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Optimizing composting parameters for nitrogen conservation in composting

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Abstract

A central composite experimental design was used to investigate the influence of environmental composting parameters (moisture, aeration, particle size and time) for legume trimming residues, used on soil restoration, on the properties of products obtained (organic matter, Kjeldahl-N, C/N ratio and nitrogen losses (N-losses)) in order to determine the best composting conditions. A second-order polynomial model consisting of four independent process variables was found to accurately describe (the differences between the experimental values and those estimated by using the equations never exceeded 10% of the former) the composting process. Results of the experiment showed that compost with acceptably chemical properties (OM, 85%; Kjeldahl-N, 3.2%), high degradation and minimum N-losses entails operating at high operation time (78 days), low particle size (1 cm), medium moisture content (40%) and medium to low aeration level (0.2–0.4 l air/min kg).
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1. Introduction

Composting is a low-cost natural way of recycling organic matter. Composting is defined as a biological decomposition and stabilization of organic substrates, under conditions that allow the development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seed and can be beneficially applied to land (Haug, 1993).

In composting, ammonia (NH_3) is largely emitted when organic matter is actively decomposed (Kuroda et al., 2004). NH_3 emission occurred in quite high concentrations and large amount of nitrogen is lost during the treatment. This causes a decline in the value of the compost as a fertilizer, as well as complaints about malodour. Kirchmann and Witter (1989a, 1989b) reported that 44% of the initial N present in a poultry manure-straw mix was lost via NH_3 volatilization. Hansen et al. (1989) reported losses up to 33% of the initial total N during composting of poultry manure. Moreover, Kithome et al. (1999) reported that NH_3 loss was 47–62% of the initial total N after 25 days of composting poultry layer manure.

Then, research for the reduction of ammonia emission during composting of manure is required to make agreeable operating condition, may lead to an alleviation of the odor problem that is usually encountered in full-scale composting facilities, and to reduce the loss of nitrogen from the compost (Jeong and Kim, 2001; Hong and Park, 2005).

The main factors in the control of composting include: (i) environmental parameters (temperature, moisture content, pH, aeration) and (ii) substrate nature parameters (C/N ratio, particle size and nutrient content).

Among environmental parameters, temperature is a key factor in composting, which has frequently been used to

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judge the efficiency and degree of stabilisation of the treatment process (Jeris and Regan, 1973; Díaz et al., 2003) and pH control is not usually applied in practical composting operations (Gray et al., 1971; Nakasaki et al., 1993). Additionally, substrate nature parameters, with except to particle size, are no usually modified in full-scale systems.

References about factors such as C/N ratio, moisture content, temperature, pH, mixing and turning, and aeration rate that can influence the NH_3/NH_4^+ balance and hence the ammonia emission during composting has been reported by several authors (Reddy et al., 1979; Kirchmann and Witter, 1989a,b; Morisaki et al., 1989; Das and Keener, 1996; Ekinci et al., 2000). Nevertheless models, in which it observes the influence of more than two variables simultaneously, have not been found.

The main objective of this work is to develop an empirical model to determine the relative influence of moisture, aeration, particle size and time to minimize nitrogen losses.

2. Methods

2.1. Composting

Lignocellulosic waste, collected from legume trimming residues used in soil restoration, was mixed to get uniform feed material and chipped at three different particle size levels. About 20 kg mixture was placed in each reactor. The most relevant chemical characteristics of the raw materials and final composts are reported in Table 1.

The cylindrical composting reactors were formed from an acrylic column (0.5 m in diameter, 1 m in depth). To minimize the conductive heat loss along the reactor wall, it was insulated with polyurethane foam. Two sensors for temperature (K thermocouples, TMC6-HA) check were placed at center and on top of the reactor. An additional sensor temperature was placed outside reactor to obtain environmental temperature (Protimeter-MMS-Plus). Temperatures were recorded every 0.5 days in each reactor by two data-loggers (HOBO U12-006). Compressed air was introduced to the bottom of each reactor and evenly distributed to the waste mixture through a perforated plate.

