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Evaluation of N recovery from mucuna placed on the surface or incorporated in a Brazilian oxisol*

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Abstract

This study was conducted to a) determine the rates of mineral N accumulation in soil (Dark Red Latosol or Typic Haplustox, oxidic, isothermic) under greenhouse conditions when leaves of *Mucuna aterrima* (Piper and Tracy) Merr. were either surface placed or mixed with the soil, and b) determine the amount of N lost from the surface placed legume which is recovered in the soil as mineral N. After 178 days, the treatment where mucuna was incorporated had a net inorganic N accumulation 60% higher than the treatment with mucuna placed on the surface. After 178 days, only 55% of N applied as surface placed legume was found in the remaining undecomposed residue or as inorganic N in the soil. The data and literature suggest that part of this unrecovered N was lost by ammonia volatilization.

Introduction

Oxisols cover 22% of the tropics, mainly in South America and in Central America (Sanchez, 1976). The Cerrados region of Brazil is an area of 1.8 million km^2 which is dominated by soils of low fertility and low soil pH. The soils of this region have low cation exchange capacities, low amounts of extractable Ca, Mg, P, and Zn, and a high degree of Al saturation (EMBRAPA/CPAC, 1976; Lopes and Cox, 1977). The use of legumes as green manures has helped to reduce these soil constraints (EMBRAPA/CPAC, 1985) and increase the yields of several crops in this area (Pereira and Peres, 1986; Quintana *et al.*, 1988).

The efficiency of transferring N from a legume to another crop is based on synchronizing the N release from the legume with the N demand of the recipient crop. The plant species and the management practice have a great influence on the success of this synchronization. The incorporation of green manures is considered by many authors to be the most efficient method of transferring N from the legume to another crop (Bowen, 1987; Sarrantonio, 1987). However, green manure is not always an appropriate agricultural practice because N may be mineralized faster than the requirement of the recipient crop. In such a case, the practice of mulching may be suitable for the transfer of N (McCalla and Russel, 1948). Generally, less inorganic N accumulates in the soil under surface placed legume management. Wilson and Hargrove (1986) suggest this is because the N release rates for surface placed plant materials are slower than for incorporated plant materials. Humfeld and Smith (1932) hypothesized that this slower inorganic N accumulation from the surface placed plant material is due to the less favorable mois-

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ture and temperature conditions for decomposition.

The literature is unclear about the N release patterns and whether different total amounts of N are released from surface placed and incorporated green manures. Kang *et al.* (1982) observed that *Leucaena leucocephala* cuttings were more effective as a N source for corn when incorporated rather than surface placed in field and pot experiments in Nigeria. Wade and Sanchez (1983) did not observe significant differencae in yields of five crops using kudzu (*Pueraria phaseoloides*) and guinea grass (*Panicum maximum*) under two management systems in the Peruvian Amazon region. Selecting between these two management techniques would depend on the amount and pattern of N demand of a particular crop cover the growing season.

One problem of mulching is N volatilization as ammonia (NH_3) from decomposing plant material on the soil surface (Kang *et al.*, 1982; Moore, 1974; Sarrantonio, 1987; Terman, 1979). Due to the practical problem of measuring N volatilization, there is little quantitative information on this N loss mechanism.

The probability of ammonium volatilization is greater in alkaline soils than in acid soils with pH 4.5–7.0 (Cornforth and Davis, 1968). However, the initial phase of plant decomposition may release enough organic compounds to increase the soil pH locally, so that ammonia volatilization can occur (Freney *et al.*, 1981). Barrow (1960) suggested that ammonia volatilization could occur from plant material mixed with soil if the ratio of plant materials to soil was sufficient for the pH to exceed 7.0 during decomposition. Moore (1974), studying the decomposition of ^{15}N labelled Rhodegrass (*Chloris gayana*) material under two management systems, attributed a 6–10% N loss to ammonia volatilization from surface placed material. This material would have less contact with the soil and in consequence diminish the opportunity for ammonium to be trapped by cation exchange in soil (Moore, 1974).

