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*Full Length Research Paper*

# Evaluating Nitrogen Dynamics in Andosols Amended with Poultry and Cattle Manure under Maize-Bean Cultivation in Nicaragua

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**An *in situ* nitrogen mineralization experiment was conducted to assess the response of chicken and cow manure application at two different rates (5 and 10 Mg DM ha$^{-1}$) on net N mineralization in a maize-bean rotation experiment in Nicaragua. The field study was carried out over four consecutive growing seasons. Soil samples of the top soil (0-0.3 m) were taken every 30 days within the season in inserted plastic tubes. The samples were analysed for content of soil mineral N and total organic N. Net N mineralization was estimated as the difference in soil mineral N over time. The net N mineralization rate in the treatment with chicken manure applied at the high rate (CHH) was on average 24.5 g N m$^{-2}$ season$^{-1}$ and significantly higher than all the other treatments and the unfertilized control, except during the first season. From season two to season four, the net N mineralization of cow manure at both high and low application rates were similar to that of low application rate of chicken manure. In the control, the net N mineralization was significantly lower than in all fertilisation treatments and on average 9.9 g N m$^{-2}$ season$^{-1}$. It also decreased significantly over time and did not show any indication to increase in the season following the $N_2$ fixating crop. Only the CHH treatment showed such a tendency. The soil total organic N did not show any clear pattern over neither time nor treatment. Consequently, the variation in specific net N mineralization per unit of total organic soil N was similar to that of net N mineralisation and ranged from 1.6 – 2.9 10$^{-3}$ 30d$^{-1}$ in the control to 4.4 - 6.7 10$^{-3}$ 30 d$^{-1}$ in CHH.**

**Key words:** Soil organic matter, low input tropical agriculture, *Zea mays* L., *Phaseolus vulgaris* L.

## INTRODUCTION

One of the most spread cropping systems in Central America region is maize (*Zea mays* L.) and common beans (*Phaseolus vulgaris* L.) cultivated in rotation and generally under low input conditions. In such conditions, the storage and release of nutrients from soil total organic matter (SOM) are the primary determinant of soil fertility (Tiessen et al., 2001). Net nitrogen (N) mineralization from SOM is largely regulated by soil carbon (C) decom-position (Weil and Maddoff, 2004), often being rapid under tropical conditions (Ayanaba and Jenkinson, 1990; Chander et al., 1997; Goyal et al., 1999), and thus having a high potential as N source. However, a high decompo-sition rate also entails a rapid decrease in the amount of SOM and amendments of organic fertilizers can be used to preserve the SOM levels (Wivstad et al*.,* 2005).

Knowledge about variation in decomposability of SOM as affected by applications of different kinds of manure is important to be able to predict its effect on the net N mineralization for effective use in agricultural systems (Facelli and Pickett, 1991; Kaye and Hart, 1997; Mary et al., 1998; Leifeld et al., 2002). The decomposability of SOM depends both on quality of the added manure and its effect on the soil microbial activity through for instance the influence on soil temperature and moisture conditions (cf. Holland et al*.,* 2000; Mikha et al., 2005).The specific decomposition rates range from 0.05 g C (g C d) $^{-1}$ for fast decomposable high quality, to 0.00001 g C (g C d)$^{-1}$ or

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**Table 1**. Monthly rainfall (mm) during four seasons in the N mineralization experiment at La Compañía, Nicaragua (INETER, 2004).

| Month | Primera 2002 | Postrera 2002 | Primera 2003 | Postrera 2003 |
|---|---|---|---|---|
| May | 369 | | 168 | |
| June | 355 | | 396 | |
| July | 147 | | 236 | |
| August | 185 | | 122 | |
| September | | 305 | | 180 |
| October | | 187 | | 240 |
| November | | 24 | | 106 |
| December | | 2 | | 16 |
| January | | 9 | | 2 |
| Total | 1058 | 527 | 924 | 545 |

even less for low quality materials (cf. Wu and McGechan, 1998).

In practical field experiments different qualities are usually not explicitly expressed and estimates of decomposability often relate to SOM. As the C/N ratio of SOM is fairly stable over shorter time periods (a few years), the specific decomposability of SOM is fairly similar to the N mineralisation rate per unit of soil total organic N. Changes in the N mineralisation rate per unit of soil total organic N then reflect changes of the specific decomp-osability. Therefore, in the current study we omitted the explicit analyses of the relations to soil carbon of the young volcanic soil, and instead N mineralisation was related to soil total organic N.

