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Nitrogen Mineralization of Two Manures as Influenced by Contrasting Application Methods under Laboratory Conditions

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The decomposition and the associated nitrogen (N) dynamics of organic N sources are affected by their contact with soil. While several authors have examined the effect of surface application or incorporation of crop residues on their decomposition rate, less information is available about the relationship between the placement of animal manure and their N mineralization rate. This study investigated the influence of chicken manure and cattle manure placement on soil N mineralization. The manures were incorporated or surface applied at 175 mg N kg^{-1}, and N release was periodically determined over 56 days by measuring inorganic N [nitrate (NO_3^-) N and ammonium (NH_4^+) N] in a 2 M potassium chloride (KCl) extract at a ratio of 1:10 (w/v). Results indicated that the control soil released a maximum of 64 mg N kg^{-1} soil at day 21, a sixfold increase over the initial concentration, which indicates its substantial mineralization potential. Manure treatments showed an initial increase in net NO_3^--N content at the start of the experiments (until day 7) before an extended period of immobilization, which ended at day 21 of the incubation. A small but positive net N mineralization of all manures was observed from 28 days of incubation. At each sampling time, the mean mineral N released from the control was significantly less ($P < 0.01$) than surface-applied chicken manure, incorporated chicken manure, and surface-applied cattle manure. Treatments exceptions were at days 21 and 28 where N immobilization was at its peak. In contrast, incorporation of cattle manure showed a different N-release pattern, whereby the mineral N amount was only significantly greater than the control soil at days 42 and 56 with 84 and 108 mg N kg^{-1} soil respectively. Incorporation of chicken manure and cattle manure did not favor nitrification as much as surface application and cattle manure caused a much greater immobilization when incorporated than when surface applied.

Keywords Cattle manure, chicken manure, incorporation, N mineralization, surface application

Introduction

Over the past two decades, urban farming has expanded enormously in most African countries, in part due to economic conditions. In Tanzania's towns, for example, this type of

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agriculture has become very common and involves the raising of livestock and the cultivation of crops. Low-income families undertake most of the vegetable production, whereas high-income families tend to raise dairy cattle and poultry to subsidize their income, although the consumption of self-produced vegetables is often valued (Mlozi 1995b). However, per-capita agricultural production in sub-Saharan Africa is declining because of depleted soil and/or low soil fertility (Bekunda, Bationo, and Sali 1997). Organic sources of nitrogen (N), including animal manure, play a key role in sustaining soil fertility and crop productivity when applied to soil (Soumare, Tack, and Verloo 2003). This practice is particularly important under low-input agricultural systems where nutrient availability is acutely constrained for agriculture and food production. The use of organic manures is therefore very important to improving the quality and fertility of these soils, and manure can serve as a source of plant nutrients, especially N and phosphorus (P) (Gilly and Eghball 2002). When manures are properly managed, they become a valuable soil amendment providing nutritive value and liming effects (Castillo, Benito, and Fernandez 2003). In addition, when managed properly, the application of manure can produce yields similar to those obtained using inorganic fertilizers (Eghball and Power 1999).

The availability of N from animal manure to plants is dependent on the rate of mineralization from organic N to inorganic N [nitrate (NO_3^-) N and ammonium (NH_4^+) N]. Management practices that optimize transformation and recycling of manure-derived N to crops are critical under field conditions for an efficient use of N in many cropping systems (Honeycutt 1999). However, it is difficult to predict the availability of manure N to plants because both N transformation processes and losses influence availability. Previous works have shown that the rate of decomposition and N release of organic N sources is largely influenced by their biochemical composition and/or quality (Serna and Pomares 1991; Chaves et al. 2004).

