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Determination of maturity indices for city refuse composts

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ABSTRACT

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A composting experiment was carried out to study which are the best parameters to use as indicators of the degree of compost maturity, and to determine 'humification' indices for practical use.

The following parameters were selected: cation exchange capacity (CEC), carbon/organic nitrogen ratio in water extract (C/N_w), C/N ratio in solid phase (C/N_s), total organic carbon (C_t), oxidizable carbon (C_o), alkaline-extractable carbon (C_{ex}), humic and fulvic-like carbon (C_{ha}, C_{fa}) humification ratio ($HR = C_{ex}/C_o \times 100$), humification index ($HI = C_{ha}/C_o \times 100$), percent humic acid ($P_{ha} = C_{ha}/C_{ex} \times 100$) and C_{ha}/C_{fa} ratio.

The regression analysis shows that the carbon (total and oxidizable), C/N_s, C/N_w, CEC, HI, P_{ha} and C_{ha}/C_{fa} ratio are correlated with a level of significance higher than 99.5%. From the integration of the deduced values, applying the obtained equations sequentially, the optimal values of these parameters to assure an acceptable degree of maturity of the compost are: $C/N_s < 12$, $C/N_w < 6$, CEC > 67 mEq per 100 g (on an ash-free basis), $C_{ha}/C_{fa} > 1.6$, $HI > 13\%$ and $P_{ha} > 62\%$.

INTRODUCTION

The composting process is an exothermal biological oxidation of organic matter carried out by a dynamic and quick succession of populations of aerobic micro-organisms (Viel et al., 1987). The heterogeneous organic matter in the starting material is transformed, after a suitable composting period which includes bio-oxidative and maturation phases, into a stabilized end product through partial mineralization and humification (Gray et al., 1971).

The physico-chemical and microbiological characteristics of city refuse composting and the effect of compost on the soil-plant system have been

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widely studied (De Bertoldi et al., 1983; Gallardo-Lara and Nogales, 1987; Marchesini et al., 1988; Hernando et al., 1989; Diaz-Raviña et al., 1989).

Evaluation of city refuse compost maturity has been widely recognized as one of the most important problems concerning the composting process and the application of this product to the soil. The most notable effect of immature compost is the biological blockage of soil-available nitrogen which may give rise to serious nitrogen deficiencies in crops with consequent depressive effects (Hortenstine and Rothwell, 1973; Terman et al., 1973).

The rapid decomposition of an immature compost may cause a decrease of the oxygen concentration and soil Eh and, as a result, the creation of a strongly reducing environment at the rhizosphere level. This causes an increase of the solubility of heavy meals (Cottenie, 1981; Van Assche and Uyttebroeck, 1981) and inhibition of plant seed germination (Hunt et al., 1972).

The presence of phytotoxic compounds is another cause of the damage noted on the application of immature compost to the soil, fundamentally the emission of ammonia (Wong, 1985), ethylene oxide (Wong, 1985; Wong and Chu, 1985) and organic acids: acetic, propionic and *n*-butyric acids (Chanyasak et al., 1983).

Therefore, it is essential to determine the degree of maturity and avoid these risks. Several methods or criteria, chemical, physical and biological, have been proposed to establish compost maturity, which were widely revised and discussed during a former study (Iglesias Jiménez and Pérez García, 1989).

A composting experiment was carried out to study the evolution of the parameters which are the most characteristic indicators of the degree of compost maturity, and a study of regression with the fundamental object to obtain a criterion which might be of practical application for commercial composting plants.

From all the proposed parameters in the literature as indicators of the evolution of organic matter and also because of their maturity, we have selected those which always maintain a uniform pattern of behavior during city refuse composting, independent of the geographical origin of the material, fundamentally the cation exchange capacity (CEC) (Harada and Inoko, 1980a,b), the carbon/organic nitrogen ratio in water extract (C/N_w) (Chanyasak and Kubota, 1981; Chanyasak et al., 1982) and the C/N ratio in solid phase (C/N_s), being the traditional approach used for estimating compost maturity. We have also employed some indices used for the evaluation of the "humification" level in the material during composting: alkaline-extractable carbon (C_{ex}), humic and fulvic-like carbon (C_{ha}, C_{fa}), humification ratio ($C_{ex}/C_o \times 100$), humification index ($C_{ha}/C_o \times 100$), percent humic acid-like carbon ($C_{ha}/C_{ex} \times 100$) and C_{ha}/C_{fa} ratio (Sugahara and Inoko, 1981; Senesi, 1989).

