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Apparent availability of nitrogen in composted municipal refuse

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Abstract. The use of composted municipal refuse on agricultural land requires prior knowledge of the interactions among compost, soil, and plants. Research into the availability of N in highly matured municipal refuse compost is particularly important considering the current concern about groundwater contamination by NO_3^--N. A greenhouse pot bioassay was conducted to determine the percentage of short-term apparent bioavailable N of a highly matured refuse compost and its relative efficiency in supplying inorganic N to the soil-plant system in comparison with NH_4NO_3. Municipal refuse (after 165 days of composting) was applied at rates equivalent to 10, 20, 30, 40, and 50 t ha^{-1} to a ferrallitic soil from Tenerife Island (Andeptic Paludult). NH_4NO_3 was applied at rates equivalent to the total N content of the compost treatments. Perennial ryegrass (*Lolium perenne* L.) was grown in 3-kg pots and the tops were harvested at regular intervals after seedling emergence. The compost increased dry matter yield, soil mineral N, and plant N uptake proportional to the applied rate. These increases were significantly higher than the control at an application rate of 20 t ha^{-1}. After 6 months the apparent bioavailable N ranged from 16 to 21%. The relative efficiency was 43% after 30 days. This suggests that large inputs of inorganic N into soil can be obtained with high rates of this kind of compost, with a potential for NO_3^--N contamination. However, applied at moderate rates in our bioassay (<50 t ha^{-1}), compost showed a low N-supplying capacity to ryegrass, i.e. a small fraction of the mineralized compost N was used by plants in the course of time. This was ascribed to a partial biological immobilization. This pattern of N availability in highly matured municipal refuse compost, positive net mineralization but partial immobilization, is similar to the pattern of N availability in biologically active soils and is therefore extremely interesting for the conservation of N in agro-ecosystems.

Key words: Compost – N mineralization – Organic N – Plant N uptake – Soil N availability – N immobilization

Land application of composted municipal refuse, produced by aerobic thermophilic digestion of the organic fraction of municipal solid wastes, is an attractive alternative for the disposal of these wastes, currently land-filled or incinerated. The recycling of organic wastes through composting can mitigate problems of both environmental pollution and soil degradation (Mathur et al. 1990). To determine the suitability of composted municipal refuse for agricultural use, it is necessary to evaluate its reaction with soils and the crop response (Sims 1990). Composted municipal refuse normally improves physical and chemical soil properties such as porosity, aggregate stability, water-holding capacity, pH-buffering capacity and cation-exchange capacity, and also releases nutrients gradually (Pagliai et al. 1981; Giusquiani et al. 1988; Piccolo and Mbagwu 1990; Iglesias-Jiménez et al. 1993). Similarly, this composted refuse has a positive influence on soil microorganisms and soil enzyme activities (Nishio and Kurano 1980; Miyashita et al. 1982; Perucci 1990). Moreover, the mature compost may reduce phytopathogenic fungi levels (Van Assche and Uyttebroeck 1981; Phae et al. 1990) and nematode plant-parasite populations (Rodriguez-Kabana et al. 1987). Nevertheless, negative effects, normally associated with a decrease in yield, have also been reported, and are caused by the application of large amounts of compost with high levels of available heavy metals (Petruzzelli 1989) and the use of immature compost, i.e., insufficiently stabilized as regards mineralization and "humification" (Iglesias-Jiménez and Pérez-García 1989).

A wide range of results has been obtained in relation to the efficiency of compost as a source of N for plants because N availability is closely related to the degree of compost maturity (Gallardo-Lara and Nogales 1987). Immature composts induce a considerable increase in soil

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Correspondence to: E. Iglesias-Jimenez microbial activity to decompose the excess of labile C compounds, potentially causing a strong immobilization of native and added available N, and consequently, N starvation and depressive effects on crop plants may occur (Iglesias-Jiménez and Pérez-García 1989; Sims 1990). In contrast, highly matured composts normally increase crop yields and a net inorganic-N accumulation may occur in the soil (King 1984). Thus, knowledge of the availability of N in composts is particularly important, given the current concern with groundwater contamination by NO_3^--N (Sims 1990) and the scarcity of values reported for N mineralization from composted domestic refuse. The objective of the present study was to evaluate the N-supplying capacity of a highly matured municipal refuse compost by means of a ryegrass pot bioassay, based on (1) the apparent availability of compost N over a period of 6 months and (2) the relative efficiency of compost as an N source compared to NH_4NO_3.