In recent years, many studies have attempted to find a relationship between the quality of plant residues and their rates of N release. Among the biochemical quality factors most often found to be correlated to N release are the total organic N content or the C/N ratio of residues (Trinsoutrot et al. 2000). Incubation methods also influence the relationship between N release and residue quality. Handayanto, Cadisch, and Giller (1994) observed that decomposition under leaching conditions in the laboratory gave relationships similar to litterbags in the field, which was not the case for a nonleaching laboratory incubation experiment. Environmental conditions such as temperature, water, and aeration are also known to affect the N release (Salomez, Moret, and Hofman 2002; Griffin and Honeycutt 2000).

The decomposition and the associated N dynamics of organic N sources is also affected by their contact with soil (Ambus and Jensen 1997). The effect of crop residue placement on the decomposition rate and N mineralization/immobilization has been well documented (Douglas et al. 1980; Coppens et al. 2006; Jin et al. 2008). However, the relationship between N mineralization and animal manure placement, particularly chicken manure (CHM) and cattle manure (CAM), is less reported (Wichern et al. 2004). Furthermore, variations in soil chemical and physical properties combined with extensive climatic and agricultural diversity across the world necessitate that researchers gain more insight in N mineralization on a regional scale (Sorensen and Jensen 1995). By understanding the N mineralization process, one can more accurately predict the net availability of manure N to crops (Sorensen 2001). We therefore investigated the influence of local manure application practices (surface application versus incorporation) on the N mineralization rate of both chicken and cattle manure.

Materials and Methods

The Study Area

The study was conducted in the Morogoro municipality, Tanzania. Morogoro municipality is located in the Morogoro region, between 37° and 39° E and between 6° and 5° S at an altitude of 500−600 m above sea level. Its temperature ranges between 27.0 °C and 33.7 °C in the dry/warm season and between 14.2 °C and 21.7 °C in the cold/wet season. Morogoro municipality experiences a subhumid tropical climate with a bimodal rainfall pattern with a dry season separating the short rains (October to December) and long rains (March to May). There are approximately 5 months of dryness, the peak being September. The mean annual rainfall is about 870 mm.

Soil Sampling and Analysis

Soil material for the laboratory incubations was collected from the topsoil of a sandy clay loam soil (69% sand, 24% clay, 11% silt) of the horticultural unit of Sokoine University of Agriculture (SUA), Tanzania. The soil selected is typical of that used for vegetable cultivation in the region. At the site, soil samples were collected from the top 20 cm and air dried. All visible fragments, including roots and stones, were removed. The dried bulk soil was thoroughly mixed to ensure uniformity and stored in a cool place prior to analysis. Physical properties and chemical composition were analyzed on subsamples sieved through a 2-mm sieve (Table 1). Particle-size analysis was determined with the hydrometer method (Gee and Bauder 1978); soil pH was analyzed using a glass electrode pH meter at a ratio of 1:2.5 soil to water (McLean 1982); organic carbon (C) content was determined by the wet oxidation method following the procedure of Walkley and Black (1934); total N was determined by the micro-Kjeldahl procedure (Bremner and Mulvaney 1982); and mineral N (NH_4^+-N and NO_3^--N) was determined by steam distillation (Bremner and Keeney 1965).

Manure Sampling and Analysis

Two organic manures (CHM and CAM) were selected based on their availability and common use by the vegetable farmers of the study area. CHM was collected from a farm near Sokoine University of Agriculture (SUA), and CAM was collected from the SUA cattle

Table 1
Basic chemical properties of the soil and manures used for laboratory incubation experiments on dry matter

	pH	OC (%)	Total N (g kg^{-1})	C/N ratio	Mineral N (mg kg^{-1})	Organic N (g kg^{-1})
Soil	7.3	1.9	1.5	13	8.7	1.49
Chicken manure	7.8	28.8	15.8	18	20.3	15.78
Cattle manure	7.8	28.3	15	19	18.6	14.98

farm. Manure samples were well mixed, and coarse fragments and stones were removed. Triplicate subsamples of each of the manures were dried and analyzed for their pH, C, total N, and mineral N content (Table 1). Organic N was calculated as the difference between total N and mineral N.

