Kasetsart J. (Nat. Sci.) 39 : 24 - 33 (2005)

Influence of Soil Moisture Content on Time Courses of Nitrogen Mineralization and Immobilization Caused by Applications of Different Plant Residue to Soils with Different Textures

Tesfaye Ertebo[1], Amnat Suwanarit[2], Visoot Verasan[3] and Jongruk Chanchareonsook[2]

ABSTRACT

A laboratory aerobic incubation experiment was conducted at room temperature to determine the influence of soil moisture contents on time courses of N mineralization and immobilization caused by application of different plant residues. The experiment was carried out in a completely randomized design with a $4 \times 3 \times 3 \times 6$ treatments and three replications. The experimental treatments were factorial combinations of four factors: (1) four plant residue types (control, leucaena, sesbania, stubble of faba bean and stubble of maize; (2) three soil textures (loamy sand, loam and clay soil); (3) three moisture levels [50, 75 and 100 % field capacity (FC)]; and (4) six incubation periods (0, 15, 30, 60, 90 and 120 days). The treated samples were analyzed for mineral N (NH_4^+ + NO^-_3) to determine mineralization and immobilization of N.

Incorporation of sesbania residue in soils resulted in N mineralization with the rates decreasing with increase in time of incubation. Throughout 120 days of incubation (DI), N mineralization increased with the increase in soil moisture content up to 100 % FC in case of the loamy sand soil but up to 75 % FC in case of the clay soil. In case of the loam soil, N mineralization was not affected by soil moisture content during 30 DI but increased with increase in soil moisture content up to 100 % FC after 30 DI. Incorporation of leucaena residue in soils resulted in either no or slight change in mineral N in the soil during 30 DI regardless of kind of soil. The mineralization and immobilization if occurred either ended after 90 DI or continued to more than 120 DI depending on kind of soil. Incorporation of faba bean stubble or maize stubble in soils mostly resulted in immobilization of N in the soils during the early stages of incubation time and thereafter it either continued up to 120 DI or stopped depending on kind of soil. Both in case of immobilization and mineralization, they mostly increased with soil moisture content up to 100 % FC. For sesbania residue, most suitable soil moisture levels for maximizing N mineralization were 100 % FC in the loamy sand and loam soils and 75 % FC in the clay soil whereas those for leucaena residue were 75 % FC in the loamy sand and clay soils and 100 % FC in the loam soil. In case of incorporation with faba bean or maize stubble, N immobilization could be limited by limiting soil moisture content regardless of soil texture. However, after some specific times of incubation, increases in soil moisture content enhanced N mineralization in the loamy sand and loam soils.

Key words: N mineralization, immobilization, soil moisture content, plant residue, incubation period

1 National Soil Research Center, P.O Box 147, Addis Ababa, Ethiopia.

2 Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.

3 Department of Soil Science, Faculty of Agriculture, Kasetsart University, Kamphaengsaen Campus, Nakhom Pathom 73140, Thailand.

Received date : 08/11/04 Accepted date : 14/02/05

INTRODUCTION

Transformation rates of the N in organic residues incorporated in soil are influenced by several interrelated environmental factors, among which is soil moisture content. Stanford and Enstein (1974) stated that soil moisture was of central importance in the soil ecosystem governing the level of microbial activity and hence resulting in the rate and pathway of transformation of N in organic residues. Moisture status has influence on the rate and time course of organic N transformation, because moisture stress inhibits the microbial growth. The inactivity of microorganisms in dry soils, and the decline in sizes and activities of decomposer community by the lethal action of moisture stress will have a retarding effect on the process of N mineralization **(**Haynes, 1986).

The microbial activity is affected by soil moisture stress by limiting movement of microorganisms and transport of nutrients in the soil solutions under drought conditions, and by the buildup of oxygen deficiency in water logged conditions (Alexander, 1977). Less N is immobilized when plant residues decompose under anaerobic conditions, because decomposition is slower under such condition (Jenkinson, 1981). It was also reported by Van Gestel *et al*. (1993) that moisture stress caused death of a portion of the community of soil microorganisms.