The objective of this work was to study the N mineralization over four growing seasons in a maize (*Z. mays* L.) - bean (*P. vulgaris* L.) rotation on a young volcanic tropical soil, in response to application of organic fertilisers of different type and rate.

## MATERIALS AND METHODS

### Experimental site conditions

An *in situ* N mineralization experiment was carried out during four consecutive rainfed growing seasons; from May to September (called Primera) and from October to January (Postrera) during the years 2002 and 2003 at the experimental station La Compañía, San Marcos, in Southern Nicaragua, located at 11$^o$54'N and 86$^o$09'W, and 450 m above sea level. The soil is classified as Mollic Andosol (WRB, 1998). The soil is moderately deep and has a top layer (0 - 0.2 m) with a silty loam texture, and has a high drainage capacity. The soil is characterized by: pH in $H_2$ 0 = 6.1, total C = 61 g kg$^{-1}$, total N = 5.7 g kg$^{-1}$, available P = 9.4 mg kg$^{-1}$, CEC (cation exchange capacity buffered at pH 7) = 54 cmol c$^+$ kg$^{-1}$. The climate is tropical dry forest with a yearly average temperature of 24ºC. Annual average rainfall is around 1500 mm allowing two growing seasons. Monthly rainfall during the seasons of the experiment is shown in Table 1. Average potential evapotranspiration is about 111 mm month$^{-1}$ (INETER, 2004). During the growing period prior the establishment of the experiment, maize was sown and fertilised with N, P and K at the rates of 15.0, 5.5 and 3.5 g m$^{-2}$, respectively.

### Experimental design and treatments

The maize, cv NB-6 (PROMESA, 2002) was sown in the seasons of Primera 2002 and 2003 and common beans, cv DOR-364 (PROMESA, 2002), in the corresponding Postrera seasons. The experiment consisted of four fertilizer treatments with application of cow and chicken manure at two rates, 500 g dry weight (DW) m$^{-2}$ (low) and 1000 g DW m$^{-2}$ (high), respectively, and an unfertilized control. The experimental plots of 20 m$^{-2}$ size were arranged in a complete randomized block design with four replicates. The manures were applied before sowing in each of the four growing seasons. Prior to applying, the manures were carefully mixed and three composite samples of each type were taken for chemical analyses of total C and N contents (Table 2). Other manure charac-teristics were: total P = 3.6 and 3.1 g kg$^{-1}$, $NH_4^+$-N = 2 and 0.2 g kg$^{-1}$, $NO_3^-$ -N = 0.9 and 0.3 g kg$^{-1}$ for chicken and cow manure, res-pectively.

### Management

The soil was ploughed and disc harrowed prior to incorporation of the manure manually by using a hoe. To achieve an even distri-bution of manure over the plot, the total manure applied to the plot was divided into equally large samples, one for each row, which were carefully distributed from the beginning to the end of the row. Maize was established in the third week of May in 2002 and in early June in 2003. Beans was established in late September and early October, respectively. Sowing was carried out by hand with 0.8 m between rows and 0.2 m between plants in the row, for maize, and 0.4 and 0.1 m, respectively for beans. Manual weed control was carried out on three occasions during the growing season using a machete. The weed residues were left on the soil surface. Pests and diseases were controlled using Methamidofos (phosphoramido-thioate) and benomyl for both maize and beans at a rate of 71.2 g m$^{-2}$ season$^{-1}$.

### N mineralization experiment

Net N mineralization was estimated in an *in situ* incubation field experiment. The method used was a modification of the method proposed by Raison et al. (1987). At sowing, after manure applications, six plastic tubes (PVC) of 0.7 m length and 0.1 m inner diameter were inserted into the soil between rows, in each experimental plot. The tubes were pressed into the top 0.65 m of the soil profile, 0.05 m of the tube being above the soil surface. To be able to control water conditions and allow gas exchange the top of the tube was covered with a curved cap of PVC with free access to the air but protecting the tube from precipitation. All through the experimental period the soil moisture in the tubes was checked and in case it was needed water was added by hand, to adjust to the soil moisture of the surrounding soil. Only small amounts of water were added and leaching of N was expected to be small in accordance to Salmerón-Miranda et al. (2007) estimating it for this experiment to be less than 3% of plant N uptake, due to high evaporative demand (an exception was in one 30-day period when it was estimated to be 10%).

