Composting of domestic refuse and sewage sludge. II. Evolution of carbon and some "humification" indexes

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ABSTRACT

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The evolution, during composting of city refuse (R-pile) and city refuse + sewage sludge co-composting (R + S-pile), of total organic matter (TOM) and some forms of carbon: total organic carbon (C_t), oxidizable carbon (C_o), alkaline-extractable carbon (C_{ex}), humic acid-like carbon (C_{ha}), and fulvic acid-like carbon (C_{fa}), was evaluated. The results were correlated with some maturity parameters, namely, C/N ratio in the solid phase (C/N_s), C/N ratio in the water-soluble phase (C/N_w), and cation-exchange capacity (CEC), to examine the relationships between the mineralization of the organic matter, biological stability of compost, and "humification".

The regression analysis was carried out considering jointly all the data points of both the R-pile and the R + S-pile, to extrapolate new maturity criteria irrespective of the initial composition of the urban raw material used for composting.

The results show that the CEC/C_t and C_{ha}/C_{fa} ratios may also be considered to be good maturity parameters. A value higher than 1.9 for both ratios, in addition to a value lower than 6 for the C/N_w ratio, may be considered as a suitable indicator of a high degree of maturity in composts of urban origin (municipal solid waste and sewage sludge composts).

INTRODUCTION

Compost maturity is one of the most important problems in the processing of compost and in its agronomic use. This is especially important when composts are applied to the soil immediately before planting or when they are used in container media [1]. Immature composts induce high microbial activity in soil, potentially causing biological blockage of soil-available nitrogen, which give rise to serious N-deficiencies in crops [2]. Immature compost also introduces phytotoxic compounds into soil (ammonia, ethylene oxide,

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low-molecular-weight fatty acids), as well as causing a decrease in the O_2-concentration and soil Eh. As a result, the creation of a strongly-reducing environment in the rhizosphere may occur, which may consequently lead to an increase in the solubility of heavy metals and the inhibition of plant seed germination [3].

Therefore, high quality composts are required to avoid these risks. Numerous methods, i.e. chemical, physical, and biological, have been suggested to evaluate the maturity of compost, but it seems impossible to point out a single suitable test as a maturity index for all composts, and a combination of several parameters is required [1,3,4].

In a previous paper [5], some physico-chemical parameters normally used as indicators of compost maturity were evaluated: temperature, pH, cation-exchange capacity (CEC), C/N ratio in the solid phase (C/N_s) and C/N ratio in the water soluble phase (C/N_w). A tentative guideline for rapid assessment of compost maturity in commercial composting plants was also suggested: the coincidence in the time of the practical temperature stabilization with a C/N_w ratio lower than 6 and a CEC value higher than 60 meq $100\,g^{-1}$, on an ash-free material basis. In the present study, the evolution of total organic matter (TOM) and some forms of carbon: total organic carbon (C_t), oxidizable carbon (C_o), alkaline-extractable carbon (C_{ex}), humic acid-like carbon (C_{ha}), and fulvic acid-like carbon (C_{fa}), were studied. Some indices used for the evaluation of "humification" degree of the material during composting: 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 polymerization ratio (C_{ha}/C_{fa}) were also employed [6,7].

MATERIALS AND METHODS

The pile composting system and the environmental control parameters during the process were presented in detail in the first part of this series [5]. Two piles were constructed, one formed exclusively of the organic fraction of the municipal solid wastes of Santa Cruz de Tenerife (R-pile: 3 m long$\times$2 m wide$\times$0.75 m high, 810 kg with 59.6% moisture) and the other pile (R+S-pile: $3\times2\times1.10$ m) formed by a mixture of domestic refuse (850 kg, 59.6% moisture) and dehydrated sewage sludge (370 kg, 17.8% moisture).

The composting trial was carried out during 165 d with 75 d of bio-oxidative period and 90 d of subsequent complementary maturity process. Samples from the piles were taken periodically, coinciding with the moment of the turning-over of the mass. Therefore, the samples corresponded to the material of the centre of the pile, exposed on the surface by the turning. Each triplicated sample (3 kg) was composed of eight subsamples (24 subsamples). The material was air-dried and crushed in a hammer mill (mesh size 1 mm) followed by further pulverization using a vibrating cutter, and analysed. Re-

sults of the chemical analysis are expressed on a dry weight basis (105°C, 4 h).