Different groups of microorganism are affected differently by different soil moisture conditions. It was reported by Linn and Doran (1984) that the activity of autotrophic bacteria increased with soil water content until a point was reached where water displaced air and restricted the diffusion and availability of oxygen, while, the mineralization and immobilization of N was performed by the heterotrophic soil organisms at moderate to excessively high moisture contents. Most of the investigations made on soil moisture content in relation to microbial activities had been short-term laboratory incubations. However, Stanford and Smith (1972) reported that only a small proportion of the potentially mineralizable N was released during short-term incubations. The N mineralization-time curves obtained during long-term incubations can provide a rational or consistent basis for estimating N supplying capacities of soils.

Much of the literature on the relationship between the optimum soil moisture content and N mineralization rates seems to be inconclusive. Alexander (1977) reported that the optimum soil moisture for organic residue decomposition and N mineralization in soil ranged from 50 to 75 % of the water holding capacity of the soil. According to Scott and Martin (1989) it fell between 50 to 90 % of the field capacity. In addition, Bradford and Hung (1994) also suggested that the optimum soil moisture content for N mineralization was at field capacity. Likewise, Stanford and Epstein (1974) described that the rate of mineralization of N from soil organic matter generally increased with increasing moisture content between permanent wilting point and field capacity. These published works lack consistency to be extrapolated for different agricultural soils. The inconsistency is presumably due to variation in texture of the soils used since texture is an important factor which determines water storage capacity and soil aeration.

Understanding of the quantitative relationships between soil moisture content and N mineralization rate in soils with different textures is essential as a basis for controlling the amounts of mineral N released to crops under specific soil moisture content. Therefore, it is very important to investigate the optimum moisture level for different soil textures at which N mineralization will be maximum. The objectives of the study were : 1) to find optimum soil moisture level for maximum N mineralization or minimum immobilization in soils with different textures and 2) to examine the effect of moisture contents of soil with different textures on time course of N mineralization and

immobilization of different plant residues.

MATERIALS AND METHODS

Experimental design

A laboratory incubation experiment was carried out in a completely randomized design with a 3×3×4×6 treatments and three replications. The experimental treatments were factorial combinations of four factor: (1) three moisture levels [50, 75 and 100 % field capacity moisture contents (FC)] on weight basis; (2) three soil textures (loamy sand, loam and clay soil); (3) four residue types (control, leucaena, sesbania, faba bean and maize stubble); and (4) six incubation periods (0, 15, 30, 60, 90 and 120 days).

Soil sample 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 from Mekele Agricultural Research station of northern Ethiopia and the clay soil from Nekemte farmers' fields of western Ethiopia. The soil samples were air-dried and gently crushed to pass through a 2-mm sieve. All the 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 (Bouyoucus**,** 1951), the upper limits of the available moisture holding capacities and the permanent wilting moisture contents of the soil 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 faba* L.) and stubbles of maize (*Zea mays* L.) were collected from research centers. The maize stubble was collected from the unfertilized plots. The plant materials were oven dried at 70ºC 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). Extractions of chemical constituent (cellulose, lignin and polyphenol) of plant material were performed following the method developed by Van Soest (1963) and Van Soest and Wine (1967). All plant analyses were also conducted on duplicate samples (Table 2).

Incubation

The incubation was carried out in 180 ml plastic containers. The soil samples were amended with desired plant residues at a rate of 125mg dry plant material per 50g soil (equivalent to 5 t ha^{-1}). The soil and residues were thoroughly mixed and adjusted to 50, 75 and 100 % F.C with deionised water. Each of the incubation bottle 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

Table1 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 (%)	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

(19 to 23°C) for required periods. To prevent the development of anaerobic condition, the incubation bottles were aerated every 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.

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. After shaking, the suspension was allowed to settle until the supernatant liquid was clear and the supernatant was then filtered using Whatman no.42 filter paper. 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 0.01 *N* 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.

