N applied with 1.25 and 5.0 grams of gliricidia prunings, and 34 and 136 mg N applied with 1.0 and 4.0 grams of sesbania prunings (Table 3.2). The three levels of the low-quality nutrient source were 0, 2.5 and 5.0 grams of maize stover, corresponding to 0, 12 and 24 mg N per pot. Because each tank carried 28 pots, 4 extra pots were available in addition to a complete replicate of 24 treatments. The extra pots were used for the control and the three fertilizer N levels, combined with 0 g of stover in one replicate, and with 5 g of stover in the other replicate. The treatments with chemical fertilizer were chosen because NH_4NO_3 acted as reference with which the other N sources were compared.

Table 3.1. Mass fractions of C, N, P and K and C:N ratios of the organic materials applied in the pot experiment.

Organic material	N mg/g	P mg/kg	K mg/kg	C mg/g	C:N ratio
Gliricidia	28	1.5	21	427	15
Sesbania	34	1.5	11	431	13
Maize stover, upper part	11	0.8	10	416	38
Maize stover, lower part	5	0.8	7	403	80

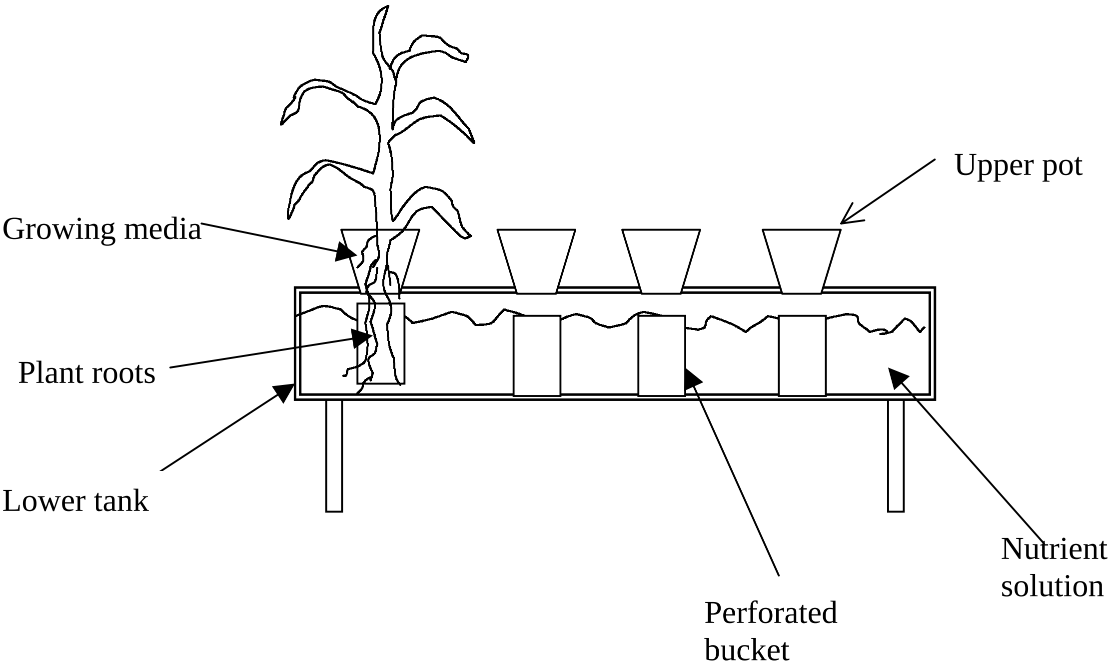


Fig. 3.1. Front view of the double pot technique set up.

3.2.4 Details of the greenhouse study

The organic materials were chopped and mixed thoroughly with 2000 g of quartz sand. The maize biomass had been dried at 40 ^{o}C for 72 hours before application in the pots whereas for gliricidia and sesbania fresh materials were applied. The organic materials-sand mixtures were potted in 2.5 L pots with bottom gauze, and moistened to field capacity with distilled water. Field capacity was 300 ml per 1000 g sand; only 60% of the water needed to bring the soil at field capacity was applied before potting and the remaining 40% was applied after sowing. For the inoculation of the pots with soil microorganisms, to each pot 10 ml were added of an extract obtained by shaking fresh forest soil in demineralized water. Ammonium nitrate (NH_4-NO_3) was used as a source of inorganic N fertilizer. The 60% of the water field capacity applied at potting consisted of a mixture of (where required) an appropriate aliquot of inorganic N (NH_4-NO_3) fertilizer solution, 10 ml of the inoculating solution from the forest soil extract and demineralized water was added to make up the balance. The pots were covered with a polyethylene sheet and left to stand for five days prior to planting. Four maize seeds were sown in each pot. After planting, the pots were watered with the remaining 40% to bring the moisture level at field capacity. The pots were then placed on the 150 L tank with a nutrient solution containing all the nutrients except N; the composition is given in Table 3.3. The pots were covered again with the polyethylene sheet until all the maize seeds had germinated. Seven days after sowing (DAS) the maize plants were thinned to three per pot. After thinning the surface of the pots were covered with 100 g gravel (0.5-1.0 mm in diameter) to reduce evaporation. The pots were watered daily with distilled water and weighed every other day to determine the amount of water required to maintain the pots at field capacity. The nutrient solution (minus N) in the lower tank was changed every 2 weeks.