Total organic matter (TOM) was determined by loss-on-ignition, at 600°C as recommended by Gallardo et al. [8]. The determination of TOM by this procedure is not really exact since there are volatile mineral compounds which prevent the value obtained by calcination from being considered true organic matter [9,10]. Thus, the parameter "volatile solids" (VS) provides an approximation, slightly in excess of the true value of TOM. However, from the point of view of the practical application of commercial composting plants, this difference may be negligible, due to the high organic content of these materials. This is the criterion followed in this paper.

Total carbon was determined by combustion in a Wösthoff (Carmhograph 12-H Ω) carbon analyzer, and nitrogen content by the Kjeldahl microanalysis. Total organic carbon (C_t) was deduced by subtracting the inorganic carbon (calcimeter test) from total carbon.

Oxidizable carbon (C_o) was determined by the modified dichromatometric oxidation method of Walkley and Black ($K_2Cr_2O_7 + H_2SO_4$ mixture), based on the external use of heat up to a temperature of 150°C for one minute [11].

Alkaline-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 of 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 the water-soluble phase (C/N_w) was determined following the proposed method by Chanyasak and Kubota [12], in a 1:5 compost–water suspension after filtration through a 0.45 μm membrane filter.

The cation-exchange capacity (CEC) was determined by the acid-washing method proposed by Harada and Inoko [13].

RESULTS AND DISCUSSION

The analytical results of TOM, C_t, C_o, C_{ex}, C_{ha}, C_{fa}, HR, HI, P_{ha}, C_{ha}/C_{fa} ratio, CEC, C/N_s ratio and C/N_w ratio during composting of the R-pile and the R+S-pile were presented in detail in the first paper of this series [5]. The results corresponding to the initial material for composting (day 1), after the bio-oxidative phase (day 75) and after the maturation phase (day 165) are shown again in Table 1.

TABLE 1

Changes in the forms of carbon, maturity parameters and "humification" indices during composting of domestic refuse (R-pile) and domestic refuse-sewage sludge (R+S-pile)

Component[1]	R-pile (d)			R+S-pile (d)		
	1	75	165	1	75	165
TOM (%)	86.2	68.9	61.3	74.6	50.1	43.6
C_t	48.3	35.5	32.5	42.8	28.9	25.1
C_o	45.2	31.9	31.0	38.6	20.9	21.7
C_{ex}	10.4	9.5	11.1	7.7	5.9	9.5
C_{ha}	5.1	5.9	7.4	3.2	4.2	6.7
C_{fa}	5.3	3.6	3.8	4.6	1.6	2.8
C_{ha}/C_{fa}	0.96	1.63	1.96	0.69	2.59	4.17
HR	19.9	20.6	22.0	15.0	14.0	16.9
HI	9.7	12.8	14.6	6.1	10.1	13.6
Pha	49.0	62.0	66.2	41.0	72.2	80.7
CEC	39.7	73.2	80.1	44.6	57.5	62.3
CEC/C_t	0.82	2.06	2.46	1.04	1.99	2.48
C/N_s	27.8	10.7	9.8	15.7	8.9	8.9
C/N_w	31.1	5.7	5.4	27.3	6.3	5.2

[1]TOM: Total organic matter. g 100 g^{-1} dry matter (d.m.). C_t: Total carbon. gC 100 g^{-1} d.m. C_o: Oxidizable carbon. gC 100 g^{-1} d.m. C_{ex}: Alkaline-extractable carbon. gC 100 g^{-1} d.m., on ash-free material basis. C_{ha}: Humic acid-like carbon. gC 100 g^{-1} d.m., on ash-free material basis. C_{fa}: Fulvic acid-like carbon. gC 100 g^{-1} d.m., on ash-free material basis. HR: Humification ratio ($C_{ex}/C_o \times 100$, C_o on ash-free material basis). HI: Humification index ($C_{ha}/C_o \times 100$). Pha: "Humic" acid percent ($C_{ha}/C_{ex} \times 100$). CEC: Cation-exchange capacity. meq100g^{-1} on ash-free material basis. C/N_s: C_t/N_t ratio in the solid phase (d.m.). C/N_w: C_o/N_t in the water-soluble phase. Compost-water $1/5$ (w/v).

