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Influence of Rates of Application of Different Plant Residues on Time Courses of N Mineralization and Immobilization in Soils with Different Textures

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ABSTRACT

An aerobic incubation experiment was conducted at room temperature (19 to 23 °C) to determine the influence of rates of application of different plant residues on time courses of N mineralization and immobilization in soils with different textures. The experiment was carried out in a completely randomized design with three replications. The experimental treatments were factorial combinations of four factors: (1) three rates of plant residue applications (0, 1.25, 2.50 and 5.00 mg of plant residue g^{-1} soil); (2) three soil textures (loamy sand, loam and clay soils); (3) four plant residue types (leucaena, sesbania, faba bean stubble and maize stubble); and (4) six incubation periods (0, 15, 30, 60, 90 and 120 days). The treated samples were analyzed for extractable mineral N (NH_4^+ + NO^-_3) to determine mineralization and immobilization of N.

From the results, the following conclusions and recommendations were drawn. (1) Application of sesbania residue into soils resulted in N mineralization with the rate that increased with fineness of soil texture but decreased with increasing time of incubation. In the cases of the loam and clay soils, N mineralization increased with increasing rate of residue up to 5.00 mg g^{-1} soil throughout the incubation period but, in the case of the loamy sand soil, N mineralization increased up to the highest rate after 30 days of incubation (DI). (2) Application of leucaena residue into soils resulted in N immobilization that increased with fineness of soil texture during 0-15 DI. N mineralization, increased with fineness of soil texture and rates of application up to 5.00 mg g^{-1} soil after 15-30 DI onwards, but decreased with time of incubation. (3) Application of faba bean stubble or maize stubble resulted in N immobilization at the rate that increased with fineness of soil texture. In the loamy sand soil N immobilization was mostly observed throughout 120 DI. In the loam and clay soils, N immobilization that increased with fineness of soil texture occurred during 0-15 DI. After 15-30 DI, N mineralization, at the rate that was independent of the rate of residue application in the case of the loam soil but decrease with increase in the application rate in the case of the clay soil, took place.

Key words: N mineralization, immobilization, rate of application, plant residue, incubation period

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INTRODUCTION

In many management options, addition of organic materials is considered as an important source of plant nutrients. Parr and Papendick (1978) stated that one of the features of sustained agriculture was its lower dependence on chemical fertilizers and recycling of on-farm residues to maintain or improve fertility of soils. Wade and Sanchez (1983) reported that the use of organic residues as a source of N for crops was particularly important in many parts of humid tropic where N fertilizers were not often economically feasible. Constantinides and Fownes (1994) also indicated that in tropical agricultural ecosystems with limited access to fertilizers, plant residues were often used to meet the N requirements of annual food crops.

However, the release of mineral N from the added plant residues might not be sufficient to satisfy the requirement of crops for the optimum yield, particularly when materials with C:N ratios above the critical levels are added. Paul and Clark (1989) reported that when the organic residues added to soil contained wider C:N ratios, microorganisms utilized the mineral N present in the soil to supplement that in the residues. Under these conditions, soil available mineral N practically disappears from the soil causing the plants to suffer from nitrogen deficiency. To avoid such deficits and satisfy the nutritional requirements of plant, it might be very important to determine the times of mineralization and immobilization of N from the decomposition of different plant materials added to soils. Fox *et al*. (1990) reported that to optimize the use of N from plant residues for subsequent or companion crops, it was necessary to predict their mineralization rates in the soil. Most of the studies conducted on the mineralization and immobilization of N from the applied residues have been short-term incubations and motivated primarily by the need for rapid methods of assessing soil N availability. Palm and Sanchez (1991) reported that short-term incubations could be useful guide for screening short-term N release and availability from legumes. However, Stanford and Smith (1972) suggested that the N mineralization-time curves obtained during long-term incubations could provide a rational or consistent basis for estimating N supplying capacities of soils.