Theoretical background for estimation of mineralized/immobilized N

During the aerobic incubation of a soil added with plant residue with C: N ratio lower than the critical ratio, some of N in the plant residue would be mineralized to NH_4^+-N which finally was converted to NO_3^-. This would result in higher NO_3^- content in the soil added with the plant material than in the soil incubated without addition of the plant residue. Since some of the NO_3^--N in the soil might be denitrified and transformed into gaseous forms and then lost from the soil, with the amount of N lost being increased with increased amount of NO_3^--N present. The amount of N lost in gaseous forms from soil with added plant residue would be larger than that from soil without added plant residue. Accordingly, the apparent difference in the Δ mineral N between the soil with plant residue addition and the soil without plant residue addition would be smaller than that should have been if there was no loss of N by gaseous forms from both soils. In other words the estimate from the difference in the total mineral N (i.e., Δ mineral N) would be an underestimated mineralization. If a soil was added with a plant residue with C/N ratio higher than the critical ratio and aerobically incubated, some of the mineral N, including NO_3^--N, originally present in the soil would be transformed to organic forms, resulting in smaller amount of NO_3^--N in the soil than the soil without plant residue addition. This would in turn render smaller gaseous loss of NO_3^--N from the soil with plant residue addition than that from the soil without plant residue addition. Accordingly, the apparent immobilization would be smaller than that should be if there was no loss of N by gaseous form from both of the soils. In other words, basing on the afore-going theoretical background, net N mineralization or net N immobilization obtained from comparison between total mineral N of the treatment with plant residue addition and that of control (treatment without plant residue addition) would ensure that mineralization or immobilization occurred. These net mineralization or net immobilization would be referred to hereafter as mineralization or immobilization.

RESULTS AND DISCUSSION

Statistical analysis

Analysis of variances of the effect of the factor under study 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) in different soils during the incubation with sesbania residue under different soil moisture contents are shown in Figure 1. In all of the soils, the rate of N mineralization mostly decreased with the increase in time of incubation. Compared with other plant materials, the addition of sesbania residue to all soils at all moisture treatments contributed more to the accumulation of available N. This might be due to the N-rich nature of the residue that resulted in readily release of mineralized N into the soils. The results were in

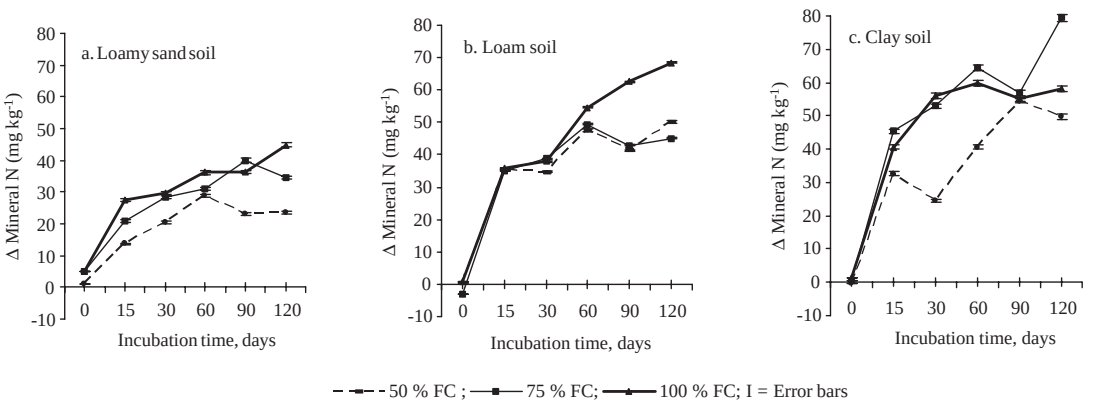

Figure 1 Time courses of change in mineral N (Δ mineral N), due to sesbania application, during incubation of soils applied with sesbania residue as affected by soil type and soil moisture content.

agreement with that of Palm *et al*. (2001) who concluded that residues with smaller C:N ratios were likely to decompose more rapidly with net mineralization of N occurring right from the beginning. In the loamy sand and loam soils N mineralization mostly increased with increase in soil moisture contents up to the highest moisture content investigated. Therefore, moisture content at 100 % FC was most suitable in enhancing mineralization of N from the decomposition of this plant residue in the cases of loamy sand and loam soils. This result wasa supported by Bradford and Hung (1994) who concluded that the optimum soil moisture content for N mineralization was at field capacity. In the clay soil, N mineralization generally increased with increase in soil moisture content up to 75 % FC. At 100 % FC, N mineralization was mostly lower than that at 75 % FC. Moisture at 75 % FC was, therefore, best in enhancing mineralization of N from the decomposition of this residue in case of the clay soil. These results indicated that when the soil moisture content was raised up to 100 % FC, aeration of the soil was too poor for the aerobic microorganisms that were responsible for N mineralization. This was supported by the result of Michael and Munns (1996) who concluded that clay soils, unless they are well managed, could be nearly saturated at field capacity.