MATERIALS AND METHODS

Composting system

The composting procedure followed was similar to that used by Kehren (1967), the simplest and least expensive system, adapted to warm countries such as the Canary Islands. City refuse was collected from different parts of the town of Santa Cruz de Tenerife. As one of the most notable characteristics of municipal waste is its heterogeneity, a greater quantity of refuse material, 1700 kg, was collected. It is approximately the daily waste production of 1800 persons. Representative garbage samples were obtained after a thorough mixing of all samples following removal of contaminant materials such as glass, gravel, plastics, and metals by hand-picking.

The compost heap was constructed from this selected sample (810 kg and 59.6% moisture) and measured 3 m in length, 2 m in width and 0.75 m in height.

The temperature evolution was followed at 10 cm (surface) and 50 cm (center of heap). Each reading is the average of four measurements taken at symmetrical locations at each level with a digital thermometer probe ($\pm 0.1\,°C$); the readings were taken every 3 days until the temperature stabilized at around 30°C. The temperature curve during the bio-oxidative phase is shown in Fig. 1.

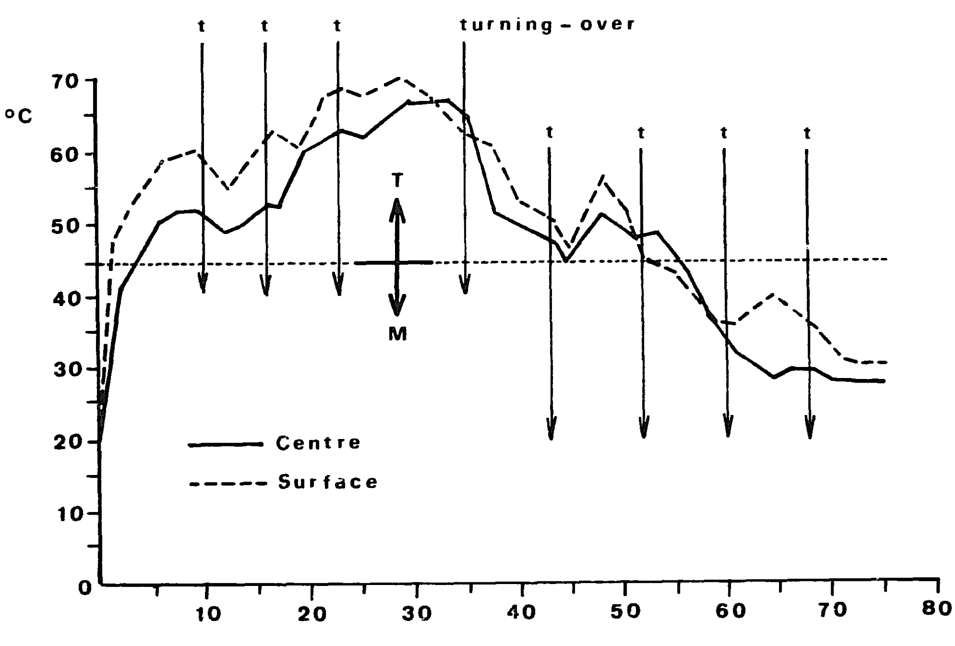

Fig. 1. Temperature evolution during composting (bio-oxidative phase) of the organic fraction of municipal solid wastes. T, thermophilic period; M, mesophilic period.