During the experiment, the greenhouse daily temperatures varied between 27 and 32 ^{o}C. Water was pumped at 30 minutes intervals into the glasshouse chamber floor to maintain the chamber humidity at 60%.

The maize was harvested at 28, 42 and 49 DAS. At harvest, the maize shoots were cut just above the gravel surface, and the roots were washed and rinsed with distilled water. Roots were subdivided into roots growing in the soil and roots growing in the solution for the second and third harvests; after the first harvest the roots growing in the soil and solution were combined. Shoots and roots were dried in an oven at 75 ^{o}C for 48 hours and dry-matter weight was determined. The dried biomass was finely ground and analyzed for N using the methods described by Temminghoff *et al.* (2000). Nitrogen contents in shoots and roots were calculated as the product of N mass fraction and dry-matter yield, and total N uptake was calculated as the sum of the N contents in the shoot and roots.

Table 3.2. Quantities of N (mg/pot) applied with the various combinations of high and low quality N sources in the upper pot. The number of pots was doubled for the treatments with one asterisk in one replicate, and for the treatments with two asterisks in the other replicate (see text).

High quality N source		Low quality N source (maize stover), g per pot		
Name	Rate, g per pot			
		0	2.5	5.0
Control	0	0*	12	24**
NH_4NO_3	0.143	50*	62	74**
	0.286	100*	112	124**
	0.429	150*	162	174**
Gliricidia	1.25	35	46	58
prunings	5.0	139	150	162
Sesbania	1.0	34	46	57
prunings	4.0	136	147	159

3.2.5 Substitution value of organic N sources

The response of a crop to an organic N source may be compared to the response to a reference N source, either in a vertical way (at common nutrient rates) or in a horizontal way (at common levels of yield or nutrient uptake). We used the horizontal comparison and N uptake. The substitution value (SV) is then the ratio of the recovery fractions (RF) of the organic N source (ONS) and the reference N source (RNS), being NH_4NO_3 in the present study. Recovery fraction (RF) is the ratio of delta N uptake (Delta UN) (the difference between N uptake in the treatment and N uptake in the control) to applied N (N_A).

$$RF = \text{Delta UN} / N_A \qquad \text{Eq. 3.1}$$

And the substitution value is given by:

$$SV = RF_{ONS}/RF_{RNS} \qquad \text{Eq. 3.2}$$

SV has to be split into an organic and an inorganic part:

$$SV = SV_O * F_O + SV_I * F_I \qquad \text{Eq. 3.3}$$

where F stands for fraction and the subscripts O and I for organic and inorganic respectively. In case F_I is negligible, as in the present study, Equation 3.2 can be used and SV equals the fraction of organic N that is mineralized. Because this fraction increases over time, also the value of SV increases over time.

For the derivation of SV from our experimental results we plotted the increases in N uptake above the Control (henceforth denoted by Delta N uptake) to the rate of N application. We then calculated the recovery fractions as the slopes of the regression lines, and the SV of the particular ONS as the ratio of the slopes of an ONS and RNS. The SV's obtained were then used to calculate the rate of equivalent N fertilizer of the organic materials:

$$EF_{ONS} = SV * N_{A,\ ONS} \qquad \text{Eq. 3.4}$$

Where, EF_{ONS} is the equivalent fertilizer rate of the organic N source and $N_{A,\ ONS}$ is the rate of N applied with the organic source.

Table 3.3. Composition of the minus N nutrient solution and amounts of the stock solutions added to each 150 L tank in a double pot technique. The solution was refreshed after every two weeks.

Stock solution	Concentration of stock solution	Volume of stock solution added in a 150 L tank (ml)
Macronutrients		
$MgSO_4.7H_2O$	2 M	112.5
KH_2PO_4	1 M	450
K_2SO_4	1 M	150
$CaCl_2.6H_2O$	1 M	450
Micronutrients[*]		
H_3BO_3	2.86 g/L	
$MnCl_2.4H_2O$	1.81 g/L	A mixture of micronutrients
$ZnSO_4$	0.22 g/L	150
$CuSO_4$	0.16 g/L	
$(NH_4)_6MO_7O_{24}.4H_2O$	0.04 g/L	
Fe(Fe-EDTA)	35.0 g/L	

*The micronutrients were dissolved in one bottle to make a mixture of micronutrients stock solution, except for Fe(Fe-EDTA) it was prepared in a separate container.