Materials and methods

Properties of composted municipal refuse

The composted municipal refuse used in this study was obtained in a controlled pile-composting trial from the organic fraction of the municipal solid waste of Santa Cruz de Tenerife (Canary Islands), after a biooxidative period of 75 days and a 90-day complementary maturity process. The composting system and the evolution of maturity during composting have been presented previously (Iglesias-Jiménez and Pérez-García 1991, 1992a). Some chemical characteristics of the final product (165 days of composting) are shown in Table 1. This compost had an exceptionally high degree of maturity; in an earlier study (Iglesias-Jiménez and Pérez-García 1992b) a C:N ratio <12 was estimated to ensure a high degree of maturity, in combination with other parameters of maturity such as a cation-exchange capacity of >67 cmol (+) kg^{-1} dry matter on an ash-free material basis, C:N (compost:water 1:5) <6, and a humic acid to fulvic acid ratio of >1.6. Moreover, the final compost had an intense black colour and a strong odour similar to that of "damp forest ground", normally attributed to the excretion of geosmine, a secondary metabolite produced by mesophilic actinomycetes, which predominate during the maturation phase of composting (De Bertoldi and Zucconi 1980). Before incorporation with the soil, the compost subsample for this experiment (8 kg) was air-dried, ground to pass a 1-mm sieve, and throughly homogenized. The total elemental content shown in Table 1 is from this subsample (average of five repetitions). The pH (H_2O, 1:5) of this subsample was 6.8 and the C:N ratio 11.3.

Table 1. Main characteristics of composted municipal refuse

Electrical conductivity (dS m^{-1} 25 °C, H_2O 1:5)			16.0
pH (H_2O 1:5)			8.4
Ash (g 100 g^{-1} dry matter)			38.3
Total organic C (g C kg^{-1} dry matter)			326
Oxidizable C (g C kg^{-1} dry matter)			309
Alkaline-extractable C (g C kg^{-1} dry matter)			111
Humic acid-like C (g C kg^{-1} dry matter)[a]			73
Fulvic acid-like C (g C kg^{-1} dry matter)[a]			38
Humic:fulvic acid ratio			1.9
C:N ratio (solid phase)			9.9
Organic C to organic N ratio (water-soluble phase)[b]			5.4
Cation-exchange capacity[c] (cmol kg^{-1})[a]			80.1
Total elemental content			
N (g kg^{-1})	31.0	Mn (mg kg^{-1})	321
P (g kg^{-1})	12.5	Zn (mg kg^{-1})	1043
K (g kg^{-1})	38.3	Pb (mg kg^{-1})	224
Ca (g kg^{-1})	92.9	Cr (mg kg^{-1})	73
Mg (g kg^{-1})	8.7	Ni (mg kg^{-1})	58
S (g kg^{-1})	5.1	Co (mg kg^{-1})	15
Na (g kg^{-1})	21.0	Cd (mg kg^{-1})	2
Fe (mg kg^{-1})	18184	Hg (mg kg^{-1})	2
Cu (mg kg^{-1})	463		

[a] Ash-free material basis
[b] Chanyasak and Kubota (1981) procedure
[c] Harada and Inoko (1980) procedure

Greenhouse study

The experiment was conducted over 7 months under a controlled greenhouse environment (temperature 16–24 °C, relative humidity 60–85%), in plastic pots containing 3 kg air-dried soil. The soil was a variable-charge soil from Tenerife, Canary Islands (Andeptic Paleudult), comprising 26% sand, 34% silt, and 40% clay, with pH (H_2O) 5.8, electrical conductivity 1.00 dS m^{-1}, organic C 16.5 g kg^{-1}, cation-exchange capacity 21.2 cmol (+) kg^{-1}, C:N ratio 11.6, $NH_4^+ + NO_3^-$ 53 mg N kg^{-1}, labile P (Olsen) 20 mg P kg^{-1}, and NH_4OAc-extractable K 321 mg K kg^{-1}. Halloysite was the dominant clay mineral and small amounts of gibbsite and allophane were also present.