Evolution of total organic matter

During the bio-oxidative phase of composting, an important loss of TOM is noted (Table 1, Fig. 1). In the R-pile, TOM loss was 20% in relation to the first sample. In the R+S-pile the loss was 33%. Considering the complete composting process (bio-oxidative phase+maturation phase), total TOM loss in the R-pile was 29% and 42% in the R+S-pile (Table 1). Therefore, the organic matter in the R+S-pile showed a greater mineralization than the R-pile, probably due to the significant metabolic rate observed in the R+S-pile during the first days of composting (temperature evolution). During the first ten days, TOM loss in the R+S-pile was 11%, whilst it was only 0.9% in the R-pile. This may be due to the abundance of indigenous micro-organisms present in the sewage sludge and their fast growth, which provoke vigorous attack of the easily decomposable organic materials [14]. The high mineralization rate in the R+S-pile during composting is also explained by the high specific surface area exposed to biological oxidation in the sludge, due to the relatively small size of the particles of the organic fraction [15].
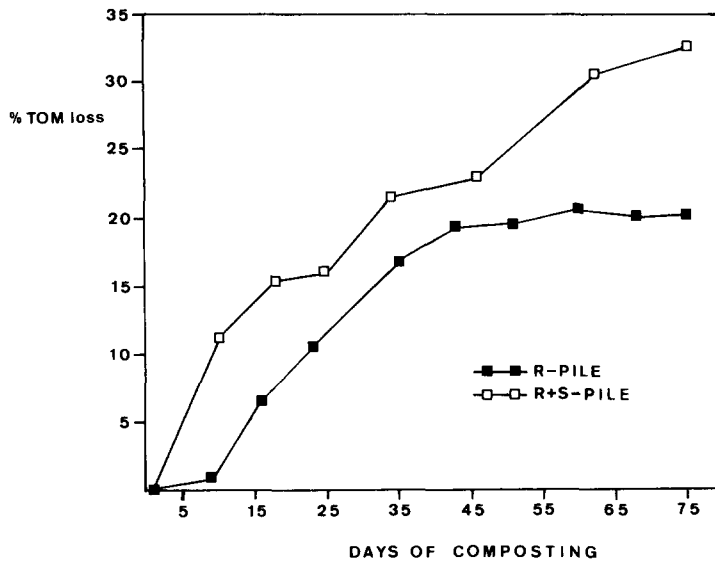
Fig. 1. Relative changes of TOM-loss during the bio-oxidative phase of the composting process of the organic fraction of urban refuse (R-pile) and urban refuse + sewage sludge (R + S-pile).

Thus, in accord with our results, the joint composting of domestic refuse (organic fraction) and sewage sludge implies, in relative terms, a lower concentration of organic matter in the final compost (and also a higher content of heavy metals), than the exclusively domestic-refuse composting. This fact should be taken into account from an operational point of view in commercial composting plants, in relation to compost quality.

During the maturation phase (75–165 d), mineralization of the organic matter continued, the TOM loss being 11% in the R-pile and 13% in the R + S-pile (Table 1). These results imply that, after temperature stabilization, organic matter mineralization is also a predominant biochemical process although the parameters C_o and C/N_s (normally used as indicators of the mineralization rate during composting) practically do not vary in either pile. Therefore, the separation in time between a bio-oxidative and a maturation phase (in relation to degradation and "humification") is only convention and its sole purpose should be to delimit the moment in which stabilization of temperature is observed. However, the determination solely of the temperature in commercial composting plants cannot be considered in all cases as a conclusive criterion of compost maturity [5]. A later phase of "maturation", as long as possible, is therefore recommended. Moreover, it leads to a still greater optimisation of some indicative parameters of the "humification" degree, fundamentally the CEC, HI, P_{ha} and C_{ha}/C_{fa} ratio (Table 1), although de novo synthesis of humic-type compounds was already negligible, since only a small increase in the HR took place during the maturation phase.