Leucaena residue

The amounts of mineralized N (Δ mineral N) in different soils after the incubation of leucaena residue under different soil moisture contents are shown in Figure 2. In the loamy sand soil, N immobilization at mostly constant low rate was observed throughout the incubation period, except in case of 75 % FC moisture content after 60 DI (Figure 2a). In the loam and clay soils, N mineralization at mostly constant low rates was observed throughout the incubation period, except in case of the loam soil at 100 % FC after 30 DI (Figures 2b and 2c). Effects of soil moisture content on the amount of mineral N mostly increased with increase in finesse of soil texture, except in some cases in the loamy sand and loam soils.

The lower rates of release of mineral N, as compared to that at the higher moisture contents, in all soils incubated at the lowest moisture levels might be due to the decreased activities of microorganisms by low moisture contents. This result was in agreement with that of Haynes (1986) which described that the decline in sizes and activities of decomposer community by the lethal

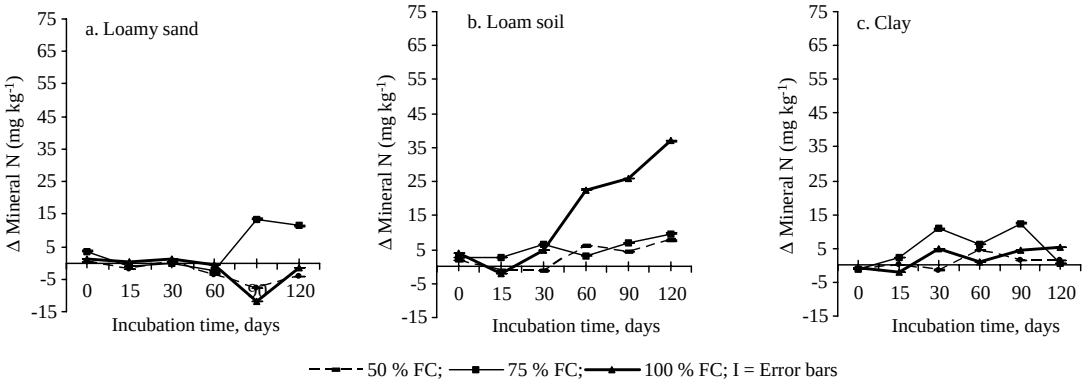

Figure 2 Time courses of change in mineral N (Δ mineral N), due to leucaena application, during incubation of soils applied with leucaena residue as affected by soil type and soil moisture content.

action of moisture stress had a retarding effect on the process of decomposition. On the other hand, decreases in release of mineral N with the increase in the moisture content from 75 to 100 % FC in case of loamy sand soil during 0-30 DI and clay soil, might be due to the excess moisture that restricted the activities of the aerobic microorganisms by preventing the movement of oxygen in sufficient quantity within the soil and caused denitrification. This was supported by the results of Aulakh *et al*. (1991) which described that denitrification occurred in soil microsites as long as there were water-saturated aggregates large enough to restrict the diffusion of oxygen to the zone of denitrification potential. In case of loamy sand and clay soils, 75 % FC was, therefore, most suitable in enhancing mineralization of N from decomposition of this residue. These results indicated that at 75 % FC, the soil moisture content and the aeration were close to optimum conditions for the microbial activity. The present results were in agreement with Miller and Johnson (1964) who concluded that maximum rate of mineralization occurred at water content at which soil aeration remained none limiting. Alexander (1977) also described that the optimum soil moisture for organic residue decomposition and N mineralization in soil ranged from 50 % and 75 % FC. In the loam soil, the highest amount of N mineralization was observed at 100 % FC after 30 DI. Moisture at 100 % FC was, therefore, most suitable in enhancing mineralization of N from decomposition of this plant residue in case of the loam soil. This result indicated that when the moisture content increased up to 100 % FC, aeration of the loam soil was optimum for microbial activities that needed less N than that at lower or higher moisture contents.

