Composting of organic wastes as a strategy for producing high quality organic fertilizers

Compostage des déchets organiques pour la production d'engrais organiques de qualité.

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Abstract

Composting is considered as a suitable way of recycling organic wastes in agriculture compatible with the environment. However, in order to obtain a final product with high value as fertilizer, the composting process should be performed adequately. Composting of organic wastes rich in easily biodegradable nitrogen compounds leads to the formation, accumulation and subsequent loss of ammonia through volatilization, mostly during the thermophilic phase of the process, where high temperatures, high ammonium concentration and pH concur. The use of a suitable bulking agent together with the Rutgers static pile composting system have been demonstrated to be useful tools for reducing and controlling such losses, obtaining a final compost rich in nitrogen.

A proper composting process procedure may ensure the absence of phytotoxic compounds and a sufficient maturity degree in the final compost. Immature compost can negatively affect the plant growth and nutrient supply. Studies of nitrogen mineralization revealed that immature or insufficiently stabilized compost can lead to nitrogen immobilization in soil and nitrogen deficiency in plants. The extension and proportion of nitrogen mineralization depended on the degree of compost stabilization. Therefore, the composting of organic wastes to obtain good quality composts, useful as organic fertilizers, requires a correct control of the process in order to minimize the nitrogen losses and to ensuire a good degree of compost maturity.

Key-words : composting, compost maturity, nitrogen mineralization, organic fertilizer, organic wastes.

Résumé

Le compostage est considéré comme une méthode très appropriée pour le recyclage des déchets organiques dans l'agriculture d'une manière compatible avec l'environnement. Cependant, le processus de compostage doit être accompli d'une manière adéquate si l'on veut obtenir un produit final à haute valeur fertilisante. Le compostage des déchets organiques riches en composés azotés facilement biodégradables conduit à la formation et l'accumulation, puis à la perte d'ammoniac par volatilisation, principalement pendant la phase termophile, dans laquelle on obtient des températures et niveaux de pH élevés ainsi qu'une grande concentration en ammonium. L'utilisation d'un agent structurant avec le système de compostage « Rutgers » en tas statique a démontré leur efficacité pour réduire et contrôler une telle perte, en obtenant ainsi un compost riche en azote.

Par ailleurs, un processus de compostage approprié peut assurer l'absence de composés phytotoxiques et un degré de maturité suffisant dans le produit final. Un compost immature peut affecter négativement le taux de croissance des plantes ainsi que la disponibilité en éléments nutritifs. L'étude de la minéralisation de l'azote a révélé que l'emploi de compost insuffisamment stabilisé peut conduire à l'immobilisation de l'azote dans le sol et à la carence en azote des plantes. L'étendue et le taux de la minéralisation de l'azote sont reliés au taux de stabilisation du compost. Par conséquent, le compostage de déchets organiques pour la production de composts de bonne qualité, utilisables comme engrais organiques, exige un contrôle correct du processus pour minimiser les pertes d'azote et assurer une bonne maturité du compost.

Mots-clés : compostage, maturité du compost, minéralisation de l'azote, engrais organiques, déchets organiques.

1. Introduction

The composting of organic wastes is a biooxidative process involving the mineralization and partial humification of the organic matter, leading to a stabilized final product. During the first phase of the process the simple organic carbon compounds are easily mineralized and metabolized by the microorganisms, producing CO_2, NH_3, H_2O, organic acids and heat. The accumulation of this heat raises the temperature of the pile.