Evolution of C_t and C_o

Determination of the carbon content in composts and similar materials is normally carried out following two procedures: direct determination by dry combustion in a C-analyzer (total carbon) and dichromatometric oxidation (oxidizable carbon). This determination is qualitatively more interesting because it show the oxidation state of the organic matter and thus the chemical
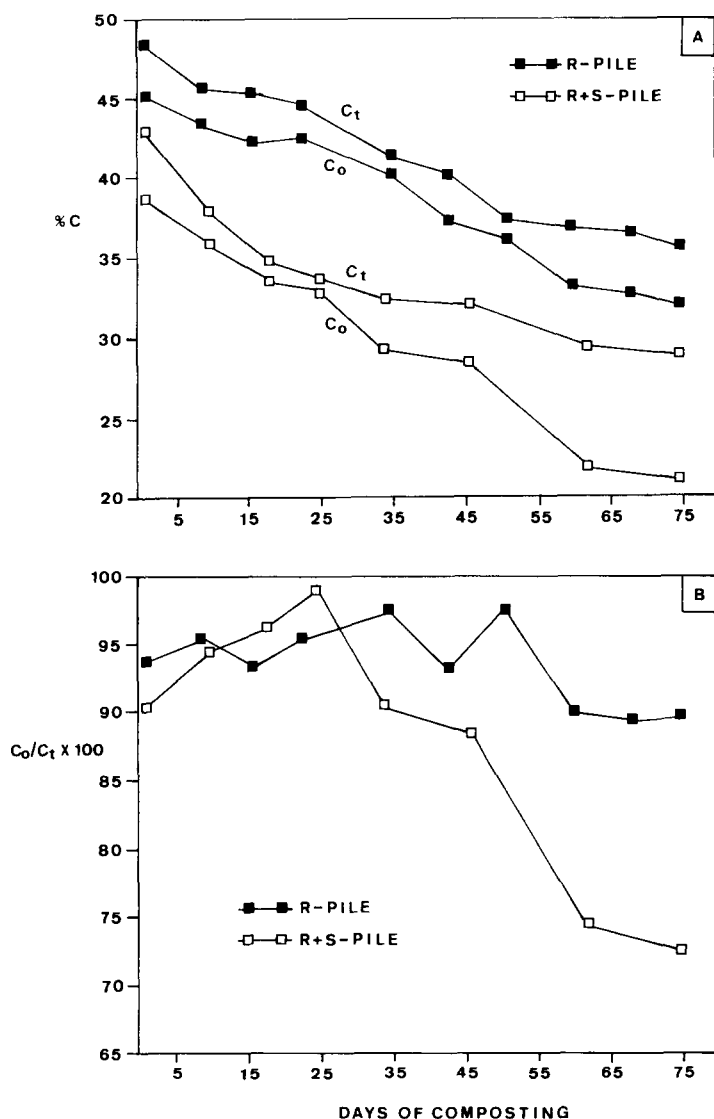

Fig. 2. A. Evolution of total organic carbon (C_t) and oxidizable carbon (C_o) during the bio-oxidative phase of composting of urban refuse (R-pile) and urban refuse+sewage sludge (R+S-pile). B. Evolution of the oxidizability degree ($C_o/C_t \times 100$).

stability of carbon. In soil-organic matter studies, the conventional 77% recovery factor is commonly used to transform oxidizable carbon to total organic carbon when the oxidation method with the heat of dilution is used, and 89% with external heat (150°C, 1 min) [11]. However, these factors are not readily applicable to newly-formed organic materials due to the different oxidizability degree of organic matter, already decomposed to various degrees [16,17]. In these materials, the oxidation rate depends on the chemical nature of the organic compounds, such as the quantity of aromatic molecules and heterocyclic nitrogenous groups, polymerization degree, etc. [10]. Therefore, variations during composting of the C_o/C_t ratio (oxidizability degree) may constitute a reflection of the organic matter evolution and thus, indirectly, of its maturity. Changes of C_t, C_o and C_o/C_t ratio during the bio-oxidative phase are shown in Fig. 2. An important fact is that the content of C_o in all the samples analysed was only slightly lower than C_t in the R-pile. The oxidizability degree ranged only between 89 and 98%. This parallel evolution in the R-pile of C_o and C_t suggests that the C-fraction mineralized during composting was both easily and non-easily oxidizable carbon. By contrary, in the R+S-pile after 25 days a gradual decrease in the C_o/C_t ratio, from 99% to 72%, was observed (Fig. 2B). This fact suggests that despite the high mineralization rate of organic materials in the R+S-pile, the easily oxidizable-C is the major fraction mineralized during the bio-oxidative phase, after 25 days. However, despite this result in the R+S-pile, the C_o/C_t ratio of the final compost (after 165 days) was practically the same as on the first day. It is evident that, considering the entire composting process, no relationship existed between resistance to chemical oxidation with dichromate (C_o/C_t ratio) and maturity, because the concept of maturity implies a greater resistance of the organic matter to enzymatic (biochemical) degradation. Therefore, the C_o/C_t ratio (oxidizability degree) cannot be considered as an index of compost maturity.