Soil sampling (0 – 0.3 m) for soil mineral N ($N_{NH4}$ and $N_{N03}$) analysis was taken four times for each growing season. At day one (after manure application and before tube insertion), eight initial soil samples were taken with a hand auger 7cm in diameter, and mixed to a composite sample. During the growing season, one soil sample was taken in the tube, using the same auger, at 30, 60 and 90 days after sowing, respectively. Two tubes per plot were used at each

**Table 2**. Manure total C and N concentrations and amounts applied in the N mineralization experiment. Numbers in brackets are *s.d.* of the means (based on three replicates).

| Manure treatments | Manure concentration | | Amounts applied | | | CN ratio |
|---|---|---|---|---|---|---|
| | Total C | Total N | DW | Total C | Total N | |
| | g (kg DW)$^{-1}$ | | g m$^{-2}$ | | | |
| Chicken high CHH | 306 (1.4) | 33 (0.2) | 1000 | 306 | 33 | 9.3 |
| Chicken low CHL | 306 (1.4) | 33 (0.2) | 500 | 153 | 16.5 | 9.3 |
| Cow high COH | 173 (1.9) | 11.3 (0.1) | 1000 | 173 | 11.3 | 15.3 |
| Cow low COL | 173 (1.9) | 11.3 (0.1) | 500 | 87 | 5.7 | 15.3 |

sampling occasion which, having four replicates, gave eight cores per treatment. The tubes were never used twice, however, not removed until after the third soil sampling to minimize the introduction of systematic disturbances. The tubes were reinstalled in undisturbed soil the next season as described above. In the Postrera seasons with beans the day 90 sampling was replaced by a sampling directly after crop harvest. All soil samples were placed in plastic bags, and stored at approximately 4°C until they were processed.

### Chemical analysis

For the manures, total N and C were determined by dry combustion according to the Dumas method using a Leco analyser CNS-2000 (Leco Corporation St. Joseph MI, USA). To determine mineral N the manure samples were extracted with 2 M KCl. The extracts were distilled to recover mineral N with MgO and Devardas alloy. Ammonia liberated by the distillation procedure was collected in 0.025 M $H_2SO_4$ and titrated with 0.05 M NaOH. Total P and K were extracted from wet digestion with nitric acid ($HNO_3$ 65%) during 4 h at 125°C and determined using an Inductive coupled plasma-optical emission spectrometer (Perkin-Elmer Optima 3000DV).

Soil mineral N was extracted by shaking 10 g of soil in 100 ml of 2 M KCl in an end- to-end shaker for 1 h at 150 rotations per min during, and filtering through Whatman # 1 filter paper. The extracts were analysed colorimetrically using a Spectronic, Modelo 21D. Soil total organic N content was measured with the widely used Kjeldahl method (Jackson, 1973). Manure C was analyzed by the Walkley and Black method (Walkley*,* 1947) because it is widely used and has a low request of equipment (Nelson and Sommer, 1996).

The DW of samples was determined by oven drying at 105°C for 24 h. Soil pH was measured with a glass electrode in a soil to water ratio of 1/2.5. Soil CEC was determined by saturation with $NH_4OAc$ at pH 7 and subsequent replacement of $NH_4^+$ by $KCl^-$ extraction (Chapman, 1965). Available phosphorus in soil was extracted with sodium bicarbonate.

### Estimations

Net N mineralization in the soil tubes ($N_{MinTube}$) was estimated as the difference in mineral N content (ammonium plus nitrate N) between sample occasions t+30 and t, where t is time in units of days.

$$N_{MinTube} = (N_{NH4Tube} + N_{N03Tube})_{t+30} \quad (N_{NH4Tube} + N_{N03Tube})_t \quad (1)$$

where $N_{NH4Tube}$ and $N_{N03Tube}$ are the observed ammonium and nitrate N contents of soil in the tubes. The methodology is not an exact representation of the N mineralization from the cultivated soil outside the tubes since it does not consider differences in losses of mineral N through denitrification and leaching between inside and outside the tubes, and neglects net mineralization or immobilisation from decomposition of the current year root turnover and possible priming effects of active roots (see further the section on discussion and Salmerón-Miranda et al. (2007)).