Independent variables were established following a three levels central composite experimental design. Moisture content, aeration and particle size was established following a central composite experimental design. The moisture (M), aeration (A), particle size (PZ) and time (t) used in the different experiments of the factorial design were 40, 55 and 70% (Madejon et al., 2002; Zavala and Funamizu, 2005), 0.2, 0.4 and 0.6 l air/(kg min) (Ekinci et al., 2004; Kulcu and Yaldiz, 2004; Yamada and Kawase, 2006), 1, 3 and 5 cm (Haug, 1993; Gray et al., 1971) and 10, 34 and 78 days, respectively. To ensure initial conditions, water losses were compensated by the addition of water during active composting.

2.2. Experimental design

In order to be able to relate the dependent and independent variables with the minimum possible number of exper-

Table 1
Chemical characterisation[a] of the raw materials (LTR) and the final composts (R1–R15, $t = 78$ days)

	pH	EC[c]dS m^{-1}	OM[d]%	N[e]%	N-NO$_3$ g kg^{-1}	N-NH$_4$ g kg^{-1}	C/N	P$_2$O%	Na%	K$_2$O%	CaO%	MgO%
LTR[b]	4.96	6.2	93.2	2.41	4.86	0.01	19.6	0.75	0.09	3.05	2.90	0.97
R1 (1, −1, 1, −1)	7.42	3.1	90.3	2.56	15.3	0.03	12.6	1.20	0.11	4.98	4.24	1.26
R2 (1, 1, 1, −1)	7.49	3.7	87.5	3.85	39.5	0.05	21.5	1.41	0.21	6.09	5.24	1.51
R3 (1, 0, 1, 0)	7.33	3.4	89.2	2.30	13.3	0.02	16.5	0.93	0.12	4.79	4.49	1.39
R4 (1, 1, 1, 1)	7.16	5.9	88.1	2.96	99.2	0.03	17.4	0.83	0.16	4.88	3.42	0.93
R5 (1, −1, 1, 1)	7.06	6.7	87.3	2.79	92.3	0.06	17.0	0.52	0.09	2.95	2.32	0.70
R6 (1, 1, 0, 0)	7.20	6.5	90.5	2.95	79.4	0.01	16.0	1.05	0.11	4.98	4.21	1.13
R7 (1, 0, 0, 0)	7.38	6.4	84.2	2.91	33.2	0.47	20.0	0.96	0.10	4.05	3.34	0.99
R8 (1, 0, 0, 1)	7.50	8.2	91.3	2.53	129.4	0.09	15.9	0.80	0.27	3.78	3.46	0.76
R9 (1, 0, 0, −1)	7.35	6.4	90.7	3.16	28.5	0.08	19.5	1.17	0.11	5.27	3.96	1.18
R10 (1, −1, 0, 0)	7.36	6.5	90.6	2.59	42.5	0.05	18.3	0.91	0.11	4.06	3.42	0.92
R11 (1, −1, −1, −1)	7.16	6.3	91.6	2.79	29.4	0.06	15.4	0.99	0.19	4.40	3.37	0.98
R12 (1, 1, −1, −1)	7.45	7	91.0	3.29	59.4	0.02	16.0	0.99	0.11	5.04	4.20	1.27
R13 (1, 0, −1, 0)	7.57	8	89.9	3.12	15.4	0.21	16.7	0.90	0.10	4.12	4.24	1.11
R14 (1, 1, −1, 1)	7.26	6.5	86.8	2.88	34.1	0.33	16.7	0.41	0.14	2.25	1.53	0.44
R15 (1, −1, −1, 1)	7.38	7.5	90.0	2.99	41.8	0.37	19.6	0.64	0.07	3.11	2.21	0.66

[a] Each value is the average of three samples, dry weight basis.
[b] Ri (time, aeration, moisture, particle size.).
  Time (t), 1 (78 days).
  Aeration (A), −1 (0.2 l air/ min kg), 0 (0.4 l air/min kg), 1 (0.6 l air/min kg).
  Moisture (M), −1 (40%), 0 (55%), 1 (60%).
  Particle size (P), −1 (1 cm), 0 (3 cm) and 1 (5 cm).
[c] EC: Electrical conductivity.
[d] OM: Organic matter.
[e] N: Kjeldahl-N.