The composting of organic wastes rich in easily biodegradable nitrogen compounds, such as sewage sludge, leads to the formation, accumulation, and subsequent loss of nitrogen, mostly through ammonia volatilization. Sewage sludge is often composted before it is added to soil because this process eliminates the risk of disseminating pathogenic organisms and produces an aesthetically acceptable product for use in agriculture. However, during the first phase of composting, the combination of high temperatures, high ammonium concentration and high pH levels may lead to substantial losses of ammonia (Witter and Lopez-Real 1987), decreasing the value of the material as an N fertilizer. The addition of carbon sources to wastes rich in inorganic-N results in its partial incorporation into the organic fractions or its immobilization to form such fractions (Van Faasen and Van Dijk, 1979). It is possible to reduce ammonia losses during the composting of organic wastes with a high nitrogen concentration by adding an adequate bulking agent which provides organic carbon to the mixture (Sánchez-Monedero et al., 1996a). The loss of nitrogen from the compost piles also depends on the diffusion of NH_3 through the pile into the atmosphere, and frequent turning of the pile facilitates this NH_3-volatilization (De Bertoldi et al., 1982). The Rutgers static pile composting system maintains a temperature ceiling in the pile, providing a high decomposition rate through the on-demand removal of heat by ventilation, since high temperatures inhibit and slow down decomposition due to a reduction of microbial activity (Finstein & Miller, 1985). This system has been shown to be a good method to reduce N-losses through NH_3-volatilization and, hence, for producing a N rich compost (Sánchez-Monedero et al, 1996a) with high concentrations of NO_3^--N and total-N.

Once a compost with high nitrogen concentration has been obtained, it is important to know the fraction available to plants. According to Castellanos and Pratt (1981), the composting of animal manures reduces the value of the manure as a N fertilizer because the compost provides only half the available-N compared with non-composted manures. Bernal et al. (1998a) and Beloso et al. (1993) concluded that immature composts can promote N-immobilization in the soil, as they contain high concentrations of easily degradable C-compounds as a result of their incomplete stabilization.

Therefore, the aims of this work were twofold. The first was to study the evolution of the main parameters during the composting of a sewage sludge with an appropriate bulking agent in order to obtain a nitrogen rich compost; and the second was to evaluate the resulting compost value as a N fertilizer

2. Materials and methods

Composting performance

About 1500 kg of a mixture prepared with 46.5 % sewage sludge and 53.5 % cotton waste (fresh weight) was composted in a pilot plant by the Rutgers static pile composting system. The air was blown from the base of the pile through the holes of three PVC tubes of 3 m length and 12 cm diameter. The timer was set for 30 s ventilation every 15 min. and the ceiling temperature for continuously blown air was 55 ^oC. The biooxidative phase of composting (active phase) was considered completed when the temperature of the pile was stable and near to that of the atmosphere, this stage being reached after 49 days. The air-blowing was then stopped to allow the compost to mature over a period of two months. The pile was sampled weekly during the active phase and after the maturation period. Each sample was divided into two parts, one of which was immediately frozen and kept for NH_4^+-N and NO_3^--N analysis, while the other subsample was air-dried and ground to 0.02 mm for analysis and for a pot experiment.

Analytical methods

The composting samples were analyzed for electrical conductivity and pH in a water soluble extract 1:10 (w/v); organic matter (OM) by loss-on-ignition at 430°C during 24 hours (Navarro et al., 1993); total nitrogen and organic carbon were determined by automatic microanalysis (Navarro et al., 1991), as were the water soluble organic carbon (C_w), the 0.1 M NaOH extractable C and fulvic acid C after precipitation of the humic acids at pH 2.0 (Sánchez-Monedero et al., 1996b). The humic acid C was calculated by subtraction of the fulvic acid C from the extractable C. NH_4^+-N was extracted with 2M KCl from the frozen subsample and determined by a colorimetric method based on Berthelot's reaction (Sommer et al., 1992), adding sodium citrate to complex divalent cations; NO_3^--N was determined by ion chromatography HPLC in the water extract. The cation exchange capacity was determined with $BaCl_2$-triethanolamine (Lax et al., 1986). Total P, K and micronutrients were determined after $HNO_3/HClO_4$ digestion, P by the colorimetric method as a molybdovanadate phosphoric acid, K by flame photometry and micronutrients by atomic absorption spectrofotometry. All chemical analyses were made in duplicate. The germination index (GI) was calculated using seeds of *Lepidium sativum* L. (Zucconi et al., 1981).