Evolution of C_{ex}, C_{ha}, C_{fa}

The humification ratio (HR: alkaline-extractable carbon expressed as a percentage of the oxidizable carbon, $C_{ex}/C_o \times 100$) practically did not vary during the bio-oxidative phase of composting (Fig. 3). A slight decrease in C_{ex}, expressed as percent of the total organic matter (C_{ex}/TOM), was observed in the R+S-pile. During the maturity period (days 75–165) a slight increase in HR was produced in both piles (Table 1). This increase suggests a true de novo synthesis of humic substances during the maturation phase. However, the final values of HR and C_{ex} practically coincide with the results of the 9th day (R-pile) and the 10th day (R+S-pile). This finding may be ascribed to the alkaline coextraction undertaken and, eventually, a partial acid coprecipitation of non- or incompletely humified components of organic matter could occur. The alkaline extract might thus result in a mixture of both
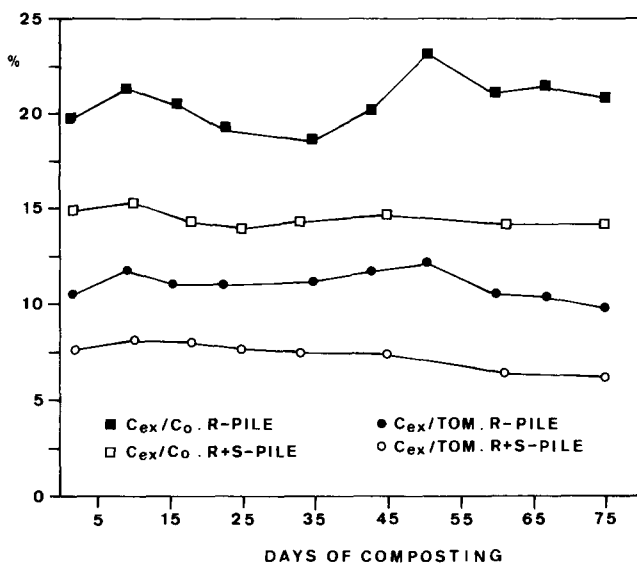
Fig. 3. Evolution of alkaline-extractable carbon, expressed as a percentage of the oxidizable carbon ($C_{ex}/C_o \times 100$) and total organic matter ($C_{ex}/TOM \times 100$), during composting of urban refuse (R-pile) and urban refuse + sewage sludge (R+S-pile).

humic and non-humic substances [7]. In fact, several experiments have provided evidence to show that the humic acid-like fraction of compost and other newly-formed organic materials are formed by a very heterogeneous mixture of components. Some of them, of an aromatic nature, can be considered to be "humic" in nature or precursors of humic compounds (phenolic acids, benzenecarboxylic acids, lignin-derived products) and others of an aliphatic nature (dicarboxylic acids, fatty acids, alkyl-phthalates, n-alkanes, etc.) derived from the lipidic fraction of domestic refuse. The non-humic compounds are present practically from the beginning of composting. All these molecules are bonded to form highly complex polymers of an aliphatic nature and with a very poor aromaticity degree, different in structure to the soil humic compounds [18,19,20,21,22]. Non-humic substances such as polysaccharides are also present in the fulvic acid-like fraction [23].

Furthermore, as Roig et al. [23], Almendros et al. [24], and Roletto and Ottino [25] have shown, the humification concept is not suitable for newly-formed organic materials in the same way as it is for soils. The expression "humic substances" has an operational meaning only when applied to city refuse compost and related products.