iments, a central composite factor design for two factors that enabled the construction of second-order polynomials in the independent variables and the identification of statistical significance in the variables was used (Montgomery, 1991; Aknazarova and Kafarov, 1982). With four independent variables (moisture, aeration, particle size and time,), 26 experiments were enough to fit a second-order polynomial model. The independent variables were normalized to values from −1 to +1 using Eq. (1) to facilitate direct comparison of the coefficients of the resulting polynomial equation and an understanding of the effects of the individual independent variables on the dependent variables considered.

$$X_n = \frac{X - \bar{X}}{(X_{\max} - X_{\min})/2} \quad (1)$$

where X is the absolute value of the independent variable concerned, $\bar{X}$ is the average value of the variable and $X_{\max}$ and $X_{\min}$ are its maximum and minimum value, respectively.

The central combination for the experimental design $(0, 0, 0, 0)$ was as follows: $M = 55\%$, $A = 0.4$ l air/(kg min), PZ = 3 cm and $t = 55$ days. The results were subjected to multiple linear regressions as implemented in SAS system package.

Experimental data were fitted to the following second-order polynomial equation:

$$Z = a_0 + \sum_{i=1}^{4} b_i X_{ni} + \sum_{i=1}^{4} c_i X_{ni}^2 + \sum_{i=1,j=1}^{4} d_{ij} X_{ni} X_{nj} (i < j) \quad (2)$$

where Z is the response or dependent variable [time (t), moisture (M), aeration (A) and particle size (PZ)]; X_n is the normalized value of the independent variable concerned; and a_0, b_i, c_i and d_{ij} are unknown characteristic constants estimated from the experimental data.

The independent variables used in the equations relating to both types of variable were those having a statistically significant coefficient (viz. those not exceeding a significance level of 0.05 in Student's t-test and having a 95% confidence interval excluding zero).

2.3. Analytical methods

Samples were collected at four randomised points. Subsamples were dried (60 °C) and ground (0–25 mm). Moisture was determined by drying a 105 °C to constant weight. The mixtures were analyzed for the following parameters: pH (1:5 w/v) using a pH electrode, total organic matter (OM) by loss on ignition (550 °C for 5 h) (Allison, 1965), total P, K, calcium (Ca), magnesium (Mg) and macro and micro elements were obtained by inductively coupled plasma (ICP) spectrometry following nitric/hydrochloric acid digestion (Barnhisel and Bertsch, 1982). Kjeldahl-N (Bremnen, 1996) and NH_4^+-N using the KCl and NO_3^--N using the H_2O extraction methods (Mulvaney, 1996). The Kjeldahl-N losses during the process

have been calculated from the initial content of N-Kjeldahl, and the evolution of the organic matter, assuming the mineral amount in each mixture is constant, according to the equation of Bernal et al. (1997) (Eq. (3)). Losses of Kjeldahl-N were calculated from the initial (X_1) and final (X_2) ash content (Table 1).

$$N_{\text{Loss}} = 100 - 100 \frac{X_1 N_2}{X_2 N_1} \quad (3)$$

Here N_1 and N_2 are the initial and final N-Kjeldahl concentrations.

3. Results and discussion

3.1. Temperature profiles

The temperature profiles of the reactors with the same conditions except aeration rate are presented in Figs. 1 (0.2 l air/min kg), 2 (0.4 l air/min kg) and 3 (0.6 l air/min kg). As usually, the temperature of the composting reactors began to rise soon after the establishment of composting conditions. For all reactors, as expected, the temperature increased relatively rapidly and the three typical phases of composting were observed during the process (Haug, 1993): (i) a short initial mesophilic phase ($T < 40$ °C) during approx. 2 days for all reactors, (ii) a thermophilic phase lasting two weeks, which the temperature increased and (iii) a mesophilic and maturation phase after 25–30 days. Shortly thereafter the temperature decreased rather gradually and the mesophilic stage developed, at 50 days of composting, compost temperature equalled that of the ambient. No changes of temperatures were observed after turning during this phase, indicating a stabilisation of the compost.