This study has the following objectives:
a) determine the rates of mineral N accumulation in soil under greenhouse conditions when leaves of *Mucuna aterrima* were either surface placed or mixed with the soil and b) determine the percentage of N lost from the surface placed legume which is recovered in the soil as mineral N.

Material and methods

The soil used in the greenhouse experiment is a clayey Dark Red Latosol in the Brazilian taxonomy (EMBRAPA/SNLCS, 1968). It is a Typic Haplustox, clayey, oxidic, isothermic, in the U.S. taxonomy (U.S.D.A. Soil Conservation Service, 1975). The soil was collected in an area at the Centro de Pesquisas Agropecuária dos Cerrados (CPAC-EMBRAPA) in Planaltina, Brazil, that had been in grass fallow since it had been cleared in 1979. The soil texture was 49% clay, 9% silt, 35% fine sand, and 7% coarse sand. One irrigated maize crop was grown in the area during the dry season of 1985 to decrease the inorganic N level. After the harvest of this corn on November, 1985, the crop residues were taken off. The area received an application of 3.0 t ha^{-1} of dolomitic limestone incorporated to a depth of 25 cm with ploughing during the rainy season on December 2, 1985. On January 14, 1986 the soil from a depth of 20 cm was collected in the area. The soil was air-dried, ground to pass a 2.0 mm sieve and mixed. The oven dry weight (105°C) of soil in each pot was 4.49 kg.

Four days before treatment establishment, the soil received an additional fertilization of 65.5 mg of P kg^{-1} soil as simple superphosphate, 41.5 mg of K kg^{-1} soil as potassium chloride and 20 mg kg^{-1} of a trace element mixture (FTE BR-12). Fertilizer rates were calculated based on the soil analysis and CPAC recommendations for this kind of soil (Goedert, 1986). The initial chemical properties of the soil are presented in Table 1.

Table 1. Soil chemical properties at the first day of experiment establishment

pH (water)	N (g kg^{-1})	Organic matter (g kg^{-1})	Avail. P[a] (mg kg^{-1})	Extractable cations		
				K (mg kg^{-1})	Al	Ca + Mg (mol kg^{-1})
5.5	1.5	26.1	3.7	54	16.2	2.2

[a] Extracted by double acid Mehlich procedure (EMBRAPA, 1979).

The soil pH was measured in water in a proportion of 1:1 water:soil. Potassium was measured by a flame photometer using extracts from a double acid (0.05*N* HCl + 0.025*N* H_2SO_4). Phosphorus was measured by a colorimeter using the same double acid extract as used for potassium. Calcium, magnesium, and aluminum were extracted with unbuffered 1*M* KCl in a ratio of 1:10 for soil:solution. Calcium and magnesium were measured by an atomic absorption spectrophotometer. Aluminum was measured by titrating the extract with 0.10*N* NaOH to the bromothymol blue endpoint. Organic matter was determined by the Walkley-Black procedure and total N was determined by the micro-Kjeldahl method. All these methodologies are described by EMBRAPA (1979).

The plant material utilized was leaves of *Mucuna aterrima* (Piper & Tracy) Merr. This fast growing tropical legume has been used mainly as a green manure or cover crop in Central Brazil and its chemical composition is published elsewhere (Duke, 1981). The plants were approximately three months old at harvest and the leaves contained 5.3% N. Each pot received fresh chopped leaves. The mass of leaves added to each pot was 13.4 g on a dried weight basis. The dry weight of the leaves was determined after oven drying at 65°C for 72 hours. Each pot received 713 mg N as legumes. The pots received an amount of water required to achieve gravimetric soil moisture of 27.8% (84% of field capacity). The soil moisture was adjusted daily by adding water to initial weight. The mulch decomposed very rapidly in the first two weeks. The upper part of the mulch dried within an hour after water addition and the bottom part in contact with the soil was always moist. The air and soil temperature was monitored and no trend was observed. There was not a significant difference in soil temperature among the treatments. The mean soil temperature from February to May was 23.5°C and from June to August was 20.5°C.