To express the net N mineralization per unit of soil organic matter the mineralization was estimated as a proportion (*a*) of the soil total organic N content ($N_{OrgTube}$; i.e. N mineralization = $a \cdot$ Soil organic N):

$$a = N_{MinTube} / N_{OrgTube} \quad (2)$$

### Statistical analysis

Analysis of variance was performed to evaluate statistical differ-rences in measured and estimated variables between treatments. A separate analysis was done to explore differences between seasons for each manure treatment. The SAS statistical program with GLM procedure and Fischer's LSD test were applied (at 5% significance level; SAS Institute 2001).

## RESULTS

## Mineral N

The soil mineral N content of the tubes increased over time and achieved high values at the end of the seasons (Table 3) . The net N mineralisation per unit ground sur-face and 0.3 m soil depth ($N_{MinTube}$) was estimated as the difference between the subsequent samples of soil min-eral N (Eq. 1). For the control average $N_{MinTube}$ decreased from 4.7 g N m$^{-2}$ 30 days$^{-1}$ during the first season to 2.6 g N m$^{-2}$ 30 days$^{-1}$ in the fourth season, and did not show any tendency of increase in the season after the N fixa-ting bean cultivation (Figure 1). The net N mineralisation of the fertilised treatments showed a weak decrease or no change from season one to four, except for CHH which increased and especially much in the third season after the bean crop. From season two to four, the excess of net N mineralization of the fertilised treatments com-pared to the control increased from about 1.1 to 1.9 g N m$^{-2}$ 30 days $^{-1}$, except for the CHH treatment where the excess was 2.0 g N m$^{-2}$ 30 days$^{-1}$, already in the first season, and increased to 6.2 g N m$^{-2}$ 30 days$^{-1}$ by season four (Table 3). The accumulated net N mineralization during the whole growing period of 90 days was large. For the high application treatment of chicken manure the seasonal average was 24.5 g N m$^{-2}$ season$^{-1}$, whereas for