3.2.6 Data analysis

Data was analyzed using two way ANOVA in a RCB design using GENSTAT version 5. Significance test for the mean separation was done by Duncan's Multiple Range Test (DMRT). Linear, power and exponential regressions were done to relate Delta N uptake and equivalent fertilizer N and hence derive substitution rates and fraction of N immobilized.

3.3 Results

3.3.1 Maize biomass yield

Inorganic N fertilizer significantly ($P>0.001$) increased maize biomass yield (Table 3.4 and Appendices 3.1, 3.2 and 3.3) up to the highest application rate. Maize growth was faster in the pots with inorganic N fertilizer than in the pots with organic materials. Although 136 mg organic N was applied per pot through the application of 4 g sesbania prunings, maize biomass yield was equivalent to 50 mg fertilizer N only. Despite the organic N addition (139 mg/pot) through 5 g Gliricidia prunings, maize shoot yield was as low as or even lower than that in the control (Appendices 3.1, 3.2 and 3.3). The maize plants growing in pots with gliricidia had characteristic white buds on the leaves that lasted for about three weeks after emergence. The gliricidia prunings, especially at the high rate of 5 g per pot, apparently inhibited root development and only a few roots extended below the upper pot into the lower tank containing the nutrient solution (Appendices 3.2, 3.3 and 3.4C). Because of these problems we decided to leave out of consideration the treatment of 5 g gliricidia in the further interpretation of the results.

Application of 2.5 and 5 g maize stover reduced average maize shoot yield at 28 DAS by 4 and 16%, respectively, but the pattern for the various N sources was rather irregular. The reductions were 9 and 17% at 42 DAS and 7 and 16% at 49 DAS.

Table 3.4. Maize shoot yield (mg DM/pot) harvested at 28, 42 and 49 days after sowing. Data for the highest rate of gliricidia, 139 mg N, were not included in these calculations.

		Maize stover rate, g per pot			
N source	N rate, mg/pot	0	2.5	5.0	Mean
At 28 DAS					
Control	0	962de*	1076d	838de	958
NH_4NO_3	50	1731c	1924c	1381c	1678
	100	2277b	2682b	2265b	2408
	150	3679a	3184a	3359a	3407
Gliricidia	35	789e	685e	700e	724
Sesbania	34	1296d	1083d	1073cd	1150
	136	2166b	1834e	1401c	1800
	Average	1843	1781	1574	1732
At 42 DAS					
Control	0	1771e	1796e	1575e	1714
NH_4NO_3	50	3928c	3584c	2979c	3497
	100	6281b	6212b	5090b	5861
	150	10586a	9139a	9053a	9592
Gliricidia	35	1816e	1187f	1503e	1502
Sesbania	34	2775d	2299d	2155d	2409
	136	4244c	3738c	3330c	3771
	Average	4486	3993	3669	4049
At 49 DAS					
Control	0	1855e	1927e	1617e	1800
NH_4NO_3	50	4547c	3923c	3775c	4082
	100	8103b	8056b	7079b	7746
	150	13012a	11639a	10281a	11644
Gliricidia	35	1822e	1993e	2215e	2010
Sesbania	34	2989d	3056d	3023d	3023
	136	5197c	4355c	3507cd	4353
	Average	5361	4993	4500	4951

*In a column means followed by a common letter are not significantly different at 5% level by DMRT.

3.3.2 Maize N uptake

The N uptake by maize increased over time, except for the controls (Table 3.5). The control plants could derive N only from the seeds (5.4 mg N/per seed) and 2 mg N (from the forest soil extract). Apparently, seeds had already been emptied for N at the first harvest date. A clear response was found to the inorganic as well as to the organic N sources.

Gliricidia prunings gave the lowest N uptake, and as said above we decided to leave out of consideration the treatment of 5 g gliricidia in the further interpretation of the results. Application of maize stover on average reduced maize N uptake at 28 DAS, but not for the control and when combined with 5 g gliricidia (Table 3.5). The average reductions for the other treatments than control and 5 g gliricidia were 17 and 22% in the case of 2.5 and 5 g maize stover, respectively. At 42 DAS, these figures were 12% for 2.5 g stover and 23% for 5 g maize stover, and at 49 DAS 10 and 21%, respectively.

3.4 Data processing

3.4.1 Substitution values

Figure 3.2 shows the graphs of Delta N uptake against N application for NH_4NO_3 and the organic N sources (the uptake for the controls were averaged over the three stover treatments). Only the treatments without maize stover were included in the regression graphs. Again only the lower application level of gliricidia was considered.