Laboratory Experiment

Net N mineralization from both manures was studied during laboratory incubation experiments under controlled conditions. Four treatments were conducted with 300 g of air-dried soil (equivalent to 286 g of oven dry soil) and manure applied at a rate of 175 mg N $(\text{kg soil})^{-1}$ were studied: (1) incorporated CHM, (2) surface-applied CHM, (3) incorporated CAM, and (4) surface-applied CAM. Composite samples were placed in containers 8 cm high and 10 cm inner diameter and slightly compacted to obtain a soil bulk density of approximately 1.3 g cm^{-3}. A control treatment (soil without addition of manure) was included to determine the net N mineralization rate from soil organic matter. Distilled water was added to bring the soils up to 50% water-filled pore space (WFPS), equivalent to 85% field capacity (FC). The initial weight of all containers was recorded. Containers were closed with holed aluminum foil to allow exchange of gases and minimize water loss and were incubated in triplicate at 24 °C for 56 days. Soil moisture content was regularly adjusted by weighing the containers, and distilled water was added when the evaporation loss was greater than 5% (relative) of its initial water content. Destructive sampling was performed by removing containers in triplicate for each treatment at 0, 3, 7, 14, 21, 28, 42, and 56 days after the start of the incubation experiment. Inorganic N (NO_3^--N and NH_4^+-N) was measured in a 2 M KCl extraction solution (1:10 w/v). The soil suspension was shaken for 1 h on a reciprocating shaker and filtered through Whatman filter paper no. 41. Inorganic N was measured in the filtrate using a steam distillation method (Bremner and Keeney 1965). Soil water content was determined by drying a subsample to constant weight at 105 °C for 24 h. Inorganic N was expressed on a dry-weight basis.

Statistical Analysis

Data were statistically analyzed by multifactor analysis of variance (ANOVA) for a completely randomized design using the MSTAT-C package (Freed 1992). To determine the statistical significance of mean differences between treatments, we carried out the least significant difference (LSD) tests based on Duncan's multiple-range tests. A probability level of $P < 0.05$ was considered significant.

Results and Discussion

Net Nitrogen Mineralization in Control Soils

Results on net N mineralization of the control soil are shown in Figure 1. The net N mineralization equals the net increase of the soil mineral N content (NH_4^+-N + NO_3^--N) over a period of time. As indicated in the figure, the NH_4^+-N content showed a steep increase at the start of the incubation experiment, most probably due to sample handling and a consequent flush of mineralization, but from day 14 on a decrease was observed. The soil showed a positive net N mineralization, reaching a maximum of 65 mg N kg^{-1} dry soil at day 21. These results indicate that the soil under investigation has a substantial mineralization potential, most probably due to a long history of application of organic materials (i.e.,

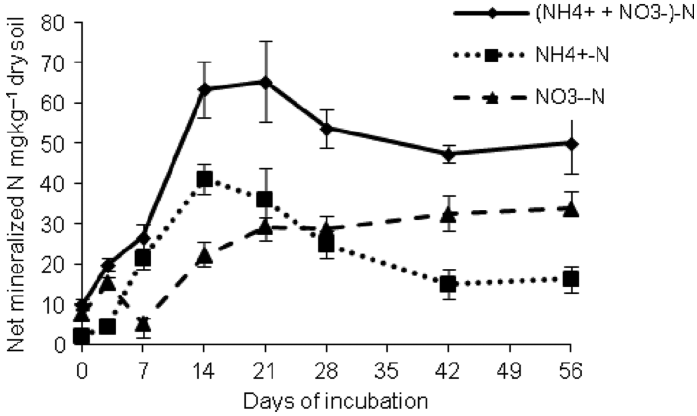

Figure 1. Mineralized N in control soils during 56 days of incubation.

animal manure) as practiced by the farmers in the Morogoro region. The manure application history influences N mineralization. Whalen, Chang, and Olsen (2001) reported that long-term manure application increased the potentially mineralizable N in soil.