Moisture was maintained, during the whole of the bio-oxidative phase, between the limits of 40 and 60%, this being considered the optimum (Spohn, 1978). To control these levels, tensiometers, placed at depths of 10 and 50 cm, were used. In addition, we followed the criterion of Golueke (1972) who recommends that moisture determinations should be taken periodically in samples during composting because of the lack of uniformity in unenclosed heaps. To maintain the optimal range, it was necessary to apply an average of 10 l of water every 3 days during the first 63 days of composting. To dampen the pile, treated waste water was used; this water helps to enrich the final product and offset, in part, nitrogen losses through volatilization of ammonia during composting.

Aeration was carried out by a natural method — turning over the heap. The frequency of turning over the compost heap was established by Kochtitzky et al. (1969), who demonstrated that six to eight turnings over are sufficient to insure an adequate oxygen supply, for a composting period of 8–10 weeks (bio-oxidative phase). The windrow was left unturned for an additional 12 weeks (maturation phase). The times at which the heap was turned over are shown in Fig. 1.

Analytical determinations

During the process of composting, a series of samples was collected periodically, coinciding with the moment of the turning over of the mass. Therefore, the samples were taken from material previously at the center of the pile, but exposed on the surface by the turning. Samples were obtained on the following days: 9, 16, 23, 35, 43, 51, 60, 68, 75 (bio-oxidative phase) and 165 (maturation phase). Each sample (approximately 3 kg) was composed of eight subsamples taken from the surface of the heap just formed after turning over. In total, each time, three repetitions were taken (24 subsamples). The moisture was determined in a fraction of approximately 1 kg (80°C, 5 h) and the remainder air dried and crushed in a hammer mill (mesh size 1 mm) followed by further pulverization using a vibrating cutter, and analyzed.

The preparation of the samples (drying and grinding) is similar to that indicated by other authors who analyzed soluble and extractable carbon in compost samples (Chanyasak and Kubota, 1981; Chanyasak et al., 1982; Riffaldi et al., 1983; González-Vila and Martín, 1985). Nevertheless, drying and grinding the samples may increase the amount of extractable and water soluble carbon and possibly fulvic acid-like carbon concentrations, a well-known treatment effect. Therefore, it is necessary to standardize the sample preparation because of the great heterogeneity of this material. This is essential if the results of this study are to be compared with those of other authors.

Total organic carbon (C_t) was determined by combustion in a Carmhograph carbon oven, 12-H Omega, and nitrogen content by the Kjeldahl method. Inorganic carbon was found to be negligible.

Oxidizable carbon (C_o) was determined by dichromate oxidation at 150°C ($K_2Cr_2O_7 + H_2SO_4$ mixture).

Extractable carbon (C_{ex}) was determined by 0.1 M $Na_4P_2O_7$+0.1 N NaOH solution (1:1) and humic acid-like carbon (C_{ha}) after precipitation at pH 1 with sulphuric acid. This fraction has the same solubility properties as the soil humic acids (HAs) and was referred to as an HA-type substance. Fulvic acid-like carbon (C_{fa}) was deduced from the difference between C_{ex} and C_{ha}.

The carbon/organic nitrogen ratio in water extract (C/N_w) was determined following the proposed method by Chanyasak and Kubota (1981), in a compost–water suspension (1:5), after filtration through a 0.45 μm membrane filter.

The cation exchange capacity (CEC) of the compost was determined by the acid-washing method proposed by Harada and Inoko (1980a): a 200 mg sample of milled compost was washed with 0.05 N HCl solution to replace exchangeable cations. After removal of the excess HCl by washing with distilled water, 1 N $Ba(OAc)_2$ solution (pH 7.0) was added to the sample, and the mixture was allowed to stand overnight. After filtration, the sample was leached with another portion of 1 N $Ba(OAc)_2$ solution, and the released proton was then titrated against 0.05 NaOH solution using a potentiometer (with an endpoint pH of 8.9). The amount of released proton was equated with the CEC.

A Statistical Graphics System Program (STSC) was used to calculate regression equations and correlation coefficients relating maturity parameters.