The soil sample was passed through a 4-mm screen to remove rocks, roots, and other large particles. Complete randomized blocks were chosen as the experimental design (Little and Hills 1975). Five compost treatments equivalent to 10, 20, 30, 40, and 50 t ha^{-1} were established as well as five treatments with NH_4NO_3 on the basis of the N content of the compost treatments. The NH_4NO_3 treatments were also supplied with P, K, Ca, Mg, S, Na, Cu, Fe, Mn, and Zn at rates equivalent to that supplied in the compost treatments. A control (no treatment) was also established. Perennial ryegrass (*Lolium perenne* L.) was used as the test plant. In each pot 1000 seeds were planted and 400 ml deionized water was added immediately after planting to germinate the seeds. Germination was completed in 7 days. The pots were watered daily with deionized water to bring the soil moisture to a level corresponding to 33 kPa tension (25% moisture). All pots were harvested 30, 60, 90, 120, 150, and 180 days after seedling emergence by cutting the plant tops 2 cm above the soil surface. The total number of pots used was 253, 55 of which were used for plant nutrient assays (11 treatments×5 replications) and 198 to study nutrient changes in the soil (11 treatments×3 replications×6 harvesting periods).

The ryegrass tops were dried at 80 °C in a forced-draught cabinet oven to a constant weigth. The dried plant material was ground to powder in a stainless steel mill and, just before the analytical process, the ground samples were dried again at 105 °C for 2 h. Plant N was determined titrimetrically following a semimicro-Kjeldahl digestion method (Bremner 1965a). Soil samples were air-dried, ground, sieved (2 mm) and stored at 4 °C. Subsamples (10 g) were extracted with 2 *N* KCl (1:10, w:v) and inorganic N ($NH_4^+ + NO_3^-$) was determined titrimetrically following steam distillation with MgO and Devarda's alloy (Bremner 1965b).

Statistical analyses

Plant and soil analysis data were subjected to analysis of variance. Whenever the analysis of variance *F* value was significant, Duncan's new multiple range test was used to determine difference among treatments at $P = 0.01$ (Little and Hills 1975). To calculate regression equations and correlation coefficients relating plant growth, plant N uptake and soil mineral N, the Statistical Graphics System Program (STSC, Lauer Software) was used.

The percentage of apparent bioavailable nitrogen (ABN%) was calculated according to the expression ABN% = $100\,(N_f + Ni_f)/F$, where N_f is the N taken up by ryegrass tops from the applied fertilizer, calculated as $N_f = N_t - N_s$ [N_t, total plant N uptake; N_s, N derived from the soil N reserve, assumed to be equivalent to the N uptake by the control (Greenwood et al. 1987)]; Ni_f is the soil inorganic N derived from the applied fertilizer, calculated as $Ni_f = Ni_t - Ni_s$ (Ni_t, total inorganic N; Ni_s, inorganic N derived from the soil N reserve); and F is the total N applied in the fertilizer.

The sum $N_f + Ni_f$ is considered the net ("apparent") mineralized N, since the possible losses of N by denitrification or volatilization, and N in the roots are not taken into account. However, it was assumed that no leaching losses of NO_3^--N occurred under our experimental conditions. From N_f the percentage of N-fertilizer use by the plant (NFU%) was calculated as NFU% = 100 (N_f/F), and the percentage of N in the plant derived from the applied fertilizer (NPF%) was calculated as NPF% = 100 (N_f/N_t).