Nitrogen Mineralization from Organic Manures

The evolution of inorganic N of both CHM and CAM treatments, taking into account the inorganic N content in the control soil (Figure 2a), shows their N release and N immobilization during the experimental period. Statistical analysis showed a significant difference among manures, application method, sampling times, and their interactions ($P < 0.01$). At days 21 and 28, when N immobilization was at its peak, only soils with surface-applied cattle manure (CAS) and surface-applied chicken manure (CHS), respectively, released slightly more mineral N than the control soil (75 and 55 mg N kg^{-1} dry soil, respectively). However, compared to the control soil, a positive increase of net N mineralization was observed from 28 days of incubation on (Figure 2b) in all amended treatments.

To assess the risks of $NO_3{}^-$-N leaching and $NO_3{}^-$ accumulation in leafy crops under field conditions, it is important to consider the $NH_4{}^+$-N and $NO_3{}^-$-N contents separately as a function of time. CHS and incorporated chicken manure (CHI) increased the initial content of extractable ammonium N at day 3 by 14 and 30 mg kg^{-1} soil, while also surface-applied CAM showed a significant ($P < 0.01$) ammonium N increase (11 mg N kg^{-1} soil). However, incorporation of cattle manure (CAI) showed a lower $NH_4{}^+$-N content (-3 mg N kg^{-1} soil) than initially measured after 3 days of incubation (Figure 3a). CHM treatments also showed an initial net $NO_3{}^-$-N mineralization before a 1-week period of immobilization (Figure 3b). This high initial net N mineralization from the CHM compared to the CAM treatments and the unfertilized control may be explained by its higher specific mineralization rate (Griffin and Honeycutt 2000), probably related to the somewhat lower C/N ratio of CHM compared to CAM.

For all treatments, with the exception of incorporated CAM, a marked decrease in $NH_4{}^+$-N content was observed from day 3 up until day 28. Incorporated CAM already showed an $NH_4{}^+$-N decrease from day 0, reaching its lowest point 2 weeks after the initiation of the incubation (-38 mg N kg^{-1} soil) (Figure 3a). The fluctuations of $NH_4{}^+$-N (Figure 3a) during the first weeks of incubation may be explained by an event of rapid