Three replications (pots) of each one of the three treatments were sampled every sampling date. First, the plant material remaining on the surface of the mulch treatments was collected with tweezers and put in a paper bag for subsequent weighing. A small brush was used to remove the soil that was attached to the plant residues. The plant materials collected as mulch were weighed after drying at 65°C for 48 hours, and subsequently a 0.2 g ground sample was digested with H_2SO_4 and H_2O_2. The nitrogen digest included a potassium sulfate-catalyst mixture. The total N was determined by the micro-Kjeldahl procedure (EMBRAPA, 1979). Soil samples were analyzed for ammonium (NH_4^+) and for nitrite (NO_2^-) plus nitrate (NO_3^-) by steam distillation (Keeney and Nelson, 1982) from 1*M* KCl extracts. The results are presented as mg N kg^{-1} soil. The soil extracts were analyzed for inorganic N within 6 hours after sampling.

The experiment had 16 sampling dates and a total duration of 178 days. In the first 3 weeks the soil was sampled every 3 days, during the next two months every two weeks and during the next three months every three weeks. The interval between the last two sampling dates was of 17 days.

Results and discussion

Decomposition and N mineralization

Figure 1 shows the accumulation of inorganic N in the soil for the three treatments over the 178 days of the experiment. The rate of N accumulation was rapid in the first 25 days, and slower after 50 days. More inorganic N accumulated in the soil where the plant material was incorporated compared to that where the plant material was on the surface (mulched), although the same amount of N was applied to both treatments. The net N mineralization is defined as the inorganic N accumulated in the treated soils minus that in the untreated soils: after 178 days, the net accumulation of inorganic N in the mixed treatment was 60% greater than that in the mulched treatment.

The results in Figure 1 may be interpreted by the following two hypotheses: (1) the rate of accumulation of inorganic N under the mulched treatment is less than under the incorporated treatment because a) the conditions for substrate

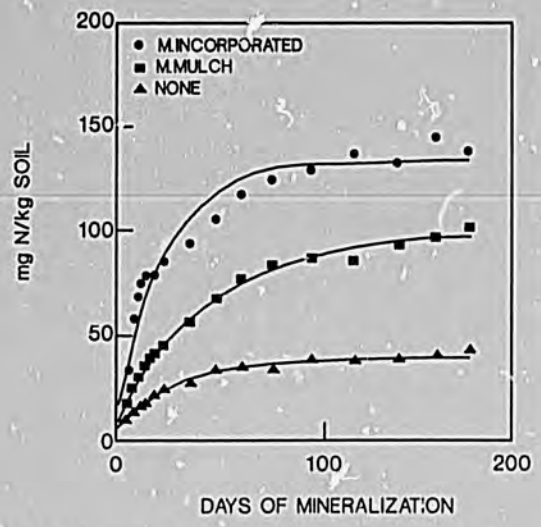

Fig. 1. Inorganic N accumulation in the soil plotted against time. The organic material was added as 159 mg N kg^{-1} soil. Data points are means of 3 replications for each treatment and the lines are exponential regression equations fitted to the data. Mucuna incorporated, $y = 133 - 108e^{(-0.043t)}$ $r^2 = 0.93$. Mucuna mulch, $y = 98 - 83e^{(-0.023t)}$ $r^2 = 0.97$. None, $y = 39 - 27e^{(-0.035t)}$ $r^2 = 0.93$.