RESULTS AND DISCUSSION

The evolution during composting of C_t, C_o, C_{ex}, C_{ha}, C_{fa}, HR, HI, P_{ha}, C_{fa}/C_o ratio, C_{ha}/C_{fa} ratio, C/N_s ratio, C/N_w ratio and CEC is presented in Table 1 and the matrix of linear correlation between these parameters is shown in Table 2. The values of C_{ex}, C_{ha}, C_{fa} and water-soluble carbon may be slightly overestimated, as the preparation of the samples (drying and grinding) increase the specific surface. Also, the possible alteration of some humic-type compounds may occur. Nevertheless, in the samples collected during the composting process, there was only about 1.2–1.8% more water-soluble carbon in dried and ground samples than in fresh samples. No appreciable variations were observed in alkaline-extractable carbon and humic and fulvic-like carbon.

A significant fact is that, with the exception of C_{ex} and HR, all the considered parameters are correlated significantly in all cases. The results obtained, in accordance with the coefficients of the regressions, confirm the expected variations with respect to the mineralization and maturation of this type of

TABLE 1

Changes in the forms of carbon, maturity parameters and humification indices during city refuse composting

	Days										
	1	9	16	23	35	43	51	60	68	75	165
Moisture (%)	59.6	58.5	56.3	57.8	52.3	52.0	55.2	47.7	46.8	42.0	35.2
C_t[1]	48.35	45.50	45.30	44.50	41.29	39.96	37.16	36.78	36.63	35.55	32.55
C_0[2]	45.21	43.40	42.15	42.51	40.28	37.12	36.31	32.99	32.72	31.86	30.96
C_{ex}[3]	10.41	11.20	10.68	10.54	10.47	10.88	12.09	10.20	10.12	9.55	11.15
C_{ha}[4]	5.10	5.24	5.32	6.12	6.32	6.53	7.28	6.41	6.38	5.92	7.38
C_{fa}[5]	5.31	5.96	5.35	4.42	4.15	4.35	4.81	3.78	3.73	3.63	3.77
C_{ha}/C_{fa}	0.96	0.88	0.99	1.39	1.52	1.50	1.51	1.70	1.71	1.63	1.96
HR[6]	19.85	21.30	20.42	19.16	18.66	20.41	23.17	21.16	21.32	20.64	22.05
HI[7]	9.72	9.96	10.18	11.13	11.26	12.25	13.96	13.31	13.45	12.79	14.60
P_{ha}[8]	48.97	46.76	49.85	58.09	60.34	60.02	60.25	62.90	63.09	61.97	66.21
C_{fa}/C_o(%)	10.13	11.34	10.24	8.03	7.40	8.16	9.21	7.85	7.87	7.85	7.45
C/N_s[9]	27.79	19.78	16.47	15.72	15.35	13.28	11.69	12.18	12.05	10.74	9.83
C/N_w[10]	31.10	26.28	19.25	11.06	8.12	7.41	6.28	5.95	5.48	5.69	5.37
CEC[11]	39.65	46.69	51.35	54.46	51.40	59.22	71.17	69.73	68.85	73.17	80.14
Ash (%)	13.76	17.47	19.39	22.71	28.19	30.38	30.42	31.54	31.05	31.15	38.75

[1]Total carbon (g per 100 g dry matter (DM)).
[2]Oxidizable carbon (g per 100 g DM).
[3]Alkaline-extractable carbon (g per 100 g DM, ash-free basis).
[4]Humic acid-like carbon (g per 100 g DM, ash-free basis).
[5]Fulvic acid-like carbon (g per 100 g DM, ash-free basis).
[6]Humification ratio ($C_{ex}/C_o \times 100$). C_o on ash-free basis.
[7]Humification index ($C_{ha}/C_o \times 100$).
[8]Percent humic acid ($C_{ha}/C_{ex} \times 100$).
[9]C_t/N_t ratio in solid phase.
[10]C_t/N_t ratio in water-soluble phase.
[11]Cation exchange capacity (mEq per 100 g DM, ash-free basis).

refuse. Taking C_t as the reference parameter to follow quantitatively the process of mineralization, it will be observed that owing to the proportion of the organic matter decreasing as it transforms (loss of carbon in the form of CO_2), an increase of the cation exchange capacity takes place (r C_t − CEC = −0.963), of the C_{ha} content (r $C_t - C_{ha} = -0.749$), of the humification index (r $C_t - HI = -0.948$), of the percent humic acid (r $C_t - P_{ha} = -0.882$) and of the C_{ha}/C_{fa} ratio (r TOC $- C_{ha}/C_{fa} = -0.902$) (where r is the linear correlation coefficient).