Studies have indicated that the amounts of plant residue added to soils have a marked influence on the rate of residue decomposition and N mineralization. Jenkinson (1977) described that decomposition and mineralization of N from the applied organic residues was considerably more rapid at lower rates of application than when added at higher rates. Melillo and Aber (1984) reported that application of higher rates of wheat straw and deciduous trees resulted in immobilization of mineral N due to the increased demand for biomass synthesis by the micrroganisms. Power (1968) also concluded that the amount of N immobilized was in proportion to the quantity of residues added to the soil. On the other hand, some authors have reported that increasing amounts of residue application suppressed the activities of aerobic microorganism that were responsible for nitrification and instead it enhanced the denitrification of mineral N. Amberger (1989) described that application of higher amounts of wheat straw to heavy soils where oxygen diffusion was temporarily depressed, led to anaerobic fermentation and denitrification also occurred. Likewise, Alexander (1977) also stated that large addition of organic residues led to oxygen deficiency especially during the first few days when microbial activity was high, because anaerobic sites were developed in the soil and nitrate-N was denitrified. The greater the quantity of residues added the longer the period of nitrification will be blocked (Brady, 1990).

For efficient utilization of locally available organic resources, it will be very important to investigate and determine the N mineralization and immobilization processes in relation to the amounts added to soils. The objectives of the study were: 1) to find suitable times, prior to planting, for application of different plant residues to soils with different textures 2) to examine the effect of rate of applications of different plant residues on time course of N mineralization in soils with different textures so that suitable rate of application might be determined.

MATERIALS AND METHODS

The experiment was done at the laboratory of the National Soil Research Center, Addis Ababa, Ethiopia.

Experimental design

A laboratory incubation experiment was carried out using a completely randomized design with $3 \times 3 \times 4 \times 6$ treatments and three replications. The experimental treatments were factorial combinations of four factors: (1) three rates of residue application (0, 1.25, 2.50 and 5.00 mg of plant residue g^{-1} soil, equivalent to 2.5, 5.0 and 10.0 t ha^{-1}, respectively); (2) three soil textures (loamy sand, loam and clay soils); (3) four residue types (leucaena, sesbania, faba bean and maize); and (4) six incubation periods (0, 15, 30, 60, 90 and 120 days).

Soil samples collection and preparation

The soils used in the investigation were collected from the 0-15 cm layers of soil in cultivated fields. The bulk samples of loamy sand soil were collected from farmers' fields in Dengego area of eastern Ethiopia, the loam soil was collected from Mekele Agricultural Research Station of northern Ethiopia and the clay soil was collected from Nekemte farmers' fields of western Ethiopia. The soil samples were air-dried and gently crushed to pass through a 2-mm sieve. All visible organic residues were removed by hand after sieving and then each soil was thoroughly mixed and stored at room temperature in moisture proof containers.

Properties of the soil used

Particle size distribution of the soil was determined by the hydrometer method (Bouyoucos, 1951), the upper limits of the available moisture holding capacities and the permanent wilting moisture contents of the soils were determined at -33 and -1500 kPa, respectively, by the pressure-membrane method (Richards, 1965), soil pH by the potentiometrical method with soil:water ratio of 1:2.5 (Van Reeuwijk, 1992), cation exchange capacity by 1*M*-ammonium acetate method at pH 7 (Chapman, 1965), organic carbon by the dichromate method (Walkley and Black, 1934), total N by the micro-Kjeldahl method modified to include nitrate and nitrite-N (Bremner and Mulvaney, 1982) and extractable NH_4^+ and NO_3^--N by steam distillation (Keeney and Nelson, 1982). All soil analyses were conducted on duplicate samples. The results are shown in Table 1.