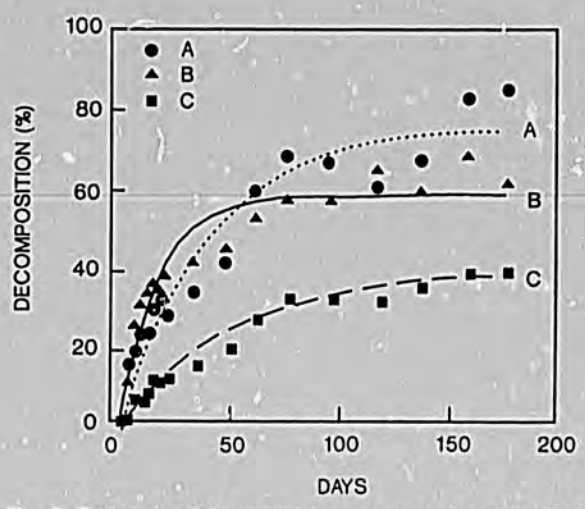

Fig. 2. Estimates of decomposition, as percentage of applied mucuna, plotted against time. *A* = Loss of *N* from surface mulch, $y = 73(1 - e^{(-0.026t)})$ $r^2 = 0.90$. *B* = Apparent decomposition, incorporated, $y = 57(1 - e^{(-0.064t)})$ $r^2 = 0.89$. *C* = Apparent decomposition, mulch, $y = 37(1 - e^{(-0.021t)})$ $r^2 = 0.95$.

decomposition are less favorable under mulched treatment and/or b) some N was lost by NH_3 volatilization. and (2) the rate of accumulation of mineral N decreases rapidly with both treatments because c) the amount of substrate decreases and d) the remaining substrate becomes more resistant to decomposition. These hypotheses are examined further in the following paragraphs.

An 'apparent decomposition' for the incorporated and mulched treatments is defined as the amount of inorganic N accumulated in the treated soils minus the amount of inorganic N accumulated in the untreated oil (the latter difference is referred to as net mineralization). In other words, 'apparent decomposition' is the amount of N that is found in the mineral N pool. That is only a component of decomposition, *i.e.* 'apparent decomposition' N = mineralized N − N lost − immobilized N. In addition, the decomposition of the mulched material was calculated more directly based on the loss of N in the material recovered from the surface. These 3 quantities are plotted in Fig. 2 together with the equations fitted to the data.

The average increase in inorganic N in the soil compared with the control in the period 60 to 178 days was 33% to 60% of that added for the mulch and incorporated treatments, respectively. This is the expected maximum amounts which a crop may derive from the legume during the sampling period. Thus the mulch treatment would supply about 55% as much N to a crop as the incorporated treatment.

The data in Figure 2 illustrate hypothesis 1(a); the rate of 'apparent decomposition' of the incorporated material is somewhat faster than of the mulched material However, by day 50, the total amount of apparent decomposition for the incorporated material was not very different from the disappearance of N from the mulched treatment, although there is a significant difference. The apparent rate of decomposition of the mulched treatment is considerably less than these two because of the presumed loss of N from the system with the mulched treatment (hypothesis 1(b)).

The net accumulation of inorganic N becomes very slow after 50 days and, there were no significant differences among sampling dates for loss of N from the surface mulch (but last two sampling dates) or apparent decomposition rates for the two treatments. The last two sampling dates from the surface mulch are suspect (Fig. 2,

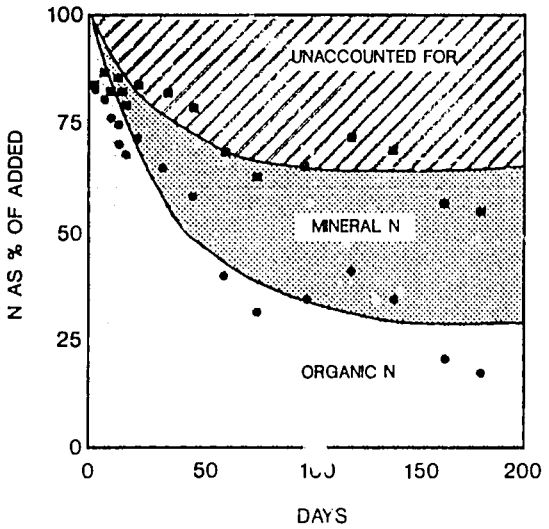

Fig. 3. Balance sheet for the mulched treatment - The total *N* in the mulch (organic *N*), net inorganic *N* accumulated in the soil (mineral *N*), and the unaccounted for *N*. Data points are mean over 3 replications for each parameter.