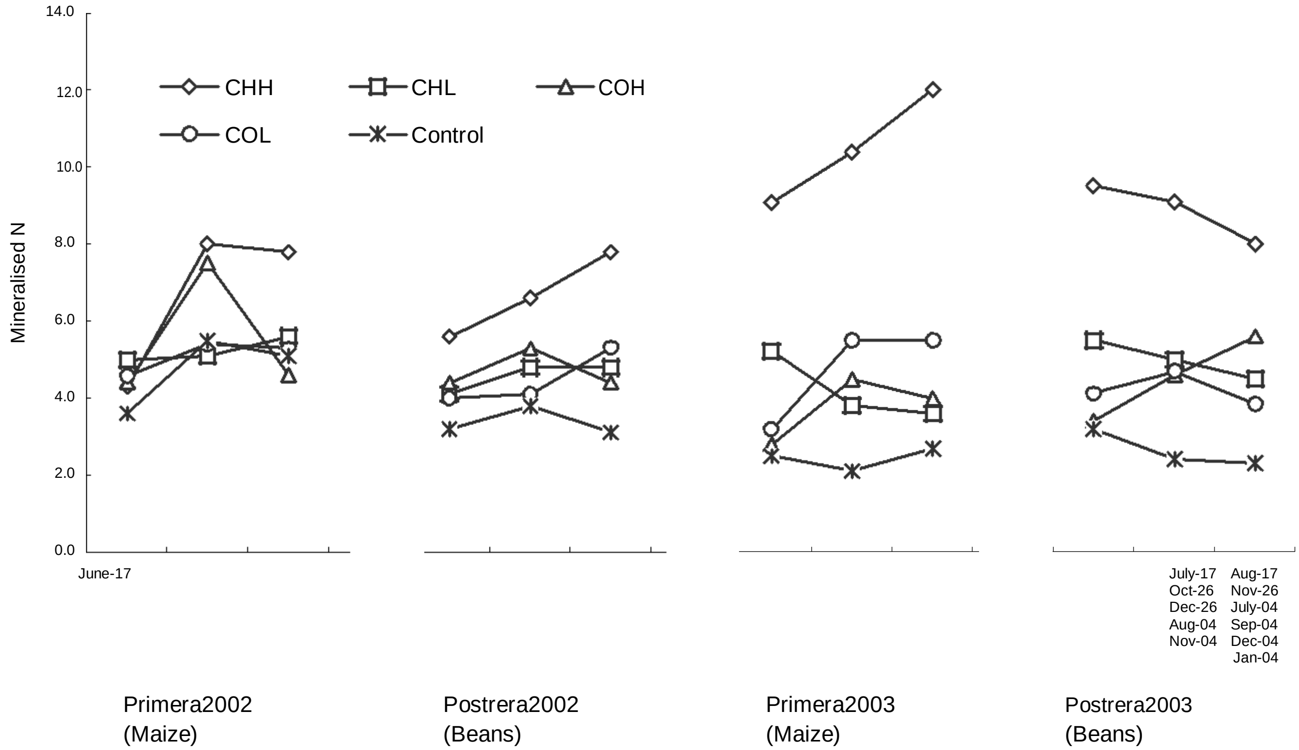


**Figure 1**. Net N mineralization of the soil layer 0 – 0.30 m ($N_{MinTube}$; g N $m^{-2}$ $30d^{-1}$) between sampling occasions in the four manure treatments and the control. CHH = chicken high, CHL = chicken low, COH = cow high, COL = cow.

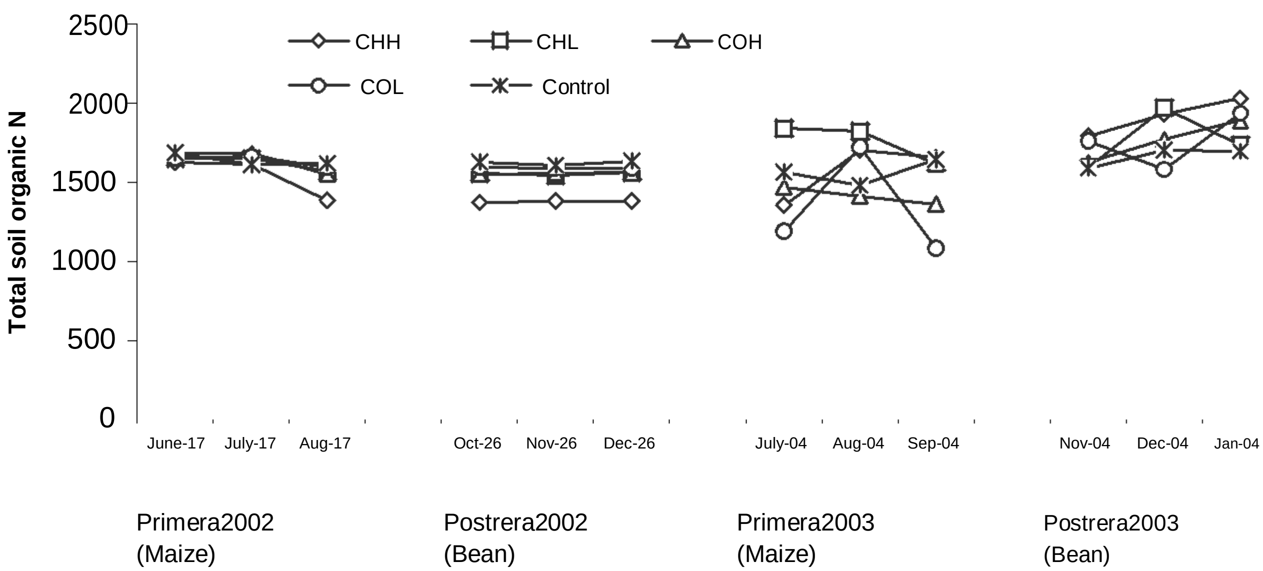


**Figure 2.** Total soil organic N content of the soil layer 0 – 0.30 m ($N_{OrgTube}$; g N $m^{-2}$) in the four manure treatments and the control. CHH = chicken high, CHL = chicken low, COH = cow high, COL = cow low.

the control it averaged 9.9 g N $m^{-2}$ $season^{-1}$ (Figure 1).