To compare the relative efficiency (RE) of the compost with that of NH_4NO_3 the following expression was used:

$$\mathrm{RE\%} = \frac{\beta_{\mathrm{compost}}}{\beta\, \mathrm{NH_4NO_3}} \times 100$$

where β compost and β NH_4NO_3 represent the slopes of the linear (or semilog) functions used to describe the relationship between the total amount of N applied by the N source (F) as an independent variable, and N_f (or $N_f + Ni_f$) as a dependent variable.

Results and discussion

The response in plant growth (Y) to the compost-N rate (X) after 6 months was linear in form: Y (g pot^{-1}) = 8.3+3.7 X (g N pot^{-1}), $r^2 = 0.993$. The response to NH_4NO_3 fertilizer was greater, but the regression equation had a significant quadratic component: $Y = 7.4 + 27.9\ X - 4.4\ X^2$, $r^2 = 0.992$. The plant N uptake with both treatments followed a similar pattern, which was linear for the compost treatments: Y (mg N pot^{-1}) = 156.6+104 X (g N pot^{-1}), $r^2 = 0.988$, and polynomial for the NH_4NO_3 treatments: $Y = 117.9 + 926.8\ X - 97.2\ X^2$, $r^2 = 0.991$. The response in cumulative yield and cumulative N uptake was consistently proportional to the compost rate (Fig. 1), and significantly higher than that of the control at rates of 20 t ha^{-1} and upwards. A slight increase in the slope of the regression lines was also observed, both for cumulative yield and cumulative N uptake versus time. After 6 months the compost-induced increase in yield in relation to the control was 30% (10 t ha^{-1}), 43% (20 t ha^{-1}), 72% (30 t ha^{-1}), 94% (40 t ha^{-1}), and 106% (50 t ha^{-1}). The increase in yield with the NH_4NO_3 treatments ranged from 136 (10 t ha^{-1} equivalent-rate) to 495% (50 t ha^{-1} equivalent-rate). These results showed the limited capacity of the compost to supply N to the plants in comparison with NH_4NO_3. However, the compost did not depress crop yields. The increase in cumulative yield and cumulative N uptake, proportional to the rate of compost application, occurs only with highly matured composts. Decomposition of organic materials with C:N ratios >25 is known to result in net immobilization of native or added inorganic N (Sims 1990). Moreover, immature composts introduce phytotoxic compounds into the soil (NH_3, ethylene oxide, low-molecular-weight fatty acids), and also decrease the O_2 concentration and the redox potential (Iglesias-Jiménez and Pérez-García 1989; Mathur et al. 1990). As a result, a reducing environment may be created in the rhizosphere which may lead to a decrease in root respiration and nutrient absorption, depressing plant growth compared with unamended soils (Iglesias-Jiménez and Pérez-García 1989).