Greenhouse experiment

The effect of compost maturity on crop yield and its effectiveness as organic nitrogen fertilizer was studied in a greenhouse pot experiment. Four samples were selected at different stages of the composting process: (i) the initial non-decomposed mixture at day 0 (I), (ii) the thermophilic phase at day 21 (T), (iii) the end of the active phase at day 49 (A) and (iv) the mature compost at day 105 (M). The I, T, A and M composting samples were added at a rate of 2 % (48 t ha^{-1}) to a calcareous silt loam soil, classified as a Xerollic Calciorthid (American Soil Taxonomy). Its main characteristics were: pH 7.8, electrical conductivity 0.028 S/m, organic matter 1.72 %, total-N 1.1 g/kg, available-P 9.0 mg/kg, cation exchange capacity 119.0 mmol/kg, exchangeable-K 7.2 mmol/kg, and water holding capacity 33.5 % The soil was passed through a 4 mm screen to remove large particles. Pots of 500 g capacity were used for the experiment. Five treatments were run: soil without any fertilization (S) to estimate the soil's fertility, soil fertilized with 20-20-20 N-P-K mineral fertilizer (0.135 g/pot/month; 13 g m^{-2} per month) (S+F), soil amended with the initial composting sample (S+I), soil amended with the sample at the thermophilic phase (S+T), soil amended with the sample at the end of the active phase of composting (S+A) and soil amended with the mature compost (S+M). The pots were immediately sown with ryegrass (*Lolium perenne* L.) at a rate of 0.5 g per pot (265 seeds/pot), which was equivalent to 47.6 g m^{-2}, over a 0.5 cm sand layer to facilitate seed germination. Another two sets of S, S+I and S+M treatments were incubated at 28 ^oC for 21 and 49 days before sowing. Each treatment was replicated four times, giving a total of 20 pots without incubation, and 12 pots for the 21 and 49 day incubations. The moisture of the soils was adjusted to 60 % of their water holding capacity with deionized water. The pots were watered daily with deionized water and the ryegrass plants were harvested three times at 28 day intervals. The plant materials were weighed, dried at 60 ^oC and ground to 0.5 mm for analysis. The total-N concentration of the plant material was analyzed by a CNS automatic microanalizer. The N uptake of plants was calculated from the dry weight and N concentration of the plants. Analysis of variance and Duncan's multiple range test were used to determine differences in yield and composition of plants between treatments.

3. Results and discussion

Evolution of the main parameters during composting

The organic matter and organic C concentrations of the waste mixture decreased during composting (Table 1), pointing to degradation of the organic materials during the process. This organic matter degradation led to an increase in electrical conductivity, and so the production of inorganic compounds. The N_t also increased because of the concentration effect caused by the strong degradation of the labile organic C compounds, which reduced the weight of the composting mass. The concentration of N_t usually increases during composting when volatile solids (organic matter) loss is greater than the loss of NH_3 (Witter and Lopez-Real, 1987). The N-lost from the piles during composting were determined from the initial and final ash (X_1 and X_2) and nitrogen (N_1 and N_2) concentrations. The total N losses amounted to only 9 %, which is very low in comparison with the values found by Witter and Lopez-Real (1987) (50 % N) during sewage sludge composting. More than 60 % of N can be lost during city refuse composting (Sánchez-Monedero, 1996a), while the N losses during sewage sludge composting can range from almost zero to 25 %, depending on the bulking agent used (Paredes et al., 1996). This means, therefore that the composting was properly performed because of the adequate bulking agent used and the system (Rutgers static pile), both of which were relevant factors in keeping N losses to a minimum. The mature compost had a N_t concentration higher than 10 mg kg^{-1}, which is the concentration required for composts according to Spanish legislation, and can therefore be considered as an organic fertilizer. The N_t concentration was higher than the 4.5 - 28.2 g kg^{-1} found for city refuse, sewage sludge and animal manure composts (Iglesias-Jimenez et at., 1986; Gallardo-Lara and Nogales, 1987; Warman and Termeer, 1996). The C/N ratio decreased to 9.4 during the composting process, which is below the 12 normally accepted as indicating a good degree of compost maturity (Iglesias-Jimenez and Perez-García, 1992; Bernal et al., 1998b).