On the other hand, a decrease of the C/N ratio, in solid phase, is observed (r $C_t - C/N_s = +0.888$) as well as in the water-soluble phase (r $C_t - C/N_w = +0.890$) and also in the fulvic acid carbon (r $C_t - C_{fa} = +0.798$).

Regarding the selected indicative parameters of the degree of maturity of compost, they are all significantly correlated. Considering the C/N ratio in solid phase, as it is traditionally used as a maturity index, its positive corre-

TABLE 2

Linear correlation coefficients between the different forms of carbon, maturity parameters and humification indices

	C_t	C_o	C_{ex}	C_{ha}	C_{fa}	C_{ha}/C_{fa}	HR	HI	C_{fa}/C_o	P_{ha}	C/N_s	C/N_w	CEC
C_t	1.000	0.975	0.172	−0.749	0.798	−0.902	−0.465	−0.948	0.669	−0.882	0.888	0.890	−0.963
C_o		1.000	0.323	−0.621	0.818	−0.873	−0.437	−0.905	0.644	−0.844	0.837	0.829	−0.948
C_{ex}			1.000	0.334	0.579	−0.297	0.521	0.020	0.470	−0.274	0.062	0.143	−0.120
C_{ha}				1.000	−0.575	0.795	0.409	0.868	0.626	0.814	−0.747	−0.845	0.729
C_{fa}					1.000	−0.946	0.098	−0.734	0.949	−0.942	0.699	0.855	−0.735
C_{ha}/C_{fa}						1.000	0.139	0.890	−0.908	0.997	−0.815	−0.947	0.844
$HR(C_{ex}/C_o \times 100)$							1.000	0.569	0.281	0.109	−0.349	−0.176	0.554
$HI(C_{ha}/C_o \times 100)$								1.000	−0.734	0.879	−0.831	−0.870	0.949
$C_{fa}/C_o \times 100$									1.000	−0.923	0.640	0.849	−0.583
$P_{ha}(C_{ha}/C_{ex} \times 100)$										1.000	−0.814	−0.955	0.828
C/N_s											1.000	0.937	−0.898
C/N_w												1.000	−0.860
CEC													1.000

Level of significance: $r > 0.602$, $P < 0.05$; $r > 0.735$, $P < 0.01$.

lation with the C/N ratio in water extract is observed ($r\ C/N_s - C/N_{wc} = +0.937$) and its negative correlation with the cation exchange capacity of ash-free material ($r\ C/N_s - \mathrm{CEC} = -0.898$) and also with the C_{ha}/C_{fa} ratio ($r\ C/N_s - C_{ha}/C_{fa} = -0.815$), the HI ($r\ C/N_s - HI = -0.831$) and the P_{ha} ($r\ C/N_s - P_{ha} = -0.814$).

In relation to the humic-type substances of compost, an important fact is that the C_{ex} (rate of extraction) and HR are not correlated with any of the other parameters and show an aleatory behavior during composting, independent of the tendency of the other indicative parameters of the organic matter evolution. As observed in Table 1, C_{ex} practically does not vary during the process, the same as the humification ratio ($C_{ex}/C_o \times 100$).

This result corresponds completely with the observations of Sugahara and Inoko (1981), Moré et al. (1987) and Das (1988), who found that the alkaline extraction rate ($HA+FA$) does not vary appreciably during the whole process of composting and, for this reason, this parameter cannot be considered as a good humification index of city refuse compost. A large body of evidence exists of alkaline co-extraction and, eventually, partial acid co-precipitation of not or incompletely humified components of organic matter, the alkaline extract thus resulting in a mixture of both humic and non-humic substances (González-Vila and Martín, 1985; Senesi, 1989). In short, the extraction rate and humification ratio, assuming that they practically do not vary during composting, cannot be considered as valid parameters to establish the degree of maturity of compost and are of no value to some published indices in the literature. Furthermore, as Roig et al. (1988) indicates, the humification concept is not suitable for newly formed organic materials in the same way as it is for soils. Therefore, the expression "humic substances" has only an operational meaning when applied to the city refuse compost and related products.