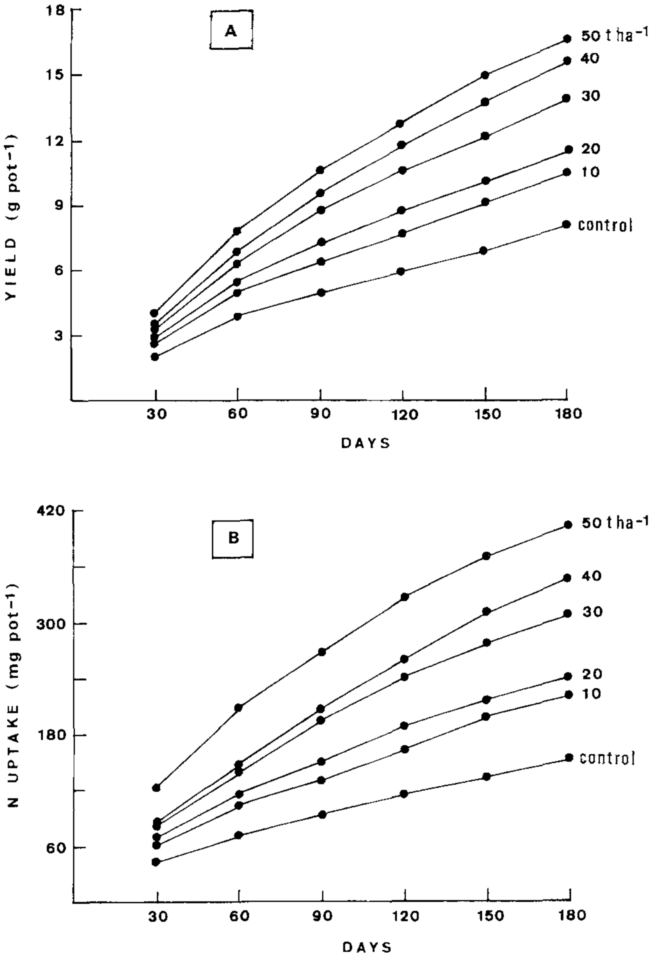

Fig. 1A, B. Cumulative yield (**A**) and cumulative N uptake (**B**) for five treatments with composted municipal refuse and the control

Plant N concentrations for all sources, rates, and harvesting periods are shown in Table 2. During the experiment there were generally small differences between the mean values of the compost treatments, but a slight increase in proportion to the applied rates was observed, especially during the first 3 months. The results of the 1st month are noteworthy since all the compost treatments significantly exceeded the control. However, plant N values were very low. Although critical values for plant N in herbage are not often cited, Bolton et al. (1976) and Goh and Kee (1978) reported critical deficient levels for *Lolium perenne* of 25 g kg^{-1} and 29 g kg^{-1}, respectively; Benton Jones et al. (1991) reported a sufficiency range for optimum yields of between 45 and 50 g kg^{-1}. Over the entire experimental period of the present study, the compost was a poor N-supplying material to ryegrass, but it provides relatively large amounts of inorganic N, particularly with compost rates of 40 and 50 t ha^{-1} (Table 3). The increase in soil available N was always significantly higher than in the control from rates of 20 t ha^{-1} and upwards, but it was especially noticeable that at 50 t ha^{-1} the compost provided significantly larger amounts of available N than the NH_4NO_3 fertilizer at 20 t ha^{-1} equivalent-rate during the first 120 days and even, in some cases, equal to the NH_4NO_3 fertilizer at 30 t ha^{-1}

Table 2. Changes in N concentrations (g kg^{-1}) in ryegrass tops grown in soil treated with municipal refuse compost or with NH_4NO_3

	Days after seedling emergence					
	30	60	90	120	150	180
Control	19.9d	17.1d	19.1e	23.4cd	19.4fg	16.9d
Compost treatment (t ha^{-1})						
10	23.7c	17.5d	19.0e	25.0c	25.5bc	16.9d
20	23.0c	18.9d	19.8e	24.7c	21.0efg	18.0cd
30	24.4c	19.1d	22.8d	25.8c	22.9cde	18.9cd
40	24.7c	18.6d	22.8d	24.7c	24.3bcd	19.4cd
50	30.2b	23.1c	21.3cd	26.5c	21.0efg	19.4cd
NH_4NO_3 treatment (t ha^{-1} compost)						
10	38.3a	23.8c	21.0de	20.4d	18.6g	17.4cd
20	39.6a	34.2b	27.6c	25.7c	22.1def	19.9c
30	38.5a	34.3b	33.0a	32.0b	26.5b	26.0b
40	39.5a	36.6a	29.9bc	38.3a	31.6a	28.2b
50	40.8a	37.4a	30.9ab	40.6a	34.2a	32.3a

Values within the same columns followed by the same letter are not significantly different at $P = 0.01$ (Duncan's multiple range test)