Stubble of faba bean and stubble of maize

The amounts of immobilized N (negative Δ mineral N) obtained in different soils during incubation with the stubbles of faba bean and maize under different moisture contents are shown in Figures 3 and 4. Very similar behaviors were observed from application with faba bean and maize stubbles of which C/N ratios were higher than the critical level indicated by Murthy (1990) who described that if the plant residues entering the soil had the C:N ratios greater than 25:1, nitrogen would be taken up from the mineral N pool or degradation would be slowed down. In the loamy sand soil, constant rates of N immobilization were mostly observed during 90 DI (Figures 3a and 4a). In the loam and clay soils, N immobilization at the rates decreased with increase in incubation time were mostly observed, except in case of the

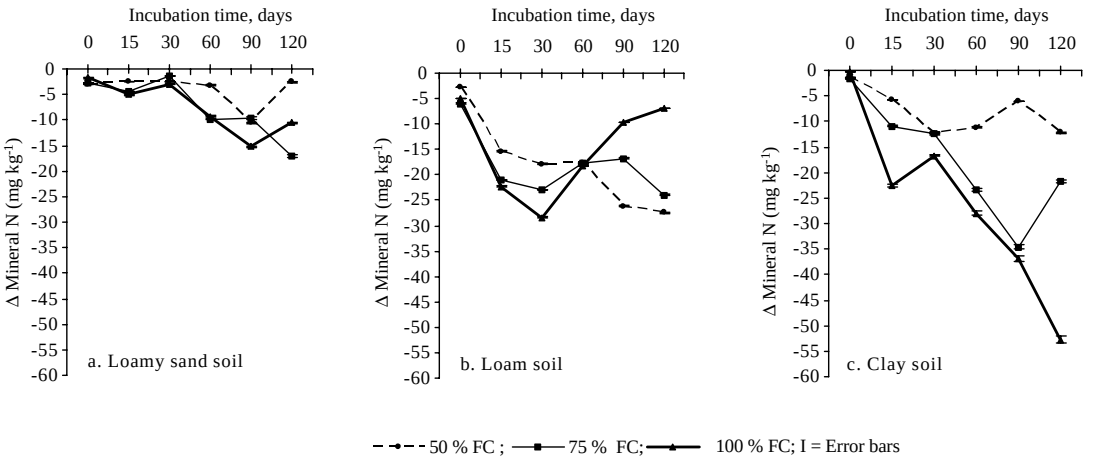

Figure 3 Time courses of change in mineral N (Δ mineral N), due to faba bean stubble application, during incubation of soils applied with faba bean stubble as affected by soil type and soil moisture content.

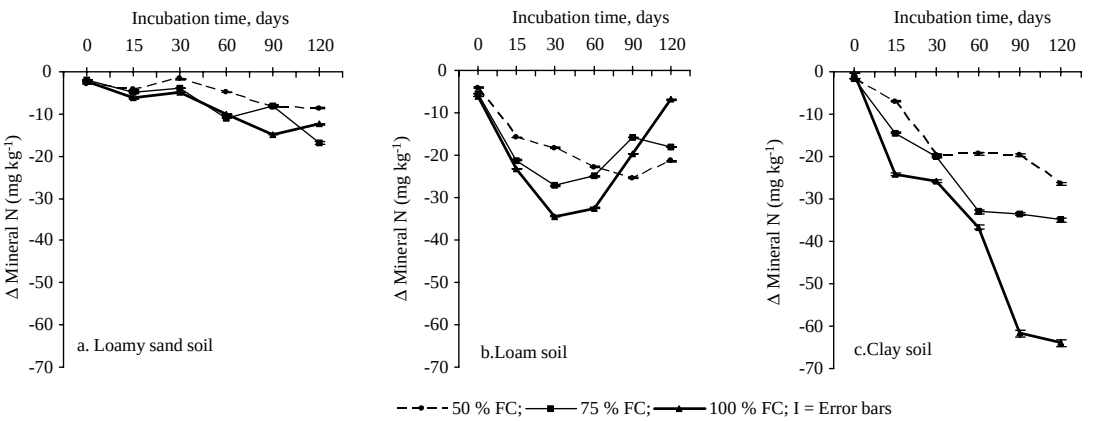

Figure 4 Time courses of change in mineral N (Δ mineral N), due to maize stubble application, during incubation of soils applied with maize stubble as affected by soil type and soil moisture content.

loam soil at 75 % FC in which N mineralization at the rate decreased with increase in incubation time was observed from either 30 or 60 DI onwards (Figures 3b and 4b). The immobilization and mineralization were mostly enhanced by increased soil moisture content up to the highest moisture content, .i.e. 100 % FC.