Nevertheless, in relation to C_{ha} and C_{fa} fractions, a clear tendency was observed: a gradual increase in C_{ha} and a decrease in C_{fa} (expressed as percent of the C_o) and, therefore, an increase in the C_{ha}/C_{fa} ratio occurred (Fig. 4).
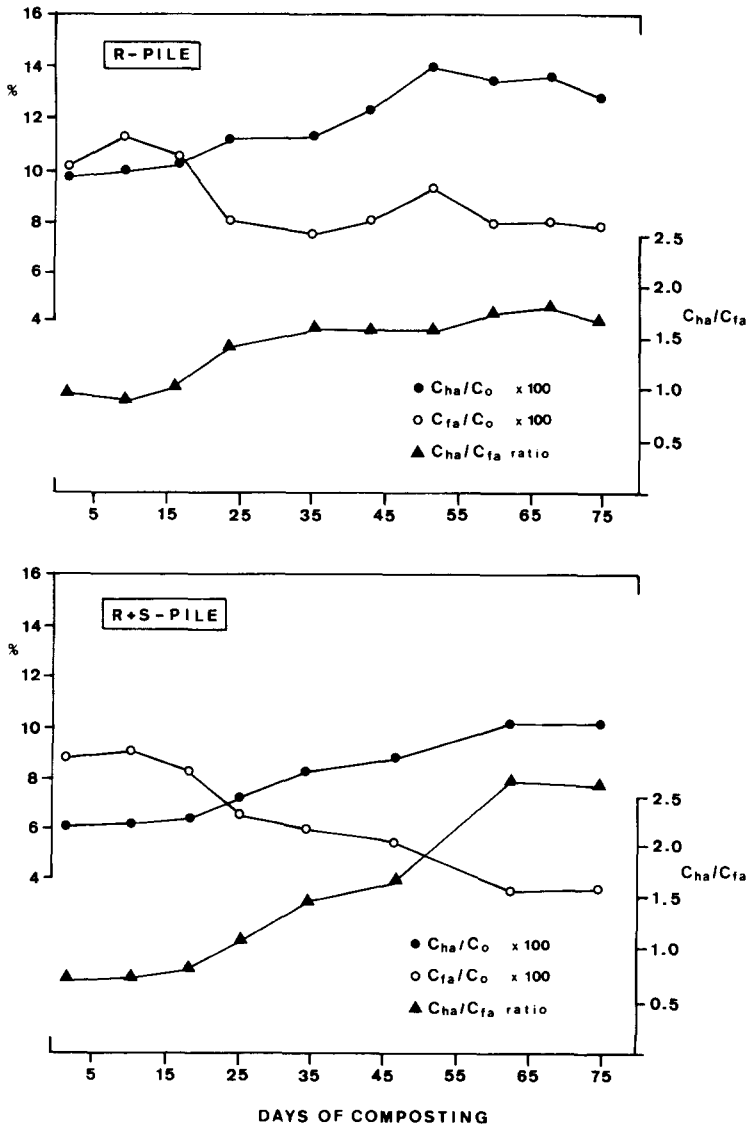
Fig. 4. Evolution of humic acid-like carbon (C_{ha}) and fulvic acid-like carbon (C_{fa}), expressed as a percentage of the oxidizable carbon (C_o), and polymerization ratio (C_{ha}/C_{fa}), during composting of urban refuse (R-pile) and urban refuse + sewage sludge (R + S-pile).

The increase was greater during the maturity period, particularly in the R + S-pile (2.6 to 4.2) and in the R-pile this increase was from 1.6 to 2.0 (Table 1).

This increase in the polymerization rate (HA/FA) during composting has been also reported for poplar bark [26], manure [22,27], sewage sludge compost [28] and city refuse compost [6,29]. This fact may be explained by the

progressive formation of polycondensated substances derived from the lignin fraction of raw refuse materials and metabolic compounds from the microbial biomass, and/or a progressive degradation (or reorganization) of the non-humic substances present in the fulvic acid-like fraction.

Relationship between maturity parameters and "humification" indexes

In Table 2, the matrix of correlation between maturity parameters (C/N_s ratio, C/N_w ratio, CEC) and "humification" indexes (HR, HI, P_{ha}, and C_{ha}/C_{fa} ratio) is shown. We have also introduced the CEC/C_t ratio, a new index proposed recently by Roig et al. [23] to determine the maturity degree of manures.

It is useful to convert r (coefficient of correlation) to $100r^2$ (coefficient of determination) as this can be interpreted as the proportion of variance in the dependent variable which can be explained by the independent variable. The values of Table 2 are the coefficients of determination corresponding to the optimized equations.

The regression analysis has been performed considering jointly all the data points of both the R-pile and the R+S-pile ($n=20$). The test for homogeneity of the slopes of Snedecor and Cohran [30] was carried out to extrapolate significant differences between the two groups of data. Thus, we have only accepted those regressions having a statistically significant coefficient of correlation ($P<0.05$) and where, moreover, the F value of the slope-homogeneity test is not significant (slopes statistically equal). The equations of the correlations which fulfil these two conditions are summarized in Table 3.

TABLE 2

Matrix of correlation of all regressions between the maturity parameters and "humification" indices. The values are the coefficients of determination (r^2 as percent) of the significant regressions ($P<0.05$) when both composting piles are considered together. The sign (*) indicates significant correlations but considering each pile independently

X^1	Y	C/N_s	C/N_w	CEC	CEC/C_t	C_{ha}/C_{fa}	HR	HI	Pha
C/N_s		100	*	*	79.9[a]	*		*	*
C/N_w			100	67.8[a]	65.3[a]	74.7[a]		*	82.3[a]
CEC				100	78.4[a]	*		*	*
CEC/C_t					100	52.9[c]		*	58.0[c]
C_{ha}/C_{fa}						100		*	99.5[b]
HR		a: $\ln Y = a + b \ln X$					100		
HI		b: $Y = a + b \ln X$						100	
Pha		c: $Y = a + b X$							100

[1]C/N_s: C/N ratio in the solid phase. C/N_w: C/N ratio in the water-soluble phase. CEC: cation-exchange capacity (meq 100 g^{-1} d.m. on ash-free material basis). C_t: total organic carbon. C_{ha}: humic acid-like carbon. C_{fa}: fulvic acid-like carbon. HR: humification ratio ($C_{ex}/C_o \times 100$. C_{ex}: alkaline-extractable carbon. C_o: oxidizable carbon). HI: humification index ($C_{ha}/C_o \times 100$). Pha: "humic" acid percent ($C_{ha}/C_{ex} \times 100$).