The soil total organic N content showed often significant differences between seasons however not in a systematic way, although all treatments and the control achieved their highest value in the last season (Figure 2). Smallest differences between seasonal averages were found for the control ranging between 1564 and 1664 g N $m^{-2}$, a variation of about 6%. The spatial variation within the plots was similar, in about one relative standard de-viation being 4 - 6%. The variation between the sea-sons of the fertilised treatments was much larger, for CHH was near 40% and for the other fertilisation treat-ments about 15 - 25%. The relative standard deviation within the plots ranged from 2 to about 20%. The average absolute values of total soil organic N content were of similar mag-nitude for the control and all f ertilisation treatments,

**Table 3.** Measurements in the tube experiment. Soil mineral N at end of season, seasonal mean values of net N mineralization, total soil N content, C/N ratio, and specific N mineralization rate (a-value) in different manure treatments and an unfertilized control during four consecutive seasons. N mineralization and the a-value are average of three 30-day periods. Soil organic N is an average of four values. Values in parenthesis are one standard deviation. Different letters denote significant differences between trials within seasons at the 0.05 level.

| Treatments | Primera 2002 Maize | Postrera 2002 bean | Primera 2003 Maize | Postrera 2003 Bean | *LSD 0.05* |
|---|---|---|---|---|---|
| **Soil mineral N at end of season (g N m$^{-2}$)** | | | | | |
| CHH | 7.80 (1.8)a | 7.80 (2.1)a | 11.95 (2.3)a | 7.95 (2.1)a | *2.3* |
| CHL | 5.62 (1.2)ab | 4.77 (1.3)b | 3.57 (1.3)c | 4.52 (1.2)c | *1.1* |
| COH | 4.62 (1.0)b | 4.40 (1.2)bc | 4.00 (1.1)c | 5.62 (1.5)b | *1.5* |
| COL | 5.25 (1.1)ba | 5.27 (1.4)b | 5.50 (1.2)b | 3.85 (1.2)c | *1.8* |
| Control | 5.05 (1.0)b | 3.12 (1.1)c | 2.70 (1.0)c | 2.27 (1.0)d | *0.95* |
| **Net N mineralization (g N m$^{-2}$ 30 days$^{-1}$)** | | | | | |
| CHH | 6.71 (2.2) a | 6.67 (1.13) a | 10.45 (1.74) a | 8.85 (0.89) a | *1.34* |
| CHL | 5.22 (0.8) b | 4.53 (0.88) b | 4.18 (1.07) b | 4.99 (0.77) b | *0.72* |
| COH | 5.52 (2.1) ab | 4.69 (1.17) b | 3.78 (1.02) b | 4.54 (1.16) bc | *1.18* |
| COL | 5.08 (1.5) b | 4.47 (1.1) b | 4.73 (1.37) b | 4.23 (0.83) c | *NS* |
| Control | 4.71 (1.1) b | 3.38 (0.70) c | 2.43 (0.67) c | 2.63 (0.63) d | *0.68* |
| *LSD 0.05* | *1.21* | *0.79* | *0.95* | *0.7* | |
| **Total soil organic N (g N m$^{-2}$)** | | | | | |
| CHH | 1544.62 (117.87) b | 1380.0 (31.31) c | 1572.7 (182.7) b | 1919.7(114.8) a | *104.8* |
| CHL | 1625.65 (59.50) a | 1555.6 (106.7) b | 1759.4 (239.2) a | 1769.5(228.4) b | *117.7* |
| COH | 1640.38 (84.33) a | 1556.4 (29.85) b | 1419.1 (53.6) cd | 1764.2(124.1) b | *67.1* |
| COL | 1639.86 (57.16) a | 1591.3 (44.53) ab | 1333.3 (298.4) d | 1761.4(181.3) b | *150.5* |
| Control | 1640.54 (45.66) a | 1624.8 (62.70) a | 1564.7 (96.0) cb | 1664.4 (78.2) b | *61* |
| *LSD 0.05* | *46.02* | *51.9* | *152.5* | *110.3* | |
| **a-value (10$^{-3}$ 30 d$^{-1}$)** | | | | | |
| CHH | 4.41 (1.6) a | 4.48 (0.8) a | 6.67 (1.0) a | 4.64 (0.6) a | *0.9* |
| CHL | 3.23 (0.6) b | 2.92 (0.6) b | 2.40 (0.7) c | 2.88 (0.7) b | *0.6* |
| COH | 3.34 (1.2) b | 3.01 (0.7) b | 2.67 (0.8) c | 2.65 (0.5) b | *0.7* |
| COL | 3.09 (0.9) b | 2.81 (0.6) b | 3.48 (1.3) b | 2.43 (0.6) b | *0.7* |
| Control | 2.88 (0.9) b | 2.08 (0.4) c | 1.55 (0.3) d | 1.59 (0.4) c | *0.4* |
| *LSD 0.05* | *0.9* | *0.6* | *0.7* | *0.5* | |

