NITROGEN MINERALIZATION FOR ASSESSING THE CORRECT AGRICULTURAL USE OF MSW COMPOST

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1. ABSTRACT

The nutrient dynamics after compost application to soil are important, especially when compost is going to be used for fertilization purposes. Mineralization of organic N (usually the main N form in composts) to NO_3^--N and NH_4^+-N, available N forms for crops, shows the potential availability of this macronutrient and helps to regulate the mineral fertilization. In this work, N mineralization of a Municipal Solid Waste Compost (MSWC) blended with two soils of different textures (sandy and clay) and the emergence of ryegrass plants treated with different N fertilizers are described.

Compost-soil samples showed initially a strong immobilization of the mineral N present in the blends. Only after 12 weeks was positive mineralization observed in both soils, although it was more intense in the case of the sandy soil. Net compost mineralization (subtracting mineralization of Control treatments with clay (S1) and sandy soil (S2)) was also calculated. In the compost-clay soil blend (S1C), net compost mineralization was negative during all the incubation period (36 weeks), and it had a lower NO_3^--N concentration than that of the control (S1). In contrast, in the compost-sandy soil blend (S2C), net compost mineralization was positive after the 19th week of incubation, due to the intense mineralization observed after the 12th week.

Ryegrass plants treated with different N sources (MSWC, Mineral Fertilizer 15-15-15 N-P-K (MF), Urea (U), MSWC+MF, MSWC+U and a Control without applying N) showed at the initial emergence stages, differences in biomass and N-content related to the N immobilization observed in the soils treated with MSWC.

It may be concluded that these composts must be applied to soils three months before sowing or before the time that a crop needs a continuous supply of N. Compost must be amended with mineral N fertilization to avoid the risk of 'N rob' for the crops.

2. INTRODUCTION

The soils usually show an uninterrupted input-output of nutrients and elements, followed by complex transformations of them. In the case of the N, during the mineralization process, microorganisms of the soil transform organic nitrogen compounds, hydrolyzing them to inorganic simple forms more easily available to plants (NO_3^--N and NH_4^+-N). At the same time a process of immobilization of inorganic N takes place, with the synthesis of proteins by microorganisms (Brady, 1990). This dynamic system has been described as a Mineralization-Immobilization Turnover (MIT, Jansson and Persson, 1982). It has been modeled by Verberne et al. (1990), who divided the organic matter of the soil in two main components depending on its origin: wastes, made up of crop residues and manure; and the native organic matter of the soil. The MIT in every soil and under various conditions results in a net mineralization rate or a net immobilization rate. The knowledge of this rate may be useful for using more efficiently organic and inorganic fertilizers and products added to the soil, minimizing the losses of NO_3^- in leachates and avoiding the negative environmental effects that it may cause in groundwater. Mineralization is affected by ammonium concentration in soil, the C\N ratio in soil and in products added, pH, moisture,temperature, other nutrients and aeration (Foncht and Verstroete, 1977; Schmidt 1982).

In general, when stabilized organic products are added to soils, and with an adequate C\N ratio (<20), the mineralization process is enhanced (Nogales et al., 1982), while products with high C/N ratios, such as straw, promote immobilization (Stemmer et al., 1999). Thus, study of mineralization of organic N of the products to be added to agricultural soils, is essential to optimize the conditions for applying them. One of methods to determine mineralization of products incorporated to the soil is the laboratory incubation under aerobic conditions, based on the method proposed by Stanford and Smith (1972). This is usually the preferred method (Herbert et al., 1991; Martín-Olmedo et al., 1995; Dejoux et al., 2000). In this method, NH_4^+ and NO_3^- concentration are determined and mineralization parameters are calculated (Jarvis et al., 1996) and modeled. In this paper, the mineralization of a Municipal Solid Waste Compost (MSWC) added to two soils with different textures (sandy and clay) under aerobic incubation is described. Furthermore, in order to know the possible effects of N mineralization of MSWC on crops, emergence of ryegrass plants, treated with different N sources (MSWC and mineral fertilizers), was also studied.