Samples (days)	pH	EC (S m^{-1})	OM (%)	C_{org} (g kg^{-1})	N_t (g kg^{-1})	C/N	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg kg^{-1})
0	7.6	0.39	81.5	438.6	21.9	21.1	1424	< 1
7	7.8	0.39	75.7	407.9	23.4	18.2	1038	nd.
14	7.9	0.45	74.1	404.7	29.9	14.0	1263	nd.
21	8.2	0.43	71.3	398.2	31.5	14.2	3406	45
28	8.2	0.45	67.6	382.0	33.4	12.4	2530	30
35	8.2	0.47	64.1	370.3	33.3	11.4	907	470
42	8.1	0.51	64.9	364.6	32.5	12.5	807	1000
49	8.0	0.50	64.9	359.8	36.5	9.9	1081	1170
105	7.3	0.67	64.8	355.5	37.9	9.4	437	4884

Table 1.
Evolution of the main parameters during composting.

The initial NH_4^+-N concentration was high and increased during the thermophilic phase as a result of organic-N mineralization, which also caused a rise in the pH values. After this phase, the NH_4^+-N concentration decreased to a final value close to 0.04 %, which is the maximum limit suggested by Zucconi and de Bertoldi (1987) and Bernal et al. (1998b) for a mature compost. Parallel to this fall in the NH_4^+-N concentration, the NO_3^--N levels increased due to nitrification, while the pH value decreased, due to the protons released by this process. There was hardly any nitrification during the thermophilic phase, because temperatures greater than 40 ^oC inhibit the activity and growth of nitrifiers. An NH_4^+/NO_3^- ratio of lower than 1 was found at the end of the active phase (49 days) and after the maturation period (105 days), the value reached at the latter time (0.09) indicating that this compost had reached a good degree of maturity (Bernal et al., 1998b).

The C_W and C_{FA} concentrations fell during composting (Table 2) because both fractions had a high proportion of easily biodegradable organic compounds (sugars, amino acids, peptides, etc.). The C_W concentration in the mature compost was below the limit of 1.7 % established by Bernal et al. (1998b) as representing a good maturity degree. The C_W/N_{org} ratio decreased during composting to a value well below the established limits for mature composts (0.7 by Hue and Liu, 1995; 0.55 by Bernal et al., 1998b). The humic acid-like fraction, C_{HA} /C_{FA} ratio and humification index increased during composting, demonstrating the humification and polymerization of the organic matter which took place. This organic matter humification process led to an increased cation exchange capacity during the biooxidative and maturation phases. The values reached were higher than the 60 and 67 cmol kg^{-1} described by Harada and Inoko (1980) and Iglesias-Jimenez and Perez-García (1992), respectively, as being the minimum values required to ensure a sufficient degree of maturity in city refuse composts. The germination index exceeded 50 %, which indicated the lack of phytotoxicity (Zucconi et al., 1981).

Samples (days)	C_W (%)	C_W/N_{org}	C_{FA} (%)	C_{HA} (%)	C_{HA} / C_{FA}	HI	CEC ($cmol_c\ kg^{-1}$)	GI (%)
0	2.27	1.17	3.75	7.18	1.91	16.4	53.5	77.8
7	2.02	0.90	5.07	6.47	1.28	15.8	67.4	n.d.
14	2.25	0.78	3.88	8.00	2.06	19.8	n.d.	n.d.
21	2.02	0.71	3.80	7.42	1.95	18.6	95.3	65.4
28	1.98	0.64	3.79	7.86	2.07	20.6	n.d.	n.d.
35	1.88	0.59	3.73	8.39	2.25	22.6	109.9	n.d.
42	1.74	0.61	3.32	7.93	2.39	21.7	n.d.	n.d.
49	2.26	0.64	3.11	7.75	2.49	21.5	100.7	71.1
105	1.12	0.34	2.57	7.90	3.07	22.2	124.4	69.4

n.d. not determined.