In all soils incubated with both of plant materials, the lowest amount of N immobilization was mostly observed at 50 % FC. This might be caused by the too low soil moisture content that suppressed the growth of microorganisms. This was supported by the result of Parkin (1987) which described that bacterial proliferation was retarded by an insufficiency of water. In the loam soil, the highest rate of N mineralization was obtained at 100 % FC with both of stubbles from 30 DI onwards. This indicated that increases in the moisture content did not limit the movement and concentration of oxygen in the soil. The results

might be attributed to the texture of the soil that created a favorable relationship between the air space and the moisture holding capacity of the soil. This result was in agreement with Smith and Arah (1990) who described that the best balance of water retention plus adequate air and water movements were in medium textured soils, such as loams. Moisture content at 50 % FC was best in minimizing N immobilization from the decomposition of these stubbles in soils. However, this moisture content is too low to sustain normal plant growth, because in most soils optimum growth of plant takes place when the soil moisture content does not approach the permanent wilting point. Therefore, the results obtained at 50 % FC could not lead to further recommendations.

CONCLUSION

1. Incorporation of sesbania residue in soils resulted in N mineralization with the rates decreasing with increase in time of incubation. Throughout 120 DI, N mineralization increased with increase in soil moisture content up to 100 % FC in case of the loamy sand soil but up to 75 % FC in case of the clay soil. In case of the loam soil, N mineralization was not affected by soil moisture content during 30 DI but increased with increase in soil moisture content up to 100 % FC after 30 DI.

2. Incorporation of leucaena residue in soils resulted in either no or slight change in mineral N in the soil during 30 DI regardless of kind of soil. The mineralization and immobilization if occurred might end after 90 DI or continued to more than 120 DI depending on kind of soil.

3. Incorporation of faba bean or maize stubbles in soils mostly resulted in immobilization of N in the soils during the early stages of incubation time and thereafter it either continued up to 120 DI or stopped depending on kind of soil. In both cases of immobilization and mineralization, they mostly increased with soil moisture content up to 100 % FC.

4. For sesbania residue, most suitable soil moisture levels for maximizing N mineralization were 100 % FC in the loamy sand and loam soils and 75 % FC in the clay soil whereas those for leucaena residue were 75 % FC in the loamy sand and clay soils and 100 % FC in the loam soil.

5. In case of incorporation with faba bean or maize stubbles, N immobilization could be limited by limiting soil moisture content regardless of soil texture. However, after some specific times of incubation, increases in soil moisture content enhanced N mineralization in the loamy sand and loam soils.

ACKNOWLEDGEMENTS

The authors extend their acknowledgement to the Ethiopian Agricultural Research Organization, Agricultural Research Training Program and the National Soil Research Center for funding and facilitating the research.

LITERATURE CITED

Alexander, M. 1977. **Introduction to Soil Microbiology**. 2nd edition. John Wiley and Sons, New York 467p.

Amato, M. 1983. The decomposition of ^{12}C and ^{14}C in plant and soil. **Soil Biol. Biochem.** 15: 611-612.

Aulakh, M.S., J. W. Doran and D.D. Francis. 1991. Crop residue type and placement effects on mineralization and denitrification. **Soil Sci. Soc. Am. J.** 55: 1020-1025.

Bouyoucos, G. J. 1951. A recalibration of the hydrometer method for making mechanical analysis of soils. **Agron. J.** 43: 434-438.

Bradford, J. M. and C. Hung. 1994. Interril soil erosion as affected by tillage and residue cover. **Soil Till Res.** 31: 353-361. USDA-ARS, Wesla Co, TX.