3. MATERIALS AND METHODS

3.1 Incubation experiment

The mineralization of a 10-mm sieved MSWC obtained from the Recycling Plant of Villarrasa (Huelva province; Southern Spain) was studied. It was mixed with two different kinds of 2-mm sieved soils (S1, silt-clay; and S2, sandy) and incubated under aerobic conditions at constant moisture and temperature. Characteristics of the compost and soils are described in Tables 1 and 2. The NH_4^+-N and NO_3^--N as they were evolved were measured following the methodology of Keeney and Bremner (1967). To study mineralization, 5 g of Soil-MSWC blend (ratio 5.0/0.5 Soil/Compost; treatments S1C and S2C), was mixed with 15 g of acid washed and ashed commercial sand to get similar field capacities and aeration. For Control 5 g of each soil mixed with 15 g of sand (Treatments S10 and S20) was used. Fifty 100 ml polyethylene flasks of each treatment were prepared, moistened with 3 ml of distilled water, and sealed with Parafilm' (Dubey, 1969), allowing the exchange of O2 and CO2 and minimizing the losses of moisture. They were incubated at 30ƒC during 36 weeks. Moisture was periodically weight-controlled, by adding distilled water when necessary. At the beginning of the incubation and at the weeks 1, 2, 4, 6, 8, 12, 16, 19, 26 and 36, NO_3^--N content was determined. During the first weeks NH_4^+-N content was also determined. For the determination of NH_4^+-N, the soil-sand (or soil-compost-sand) blend of one flask was extracted with 50 ml KCl 2M (1/2.5 w/v) and NH_4^+-N was determined with an ammonia selective electrode. NO_3^--N was extracted with 50 ml of distilled water (1/2.5 w/v) and determined also by selective electrode. All the determinations were carried out in triplicate (three different flasks), and a mean value was obtained.

	N Mineralization	Ryegrass emergence
pH	6.63	6.90
Org. Mat. (%)	26.0	38.0
C/N	23.5	21.7
Kjeldahl N (%)	0.60	0.95
P_2O_5 (%)	0.62	0.89
K_2O (%)	0.55	0.90

Table 1. Characteristics of the MSWC used for mineralization and ryegrass emergence assays.

	Soil S1	Soil S2	Ryegrass emergence
pH	7.5	7.5	7.9
Org. Mat. (%)	1.74	1.50	0.50
Kjeldahl N (%)	0.096	0.083	0.03
Sand (%)	11.5	85.6	57.0
Silt (%)	60.1	10.7	20.8
Clay (%)	28.4	3.7	22.2

Table 2. Characteristics of the soils for mineralization and ryegrass emergence assays.

3.2 N mineralization simulation model

The N mineralization process was analyzed by a one-pool model (Stanford and Smith, 1972), in which the process follows the first order kinetic equation where Nt is the cumulative amount of N mineralized in time t, No is the potentially mineralizable N (representing the pool of the organic N that might be mineralized), k is the mineralization rate coefficient and Ni is the mineral N at the beginning of the process. This equation has been widely used to describe N mineralization (Stanford and Smith, 1972; Matar et al., 1991; Serna and Pomares, 1991; S·nchez et al., 1997). The data were fitted to the equation using the Marquardt iteration method.