Plant material preparation and analysis

Four locally available crop residues, namely tops of leucaena (*Leucaena leucocephala*), tops of sesbania (*Sesbania sesban*) and stubbles of faba bean (*Vicia fabacae* L.) and stubbles of maize (*Zea mays* L.) were collected from the research centers. The maize stubbles were collected from the unfertilized plots. The plant materials were oven dried at 70°C to constant weight, ground to pass through a 1-mm sieve and stored in plastic vials. Each plant material was analyzed for organic carbon using the dry ashing method (Amato, 1983) and total N by the micro-Kjeldahl procedure (Bremner and Mulvaney, 1982). Extraction of chemical constituents (cellulose, lignin and polyphenol) of plant materials were performed following the method developed by Van Soest (1963) and Van Soest and Wine (1967). All plant analyses were conducted on duplicate samples. The results are shown in Table 2.

Incubation procedure

The incubation experiment was done in plastic bottles with 180 ml capacity. The soil samples were amended with ground plant materials at required rates. The soil and residues were thoroughly mixed. For all of the plant residues, the soil moisture was adjusted to 100 % FC in the loamy sand and loam soil and 75 % FC in the clay soil whereas it was adjusted to 75 % FC (on weight basis) in case of leucaena residue in the loamy sand soil. The moisture levels used have been found most suitable for enhancing mineralization of N in plant residues applied to each soil type (Tesfaye *et al.,* 2005). After adjustment of moisture contents, each of the incubation bottles was closed with aluminium foil on which three holes were made with a pin to allow gaseous exchange with the atmosphere. Then the treated soil samples were incubated in laboratory at room temperature (19 to 23°C) for required periods. To prevent the development of anaerobic conditions, the incubation bottles were opened to aerate at 5-day intervals for 15-20 minutes throughout the incubation period. At each interval, the losses in weight of the incubation bottles were checked and deionised water was added to bring the weight to the original. The samples of zero day incubation were analyzed for extractable mineral N (NH_4^+ and NO_3^- -N) immediately after mixing the soil and plant residues. At the end of each of the specified incubation period, the incubation bottles were re-randomized.

Table 1 Some physical and chemical characteristics of the soil used.

Properties \ Soil texture	Loamy sand	Loam	Clay
Field capacity moisture (%, w/w)	5.0	22.3	40.2
Permanent wilting point moisture (%,w/w)	2.7	10.5	25.6
Sand (%)	84.0	46.0	22.0
Silt (%)	8.0	32.0	38.0
Clay (%)	8.0	22.0	40.0
pH in water (1:2.5, soil : water)	7.7	7.7	5.0
OM (%)	1.3	2.3	5.3
Total N (%)	0.08	0.11	0.29
NH_4^+ -N (mg kg^{-1}soil)	3.7	5.0	7.3
NO_3^- -N (mg kg^{-1}soil)	4.1	7.9	5.7
CEC [cmol.(+) kg^{-1} soil]	6.6	22.3	24.5

Table 2 Chemical characteristics of plant residue used.

Plant residues	C (%)	Total N (%)	C/N	Lignin (%)	Hemi-cellulose (%)	Cellulose (%)	Poly-phenolics (%)
Leucaena	45. 3	3.9	11.7	7.4	10.6	9.8	18.2
Sesbania	45.0	4.9	9.1	4.0	1.6	12.9	13.9
Faba bean	45.0	1.7	26.8	11.5	11.0	44.9	10.8
Maize stubble	46.0	1.2	39.3	4.8	36.4	42.0	7.6

Analysis of extractable mineral N in the incubated samples

Extractable mineral N (NH_4^+ + NO_3^--N) in the soil was determined after the specified incubation period. One hundred ml of 2*N* KCl was added to each incubated bottle (2:1 KCl solution to soil ratio) and the incubation bottles were then shaken for 1 hr on a reciprocal shaker. The suspension was then allowed to settle until the supernatant liquid was clear and the supernatant was then filtered using Whatman no.42 filter papers. The filtrate was kept in refrigerator in air-tight bottle at -2°C. An aliquot of 30 ml extract was used for the determination of NH_4^+-N by steam distillation in the presence of MgO and subsequently NO_3^--N was determined by adding Devarda's alloy (Keeney and Nelson, 1982). The distillate was collected in 2 % boric acid-indicator solution. The amount of NH_4^+ and NO_3^--N in the distillate was quantified by titration with 0.01N HCl.