The highest temperature obtained for R10 (Fig. 1), R9 (Fig. 2) and R6 (Fig. 3) were 58 and 57 and 53 °C, respectively. The temperature profiles of reactors in Fig. 1 are, in general, higher than those found for Figs. 2 and 3. This fact could be due to the significant effect of the aeration level on heat lost. The largely depend of composting temperatures
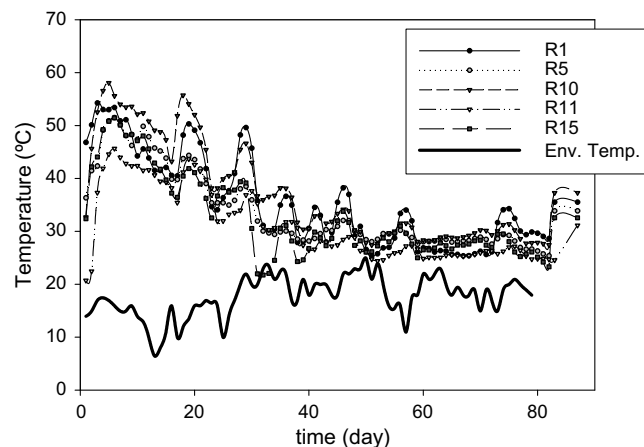

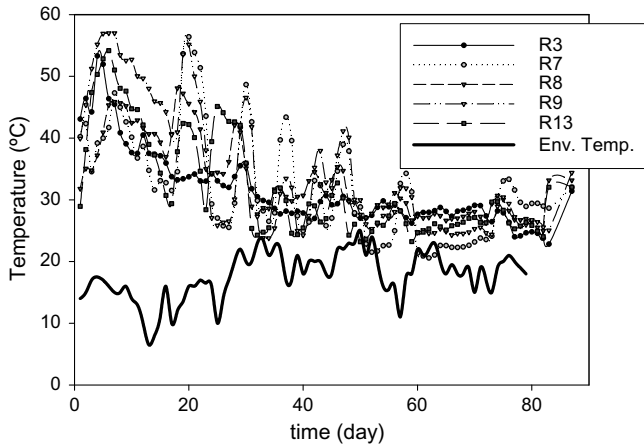Fig. 1. The temperature profiles of the reactors with 0.2 l air/min kg.

Fig. 2. The temperature profiles of the reactors with 0.4 l air/ min kg.
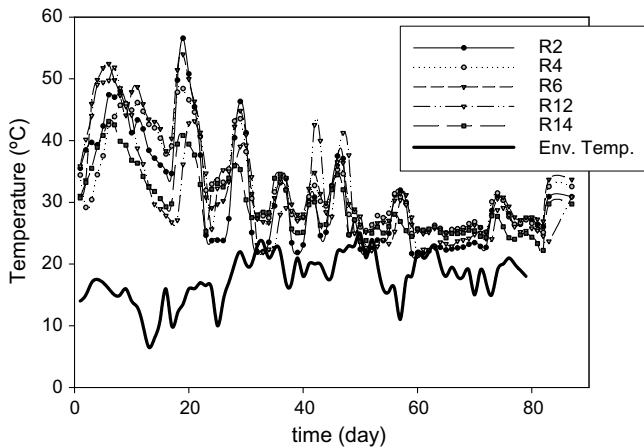

Fig. 3. The temperature profiles of the reactors with 0.6 l air/ min kg.

and the heat lost were studied by Richard (1992). For that reason, a cooler effect under a higher aeration level has been found.

3.2. Composting efficiency

To gather information on the quality and agronomic value of the obtained end-product analyses on the nutrient content were performed (Table 1). Results revealed high amounts of macronutrients, particularly nitrogen, K and P. Adequate C/N and C/P (10) values for final compost were found in all reactors. The low concentration of heavy metals found (data not shown) confirms the safety of the original materials. The quality of the composts obtained in this study can be considered comparable to the quality of other composts reported in the literature (Bertoldi De et al., 1985; Zucconi and De Bertoldi, 1987; Ayers, 1997).

Table 2, shows the normalized values of independent variables and properties of the products obtained in the incubation process, using the proposed experimental designs. Each value in experimental results is an average

of three samples. The deviations for these parameters from their respective means were all less than 5–10%.