$$N_t = N_o(1 - e^{-kt}) + N_i$$

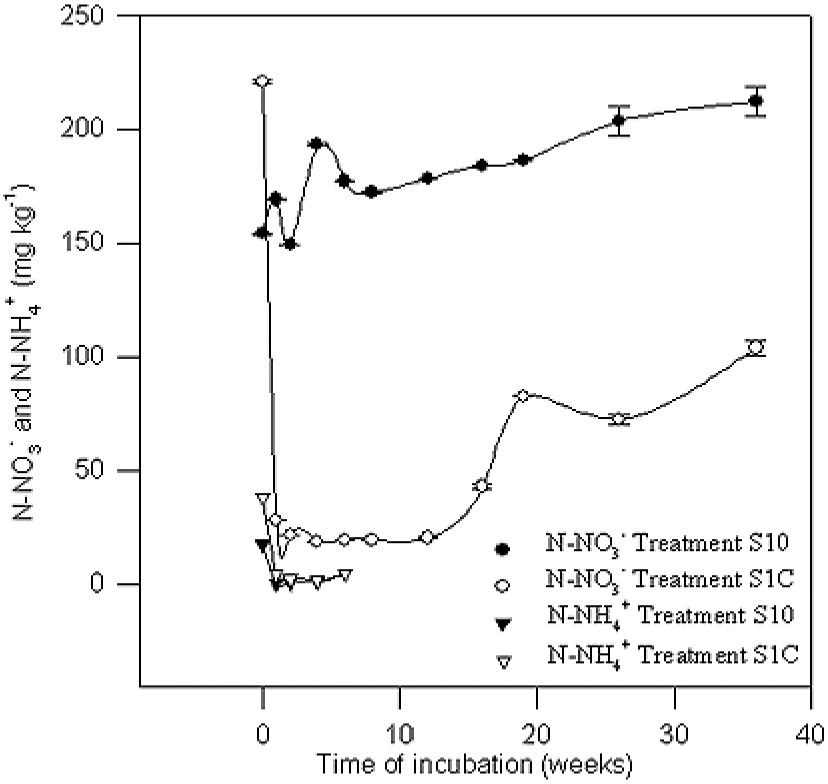
3.3 Emergence of Ryegrass

This assay was carried out in pots with 2 kg of soil (Table 2); 1 g of ryegrass (Lolium multiflorum Lam.) seeds was spread over the surface of the soil and covered with a fine layer of acid washed sand and soil. The treatments used were: Compost (C) in which MSWC (Table 1) was applied at a rate of 25 g kg^{-1}; Compost-Urea (CU), in which MSWC was applied at a rate of 12.5 g kg^{-1} and was supplemented with Urea (0.27 g kg^{-1}); Compost-Mineral Fertilizer (CMF), in which MSWC was applied at a rate of 12.5 g kg^{-1} and was supplemented with 15-15-15 N-P-K fertilizer (0.84 g kg^{-1}); Urea (U) that was applied at a rate of 0.54 g kg^{-1}, and Mineral Fertilizer (MF) applied at rate of 1.68 g kg^{-1}. A Control (0) was used, which was soil without any N addition. In this way 0.25 g N kg^{-1} was applied in all treatments, except the control. The crop was cut twice (47 and 100 days after planting), and each cutting was analyzed for Kjeldahl N. Fresh weight immediately after cutting. Plant material was washed with distilled water, dried and ground, and dry weight was determined. Fresh-weight biomass data are not shown, because the conclusions with them obtained, were similar to dry-weight-basis biomass. N contents of the crop are expressed on dry matter basis.

4. RESULTS AND DISCUSSION

4.1 Incubation experiment

The evolution of the NH_4^+-N and NO_3^--N contents in the different treatments is shown in Figure 1 for S10 and S1C, and Figure 2 for S20 and S2C.