Calculation of Δ mineral N

Δ Mineral N was calculated as the difference in the amount of extractable mineral N between the soil amended with plant residue and the control, for each incubation time. A positive value of Δ mineral N thus would indicate N mineralization whereas a negative one would indicate N immobilization due to the plant residue application.

RESULTS AND DISCUSSION

Statistical analysis

Analysis of variances of the effect of the factor studied on Δ mineral N was carried out. All individual factors alone and all of their possible combinations showed significant effects at the 99 % confidence level.

Sesbania residue

The amounts of mineralized N (Δ mineral N) produced in different soils during incubation with different amounts of sesbania residue are shown in Figure 1. In all of the soils incubated with sesbania residue, N mineralization occurred at all rates of application and at all times of incubation. The highest rate of N mineralization was observed mostly at the highest rate of residue. The rate of mineralization increased with the increase in fineness of soil texture. In cases of loam and clay soil, rates of N mineralization decreased with the increase in time of incubation but mineralization still occurred at 120 days of incubation (DI). In the loamy sand soil very low

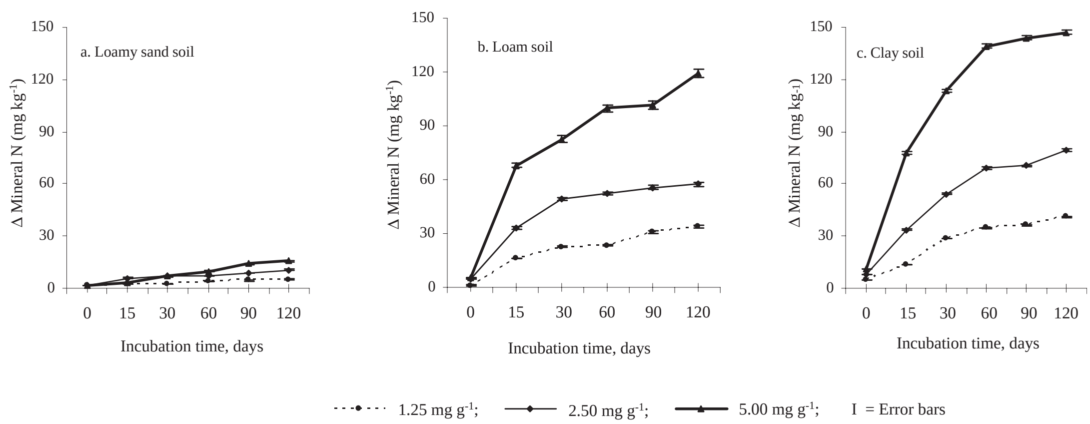

Figure 1 Time courses of change in mineral N (Δ mineral N), due to sesbania application, during incubation of soils applied with different rates of sesbania residue as affected by soil types and rates of application.

but constant rates of N mineralization were observed.

The lower rates of release of mineral N in case of the loamy sand soil, as compared with the loam and clay soil was presumably due to moisture scarcity. Since moisture content of the loamy sand soil at field capacity was very low because of large percentage of sand. In this regard, the activities of the microorganism might be slowed down. This result supported that of Haynes (1986) which concluded that crop residues N mineralization rates were reduced at low soil water contents. However, the highest N mineralization was obtained at the application rate of 5.00 mg g^{-1} soil after 30 DI onwards, but in cases of loam and clay soils, it was obtained at all times of incubation. Therefore, application rate of 5.00 mg g^{-1} soil was most suitable for mineralization of N from the decomposition of this residue in all of the soil types. The results indicated that increasing rate of application of the residue did not limit N mineralization in soils. This might be attributed to the favorable C:N ratio of the plant material that enhanced mineralization of N during the decomposition of this residue. The results supported Fox *et al*. (1990) who described that for plant residues with low C:N ratio, the N content was enough to meet the needs of microbial communities and the surplus would be mineralized. The increase in the rate of mineralization of N associated with the degree of fineness of the soil texture was most likely resulted from natural differences in capacities of soil to hold moisture. Since the moisture content of the soils studied increased with the increase in the clay content. The results confirmed that the increase in the mineralization of N in the finer-textured soils was due to high water storage capacities of soil that might accelerate the activities of microorganisms. This was in agreement with that of Chaterpaul *et al*. (1980) which described that the influence of soil texture on N mineralization was not a direct effect of clay on microorganisms but was related to soil water holding ability.