Substituting the values of the independent variables for each dependent variable in Table 2 and applying a multiple linear regression analysis for each one of the dependent variables of that table as a function of the independent variables, the polynomials mathematical models are obtained (Table 3). These equations can be used to estimate the variation of dependent variables with changes in the independent variables over the ranges considered, on the constancy of the other two variables. Only the terms with statistically significant coefficients are shown according to the proposed methodology.

Identifying the independent variables with the strongest and weakest influence on the dependent variables in equations is not so easy since the former contain quadratic terms and the others involve interactions between two independent variables.

Fig. 4 shows a plot of each dependent variable against each independent one constructed by changing all the independent variables between the normalized values from -1 to $+1$. At a given value of an independent variable, the magnitude of the difference between the maximum and minimum values of the dependent variable is related to the influence of the independent variables other than that plotted on the variation of the dependent variable concerned. Thus, if an independent variable plotted had and absolute effect on the dependent variable considered (the independent variables different from those plotted had no effect on the dependent variable considered), then the difference between the maximum and minimum values of the dependent variable in question would be zero (a point in the graphs of Fig. 4). Also, if the independent variable plotted had no effect), then the previous difference would coincide with the height of the rectangle having the range of values of the independent variable plotted, $[(X_{ni})_{max} - (X_{ni})_{min}]$, and the maximum possible difference between the maximum and minimum values of the dependent variable considered, $\{Z(X_{ni})_{max}]_{max} - Z[(X_{ni})_{min}]_{min}\}$, as its bases.

Because the influence of the other variables on the dependent variable considered can vary with each value of the independent variable plotted, the average change in the dependent variable will be given by:

$$\frac{\int_{(X_{ni})_{min}}^{(X_{ni})_{max}} [Z(X_{ni})_{max} - Z(X_{ni})_{min}] \mathrm{d}X_{ni}}{[(X_{ni})_{max} - (X_{ni})_{min}]} \tag{4}$$

The change in the dependent variable with that of the independent variable plotted can be assimilated to the difference between $[Z(X_{ni})_{max}]_{max} - Z[(X_{ni})_{min}]_{min}$ and the previous expression.

$$DZ_i = \{[Z(X_{ni})_{max}]_{max} - [Z(X_{ni})_{min}]_{min}\}$$
$$- \frac{\int_{(X_{ni})_{min}}^{(X_{ni})_{max}} [Z(X_{ni})_{max} - Z(X_{ni})_{min}] \mathrm{d}X_{ni}}{[(X_{ni})_{max} - (X_{ni})_{min}]} \tag{5}$$

Table 2
Chemical characterisation[a] of the selected points following the experimental design

t^b days	A^c l_{air}/min kg	M^d%	P^e cm	OM (%)	N (%)	C/N	N- Losses (%)
10 (−1)	0.2 (−1)	70 (1)	1 (−1)	92.7	2.54	20.2	24.58
78 (1)	0.6 (1)	70 (1)	1 (−1)	87.5	3.85	12.6	1.04
34 (0)	0.4 (0)	70 (1)	3 (0)	89.5	2.31	21.4	7.80
10 (−1)	0.6 (1)	70 (1)	5 (1)	90.4	2.60	19.3	29.57
78 (1)	0.2 (−1)	70 (1)	5 (1)	87.3	2.79	17.3	32.88
34 (0)	0.6 (1)	55 (0)	3 (0)	91.6	2.57	18.2	9.09
34 (0)	0.4 (0)	55 (0)	3 (0)	84.9	3.14	14.9	40.01
34 (0)	0.4 (0)	55 (0)	5 (1)	91.3	2.52	20.1	16.56
34 (0)	0.4 (0)	55 (0)	1 (−1)	91.8	2.84	17.9	−10.54
34 (0)	0.2 (−1)	55 (0)	3 (0)	90.9	2.48	20.3	11.51
78 (1)	0.2 (−1)	40 (−1)	1 (−1)	91.6	2.79	18.2	−39.32
78 (1)	0.6 (1)	40 (−1)	1 (−1)	91.0	3.29	15.3	−60.26
34 (0)	0.4 (0)	55 (0)	3 (0)	85.1	3.16	13.4	8.71
10 (−1)	0.4 (0)	55 (0)	3 (0)	90.9	2.77	18.1	9.78
78 (1)	0.4 (0)	55 (0)	3 (0)	84.1	2.91	16.0	37.06
34 (0)	0.4 (0)	40 (−1)	3 (0)	90.0	3.11	16.0	−41.02
78 (1)	0.2 (−1)	70 (1)	1 (−1)	90.3	2.56	19.5	34.11
10 (−1)	0.6 (1)	70 (1)	1 (−1)	90.6	3.30	15.2	4.63
78 (1)	0.6 (1)	70 (1)	5 (1)	88.1	2.90	16.5	21.02
10 (−1)	0.2 (−1)	70 (1)	5 (1)	91.7	2.43	20.8	22.95
10 (−1)	0.2 (−1)	40 (−1)	1 (−1)	92.5	2.65	19.3	−24.31
10 (−1)	0.6 (1)	40 (−1)	1 (−1)	91.8	2.58	19.7	−54.32
78 (1)	0.6 (1)	40 (−1)	5 (1)	86.8	2.88	16.7	36.95
10 (−1)	0.6 (1)	40 (−1)	5 (1)	92.0	2.63	19.4	36.60
10 (−1)	0.2 (−1)	40 (−1)	5 (1)	91.2	2.50	20.2	−9.75
78 (1)	0.2 (−1)	40 (−1)	5 (1)	90.0	2.99	16.7	−10.01