TABLE 3

Relationships between the maturity parameters and "humification" indices, considering jointly all the data points of both the R-pile (domestic refuse) and the R+S-pile (domestic refuse+sewage sludge) ($n=20$)

Y — X	Equation		r	SE
$CEC/C_t - C/N_s$	$\ln Y =$	$2.62 - 0.86 \ln X$	0.894***	0.14
$CEC - C/N_w$	$\ln Y =$	$4.58 - 0.22 \ln X$	0.824**	0.10
$CEC/C_t - C/N_w$	$\ln Y =$	$1.36 - 0.38 \ln X$	0.808**	0.18
$C_{ha}/C_{fa} - C/N_w$	$\ln Y =$	$1.82 - 0.63 \ln X$	0.865***	0.24
$Pha - C/N_w$	$\ln Y =$	$4.67 - 0.27 \ln X$	0.907***	0.08
$CEC/C_t - CEC$	$\ln Y = -$	$5.85 + 1.56 \ln X$	0.885***	0.15
$C_{ha}/C_{fa} - CEC/C_t$	$Y = -$	$0.56 + 1.29 X$	0.728*	0.19
$Pha - CEC/C_t$	$Y =$	$29.14 + 17.52 X$	0.761**	7.19
$Pha - C_{ha}/C_{fa}$	$Y =$	$50.21 + 23.02 \ln X$	0.996***	0.74

r: coefficient of correlation. SE: standard error of estimate.
Level of significance: *$P<0.05$, **$P<0.01$, ***$P<0.001$
C/N_s: C/N ratio in the solid phase. C/N_w: C/N ratio in the water-soluble phase. CEC: cation-exchange capacity (meq 100 g^{-1} d.m. on an ash-free material basis). C_t: total organic carbon (gC 100 g^{-1} d.m.). C_{ha}: humic acid-like carbon (gC 100 g^{-1} d.m., on ash-free basis). C_{fa}: fulvic acid-like carbon (gC 100 g^{-1} d.m., on ash-free basis). Pha: "humic" acid percent ($C_{ha}/C_{ex} \times 100$. C_{ex}: alkaline-extractable carbon, gC 100 g^{-1} d.m., on ash-free basis).

Of the "humification" indexes used, only the C_{ha}/C_{fa} ratio (as well as P_{ha}) was highly correlated to C/N_w and CEC/C_t. Therefore, this parameter may constitute a good index to establish the evolutional grade of the organic matter during composting, irrespective of the initial material. On the basis of equation 4 in Table 3, and of applying a value of 6 for the C/N_w ratio, a suitable value of 1.9 for the C_{ha}/C_{fa} is obtained (considering the standard error of estimate).

The HR (as well as also C_{ex}) was not correlated to CEC (and CEC/C_t) despite the fact that theoretically both parameters should be well correlated according to the nature of the cation-exchange capacity: the humification process (in soils) produces functional groups that fundamentally increase the CEC, carboxyl and/or phenolic hydroxyl groups [31]. This result is in agreement with Roig et al. [23] who found no significant correlation between CEC and C_{ex} in manures (sheep, chicken and rabbit manures). The lack of correlation could be laid on the non-humic substances present in the alkaline-extractable fraction [23]. In fact, HR and C_{ex} were not correlated to any other parameter. This fact occurred for all data points and upon considering the piles separately. This confirms that HR and C_{ex} are not true indices of "humification" during composting of city refuse–sewage sludge.

The CEC was well correlated only with the C/N_w ratio. However, the CEC/C_t ratio was very significantly correlated with C/N_s, C/N_w, C_{ha}/C_{fa} ratios and P_{ha}. It may thus be considered as a more reliable maturity index than the CEC

alone. Roig et al. [23] proposed the value of 1.7 for the CEC/C_t ratio as the lowest acceptable value for manures. According to our calculations based on the equations in Table 3, a value of 1.9 may be assumed as an index of good maturity for composts derived from city refuse and sewage sludge.