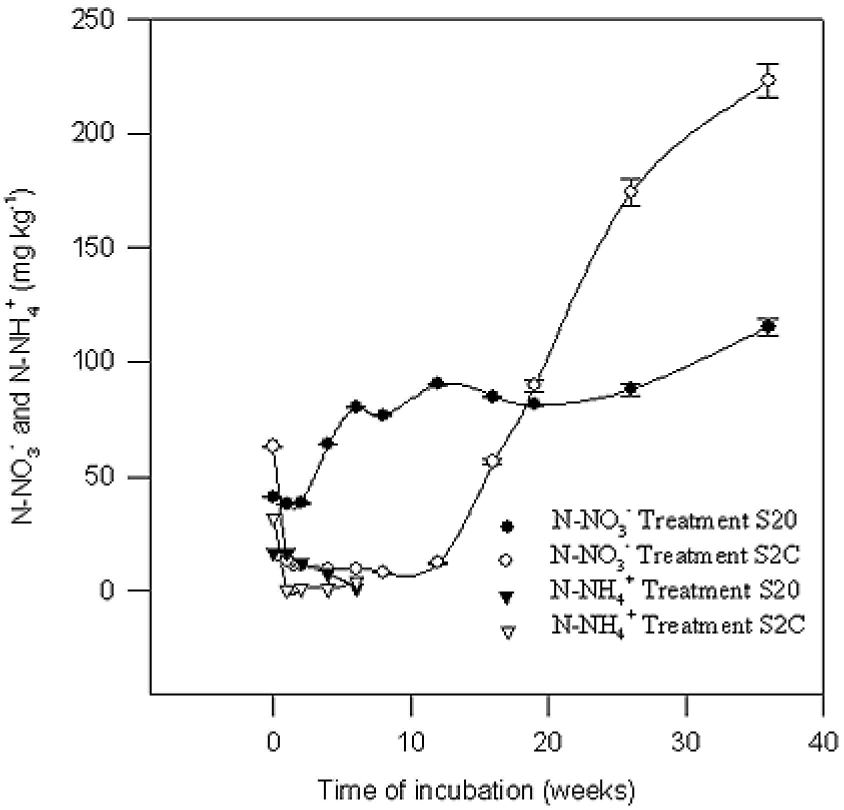


Figure 1:Right , Figure 2: Left

NH_4^+-N contents varied in a similar way for both S1 and S2 soils. At the beginning of incubation, soils treated with MSWC, that is S1C and S2C (38 and 32 mg kg^{-1}, respectively) showed higher contents than untreated soils, S10 and S20 (18 and 17 mg kg^{-1}, respectively). In the following weeks these contents decreased to small values as usually happens in aerobic incubation experiments (Simard and N'dayegamiye, 1993; S·nchez et al., 1997). The contents were in the range of 2-5 mg kg^{-1} during the 6th week of the incubation. Moreover, NH_4^+-N released from compost mineralization usually is nitrified into the NO_3^--N form (He et al., 2000), so organic-N mineralization may be monitored only by measuring evolution of NO_3^--N. At the beginning of the incubation (week 0), S10 showed a high NO_3^--N content (Fig. 1) due probably to the residual content from the previous crop or the agricultural uses of this soil. NO_3^--N content tended to increase during the incubation.

The increment was almost linear after the 8th week of incubation. This is typical for mineralization of native soil organic matter, and has been previously observed in different soils (Ajwa and Tabatabai, 1994). In contrast, the NO_3^--N content of S1C disappeared almost completely, with a drop of approximately 200 mg kg^{-1} in the first week. This big immobilization may be due to use of NO_3^--N by microorganisms in the soil, which increase their population. After this immobilization, the NO_3^--N content was stabilized until 12th week (20 mg kg^{-1} approx.), when the mineralization rate was higher than in the control S10. Net MSWC N-mineralization was calculated by subtracting S10 from S1C (Fig. 3). The immobilization at the beginning of the incubation resulted in a decrease of 260 mg kg^{-1} during the first four weeks. Therefore, it was observed that the net balance was negative during all of the incubation period, because of the high NO_3^--N contents in the soil S10. Thus, application of MSWC to the clay soil (S1) produced a decrease in the NO_3^--N content. Moreover, after 36 weeks, S1C had still not recovered its initial level (it showed a content of 125 mg kg^{-1} lower than S1C at the week 0 of incubation), and also showed a content of 120 mg kg^{-1} lower than the control S10 at the end of the incubation period.