CHH = high rate of chicken manure; CHL = low rate of chicken manure; COH = high rate of cow manure; COL = low rate of cow manure; Control = unfertilized.

except for the last season of CHH (Table 3).

### Specific N mineralisation rate

The specific N mineralization rate ( *a*; Eq. 2) of soil N, which reflects the decomposition rate per unit of substrate, not only includes effects of chemical compo-sition of the substrate, but also abiotic factors like soil moisture. It is estimated as the ratio between $N_{MinTube}$ (Figure 1) and $N_{OrgTube}$ (Figure 2), and as $N_{OrgTube}$ showed a more irregular pattern over time than $N_{MinTube}$, the pattern of the specific mineralisation rate was fairly similar to that of $N_{MinTube}$. All fertilisation treatments showed a weak tendency of decreasing *a*- values from about 3.0 – 3.3 $10^{-3}$ 30d$^{-1}$ in the first season to 2.4 - 2.9 $10^{-3}$ 30d$^{-1}$ in the fourth season, except for CHH which showed no clear trend. However, the *a*-values of the control decreased more (from 2.9 to 1.6 $10^{-3}$ 30d$^{-1}$) (Table 3), and was significantly lower than all treatments from season two to four (Table 3). The *a*-values of CHH were significantly higher (ranging 4.4 - 6.7 $10^{-3}$ 30d$^{-1}$) than all other *a* values (ranging 1.6 – 3.5 $10^{-3}$ 30d$^{-1}$) already from the first season, and showed a considerably increased value for the third season, the season following the bean cultivation.

## DISCUSSION

The net N mineralisation estimated from the tubes was intended to represent the mineralisation in the cultivation outside the tubes. However, there are basically two sources of errors making this assumption questionable.

First, the mineralization inside the tubes might have been different from outside the tube, and second the estimates of the mineralisation inside the tubes might have been uncertain. Concerning the latter, the N mineralisation estimates assumed no losses of N due to leaching or denitrification. This assumption would cause an under-estimation of the real mineralisation in the tubes. How-ever, Salmerón-Miranda et al. (2007) estimated the loss of N by leaching from the soil outside the tubes, in the current experiment, to have been quite small (0-0.8 g N $m^{-2}$ 30 $d^{-1}$) and less than 10% of the mineralisation in the first 30-day periods, and less than 3% in the second and third 30-day periods. They also assumed low denitri-fication losses due to non-saturated soil conditions.

The biophysical conditions were though different inside the tubes compared to outside. Inside the tubes there was a larger accumulation of mineral N due to the absence of root uptake, which might have stimulated the N losses of the tubes by leaching. On the other hand the water conditions might have been dryer than outside the tubes, as they were protected against rainfall with a curved open cap, which might have retarded the leac-hing. However, to avoid systematically dryer conditions compared to outside, the soil moisture in the tubes was adjusted to the soil moisture of the surrounding soil by watering at every sampling occasion. However, the need of watering was found to be small. Further, the absence of decomposition of root turnover organic material might have underestimated the N mineralisation of the tubes as many studies for diverse species have reported that available substrates (e.g. proliferation and exudation of organic substance by roots) to the soil is considered to stimulate soil organic matter mineralization, named as positive priming effect (Paterson et al., 2006; Kuzyakov et al., 2002; Fu and Cheng, 2002; Ehaliotis, 1998). In controlled environment, contribution of N associated to root and nodule turnover in leguminous crops has been quantified to range between 7 and 20% (Jenssen, 1994; McNeill et al., 1997). However, fresh root litter fall with a high C/N ratio might also act in the opposite direction, causing an increased immobilisation in the short term (days to weeks) (cf. Hamer and Marschner, 2005; Kuzyakov et al., 2000). Also, the possible priming effects of active roots might be absent (Mayer et al., 2004; Fon-taine et al., 2003). Altogether, it seems though that most factors act in a direction that the tube measurements underestimated, rather than overestimated, the N mine-ralisation of the soil outside the tubes.