Bremner, J. M. and C.S. Mulvaney. 1982. Nitrogen-total, pp. 595-624. *In* A. L. Page (ed.). **Methods of soil analysis. Part 2: Chemical and**

Microbiological Properties. Agron. 9. Amer. Soc. Agron., Madison, Wisconsin.

Chapman, H.D. 1965. Cation exchange capacity, pp. 891-901. *In* C.A. Black (ed.). **Methods of soil analysis**. **Part 2: Chemical and Microbiological Properties.** Agron. 9. Amer. Soc. Agron., Madison, Wisconsin.

Haynes, R. J. 1986. The decomposition process: mineralization, immobilization, humus formation, and degradation, pp. 52-126. *In* R. J. Haynes (ed.). **Mineral Nitrogen in the Plant-Soil System.** Academics Press, London.

Jenkinson, D.S. 1981. The fate of plant and animal residues in soil, pp. 505-562. *In* D. J. Greenland and M.B.H. Hayes (eds.). **The Chemistry of Soil Processes.** John Wiley and Sons, Belfast.

Keeney, D.R and D.W. Nelson. 1982. Nitrogen-inorganic forms, pp 648-654. *In* A. L. Page (ed.). **Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties.** Agron. 9. Amer. Soc. Agron., Madison, Wisconsin.

Linn, D.M. and J.W. Doran. 1984. Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. **Soil Sci. Soc. Am. J.** 48: 1267-1272.

Michael, J. D. and N. Munns. 1996. **Soils, an Introduction.** 3rd edition. Printice-Hall, Upper Saddle River, NJ. 480p.

Miller, R.D. and D.D. Johnson. 1964. The effect of soil moisture tension on nitrogen mineralization and nitrification. **Soil Sci. Soc. Am. Proc**. 28: 644-647.

Murthy, I. Y. N ; Hazra, C.R .and Kumar, A. 1990. Effect of incorporation of tree leaves on soil fertility**. J.Indian Soc. Soil Sci**. 38: 325-327.

Parkin, T. B. 1987. Soil microsites as a source of denitrification variability. **Soil Sci. Soc. Am. J.** 51: 1194-1199.

Palm, C. A., C.N. Gachengo., R.J. Delve., G. Cadisch, and K.E. Giller. 2001. Organic inputs for soil fertility management: some rules and tools. **Agriculture, Ecosystems and Environment** 83: 27-42.

Richards, L.A. 1965. Physical condition of water in soil, pp 128-152. *In* C. A. Black (ed.). **Methods of Soil Analysis. Part 1: Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling.** Agron. 9. Amer. Soc. Agron., Madison, Wisconsin.

Scott, D.E. and J.P. Martin. 1989. Organic matter decomposition and retention in arid soils. **Arid Soil Research and Rehabilitation** 3: 115-148.

Smith, K.A. and J.R.M. Arah. 1990. Losses of nitrogen by denitrification and emissions of nitrogen oxides from soils. **Proceedings of the Fertilizer Society**, no. 299. London.

Stanford, G. and S. J .Smith. 1972. Nitrogen mineralization potentials of soils. **Soil Sci. Soc. Am**. **Proc**. 36: 465-472.

Stanford, G. and E. Epstein. 1974. Nitrogen mineralization-water relations in soils. **Soil Sci. Soc. Am. Proc**. 38: 103-107.

Van Gestel, M., R. Merckx and K. Vlassak. 1993. Microbial biomass responses to soil drying and rewetting: the fate of fast- and slow-growing microorganisms in soils from different climates. **Soil Biol. Biochem.** 25: 109-123.

Van Reeuwijk, L.P. 1992. **Procedures for Soil Analysis**. 3rd edition. International Soil Reference and Information Centre, Wageningen (ISRIC), The Netherlands. 83p.

Van Soest, P. J. 1963. Use of detergents in the analysis of fibrous feeds. Part 2: A rapid method for the determination of fiber and lignin. **Journal of Association of Official Analytical Chemists (AOAC)** 46: 828-835.

Van Soest, P. J. and R.H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. Part 4: Determination of plant cell-wall constituents. **Journal of Association of Official Analytical Chemists (AOAC)** 50: 50-55.

Walkley, A and I.A. Black. 1934. An examination of the Degtijareff method for determining soil organic mater and a proposed modification of the chromic acid titration method. **Soil Sci.** 37: 29-38.