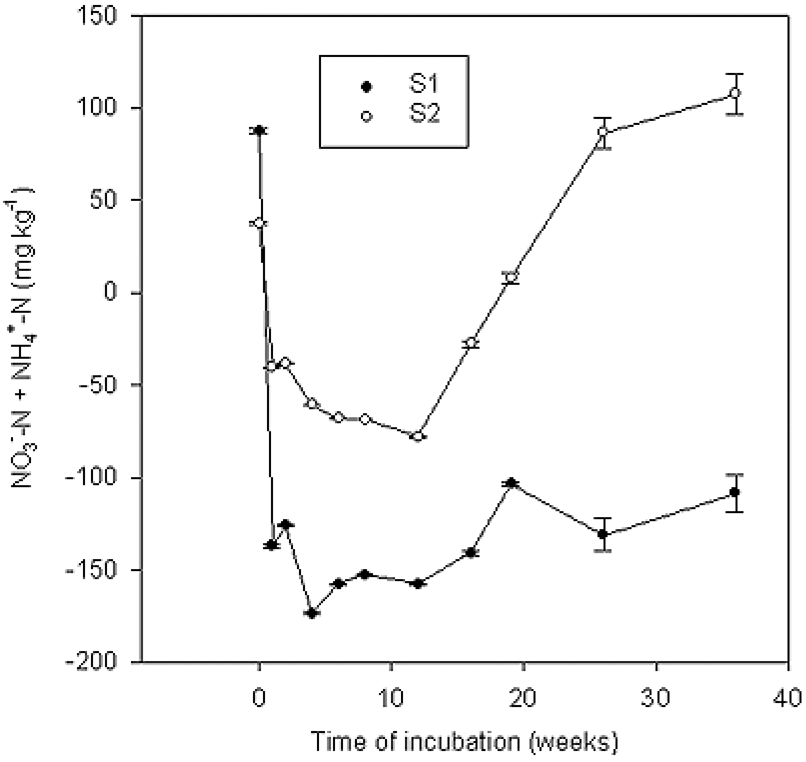


Figure 3.

Sandy soil N-mineralization showed differences compared to the clay soil. Control treatment without MSWC application (S20), had a lower NO_3^--N content (41 mg kg^{-1}) than S10, and it was nearly constant for two weeks (Fig. 2). After the 2nd week of incubation, this content tended to increase notably until the 6th week, when this increase continued more slowly. In the treatment S2C, with MSWC, there was an important reduction in the NO_3^--N content during the first week (50 mg kg^{-1}), as was observed in the case of S1C, because of the use by microorganisms of the mineral N added with the compost. After this, the NO_3^--N content stabilized around 10 mg kg^{-1} until the 12th week. Then a continuous increase in the NO_3^--N content it was observed, which was more intense than that observed in the treatment S1C. Because of this high mineralization rate, the soil had almost recovered its NO_3^--N content by the 16th week which it had at the beginning of the incubation.

In the last week (36th) it had a content 160 mg kg^{-1} higher than at week 0. Net MSWC N-mineralization in the sandy soil S2 (Fig. 3) resulted in an initial significant immobilization, as was also observed with the clay-silt soil S1 until the 12th week. At this time, a positive mineralization was observed, and by the 19th week a positive net balance had been reached. After this week, mineral N content in the soil increased due to the MSWC applied. Differences in mineralization rates of composts due to the different texture of the soil have been previously reported (Martín-Olmedo et al., 1995). Their cause has been explained as follows, higher protection of the organic matter by the humus-clay complex make microbial attack in soils with high clay contents more difficult (Herbert et al., 1991). In sandy soils a faster mineralization occur (Hassink, 1992). Because of the immobilization observed in both soils at the beginning of the incubation, applying the MSWC obtained at the Villarrasa facilities 12 weeks (3 months) before sowing or before the crop may need a continuous supply of N is advised. This could help also immobilize mineral N from the previous crop, and prevent it from being lost by leaching. Similar results were obtained by V·zquez et al. (1999), who studied enzymatic activities of soils amended with MSWC from the Plant of Villarrasa.