The results show that the soil net N mineralization was higher for the high chicken manure application rate (10 Mg $ha^{-1}$; CHH) than for all other manure applications and the control (Figure 1). A reasonable explanation is the large amount of N applied to this treatment, compared to the other treatments (Table 2), and that this addition increased the specific mineralization rate (*a* value; Table 3), suggesting that the differences to a large extent were due to a higher decomposability of CHH. It is more strange that the chicken low application treatment (CHL) achieved similar low rate of mineralisation as cow ma-nure despite higher addition of N (16.5 compared to 5.7-11.3 g N $m^{-2}$ for cow) and a lower CN -ratio (9.3 compared to 15.3 for cow) which would be expected to have increased the net mineralisation (Constantinides and Fownes, 1994; Kaye and Hart, 1997; Mary et al., 1998; Nilsson, 2004). Other studies suggest though a compli-cated relation between type of waste and type of soil that influence the mineralization (Leifeld et al., 2002) that might explain the observed little effect of the low rates.

The soil at the experiment exhibits a considerable amount of total N (5.7 g $kg^{-1}$), though we might assume that a large portion of this N is probably part of a passive pool considered to have low participation in the N minera-lization process as it is commonly reported in volcanic soil (Matus and Rodriguez, 1994). This in combination with the relative high content of soil carbon might mask the possible amount of mineralised N in the low rates. However, at higher application of total N (300 kg total N $ha^{-1}$) in the high rate of chicken manure might change the relation between stabilised pools of soil carbon and N in favour of the N mineralization process as confirmed by the results. The net N mineralization of CHH was more than 50% higher in season 3 when maize was cultivated after bean, than in season 2, when bean was cultivated after maize. This might be explained by a higher N availa-bility after the preceding $N_2$ fixing bean crop (Figure 1), and is consistent with other studies of legumes in a crop-ping system (Andersson and Domsch, 1989; Rao et al., 1994; Fuhrmann et al., 1999). Sanchez et al. (2001) com-pared a continuous maize mono-cropping system, fertili-zed with mineral NPK, with a maize-maize-soybean-wheat crop sequence fertilized with composted manure. They found that the net N mineralization of the crop sequence system was 90% higher than that of the mono-cropped system.

The higher N mineralization of CHH in season 3 might though also be caused by more favorable soil moisture conditions during this season. In a related study at the same site the N fixation per unit of bean biomass was higher in season 3 than in seasons 2 and 4 (Salmeron et al., manuscript 4), indicating a more efficient nodule activity in season 3 which might have been caused by higher moisture content due to a higher rainfall (about 900 mm compared to about 500 mm in seasons 2 and 4; Table 1).

In contrast to this, however, the other fertilization treatments and the control did not show any increased mineralization during season 3, that is, the stimulating effects of increased moisture and the N fixing bean pre-crop seems to have been retarded by some other factors. So if the increased N mineralization in season 3 for CHH is supported by other results, it is a more unexpected result that the N mineralization of the other treatments or the control did not increase for the season following bean.

## Conclusions

The higher net N mineralization of the chicken high treatment (CHH) during seasons 2 – 4 compared to the other manure treatments and the unfertilized control might be explained by a higher specific mineralisation rate, probably related to a higher decomposability and low C/N ratio of the chicken manure. For the same seasons, the other fertilization treatments had similar N mineralization to each other although both N addition rates and types of manure application differed. All fertilization treatments had significantly higher net N mineralization than the con-trol. In the control both net N mineralization and the specific N mineralisation rate decreased significantly over time. An indication of priming effect in the season follo-wing the N fixating bean crop was only found in the CHH treatment.

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