Leucaena residue

The amounts of mineralized N (Δ mineral N) in different soils during incubation with different rates of leucaena residue are shown in Figure 2. During 0-15 DI, N immobilization that increased with fineness of the soil texture was observed, but the residue effect was not significant However, after 15-30 DI, N mineralization that increased with rate of residue application but decreased with the increase in incubation time was observed in the loam and clay soils. In the loamy

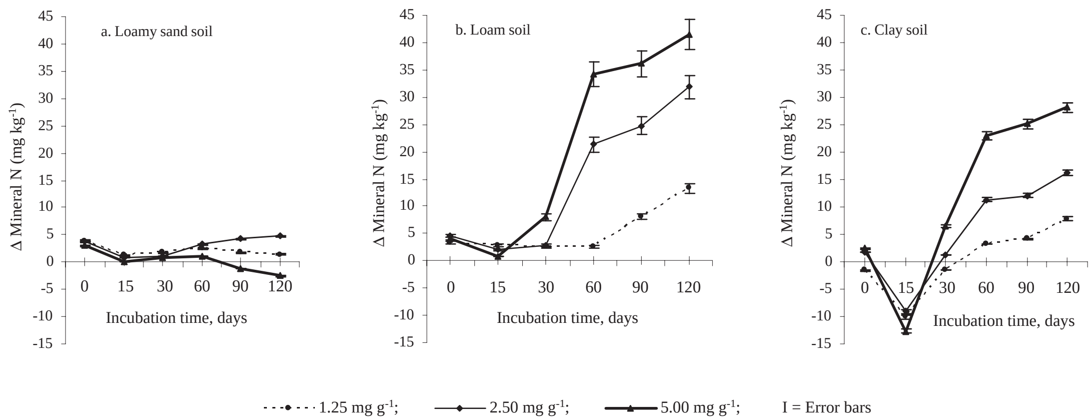

Figure 2 Time courses of change in mineral N (Δ mineral N), due to leucaena application, during incubation of soils applied with different rates of leucaena residue as affected by soil types and rates of application.

sand soil, no significant change in Δ mineral N was observed from the residue application at the lowest rate but low rate of N mineralization and low rate of N immobilization were observed at the medium and highest rates of application, respectively.

The increased rates of N mineralization up to the highest rates of residue application in cases of loam and clay soils indicated that increase in the rate of application did not limit the activities of the aerobic microorganisms in soils during the incubation periods studied. Therefore, the application rate of 5.00 mg g^{-1} soil was most suitable for mineralization of N from decomposition of this plant material in cases of loam and clay soils. This might be due to the low C:N ratio of the residue and the favorable conditions in the soils for the microbial activity. This was in agreement with the results of Swift *et al*. (1981) which described that plant residues with high nitrogen contents showed nutrient release. In case of loamy sand soil, the highest N mineralization was obtained at the application rate of 2.50 mg g^{-1} soil after 30 DI onwards. This might be attributed to the presence of adequate level of soil moisture content at the application rate that enhanced the activities of the microorganisms that needed relatively high C:N ratio, whereas at the lower and higher rates of residue application the moisture levels were too high and too low, respectively, to enhance such activities. This result supported Miller and Johnson (1964) who concluded that maximum rate of mineralization occurred at the soil moisture content at which soil aeration remained non-limiting. However, the decrease in mineralized N at the highest rate of the plant material was presumably due to moisture stress that might slow down the microbial activity. The results supported that of Haynes (1986) which described that the decline in size of decomposer communities by the lethal action of moisture stress in dry soils had a retarding effect on the plant decomposition process. Hence it could be expected that the highest rate of residue would show the highest N mineralization if the soil moisture was at the suitable level, i.e. 75 % FC. This effect of moisture level has been demonstrated by Tesfaye *et al*. (2004) who found that soil moisture at 75 % FC was more suitable than those at 50 and 100 % FC for mineralization of N in leucaena residue in the loamy sand soil. The occurrence of N immobilization in all of the soils presumably was due to non-selective growth of soil organisms at the early stages of incubation.