4.2 N mineralization simulation model

Equation 1 must be applied to a positive mineralization balance, and it is not possible to use it for a period of immobilization. In the case of MSWC added to the sandy soil S2, net mineralization began in the 12th week. Thus, this week was taken as t= 0 for the modeling. In the same way, NO_3^--N content in this time also was considered 0 (NI=0), so the equation 1 simplifies to

$$N_t = No(1 - e^{-kt})$$

The experimental data fitted very well (r^2=0.98) this equation; values of No=232±34 mg kg^{-1} and k=0.073±0.020 week^{-1} were calculated. The value of the coefficient is similar to that obtained by LÛpez (1992) in an incubation experiment with olive mill wastewater composts applied to a loam-clay-sandy Xerorthent soil and a sandy Xeropsamment soil, but

higher than obtained by S·nchez et al. (1997) for MSWC applied to a sandy-loam soil (0.0064 week^{-1}). This difference could be due in part to the lower temperature that these authors used during the incubation (28ƒC), because temperature changes in the range between 25 and 35ƒC have strong effects on N mineralization (Marion and Black, 1987).
With the value of k, one may calculate the time necessary to mineralize No/2 that would be called t1/2. Substituting in Eq. 2 Nt=N0/2,

$$t_{1/2} = \frac{0.693}{k} = 9.5 \text{ weeks}$$

Actually, this value has to be increased in 12 weeks, because that was the period of immobilization at the beginning of the incubation process. Using the value of No, and knowing the soil:compost ratio used for the incubation which was 5:0.5, the potentially mineralizable N of S2C was 2550 mg N kg^{-1} MSWC, which is 42.5% of the initial Kjeldahl N of the MSWC applied (0.6%). Nevertheless, from the calculated value of No, 115 mg NO_3^--N kg^{-1} had been immobilized in the first 12 weeks of incubation, the period that was not modeled. Thereby the net potentially mineralizable N of MSWC was117 mg kg^{-1}, and the net potentially mineralizable N of the compost was 1290 mg N kg^{-1} MSWC (21.5% of the initial Kjeldahl N of the MSWC). At the end of the incubation period, the N mineralized was 12.8% of the Kjeldahl N initially applied to the soil. If these results were extrapolated to field conditions, and with moderate doses of MSWC (10 t ha^{-1}), the compost would add to the soil in the first crop approximately 7-8 kg ha^{-1} of mineral N. The mineralization rate of the process can be obtained by taking the derivative of the equation 2

$$\frac{dN_t}{dt} = \left(N_o k\right)e^{-kt}$$

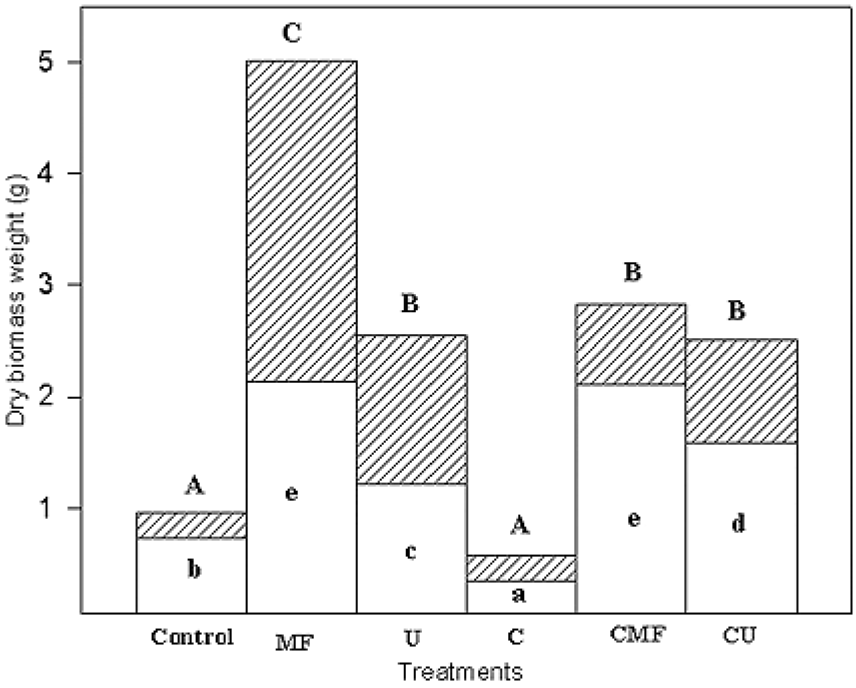
and determining the derivative at the beginning of incubation (t=0)