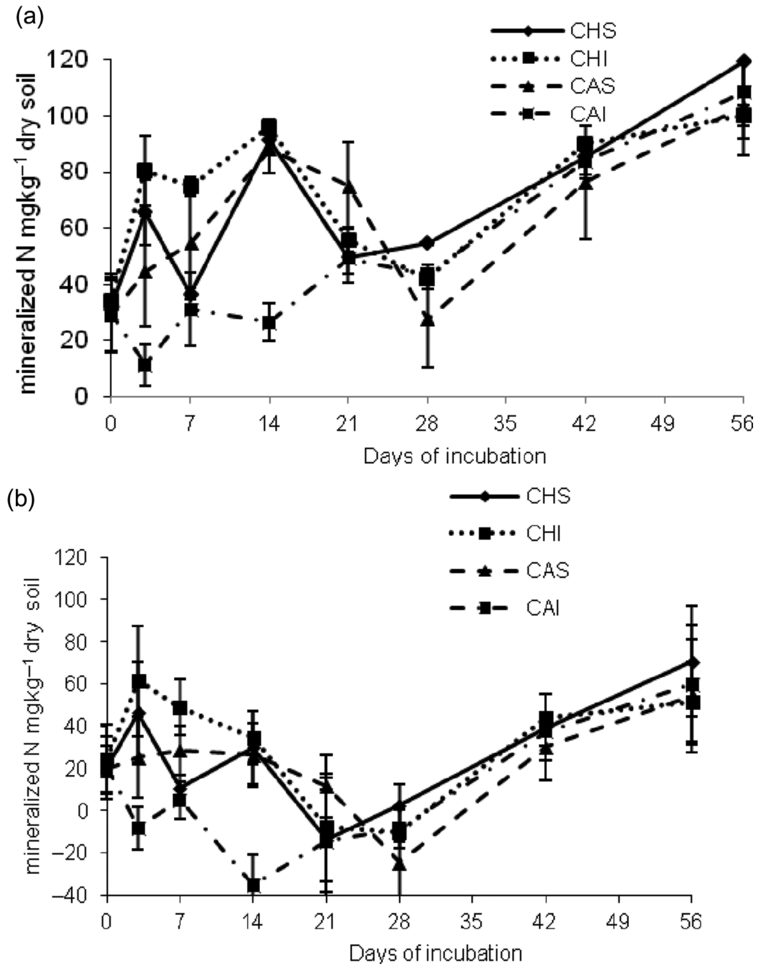

Figure 2. (a) Mineralized N from amended soils and (b) net mineralized N from chicken and cattle manure over 56 days of incubation. CHS, surface-applied chicken manure; CHI, incorporated chicken manure; CAS, surface-applied cattle manure; and CAI, incorporated cattle manure.

nitrification. This trend was also observed by Calderon, McCarty, and Reeves (2005). However, nitrate N did not follow the NH_4^+-N mineralization pattern and started to decrease from day 7 up until day 21 (Figure 3b). All treatments showed positive net increases of both NH_4^+-N and NO_3^--N content after 4 weeks of incubation.

The manure used in this study had C/N ratios of 18:1 and 19:1 for CHM and CAM respectively, and it is well documented that organic materials with a C/N ratio less than 20:1 release mineral N rapidly through mineralization (Mary, Recous, and Robin 1998). Our results (initial immobilization) are also in accordance with those of Probert et al. (2005), who studied cattle manure mineralization from central Kenya and found that there was immobilization or delay in mineralization that lasted for several weeks. Other authors also reported N immobilization followed by net mineralization in an incubation experiment with animal manures having a C/N ratio as low as 4:1 (Abbasi et al. 2007). This pattern of response is different to studies of N mineralization from plant materials. Plant materials with low C/N ratio typically and consistently exhibit positive net mineralization from the