Faba bean and maize stubble

The amounts of immobilized N (negative Δ mineral N) obtained in different soils during incubation with different amounts of faba bean stubble and maize stubble are shown in Figures 3 and 4. During 0-15 DI, N immobilization that increased with fineness of soil texture was observed. In the loamy sand soil, very low rates of N immobilization that mostly increased with increase in incubation time up to 120 DI was observed. In the loam and clay soils, N immobilization at the rates that decreased with increase in incubation time up to 15-30 DI and thereafter N mineralization occurred except in case of the two higher rates of plant residue in the clay soil. The N immobilization occurred at the rates that mostly increased with increase in fineness of soil texture and in rate of plant residue application.

In case of loamy sand soil, higher amounts of N immobilization was observed at the higher rates of residue after 30 DI onwards whereas the lowest amount of N immobilization was mostly obtained at the residue application rate of 1.25 mg g^{-1} soil (Figures 3a and 4a). Therefore, the application rate of 1.25 mg g^{-1} soil was most suitable for minimizing immobilization of N from decomposition of these stubble in the case of loamy sand soil. This result supported the results of Power (1968) which concluded that the amount of N immobilized was in proportion to the quantities of residue added to the soil. The immobilization of N during the early stages of incubation in the loam and clay soils might be attributed to the low N contents of the plant material that could not satisfy the increased demand for mineral N. This was in agreement with Jenkinson (1981) who concluded that temporary immobilization of N occurred when organic residues with wide C:N ratios were added to the soil. The increase in rate of N immobilization with increase in finess of soil texture and in rate of residue application up to the second rate in the loam soil suggested that the moisture content of the loam soil limited N immobilization at the highest rate of residue. This result was in agreement with the result of Parkin (1987) which described that bacterial proliferation was retarded by an insufficiency of water. Hence, the immobilization of N would increase with increase in the rate of residue if the moisture content of the soil-residue mixture was at the desired level. The amounts of N mineralized during the later stage of incubation essentially comparable among

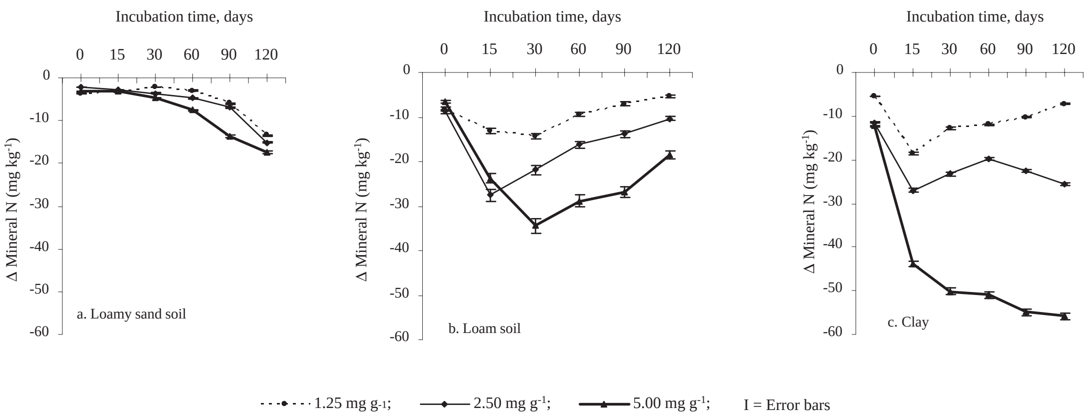

Figure 3 Time courses of change in mineral N (Δ mineral N), due to faba bean stubble application, during incubation of soils applied with different rates of faba bean stubble as affected by soil types and rates of application.