$$\frac{dN_t}{dt_0} = \left(N_o k\right)e^{0} = N_o k$$

Campbell et al. (1991) defined N0k as the initial potential rate of the N mineralization process. According to Campbell et al. (1996), N0k is an excellent index of the N-supplying power of the soil. In this case, for the MSWC applied to the sandy soil S2, this parameter was 16.9 mg kg^{-1} week^{-1}, in the range of values obtained for several soils by Simard and N¥dayegamiye (1993) (7.4-37.3 mg kg^{-1} week^{-1}) and Broersma et al. (1996) (7.5-24.2 mg kg^{-1} week^{-1}). For the clay soil, the net N-mineralization process could not be modeled.

4.3 Emergence of ryegrass

Plants with different N sources showed differences in their biomass during emergence (Figure 4). After the first cut (47 days), treatment C had the lowest biomass, and even the Control 0, without additional N, showed a greater development. For all the other treatments, significantly greater amount of growth were observed. The CMF treatment had a biomass similar to that of plants treated with mineral fertilizer only (MF), while the CU biomass was statistically higher than the urea treatment (U) after the first cut. In the second cut (100 days), all the treatments with MSWC (C, CMF and CU) and the Control had less growth than was observed in the first cut, while U and specially MF showed more growth. In this way, MF had the highest total biomass (sum of two cuts), and CMF, CU and U had similar total biomasses. Control and C treatments had the lowest total biomasses, as in the first cut. In addition to the lowest biomasses, Control and C treatments showed also the lowest N content after the first cut (Figure 5). Treatments with application of N exclusively from fertilizer origins, MF and U, had the highest N contents, while treatments that had N from blends MSWC-fertilizer, CMF and CU, showed slight but statistically lower N contents in the first cut. These two treatments had the largest drop in N contents in the second cut, although they maintained higher contents than Control and C treatments (Figure 5). These results agree with those obtained in the incubation experiment to determine N mineralization, described above. They show the 'N rob' effect due to the immobilization of the mineral N by the application to the soil of MSWC, which causes not only lower N contents in plants treated with the compost, but also lower biomass during the growth. The addition of mineral N with the MSWC helped to avoid this problem at the beginning of growth, although plants of these treatments never reached the amount of growth observed with of the plants treated only with mineral nitrogen fertilizers, which provided N was easily available for the crop from the beginning of the experiment.



The decrease observed in the N content in the second cut for the treatments CMF and CU may be due to two reasons: 1) the depletion of the mineral N applied, and 2) the mineralization/immobilization rate of the compost was not high enough to supply the N that the crop needs. First, in these treatments, CMF and CU, the crop had already used before the first cut the 37-42% of the mineral N applied with the fertilizers, so a higher dose or successive applications would be needed. Second, immobilization by the MSWC had tied up the soil solution part of the mineral N applied before sowing, and so the crop could not use it. Madrid et al. (2000) have previously described what dose of urea should be applied to improve MSWC produced in the plant of Villarrasa and to avoid N immobilization problems in the crops.

5. CONCLUSIONS

The addition to two differently textured soils (silt-clay and sandy) of MSWC resulted in an important N immobilization of 12 weeks. Therefore we advise that the compost be applied on agricultural land, 3 months before the N may be needed by a crop. Mineral N supplies at the beginning of crop growth would be necessary to overcome the problems of N immobilization. The additional supplies of N would help stabilize the compost organic matter in the soil and would remain as a pool that would increase the soil available N in following years.