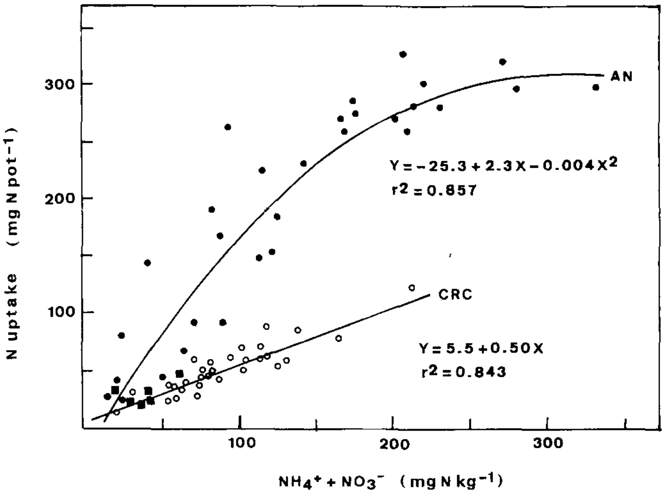

Fig. 2. Relationships between plant N uptake and soil inorganic N for city refuse compost (*CRC*) and NH_4NO_3 treatments (*AN*). The regression analysis was performed by taking into account all the data points (average values) from all treatments and harvesting periods ($n = 36$)

equivalent-rate. The evolution with time in soil-available N was negative, but a positive net N accumulation (adjusted for native soil mineral N) always took place, suggesting that only a fraction of the net mineralized compost N was used by the ryegrass during the experimental period. Figure 2 shows that the ryegrass plants observed more N from the fertilizer source than from the compost source for the same soil available-N level. A greater NO_3^--N:NH_4^+-N ratio in the NH_4NO_3-amended soil during the whole experimental period may account for this finding, assuming that the plants were able to absorb more NO_3^- than NH_4^+. Although Jarvis (1987) demonstrated that the rate of absorption for NH_4^+ in *Lolium perenne* growing in solution culture was greater than that for NO_3^- with moderate supplies of N, in general the effects of the different forms of N on growth were slight. Regression analyses between nutrient uptake and soil available P, K, Ca, and Mg, and between dry-matter yields and plant nutrient concentrations showed that none of these nutrients was a yield-limiting factor. As discussed below, significant NH_3 volatilization in compost-amended soil was not expected under our experimental conditions. Thus, differences in the rate of plant uptake of soil mineral N may be ascribed to competition between plants and soil microorganisms for this nutrient, suggesting that partial biological immobilization may have taken place. This may also have occurred in the NH_4NO_3-amended soil, but the extent of N immobilization seems to be greater in compost treatments due to stimulation of soil microbial biomass and enzyme activities, a well-known effect of mature composts (Miyashita et al. 1982; Marchesini et al. 1988; Perucci 1990).

The percentages of N-fertilizer use by the plant, plant N derived from fertilizer, and apparent bioavailable N are given in Table 4 for the five compost and NH_4NO_3 treat-

Table 3. Variations in inorganic N (NO_3-N + NH_4-N, mg N kg^{-1}) in soil amended with municipal refuse compost or NH_4NO_3

	Days after ryegrass seedling emergence					
	30	60	90	120	150	180
Control	60g	43f	32f	36e	20f	22e
Compost treatment (t ha^{-1})						
10	93fg	51f	61e	74d	42e	30e
20	101f	74e	63de	86cd	71d	56d
30	138de	102d	71de	102c	65d	65d
40	163d	112d	114c	126b	79d	58d
50	206c	117d	113c	129b	76d	61d
NH_4NO_3 treatment (t ha^{-1} compost)						
10	87fg	38f	25f	22e	16f	24e
20	114ef	86e	83d	72d	67d	51d
30	211c	175c	167b	126b	114c	93c
40	279b	204b	169b	230a	174b	123b
50	334a	270a	204a	215a	224a	144a

See footnote to Table 2

Table 4. Percentage of N-fertilizer use (NFU%), plant N derived from fertilizer (NPF%), and apparent bioavailable N (ABN%) in treatments with city refuse compost (CRC) and NH_4NO_3 (AN)