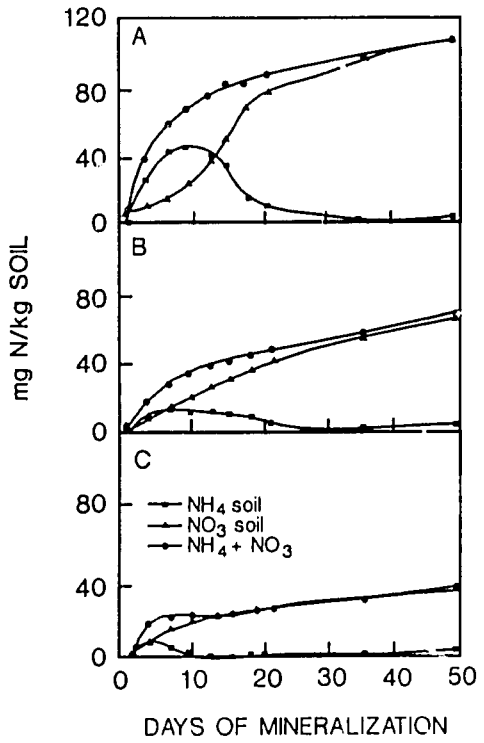

Fig. 4. Soil inorganic *N* species plotted against time for the treatments mucuna leaves incorporated (**A**), mucuna leaves surface placed (**B**) and check (**C**). The accumulated inorganic N is in the NH_4, NO_3, and $NH_4 + NO_3$ form. Data points are means of 3 replications for each treatment, and lines are drawn to connect the individual points.

curve A). The sampling of all remained plant material was difficult at the latter period of experiment due to high stage of decomposition.

The comparison of apparent decomposition (net inorganic N accumulation) for the mulch treatment with the measured loss reveals a large discrepancy between the two and the results are illustrated in more detail in Figure 3. Part of the apparent loss (unaccounted for) is attributed to NH_3 volatilization from the surface placed material. This is consistent with the explanation advanceead by others, but we did not attempt to confirm this mechanism by measurements of gaseous NH_3 losses.

During the first 10–15 days, there was a flush of ammonium in the soil for the three treatments (Fig. 4). However, after this initial period nitrification was rapid and the inorganic N in the soil was largely NO_3 plus NO_2. After 35 days no significant amount of ammonium is found in the soil.

Conclusions

a) The treatment where mucuna was incorporated had a net inorganic N accumulation 60% higher than the treatment with mucuna placed on the surface after 178 days.

b) Significant amounts of N applied as surface placed legume were not found in the remaining undecomposed residue or as inorganic N in the soil. After 3 and 178 days 15 and 45% of the N applied was not recovered, respectively. The data and literature suggest that part of this unrecovered N was lost by ammonia volatilization.

c) In the initial stages of decomposition, ammonification does exceed nitrification, and there is a short term accumulation of NH_4 (up to 45 mg N/kg soil), but after 20 days very little NH_4 is found.

This work plus evidence in the literature supports the hypothesis that volatilization can occur from decomposing plant materials placed on the soil surface even if the soil is acid.

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References

Barrow N J 1960 Stimulated decomposition of soil organic matter during the decomposition of added organic materials. Aust. J. Agric. Res. 11, 321–338.

Bowen W T 1987 Estimating the N Contribution of Legumes to Succeeding Maize on an Oxisol in Brazil. Ph.D. Thesis. Cornell University, Ithaca, NY.