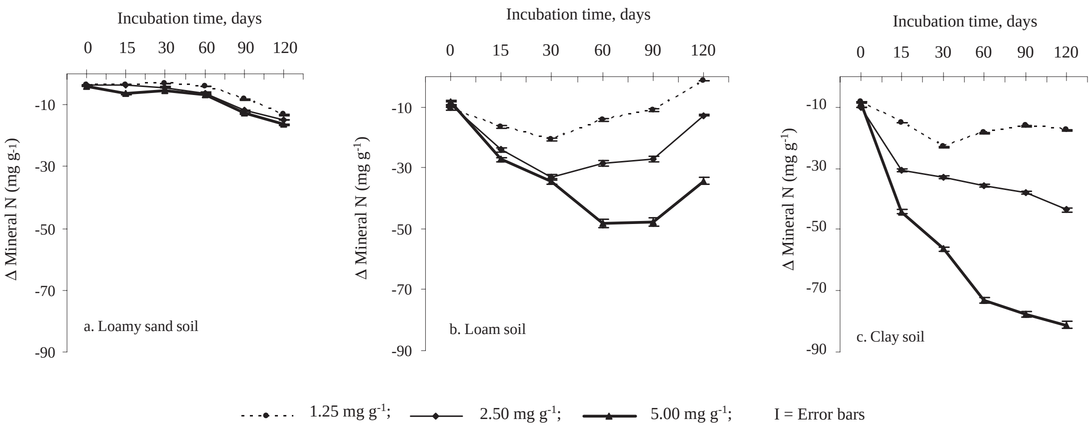

Figure 4 Time courses of change in mineral N (Δ mineral N), due to maize stubble application, during incubation of soils applied with different rates of maize stubble as affected by soil types and rates of application.

different rates of residue application in the loam soil and the occurrences of mineralization at the lowest rate of plant residue and of N immobilization at the highest rate of plant residue in the clay soil suggested that aeration was the factor that determined the net result of change in the soil mineral N. With limited aeration, N mineralization was limited and N immobilization was enhanced. In view of minimizing N immobilization, a lower rate of faba bean and maize stubble would be more desirable than a higher rate.

CONCLUSION

1. Application of sesbania residue into soils resulted in N mineralization with the rate that decreased with increase in time of incubation. In cases of loam and clay soil, N mineralization increased with the increasing rate of residue up to 5.00 mg g^{-1} soil throughout the incubation period but, in case of loamy sand soil, N mineralization increased up to the highest rate after 30 DI.

2. Application of leucaena residue into soils resulted in either immobilization or no change in mineral N during 30 DI. N mineralization at the rate that decreased with time of incubation increased with the increasing in rates of application up to up to 5.00 mg g^{-1} soil after 15-30 DI.

3. Application of faba bean stubble or maize stubble into loamy sand soil mostly resulted in immobilization of N throughout 120 DI. In case of loam soil with stubble of faba bean and stubble of maize, N mineralization increased with the increasing rate of application up to 5.00 and 2.50 mg g^{-1} soil after 30 DI, respectively. In case of clay soil with both of plant materials, the amounts of mineral N decreased with the increasing rate of residue application throughout the course of incubation.

4. With view point of maximizing amount of mineralized N and minimizing amount of immobilized N, application at a higher rate would be more desirable than at a lower rate in cases of sesbania and leucaena residues whereas a lower rate would be more suitable than a higher rate in cases of faba bean and maize stubble.

5. In order to enhance supply of N mineralized from plant residue and/or minimized amount of N fertilizer to compensate the immobilized N for crop, application at planting might be recommended for sesbania residue whereas preapplication by at least 15 days before planting was recommended for faba bean and maize stubble.

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