Table 2.

Evolution of the organic matter during composting.

Greenhouse studies

The macro and micronutrient concentrations of the composting samples used as fertilizers are shown in Table 3. These materials were taken from the air-dried subsamples and, since most of the NH_4^+-N was lost during drying, their NH_4^+-N and, hence, N_t concentrations were slightly different from the values presented in Table 1. The yield of ryegrass 28 days after emergence (first harvest) decreased from soil (S) to the soil amended with T (S+T) and with I (S+I) (Table 4). The results obtained in the soil treated with mineral fertilizer (S+F) were not statistically different from those of the S+A and S+M treatments but were greater than those of the S, S+I and S+T. When the S+I treatment was incubated for 21 days before sowing, the yield increased to values similar to those found in S, and the difference was not statistically significant. The best result with I was obtained in the treatment incubated for 49 days. Plants in the S+I and S+T treatments had the lowest N concentrations, which were statistically different from plants grown in S. This may indicate that the low yield in those treatments was due to N deficiency in plants. Twenty one days of incubation led to an increase in the N concentration of plants in S+I. Treatments with M compost led to the highest N concentration in plants, this mature compost containing a high proportion of available N in nitrate form (Table 3).

	I (0 days)	T (21 days)	A (49 days)	M (105 days)
N_t (g kg^{-1})	20.8	28.3	35.4	37.9
NH_4^+-N (mg kg^{-1})	366	172	158	437
NO_3^- -N (mg kg^{-1})	<1	45	1170	4884
P (g kg^{-1})	2.2	4.1	6.6	7.1
K (g kg^{-1})	31.9	25.9	30.5	40.6
Na (g kg^{-1})	3.1	3.9	4.4	6.2
Ca (g kg^{-1})	28.4	n.d.	n.d.	64.8
Mg (g kg^{-1})	5.0	n.d.	n.d.	10.6
Fe (g kg^{-1})	1.5	1.8	1.8	3.8
Cu (mg kg^{-1})	20	25	38	38
Mn (mg kg^{-1})	111	147	164	220
Zn (mg kg^{-1})	112	94	118	213

Table 3.

Macro and micronutrients of the composting samples used in the pot experiment.

	First harvest		Second harvest		Third harvest	
Treatments	Yield (g/pot)	N (%)	Yield (g/pot)	N (%)	Yield (g/pot)	N (%)
S	4.10 de	3.58 e	1.59 e	1.85 de	0.73 f	1.59 d
S+F	5.54 c	4.49 d	4.19 bc	2.33 abc	3.50 a	2.41 a
S+I	1.75 f	2.49 fg	3.77 bcd	1.82 de	2.86 bc	1.65 cd
S+T	2.92 ef	2.40 g	2.94 d	2.01 cde	2.32 cd	1.72 cd
S+A	5.58 c	4.41 cd	3.55 ed	2.18 bcd	2.32 cd	1.64 cd
S+M	6.52 bc	5.30 ab	4.47 b	1.95 de	2.07 de	1.63 cd
S 21 days	3.34 de	4.61 cd	1.63 e	1.79 e	0.89 f	1.92 bc
S+I 21 days	3.90 de	3.62 e	3.13 d	1.69 e	2.38 bcd	1.98 bc
S+M 21 days	4.30 d	5.37 a	5.75 a	2.62 a	2.71 bc	2.05 abc
S 49 days	3.62 de	4.25 d	2.03 e	1.80 e	0.79 f	1.79 bcd
S+I 49 days	7.10 ab	2.96 f	2.97 d	1.83 de	1.71 e	2.20 ab
S+M 49 days	8.08 a	4.84 bc	4.00 bc	2.38 ab	1.66 e	1.77 bcd
ANOVA *P*<	0.001	0.001	0.001	0.001	0.001	0.05
LSD	1.22	0.52	0.77	0.37	0.48	0.45

LSD= least significant difference at *P*<0.05.