6. ACKNOWLEDGMENTS

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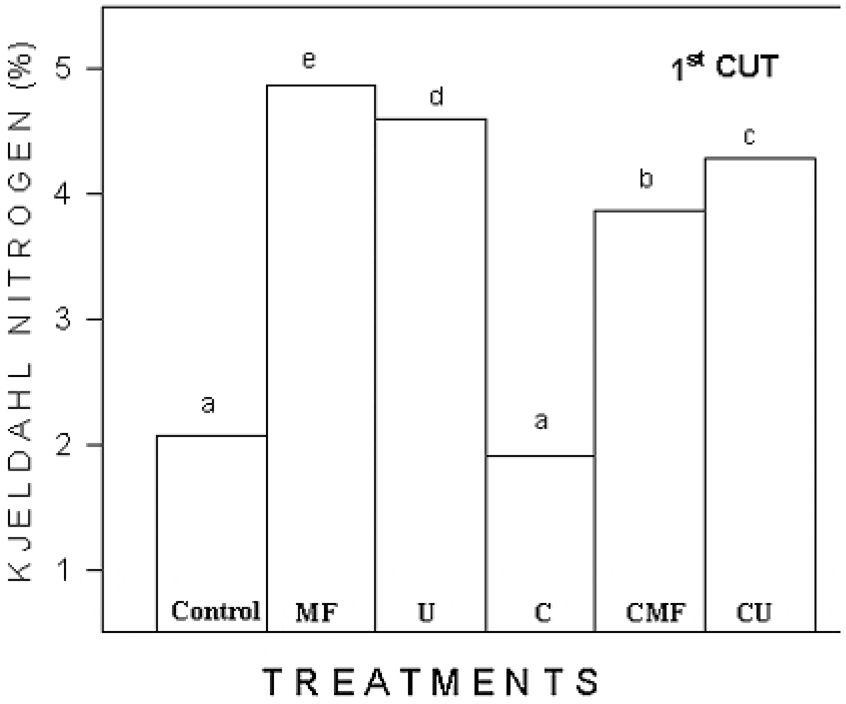

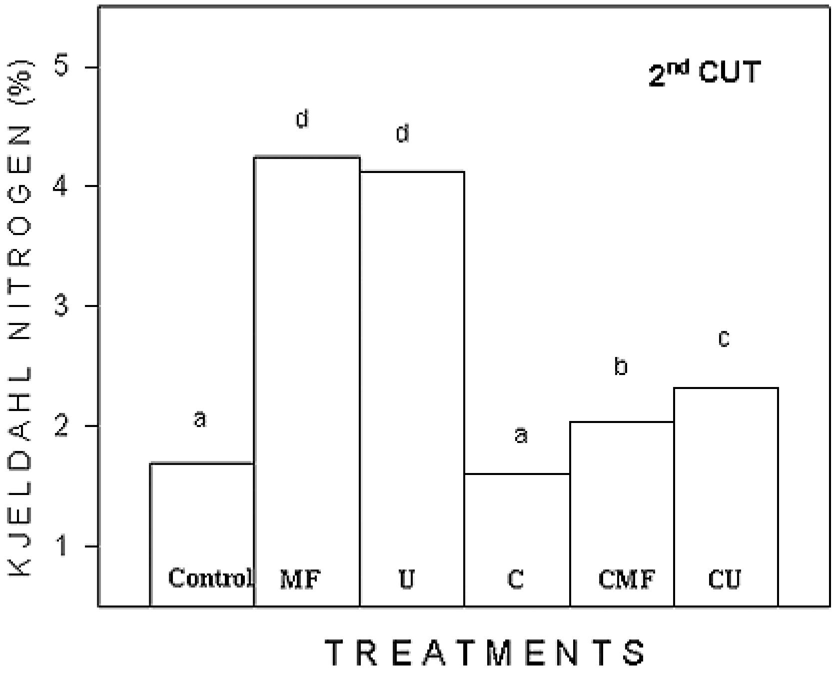

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