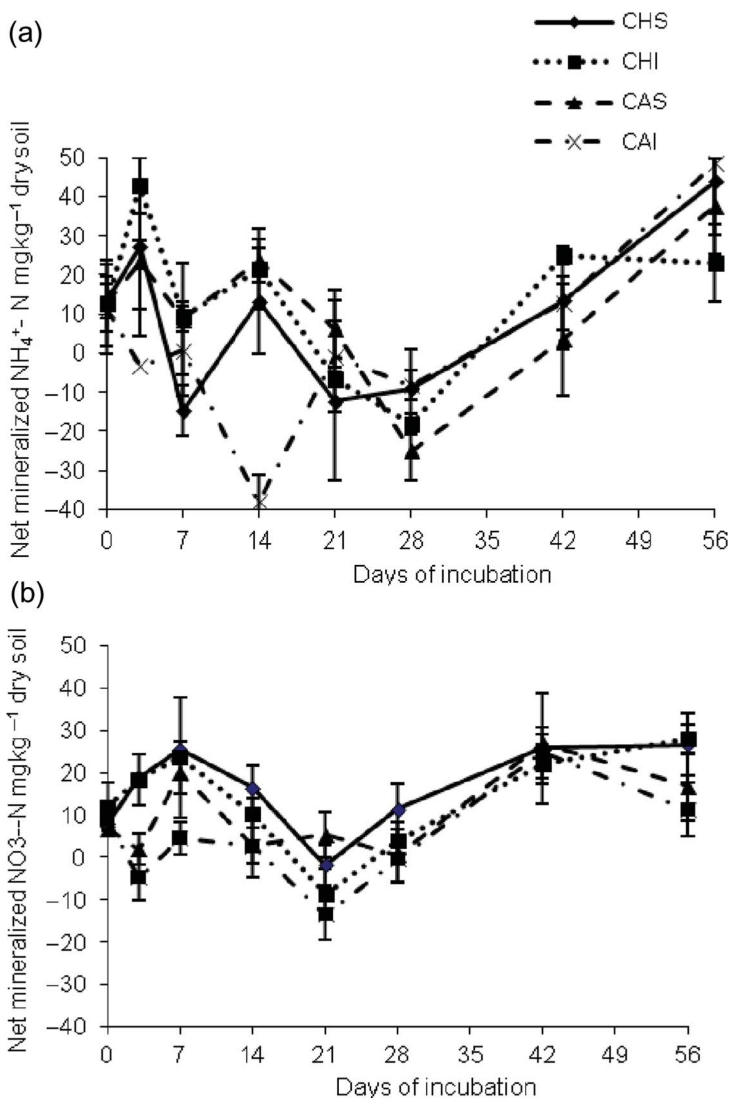

Figure 3. Net mineralized ammonium N (a) and nitrate (b) from chicken and cattle manure over 56 days of incubation. CHS, surface-applied chicken manure; CHI, incorporated chicken manure; CAS, surface-applied cattle manure; and CAI, incorporated cattle manure.

commencement of the incubation (Constantinides and Fownes 1994). Mineralization of the organic manures is attributed not only to their C/N ratio but also to other factors such as temperature, soil moisture content, and soil bulk density with respect to the specified conditions (De Neve and Hofman 1996).

At each sampling time, the net N mineralization rate (Figure 4) was calculated by subtracting the amount of N mineralized of the control soil from the initial mineral N of manures from the mineral N content of the manure-amended soils (Abbasi et al. 2007). During the first 28 days, the calculated values showed a broad range (i.e., −1.7 to 8.2, −1.5 to 12.2, −1.6 to 1.9, and −9.5 to 0.7 mg kg^{-1} soil day^{-1} for CHS, CHI, CAS, and CAI respectively), where negative values at different times in all treatments were observed.

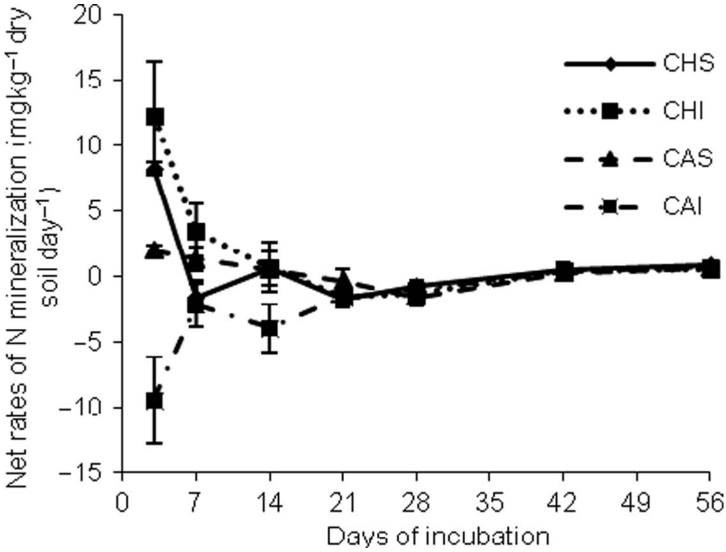

Figure 4. Net N mineralization rates of chicken and cattle manure at different periods of incubation. CHS, surface-applied chicken manure; CHI, incorporated chicken manure; CAS, surface-applied cattle manure; and CAI, incorporated cattle manure.

All treatments, however, showed negative values at day 28, but were positive from this sampling date forward. However, low N mineralization rates were observed for all treatments. Other researchers also found that laboratory incubations of manured soil lasting only for a few weeks did result in N immobilization, while longer incubations resulted in positive values (Calderon, McCarty, and Reeves 2005). Our results are also in accordance with those of Wichern et al. (2004) and Abbasi et al. (2007), who reported a high initial net N mineralization rate and negative values at different times of the incubation period. From day 21 onward, the net N mineralization rates were not significantly different ($P = 0.05$) between treatments.