[a] Where each value is the average of three samples, dry weight basis.
[b] *t* (time. The values between parentheses correspond to the normalized values used in the equations).
[c] *A* (aeration).
[d] *M* (moisture).
[e] *P* (particle size).
[f] EC: Electrical conductivity.
[g] OM: Organic matter.
[h] *N*: Kjeldahl-N.

Table 3
Equations yielded for each dependent variable

No.	Equation	r^2	F	df
6	OM $= 89.46021 - 2.33364\ t + 1.2659\ M + 0.63761\ P + 1.8182\ t^2 - 2.96218M^2 + 1.9058P^2 - 0.32859AM + 0.6344AP - 0.43019MP$	0.87	35.77	5.2
7	CN $= 18.03 - 1.18\ A - 1.15\ t + 0.81\ A\ P + 0.59\ P - 0.56\ t\ M - 1.31\ t^2 + 1.17\ A^2$	0.83	12.88	7.18
8	KN $= 2.81 + 0.15\ t + 0.18\ A - 0.13\ P + 0.10\ AM - 0.15\ t\ P$	0.74	11.32	5.2
9	NL $= 9.0815 + 19.1156M + 16.7333P + 24.774t^2 - 30.372M^2 + 12.009AP - 11.872MP$	0.90	45.18	7.18

Where OM the organic matter content (%), CN the C/N ratio, KN denotes the Kjeldahl-N content (%) and NL the nitrogen losses (%). *t, A, M, P* denotes the normalized value of the operation time, aeration, moisture and particle size, respectively.
The differences between the experimental values and those estimated by using the previous equations never exceeded 10% of the former.

Fig. 4 also shows the DZ_i percentages. These values allow one to weigh the relative influences, as percentages, of each independent variable on the variation of each dependent variable.

To determine the values of the independent variables giving the optimum organic matter, Kjeldahl-N, C/N and N-losses evolution, the response surfaces for each dependent variable were plotted three levels of the independent variable most strongly (Figs. 5–7), for Kjeldahl-N evolution figure is not shown.

As can be seen in Fig. 4, with the exception of the time, the moisture content is the variable most strongly influenc-ing the organic matter and N-losses evolution, whereas the aeration is that having the strongest effect on Kjeldahl-N and C/N evolution. The particle size has a great influence on the organic matter C/N and N-losses evolution. On the other hand, no independent variable has the strongest influence on the evolution of composting process.