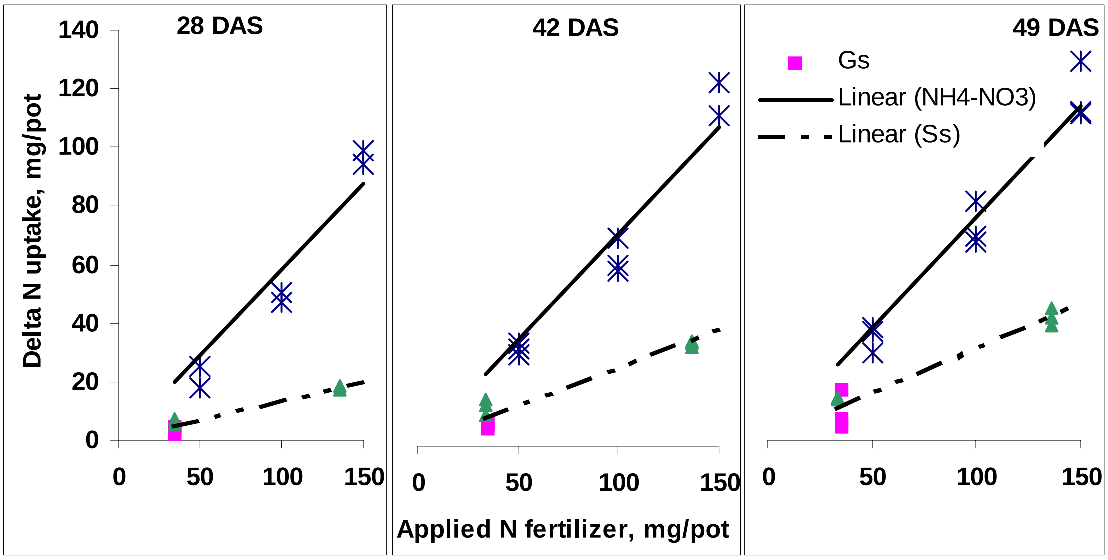


Fig. 3.2. The relationship between Delta N uptake and total N applied for the harvests at 28, 42 and 49 DAS.

Table 3.5. Total N uptake (mg/pot) by maize grown in a glasshouse using a double pot technique sampled at 28, 42 and 49 days after sowing. The data for the highest rate of gliricidia treatment (139 mg N/pot) has not been included.

		Maize stover rate, g per pot			
N source	N rate, mg/pot	0	2.5	5.0	Mean
At 28 DAS					
Control	0	24.5d*	25.3d	22.0c	23.91
NH_4NO_3	50	45.7c	43.9c	33.4c	41.02
	100	72.8b	65.0b	63.7b	67.13
	150	120.5a	84.5a	91.0a	98.67
Gliricidia	35	27.3d	22.2d	21.9c	23.78
Sesbania	34	30.2d	27.4d	25.5c	27.69
	136	48.4c	44.2c	34.0c	42.20
	Average	52.77	44.63	41.63	46.34
After 42 DAS					
Control	0	23.9e	22.5de	20.4d	22.26
NH_4NO_3	50	53.1c	45.2c	38.1c	45.47
	100	81.9b	76.6b	61.5b	73.31
	150	132.5a	108.7a	99.8a	113.65
Gliricidia	35	30.9d	20.2e	20.5d	23.87
Sesbania	34	35.0d	28.3d	25.9d	29.73
	136	49.5c	45.8c	39.8c	45.02
	Average	58.11	49.61	43.70	50.47
At 49 DAS					
Control	0	21.5e	21.3e	19.7f	20.82
NH_4NO_3	50	53.9c	43.2cd	39.6cd	45.57
	100	89.5b	84.7b	72.9b	82.35
	150	131.5a	115.7a	97.7a	114.97
Gliricidia	35	29.8d	28.6e	30.2e	29.54
Sesbania	34	34.5d	36.9d	33.6de	34.98
	136	60.3c	51.0c	42.4c	51.23
	Average	60.12	54.49	48.01	54.21

*In a column means followed by a common letter are not significantly different at 5% level by DMRT.

Regression lines were forced through the origin because by definition Delta N is zero when no N is applied. Linear functions ($y = ax$), power functions ($y = ax^b$) and exponential functions ($y = ae^b$), regressions were explored because the response to NH_4NO_3 seemed to increase with increasing application rates. Although the exponential function gave the highest R^2 values for the regression graphs, the regression lines did not comply with our definition of delta N = 0, when x = 0. As the power function gave lower R^2 values than the linear regression, the linear regression was opted for. Table 3.6 presents the regression coefficients and the substitution values (SV) derived from the linear function.

Table 3.6. Values of the regression coefficient a and of R-square of the linear regression equations (y = ax) relating Delta N uptake to applied N, and substitution values for gliricidia and sesbania. ESV stands for 'equation' SV and PSV for 'practical' SV (see text). Harvests were at 28, 42 and 49 DAS.