	Fertilizer rate (t ha^{-1} compost)				
	10	20	30	40	50
N applied (mg N pot^{-1})	464	928	1392	1856	2320
NFU% CRC	14.7	9.5	11.2	10.4	10.8
NFU% AN	70.3	79.0	76.3	76.7	67.0
CRC:AN ratio (%)	20.9	12.0	14.7	13.6	16.2
NPF% CRC	31.0	36.7	50.7	56.1	62.2
NPF% AN	68.2	82.9	87.5	90.4	91.1
CRC:AN ratio (%)	45.5	44.3	57.9	62.1	68.3
ABN% CRC	19.9	20.5	20.5	16.3	15.8
ABN% AN	71.6	88.4	91.6	93.0	82.7
CRC:AN ratio (%)	27.7	23.2	22.4	17.5	19.1

ments. The mean N-fertilizer use from the compost source was 11.3% (range 9.5–14.7%), and 73.0% from the NH_4NO_3 source (range 67.0–79.0%). Plant N derived from fertilizer increased gradually with increasing compost rates (from 31.0 to 62.2%) and NH_4NO_3 rates (from 68.2 to 91.1%), due to the increase in soil available N, but the compost: NH_4NO_3 ratio increased from 45.5 to 68.3%. In contrast, there was a decrease in apparent bioavailable N in the compost, from 20.5 (30 t ha^{-1}) to 15.8% (50 t ha^{-1}). A decrease in the compost: NH_4NO_3 ratio was also observed. This implies that the extent of compost-N mineralization was dependent on the rate of compost application, a result consistent with incubation studies of sewage sludge, where an inverse relationship between the percentage of organic N mineralized and the rate of application is commonly observed (Garau et al. 1986; Fine et al. 1989). This finding has been attributed (1) to a high C : N ratio, inducing net N immobilization (Barbarika et al. 1985). (2) to induced soil salinity, inhibiting microbial activity (Tester and Parr 1983), and (3) to NH_3 volatilization (Ryan and Keeny 1975). In pot bioassays, gaseous N losses are not determined, as occurs in many incubation studies. The results are related to "apparent" mineralization (inorganic N accumulation) rather than to total ammonification of organic N. Fine et al. (1989) reported high N volatilization when high rates of sludge mixtures with sandy soils were used in incubation studies. The NH_3 volatilized was correlated positively with the sludge content but negatively with cation-exchange capacity. In finer textured soils, superfluous N was susceptible to volatilization which was related to NH_4^+ adsorption. The soil used in the present study had a 40% clay content and a high cation-exchange capacity (21.2 cmol kg^{-1}). Moreover, increasing rates of compost application increased the soil cation-exchange capacity from 2% at 10 t ha^{-1} to 17% at 50 t ha^{-1} compared with the control. This implied a higher level of NH_4^+ adsorption and thus, under the present experimental conditions, significant losses of NH_3 cannot be expected to explain the decrease in apparent bioavailable N (ABN%). Compost-induced salinization is a better explanation of this finding. Electrical conductivity values in the soil solution after 6 months were 1.2, 2.2, 3.1, 3.8 and 4.1 dS m^{-1} with increasing rates of compost application. Possibly, 3 dS m^{-1} is the limit value, beyond which a significant decrease in soil biological activity is produced.

Figure 3 shows the variations in relative efficiency over time. After 30 days, the compost was 43% as effective as NH_4NO_3 in supplying available N to the soil-plant system ($N_f + Ni_f$), 41% considering ryegrass N removal (N_f). Compost N efficiency gradually decreased with time. After 180 days, the relative efficiency for cumulative N_f was 16% and 17% for cumulative $N_f + Ni_f$. For non-cumulative N_f data the negative trend was even more pronounced, from 41% in the 1st month to only 6% in the 6th month. In comparison to the relative efficiency of non-cumulative $N_f + Ni_f$, an important difference was observed from day 60, reflecting the lower rate of plant uptake of net mineralized N.