Nevertheless, in relation to C_{ha} and C_{fa} fractions, a clear tendency is observed during the whole process: a gradual increase of C_{ha} (except at Days 60–75), and a parallel decrease of C_{fa} (expressed as a percentage of C_o) and, therefore, an increase of the C_{ha}/C_{fa} ratio. These results are in agreement with the observations of other authors (Fioramonti and Marty, 1966; Sugahara and Inoko, 1981; Das, 1988), who find a gradual increase of the polymerization rate (HA/FA) during composting from values lower than 1 to values higher than 1, including higher than 3 (Martín et al., 1984). It seems that therefore a constancy exists concerning the type of predominant process in the evolution of organic matter during composting: a gradual increase of the polymerization grade or molecule size of the humic-type polymers of compost. Furthermore, the C_{ha}/C_{fa} ratio is correlated in a highly significant way, negatively with the indicative parameters of mineralization (C_t, C_o, C/N_s, C/N_w) and positively with CEC, an index of a gradual increase of the oxidated groups of humic-like substances of compost, and also with HI and P_{ha}. For this reason, we think that the C_{ha}/C_{fa} ratio might constitute a valid parameter to establish the evolutional grade of the organic matter during city refuse composting and therefore of the degree of compost maturity.

From the deduced equations of regression, the optimal values of the selected maturity parameters for our experimental conditions would be as follows:

C/N ratio (solid phase, dry matter) <12.0
C/N ratio (water-soluble phase, 1:5 extract) <6.0
CEC >67 mEq per 100 g (ash-free material)
C_{ha}/C_{fa} ratio >1.6 (increase factor: 1.7)
HI ($C_{ha}/C_{o}\times 100$) $>13.0\%$ (increase factor: 1.34)
P_{ha} ($C_{ha}/C_{cx}\times 100$) $>62.0\%$ (increase factor: 1.27)

In relation to the C/N ratio in solid phase, the value deduced approaches the value around 10, as cited for well-humified soils (Roig et al., 1988). Nevertheless there are variations according to the type of soil and the conditions of its formation. Therefore, we think that this value, lower than 12, is more suited to insure a good degree of maturity, compared with the accepted value of less than 20 (Poincelot, 1974; Golueke, 1981). Furthermore, the C/N_s ratio cannot be considered an absolute indicator of the degree of compost maturity as raw materials used may have a wide range of lignin to cellulose ratio and, therefore, varying biodegradability (Senesi, 1989) and it depends on the relative nitrogen richness of the original material (Morel et al., 1985). This is frequent when the bio-oxidable fraction of domestic refuse is composted with sewage sludge. Therefore, a C/N_s ratio of less than 20 can only be considered a necessary, but not sufficient, condition for compost maturity.

As an alternative to the C/N ratio in solid phase, Chanyasak and Kubota (1981) proposed the organic carbon/organic nitrogen ratio in water extracts as a more reliable index of compost maturity based on the consideration that the composting reaction is a biochemical transformation of organic matter by micro-organisms whose metabolism occurs in the water-soluble phase. These authors found that the C/N_w ratio decreases gradually during composting to reach a stable value between 5 and 6. This occurred in all cases studied, irrespective of the geographic origin of the material and of their initial and final C/N_s ratios. Therefore, this value was proposed as a general index of maturity (Chanyasak and Kubota, 1981; Chanyasak et al., 1982). The results of our study confirm completely the proposition by these authors, that a value lower than 6 is necessary to assure an acceptable degree of maturity.