The HI (humification index: $C_{ha}/C_o \times 100$) was not correlated with any other parameter when both piles are considered. However, upon considering both piles separately, HI was highly correlated with all the parameters, except HR. For instance, Fig. 5 illustrates the relationship between HI and C/N_w. This implies that the extent of HI-decrease during composting depends on the nature of the raw materials, since the evolution of the C/N_w ratio was, except for slight fluctuations, nearly coincident in both the R-pile and the R+S-pile [5].

Fig. 6 shows a highly significant correlation between C/N_s and CEC/C_t when all data points are considered. However, this is the only significant correlation of C/N_s when both composting piles are considered together. Thus, in general, the behaviour of C/N_s and HI during composting depends on the composition of the raw material and cannot be used as maturity indices for all composts.

CONCLUSIONS

In the first part of this series a tentative guideline for rapid assessment of maturity in commercial composting plants was proposed, using temperature, C/N_w ratio, and CEC. These criteria were considered only for composting
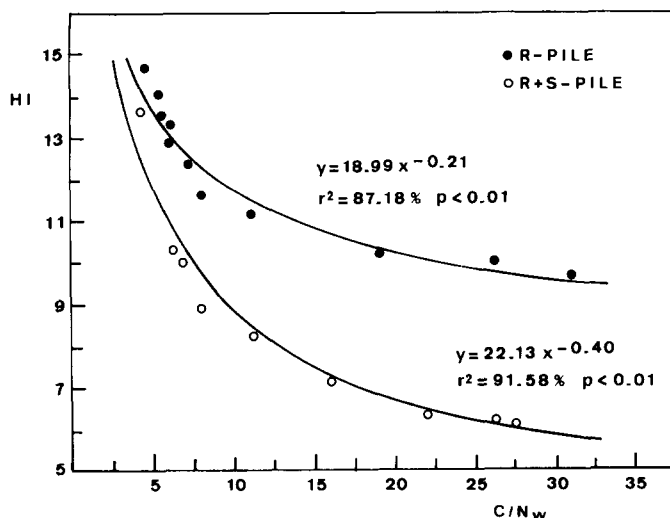

Fig. 5. Relationship between humification index (HI: $C_{ha}/C_o \times 100$) and carbon/nitrogen ratio in the water-soluble phase (C/N_w).
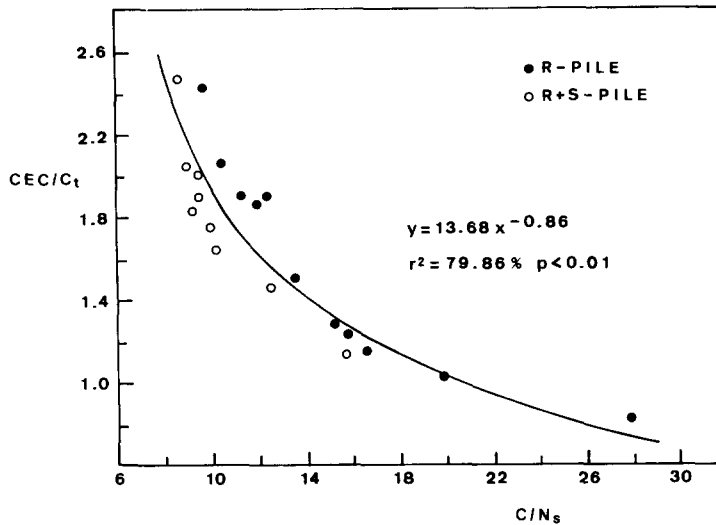
Fig. 6. Relationship between cation-exchange capacity/total organic carbon ratio (CEC/C_t) and carbon/nitrogen ratio in the solid phase (C/N_s).

(the process). Because a combination of several parameters is required for assessment of compost maturity (the product), a complementary combination of more parameters is recommendable. The study of evolution of some indices used for the evaluation of "humification" degree showed that only the C_{ha}/C_{fa} ratio (or P_{ha}) may usefully be introduced when materials of a different origin and composition, of urban nature, are considered. Summarizing, the practical stabilization of the temperature curve, a C/N_w lower than 6, a CEC/C_t ratio higher than 1.9 (with a CEC higher than 67 meq 100 g^{-1} dry matter on ash-free basis), and a C_{ha}/C_{fa} ratio higher than 1.9 (or a P_{ha} higher than 66%), may be assumed to be a suitable guideline to a high maturity degree, irrespective of the initial composition of raw materials for composting.

These criteria are valid only for composts produced from the organic fraction of urban refuse and also for co-composting of domestic refuse and sewage sludge. However, the results described in this paper must be considered provisional and other experimental data, from other parts of the world, shall be necessary to confirm them, owing to the high heterogeneity characteristic of the composts produced.

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