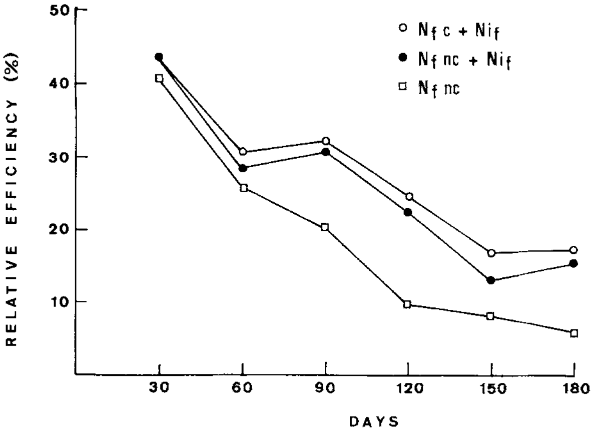

Fig. 3. Changes in relative efficiency over time of composted municipal refuse as a source of N compared to NH_4NO_3. N_f, fertilizer N taken up by ryegrass tops; Ni_f, soil inorganic N ($NH_4^+ + NO_3^-$) derived from fertilizer; *c*, cumulative N values; *nc*; non-cumulative N values

The decrease in compost relative efficiency values was apparently in contradiction with the general idea that composted organic materials have a greater residual effect on the N supply than inorganic N fertilizers, i.e., that the relative efficiency increases with time (Gallardo-Lara and Nogales 1987). This may be explained in terms of maturity (degree of "humification") of the compost. Positive net N mineralization in soils amended with immature compost is observed to a greater extent after a certain period and therefore the relative efficiency increases with time. The time necessary to reach maximum RE value depends on the degree of maturity attained during the composting process. Negative net N mineralization (net N immobilization) may even occur in composts with a C : N ratio of >25 (Sims 1990). Our research implies that very mature composts (C : N ratio <12) release large amounts of mineral N after incorporation into soil, that the maximum RE value is quickly reached and subsequently RE decreases with time. This suggests that only the very labile organic N was mineralized during the first weeks of our experiment. As the more labile organic N disappears, and the most recalcitrant organic N predominates in the organic N pool, the mineralization rate can be expected to slow. This N pool includes, above all, "humified" organic matter which releases N slowly, and dead microbial tissue from compost, which is more resistant to decomposition (Mathur et al. 1990).

Conclusions

The results of this research imply that highly mature municipal refuse compost should not be considered a material that releases N poorly; after 30 days, this compost was 43% as effective as NH_4NO_3 in supplying inorganic N to the soil-plant system, and after 6 months, the percentage of apparent bioavailable N ranged from 16 to 21% of the total compost N. This suggests that large inputs of inorganic N can be provided to the soil with high rates of this kind of compost, with a potential for NO_3^--N contamination. The use of highly matured composted municipal refuse may therefore be limited to agronomic application rates (<50 t ha^{-1}). However, the moderate rates of compost applied in the present bioassay provided low levels of

N over the experimental period as a whole, i.e., only a small fraction of the net mineralized compost N was taken up by the plants over this time. This result was ascribed to a partial biological immobilization. It should be pointed out that this apparent immobilization occurred with a highly matured compost (C:N ratio < 12), but a net increase in yield and plant N uptake, in proportion to the rate of compost application, was observed throughout the assay. This pattern of N availability in highly matured municipal refuse compost, positive net mineralization but partial biological immobilization, is similar to the pattern of N availability in biologically active soils in which there is a continuous immobilization of inorganic N into organic phases and a mineralization of organic N into inorganic forms. Generally, a high input of N fertilizer into soil leads not only to a rapid increase in crop yields, but also to alterations in the equilibria of soil microbial populations, and groundwater contamination may occur. Thus, only the use of agronomic rates of highly matured compost, with a suitable and controlled supplement of N fertilizer, may be recommended as an agronomic management strategy. Moreover, the improvement in soil physical and nutritional qualities after compost amendment may result in a more efficient use of fertilizers, basically due to stimulation of the root system.

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