The net N mineralization rates estimated from this study are intended to predict the mineralization rate in the field, including during the cropping season. However, there are reports in the literature concerning the influence of plants on N mineralization in investigations of root decomposition (Malpassi et al. 2000). Wheatley, Ritz, and Griffiths (1990) reported an apparent stimulation of net N mineralization by growing plants. Reasons for this phenomenon include increased microbial activity due to root C inputs (Clarholm 1985) or decreased microbial immobilization resulting from more effective competition for N by plants (Griffiths and Robinson 1992). Therefore, in the absence of plants in the system, the N that otherwise would have been taken up by plants is immobilized by the microbes, therefore possibly resulting in lower or negative net mineralization estimates in incubation studies.

Effect of Manure Placement on Net N Mineralization

Incorporation of CHM and CAM did not favor nitrification as much as surface application, although the difference was not significant (Figure 3b). The mean values of NO_3^--N for

CHS and CHI across the incubation period were 38 and 37 mg kg^{-1} soil (LSD = 4.5). Moreover, incorporation of CAM caused a much greater N immobilization than when applied to the soil surface. However, the situation lasted for 28 days of incubation, and thereafter CAM incorporated showed a greater net N release than surface-applied manure (Figure 2).

Our results are in agreement with those of Wichern et al. (2004), who reported a significant increase in inorganic N due to the presence of manure as a mulch layer on the soil surface, and with findings by Jin et al. (2008), both working on crop residues. The effect of manure placement observed in our study could be due to the differences in contact of manure microbes with soil particles. The facilitated contact between manures and soil particles after incorporation may have stimulated immobilization. Bending and Turner (1999) found that increased accessibility of low-quality residues ($C/N > 38$) increased net immobilization of N and had no effect in the case of high-quality residue ($C/N = 10$). Our results are supported by Corbeels et al. (2003), who reported that manure with a C/N ratio between 18.7 and 55.6 immobilized more N when incorporated than when surface applied. This can explain why CAI ($C/N = 19$) was more immobilized than CHI ($C/N = 18$).

The effect of application method and manure type only lasted for 28 days, since there was no significant difference ($P = 0.05$) for the following weeks. However, it is important to note that the N mineralization in this study was evaluated by maintaining ideal temperature and moisture conditions through the entire incubation period. This is different from agricultural production systems where large fluctuations in soil moisture and temperature may occur under cropping conditions. These factors can also influence N mineralization. Moreover, the removal of stones and mixing of the soil associated with laboratory studies impacts N mineralization. However, under field conditions, soils do not undergo such level of disturbance. Dharmarkeerthi Kay, and Beauchamp (2004) reported a decreased mineral N in disturbed soil under laboratory condition, whereas under field conditions tilled soils had a greater mineral N content than no-tillage soils. From our results, we suggest that for the soils receiving repeated manure application, incorporation of manure should be promoted to avoid N loss and environmental problems associated with N leaching. In general, incorporation of manures will additionally reduce or avoid possible N losses by ammonia (NH_3) volatilization.

Conclusion

Generally, the addition of CHM and CAM increased mineral N of the soil, though CHM showed a greater N mineralization rate than CAM. The trends of N mineralization and immobilization were different depending whether manures were surface or incorporated applied, with the latter causing more temporary immobilization. Surface-applied manure showed greater NO_3^--N concentration than incorporated, which may lead to N loss especially during the early stage of the crops when N demand is low. The high initial net mineralization rates of CHS, CHI, and CAS suggest that manure application several weeks before sowing, as some farmers do, may lead to losses of mineralized N. Thus, from a plant nutrient point of view, for maximum N utilization by crops, manure application as close as possible to sowing time is recommended. However, because of environmental factors that influence N mineralization, such as temperature and soil moisture content, further field experiments are necessary to derive more practical conclusions.

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