DAS	N source	Constant a	R square	ESV	PSV
28	NH_4NO_3	0.5847	0.9753		
	Gliricidia	0.0954 [a]	[b]	0.16	0.22
	Sesbania	0.1345	0.9256	0.23	0.30
42	NH_4NO_3	0.6726	0.9364		
	Gliricidia	0.1837	[b]	0.27	0.30
	Sesbania	0.2461	0.8787	0.37	0.39
49	NH_4NO_3	0.7177	0.9567		
	Gliricidia	0.2575	[b]	0.36	0.38
	Sesbania	0.2968	0.9456	0.41	0.44

[a] Calculated as the ratio of N uptake to N applied for the treatment of 1.25 g gliricidia.

[b] Not applicable, because only one level of gliricidia is used.

As the maximum N uptake with the organic N sources was about equal to the N uptake obtained with an application of 50 mg N in the form of NH_4NO_3 (Table 3.5), the ratio of the recovery fraction of the organic N source and the recovery fraction of NH_4NO_3-N obtained at the rate of 50 mg N was also calculated (Eq. 3.2), to serve as a practical solution for SV (PSV in Table 3.6).

Substitution values of both gliricidia and sesbania (Table 3.6) increased as mineralization progressed with time. Substitution values for sesbania were higher throughout the 49 days than the SV's for gliricidia. The substitution values of gliricidia were low because of the presence of phytotoxins produced by gliricidia prunings that hindered the development of the young maize seedlings. The SV values obtained with the various methods increased from 0.16 to 0.38 for gliricidia and from 0.23 to 0.44 for sesbania.

Using the PSV values, the application rates of 1.25 g gliricidia can be translated into 5.6, 9.5 and 12.6 mg fertilizer N equivalents for the harvests after 28, 42 and 49 DAS. The rate of 1.0 g sesbania can be translated into 7.8 mg N at 28 DAS, 12.6 mg N at 42

DAS and 13.9 mg N at 49 DAS whereas the rate of 4.0 g sesbania can be translated into 31.3 mg N at 28 DAS, 50.3 mg N at 42 DAS and 55.8 mg N at 49 DAS.

3.4.2 Nitrogen immobilization by maize stover

The fraction immobilized N was calculated from the regression lines as the difference between the slopes of the regression lines without maize stover and with maize stover. The Delta N uptake versus N application, for gliricidia and sesbania expressed in the above-calculated fertilizer N equivalents were plotted in Fig. 3.3. The resulting regression coefficients and R-square are shown in Table 3.7. At 28 DAS, 2.5 g maize stover immobilized 18% and 5 g maize stover immobilized 24% of the added fertilizer N. For the pots that received 2.5 g immobilization decreased over time indicating that remineralization had taken place. For the 5.0 g stover treatment, the fraction immobilized N stabilized at 22 % at 42 and 49 days, hardly lower than initial 24%. The difference between 2.5 and 5.0 g maize stover in fractions immobilized N increased over time.

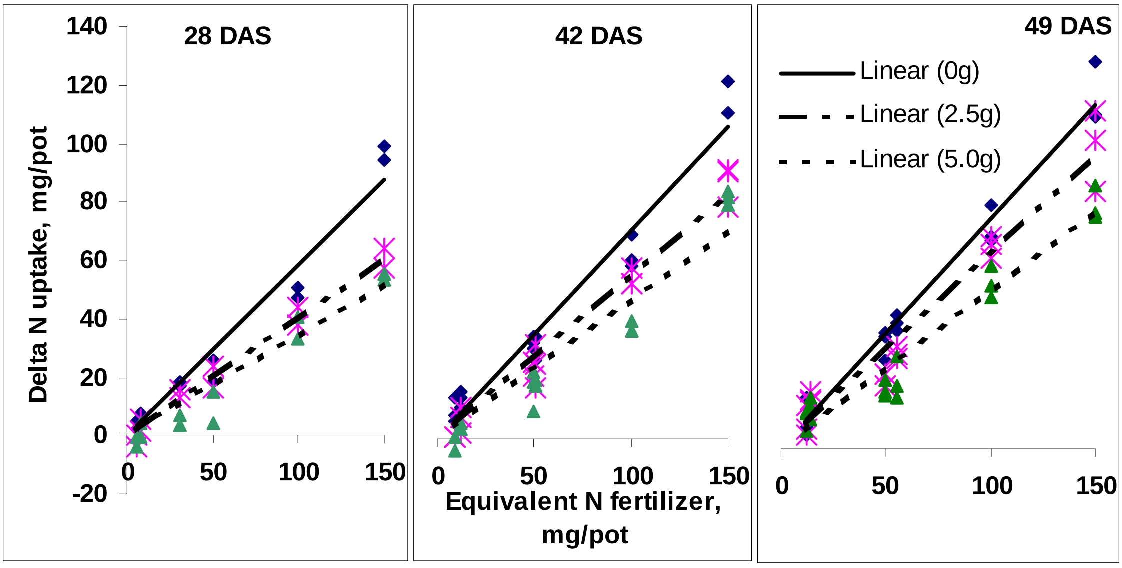


Fig. 3.3. The relations between Delta N uptake and applied equivalent fertilizer N for the harvests at 28, 42 and 49 DAS.