The cation exchange capacity of the organic fraction has been used in the study of soil to evaluate the degree of humification, as the humification process produces functional groups that increase the CEC (Roig et al., 1988). It is sensible to think that a similar process occurs in newly formed organic materials. Hence, Harada et al. (1981) found in a controlled experiment of composting that the CEC increases progressively from 40 mEq per 100 g at the start to stability in the final phase of bio-oxidation at about 80 mEq per 100 g after 12 weeks of composting. They also found a negative correlation between CEC and the C/N ratio. Moreover, CEC is correlated with the reducing sugars and the ratio carbon reducing sugars/total organic carbon, a parameter which is another valid index for establishing the degree of maturity (Iglesias Jiménez and Pérez García, 1989). They concluded that the necessary minimum value to assure an acceptable maturity, for city refuse compost, is 60 mEq per 100 g on an ash-free material basis. The results we have found are in accordance with the observations of these authors, being of an optimal value of 67 mEq per 100 g.

Besides the considered parameters, as observed in Table 2, C_t is equally correlated with C/N_s, C/N_{wc}, CEC, C_{ha}/C_{fa}, HI and P_{ha} at a level of significance higher than 99.9%. This fact allows, with enough flexibility, for the calculation of a loss factor of carbon, from which one might deduce indirectly the degree of maturity of compost and therefore the minimum period of composting. In our experimental conditions the parameters of maturity obtain optimal values when the material contains 1.29 times less total carbon than the original material.

Likewise, all these minimum conditions of maturity take place within 50–60 days of composting, which coincides practically with the end of the bio-oxidative phase of composting (cooling period). However, a later phase of maturation can take effect to give an even higher level of optimization. As may be seen in Table 1, fundamentally this optimization during the maturation phase (75–165 days) occurs with respect to CEC, HI, P_{ha} and C_{ha}/C_{fa} ratio, the indicating parameters of a gradual increase of the humification grade of organic matter, because the parameters C_t, C_o and C/N ratio (solid and water-soluble phases) practically do not vary, which show a practical stabilization of bio-oxidation or mineralization rate of the compost.

Independently of the values for these maturity parameters, and other ones published in the literature (Iglesias Jiménez and Pérez García, 1989), a trial with test plants is recommended, because definitively the compost maturity is determined by plant yield response.

CONCLUSIONS

The regression analysis between the indicative parameters of evolution of the degree of maturity during the piling test, shows that the C/N_s, C/N_w, CEC, HI, P_{ha} and C_{ha}/C_{fa} ratio are correlated with a level of significance higher than 99.5%. Therefore, either the decrease in the C/N ratio (solid phase and water-soluble phase) or the increase in CEC, HI, P_{ha} and in C_{ha}/C_{fa} ratio can be employed as useful parameters for estimating the degree of compost maturity. The optimal values of these parameters, for our experimental conditions, are as follows: $C/N_s < 12$, $C/N_{we} < 6$, CEC > 67 mEq per 100 g (on an ash-free material basis), $C_{ha}/C_{fa} > 1.6$, $HI > 13\%$ and $P_{ha} > 62\%$.

The rate of alkaline extraction (C_{ex}) and humification ratio ($C_{ex}/C_o \times 100$) do not vary appreciably during composting and are not correlated with the other maturity indices. Therefore, they cannot be considered as valid parameters to establish the degree of maturity of city refuse compost.

The correlation of total carbon with C/N_s, C/N_{we}, CEC, HI, P_{ha} and C_{ha}/C_{fa} is highly significant. This fact allows for the calculation of a carbon loss factor, from which one might deduce indirectly, with enough approximation, an acceptable degree of maturity of compost for agricultural use and therefore the minimum period of composting in commercial plants. In our experimental conditions the calculated loss factor of carbon is 1.29.

All these optimal values are realized within the compost heap between 50 and 60 days of composting. As the temperature stabilization is produced towards Day 60, we could conclude that this is the minimum period of duration of the bio-oxidative phase of composting which has to be accomplished on an industrial scale, always when the conditions of the compost plant are similar to our experimental conditions. However, a later phase of maturation of as long as possible a duration, is commendable, as it leads to a still higher optimization of the indicative parameters of the humification, fundamentally the CEC, humification index, percent humic acid and polymerization ratio.

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