Cornforth I S and Davies J B 1968 N transformations in tropical soils. I. Mineralization N rich organic materials added to the soil. Trop. Agr. (Trinidad) 45, 211–221.

Duke J A 1981 Handbook of Legumes of World Economic Importance. Plenum Press, New York.

EMBRAPA 1979 Manual de métodos de análise de solo. Serviço Nacional de Levantamento e Conservação de Solos, Rio de Janeiro, RJ, Brazil.

EMBRAPA/CPAC 1976 Relatório Técnico Anual do Centro de Pesquisa Agropecuária dos Cerrados 1975–1976. Planaltina-DF, Brazil.

EMBRAPA/CPAC 1985 Relatório Técnico Anual do Centro de Pesquisa Agropecuária dos Cerrados 1981–1982. Planaltina-DF, Brazil.

EMBRAPA/SNLCS 1968 Levantamento de reconhecimento dos solos do Distrito Federal. Bull. Tec. No. 8. Rio de Janeiro, Brazil.

Freney J R, Simpson J R and Denmead O T 1981 Ammonia volatilization. *In* Terrestial Nitrogen Cycles. Eds. F E Clark and U Sinhu. Ecol. Bull. 33, 291–302. Stockholm, Sweden.

Goedert W J (Ed.) 1986 Solos dos Cerrados; Tecnologias e estratégias de manejo. Nobel, Brasilia; EMBRAPA-CPAC.

Humfeld H and Smith N R 1932 The decomposition of green vetch manure in relation to the surrounding soil. J. Agric. Res. 44, 113–120.

Kang B T, Sipkins L, Wilson G F and Nangju D 1982 Leucaena (*Leucaena leucocephala* Lam. de Witt) prunings as N source for maize (*Zea mays* L.). Fert. Res. 2, 279–287.

Keeney D R and Nelson D W 1982 N – inorganic forms. *In* Methods of Soil Analysis, Part 2, second edition. Eds. A L Page, R H Miller and D R Keeney Agronomy 9, 643–698.

Lopes A S and Cox F R 1977 A survey of the fertility status of surface soils under 'cerrado' vegetation in Brazil. Soil Sci. Soc. Am. J. 41, 742–747.

McCalla T M and Russel J C 1948 Nitrate production as affected by sweetclover residues left on the surface of the soil. Agron. J. 40, 411–421.

Moore A W 1974 Availability to Rhodegrass (*Chloris gayana*) of N in tops and roots added to soil. Soil Biol. Biochem. 6, 249–255.

Pereira J and Peres J R R 1986 Manejo da matéria orgânica. *In* Solos dos Cerrados; Tecnologias e estratégias de manejo. Ed. W J Goedert. pp 261–282. Nobel, Brasília; EMBRAPA-CPAC.

Quintana J O, J Pereira, Boaldin D R and Lathwell D J 1988 Screening legume green manures as nitrogen sources to succeeding non-legume crops. II. Incubation in laboratory. Plant and Soil 111, 81–85.

Sarrantonio M 1987 Effects of Tillage on Mineralization of N from a Winter Green Manure Crop. Ph.D. Thesis. Cornell University, Ithaca, NY.

Sanchez P A 1976 Properties and Management of Soils in the Tropics. John Wiley and Sons, New York.

Terman G L 1979 Volatilization losses of N as ammonia from surface-applied fertilizers, organic amendments, and crop residues. Adv. Agron. 31, 189–223.

U.S.D.A. Soil Conservation Service. 1975 Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agriculture Handbook No. 436.

Wade M K and Sanchez P A 1983 Mulching and green manure applications for continuous crop production in the Amazon Basin. Agron. J. 75, 39–45.

Wilson D O and Hargrove W L 1986 Release of N from crimson clover residue under two tillage systems. Soil Sci. Soc. Am. J. 50, 1251–1253.

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