Table 4.
Yield (fresh weight) and nitrogen concentration of rye-grass in the three harvests.

At the second harvest, the yield in S was very low due to the depletion of soil nutrients and the results were significantly different from those of the rest of the treatments, which showed similar values statistically, including S+I (Table 4). The plant yield in S+M was the highest of both harvests, although it was not statistically different from that obtained in S+F. The incubation time had no effect on the yield of the S+I treatment, and only a slight increase was observed in S+M after 21 days' incubation. The N concentration of plants was very similar in all treatments, and only the S+F in the non-incubated treatments and S+M with 21 and 49 days' incubation were significantly different from the rest. In general the results, including those for the treatment with mineral fertilizer, decreased from the first to the second harvest, which may be due to plant physiology rather than the effect of the compost.

The yield at the third harvest showed the same pattern as the second. The soil had the lowest results, which demonstrated the depletion of nutrients, while the best result was obtained with S+F. There were no statistically significant differences between the yield and N concentration of plants in any of the treatments using composts. The highest N concentration was recorded in plants from S+F, since the nutrients were added weekly throughout the experiment. Incubation slightly increased the N concentration although only the result from S+I with 49 days' incubation was significantly different from the non-incubated treatments.

The N efficiency of the composting samples and the mineral fertilizer was calculated by subtracting the N uptake of the soil from that recorded in the amended soil, and expressed as a percentage of N added to soil. The maximum N efficiency always occurred in the S+F treatment (Fig. 1), as the N it contained was directly available to plants. The N efficiency of sample I showed negative values after the three harvests in the non-incubated treatment, and after two harvests in the 21 days' incubation treatment, indicating that plants in S+I had lower amount of N available than those grown in the control soil. Sample I had NH_4^+-N, which is readily available to plants (Table 4), but it also had a high amount of easily decomposable organic C compounds (Bernal et al., 1998a). For this reason, the microorganisms attacking this fresh organic matter found a surplus of organic C with respect to organic N, which led to inorganic-N immobilization, and a competition between plant roots and microorganisms for inorganic-N may have occurred. When the S+I was incubated for 49 days before sowing, the N efficiency of I showed positive values after each harvest, which indicated that re-mineralization of the immobilized N had occurred and that inorganic-N had formed in the soil. Studies of N-mineralization in soil pointed to the immobilization of inorganic-N in sample I during most of the incubation period. Only 2.4 % of N_t was present in the forms of inorganic-N after 70 days, giving it a net N-immobilization of 4.3 % N_t (Bernal et al., 1998a).

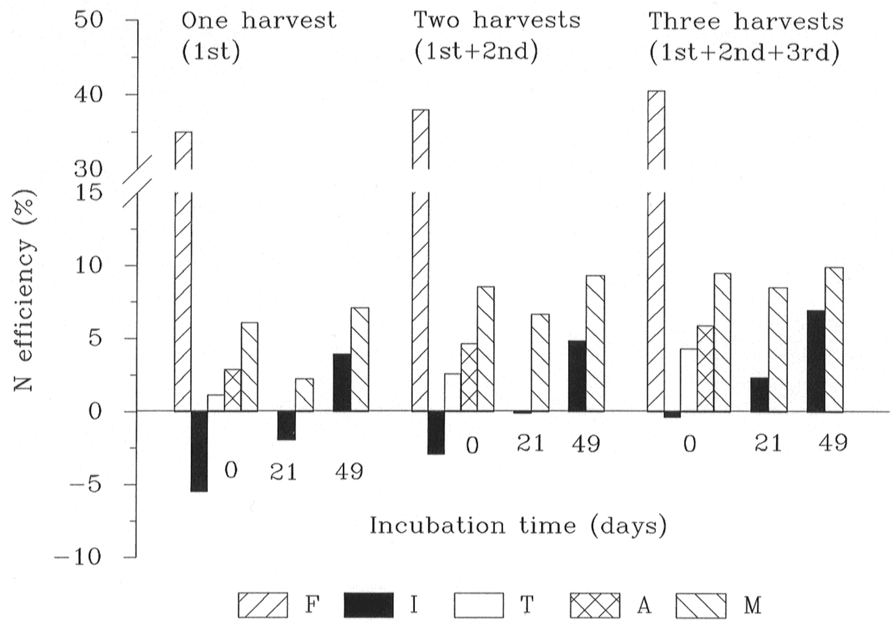

Figure 1.
Nitrogen fertilizer efficiency of the materials used in the different treatments of the pot experiment. The figures referring to harvest are accumulative.