Table 3.7. Values of the regression coefficient **a** and R-square of the relations between Delta N uptake and applied equivalent fertilizer N.

Harvest date, DAS	Maize stover rate, g/pot	Regression coefficient a	R-square	Fraction immobilized
28	0	0.5847	0.9593	
	2.5	0.4061	0.9778	0.18
	5.0	0.3461	0.9332	0.24
Difference (5.0-2.5)				0.06
42	0	0.6691	0.9600	
	2.5	0.5281	0.9711	0.14
	5.0	0.4477	0.9212	0.22
Difference (5.0-2.5)				0.08
49	0	0.7210	0.9776	
	2.5	0.6174	0.9473	0.10
	5.0	0.4987	0.9419	0.22
Difference (5.0-2.5)				0.12

3.5 General discussion

The poor performance of maize in the pots with gliricidia, especially the poor development of roots, was ascribed to phytotoxins released by the decomposing prunings. Only a few roots grew in the upper pot (Appendices 3.1 and 3.4B, C) and probably they did not adequately explore the sand mixture to absorb the mineralized N. The number of roots passing the gauze bottom of the upper pots was also low, especially at the higher rate of gliricidia, so that we had to exclude this treatment in the further data processing. Similar negative effects were found in some other studies. In laboratory tests, gliricidia leaf leachates inhibited maize seed germination and depressed the growth of the seedlings (Akobundu, 1986; Tian and Kang, 1994). In a field experiment conducted at IITA, Nigeria, Tian and Kang (1994) observed maize leaf chlorosis in the gliricidia mulch treatments. On the other hand, also positive effects have been reported (also in our trials described in Chapers 4 and 5). In pot and field experiments, gliricidia prunings significantly increased crop yields (Kettler, 1997; Ikerra *et al.*, 1999; Makumba and Maghembe, 1999; Akinnifesi and Kwesiga, 2000; Makumba *et al.*, 2000). Since the phytotoxins have a short life span and easily disintegrate (Kimber, 1973), proper timing of pruning incorporation, well in advance of maize planting, may reduce the phytotoxic effect of gliricidia. Moreover, under field conditions the toxic compounds may rather rapidly leach and the problem may not be prolonged. The recovery fractions of 13% (at 28 days), 25% (at 42 days), and

30% (at 49 days) of N applied with sesbania are quite normal. The recovery fractions of gliricidia were 10% at 28 DAS, 18% at 42 DAS and 26% at 49 DAS. These recovery fractions are within the range of N recoveries of agroforestry prunings reported by other scientists. Akinnifesi *et al.*, (1997) reported a 10-16% recovery in maize plants from the application of ^{15}N labeled *Leucaena leucocephala* (Lam.) de Wit. In a laboratory experiment Handayanto *et al.*, (1994) found 14% to 44% N recovery by maize from different mixtures of gliricidia and peltophorum prunings. Cobo *et al.* (2002) in a glasshouse experiment found N recoveries by rice ranging from 13.1 to 54.6% after applying leaves of nine different green manure.

Roughly, 2.5 and 5.0 g of stover immobilized about 18 and 24% of the available fertilizer N during the first period of 28 days, 14 and 22% in 42 days, and 10 and 22% in 49 days, respectively. Amount of N immobilized was consistently lower in the mixtures for 2.5 g stover than for 5.0 g maize. The decline of fraction immobilized N from 18% at 28 DAS to 10% at 49 DAS in the treatment with mixtures of 2.5 g maize stover is likely the result of re-mineralization of the earlier immobilized N.

The reductions in maize dry-matter yield induced by addition of maize stover are comparable to the results obtained in Kenya where maize grain yield was reduced by 3-30% after incorporating maize stover (Qureshi, 1987; Nandwa, 1995). Apparently both the uptake by plants and the uptake by microorganisms were constant portions of the available N, irrespective of the amounts. Intuitively, one would expect that the portion taken up would be higher at low than at high quantities of available N. The opposite seemed to have been found, as Delta N uptake gave the impression of increasing with increasing quantities of NH_4NO_3-N, independent of the presence of maize stover (Fig. 3.3). We assume this was coincidental. Alternatively, there might be some N immobilized due to soluble C released by roots and maize stover, apparently in constant amount, independent of treatments. The calculated fractions of immobilized N by maize stover were similar for fertilizer N and N released from gliricidia and sesbania. The effects of the low and high quality organic materials seemed just additional without any special interaction between the organic sources.

3.6 Conclusions

The substitution values (SV) of both gliricidia and sesbania increased over time. SV’s of sesbania were much higher than SV’s of gliricidia, as the presence of phytotoxins probably affected the release of N from the gliricidia prunings in the pot experiment. Maize N uptake was lower in the treatments with maize stover than in the treatments without. Apparently, maize stover immobilized mineral N.

The immobilized N was later partially released again, and was taken up by the maize crop (especially in 2.5 g stover). However, the experiment did not run long enough to allow for complete decomposition of the maize stover. No significant interactions were found between the effects of low quality organic materials and high quality organic materials.

Appendix 3.1. Maize dry-matter (mg/pot) production at 28 DAS.

		Total root dry-matter			Shoot + roots dry-matter		
Maize Stover rate (g)		0	2.5	5.0	0	2.5	5.0
N source	N, mg/pot						
Control	0	1246bc*	1276d	1179cd	2207cd	2351d	2016de
NH_4NO_3	50	1681ab	1754b	1282c	3412b	3676c	2663cd
	100	1689ab	1703bc	1832ab	3965b	4385b	4097b
	150	2141a	2148a	2095a	5820a	5335a	5454a
Gliricidia	35	947cd	716e	840de	1736de	1401e	1540e
	139	527d	583e	661e	1143e	1321e	1311e
Sesbania	34	1343bc	1318d	1336c	2639c	2400d	2408cd
	136	1676ab	1571c	1488bc	3842b	3405c	2889c
	Average	1406	1384	1339	3095	3034	2797

*In a column means followed by a common letter are not significantly different at 5% level by DMRT.

Appendix 3.2. Maize dry-matter (mg/pot) production at 42 DAS.

		Root growing in soil			Roots growing in solution			Total Roots dry-matter			(Shoot + roots) dry-matter		
Maize Stover rate (g)		0	2.5	5.0	0	2.5	5.0	0	2.5	5.0	0	2.5	5.0
N source	N rate, mg/pot												
Control	0	685e	661c	590e	1338d	1244d	1044c	2023e	1905de	1634e	3794e	3701d	3208e
NH_4NO_3	50	1698c	1242bc	1252c	1766c	1799c	1163c	3464c	3041c	2415cd	7391c	6624c	5394c
	100	2306b	2001b	1770b	2523b	2536b	1940b	4829b	4524b	3710b	11110b	10749b	8800b
	150	3170a	3196a	2358a	3227a	3194a	2829a	6397a	6390a	5187a	16372a	15529a	14239a
Gliricidia	35	894de	677c	638e	597e	610e	619d	1491f	1287ef	1257ef	3307e	2473e	2760e
	139	872de	793c	827de	139f	138f	21e	1011g	931f	848f	2905e	2459e	2293e
Sesbania	34	1310cd	1073c	1048cd	1545cd	1089d	1085c	2855d	2162d	2133d	5629d	4460d	4287d
	136	1567c	1440bc	1359c	1826c	1814c	1310c	3393c	3254c	2669c	7637c	6992c	6000c
	Average	1563	1385	1230	1620	1553	1251	3183	2938	2481	7268	6624	5873

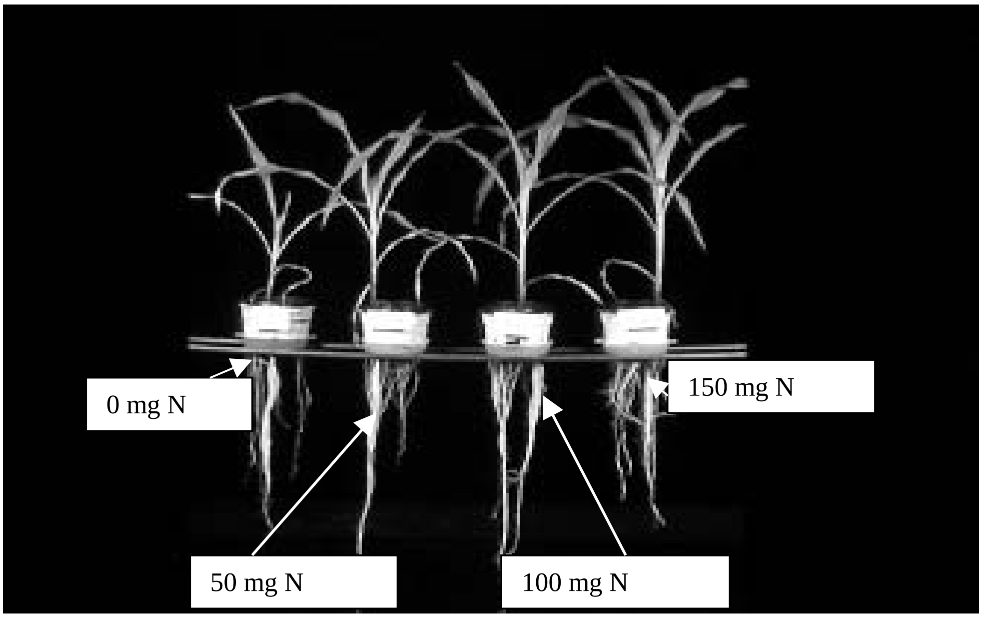
*In a column means followed by a common letter are not significantly different at 5% level by DMRT.