The N efficiency of composting samples increased as composting progressed (Fig. 1). The efficiency of T sample although greater than that of I was still very low, especially at the first harvest, pointing to NH_4^+-N immobilization in the soil as a consequence of low microbial stabilization. Substantial proportions of inorganic-N immobilization have been reported in soils treated with immature composts made from animal manure and sewage sludge (Beloso et al., 1993; Bernal et al., 1998a). Sims (1990) also found N-immobilization in a soil treated with 7-day old sewage sludge/city refuse composts, which diminished when one of them was mixed with a commercial mature compost.

The sample A had a higher N efficiency than I and T, but lower than the mature compost. The sample A had a lower NO_3^--N concentration than the mature compost (Table 3), and the N mineralization studies also showed lower proportion of potentially mineralizable N (5.45 % N_t in A, 8.45 % N_t in M) and a slight initial N-immobilization in the soil, which only lasted only for 2 days (Bernal et al., 1998a). The immobilization was not strong enough to have any effect on plant growth, since the material had a sufficiently high concentration of inorganic-N for adequate plant nutrition, and it had reached a good degree of stability during the 49 days of composting. It had also a relevant proportion of mineralizable N (inorganic-N = 9 % of N_t after 70 days of incubation) giving it a net N-mineralization figure of 4.7 % N_t (Bernal et al., 1998a). The highest efficiency was found in the M sample, because it had the highest NO_3^--N concentration and proportion of potentially mineralizable N. It was observed that the

NO_3^--N concentration of the compost increased during the maturation phase of composting (Table 1), and also this mature material had stabilized during the active and maturation phases of composting, and net N-mineralization occurred after its addition to soil. According to Bernal et al. (1998a), almost 20 % of N_t was present as inorganic-N in soil after 70 days of incubation, giving it a net N mineralization of 8 % of total-N. Both factors provided a high amount of readily available N for plants, and the greatest N uptake by plants.

4. Conclusions

The composting of sewage sludge can provide a compost rich in N, if the process is properly performed, which can be used as an organic fertilizer. The use of a bulking agent, such as cotton waste, which supplies organic carbon to the microorganisms, together with the Rutgers static pile system are the main strategies for controlling and reducing N losses during composting. Two months of maturation after temperature has fallen are enough to ensure a good degree of compost maturity and a certain humification of its organic matter.

Maturation improves the short-term fertilizer N value of a compost because NO_3^--N is formed during this phase and because of its potentially mineralizable N. A mature compost can, therefore, be considered as an organic N fertilizer. Its N mineralization rate should be taken into account for the balanced N fertilization of crops and it can even be added to the soil when the crop is growing. The use in soil of non-decomposed organic waste mixtures or of wastes which have only been slightly transformed in the thermophilic phase of composting, requires a safety period of at least 49 days after addition and before sowing, to avoid plants suffering N deficiency and to ensure that the microbial N-immobilization phase has finished and inorganic-N is being produced by re-mineralization of the immobilized-N. This is necessary to obtain a good efficiency of its nitrogen. A compost which has undergone a biooxidative phase of composting but not a maturation phase, although it may cause slight N-immobilization immediately after its addition to soil, it is also valuable as a N fertilizer. It can have a similar effect on plant nutrition as an inorganic fertilizer, because its N will have been mineralized at a similar rate as that of a mature compost. However, its N fertilizer value is lower than that of the mature compost because the nitrification process occurs mainly during maturation. This increases the concentration of N available to plants in nitrate form.

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