Appendix 3.3. Maize dry-matter (mg/pot) production at 49 DAS.

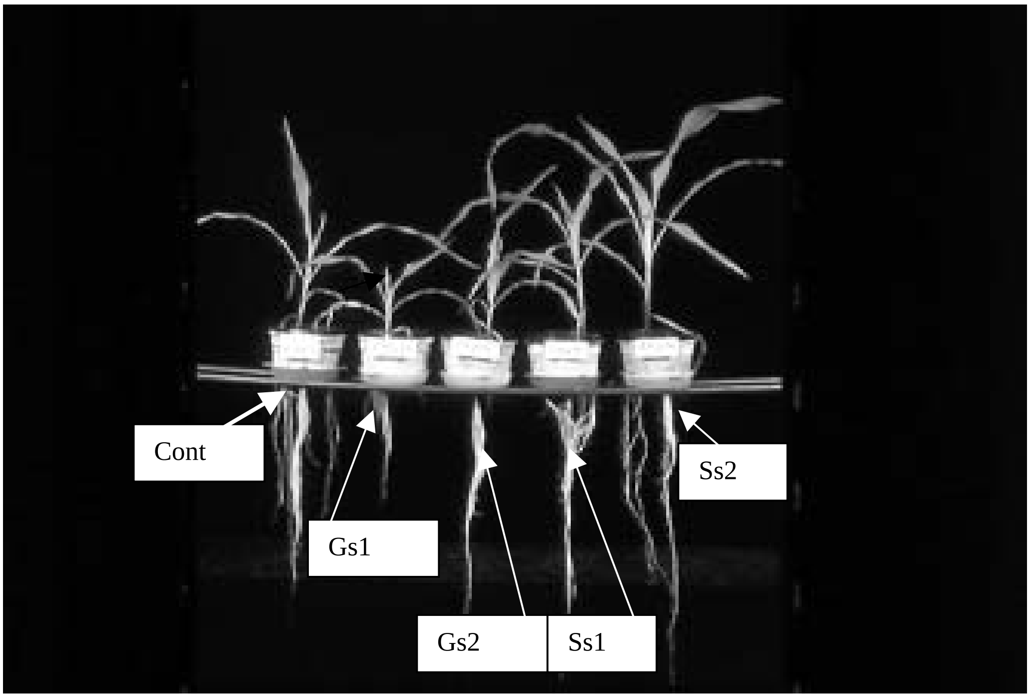
		Roots growing in soil			Roots growing in solution			Total Roots dry-matter			(Shoot + root) dry-matter		
Maize Stover rate (g)		0	2.5	5.0	0	2.5	5.0	0	2.5	5.0	0	2.5	5.0
N source	N rate, mg/pot												
Control	0	679e*	672e	658d	1080d	910d	1134cd	1759e	1582e	1792de	3615e	3509e	3408e
NH_4NO_3	50	1679c	1262c	1201c	1714c	1644c	1383c	3393c	2906c	2584c	7940c	6829c	6359c
	100	2284b	2015b	1718b	2475b	2471b	2241b	4758b	4486b	3959b	12861b	12541b	11038b
	150	2988a	2693a	2344a	2950a	3109a	2745a	5938a	5802a	5088a	18950a	17441a	15369a
Gliricidia	35	816e	740de	621d	510e	581e	825d	1326ef	1321e	1447e	3148e	3313e	3662e
	139	788e	683de	748d	380e	132f	165e	1168f	815f	913f	3336e	2619f	2882e
Sesbania	34	1054d	949d	814d	1328cd	1374c	1088cd	2383d	2323d	1902d	5371d	5379d	4925d
	136	1546c	1254c	1238c	1793c	1639c	1305c	3339c	2893c	2543c	8536c	7247c	6050c
	Average	1479	1284	1168	1529	1482	1361	3008	2766	2528	7969	7360	6712

*In a column means followed by a common letter are not significantly different at 5% level by DMRT.

Appendix 3.4. The effects of inorganic fertilizer, gliricidia and sesbania prunings on above and belowground development of maize.



Appendix 3.4a. Inorganic fertilizer applied as NH_4NO_3 in solution form at rates of 0, 50, 100 and 150 mg N/pot.



Appendix 3.4b. Gliricidia at rates of 35 (Gs1) and 139 (Gs2) mg N/pot and sesbania at the rates of 34 (Ss1) and 136 (Ss2) mg/pot.

Appendix 3.4 continued.

Appendix 3.4C. Poor maize root development and leaf chlorosis in pots with gliricidia prunings (observed from the time of germination up to 28 Days after sowing).

Maize treated with gliricidia prunings in a gliricidia-maize simultaneous intercropping system.