3.3. Organic matter and C/N evolution

As can be seen from Fig. 5 and Eq. (6), the organic con-tent was less influenced by the aeration than by the mois-ture and particle size. That is to say, low increments on
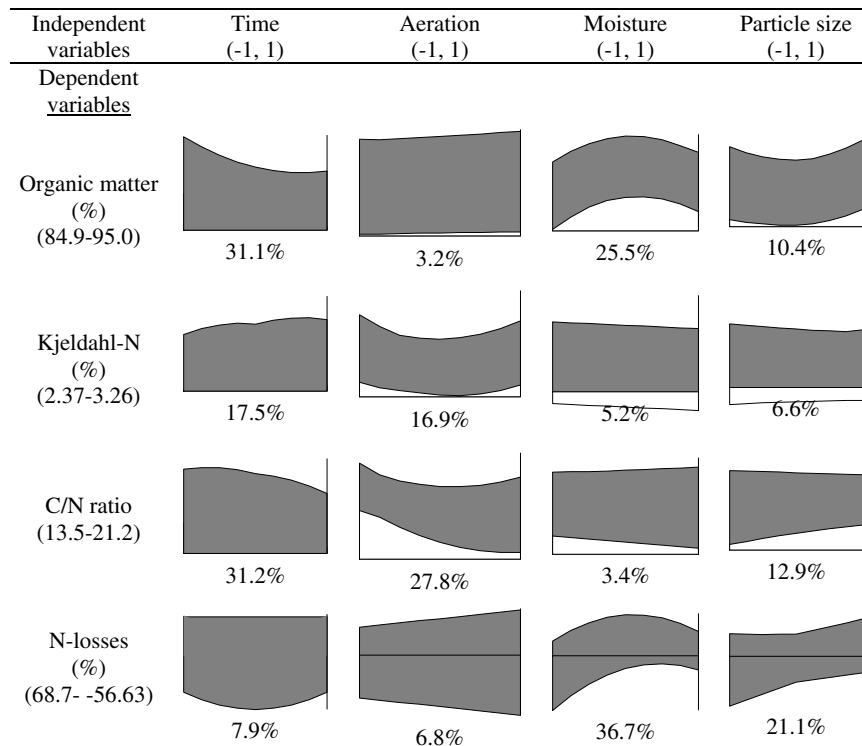
Independent variables	Time (-1, 1)	Aeration (-1, 1)	Moisture (-1, 1)	Particle size (-1, 1)
Dependent variables				
Organic matter (%) (84.9-95.0)	31.1%	3.2%	25.5%	10.4%
Kjeldahl-N (%) (2.37-3.26)	17.5%	16.9%	5.2%	6.6%
C/N ratio (13.5-21.2)	31.2%	27.8%	3.4%	12.9%
N-losses (%) (68.7- -56.63)	7.9%	6.8%	36.7%	21.1%

Fig. 4. Variation of dependent variables as a function of normalized independent variables.
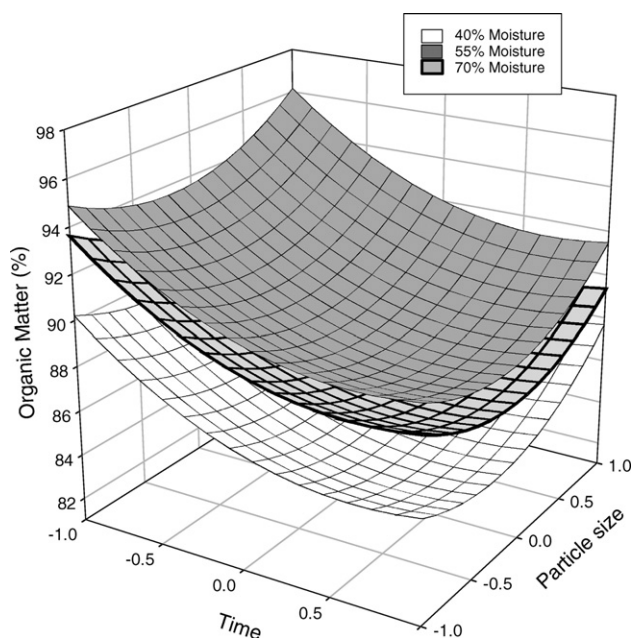
Fig. 5. Organic matter losses variation as a function of operation time and particle size.

organic matter content were found among high and low aeration levels. This fact could be related with the oxygen available for the microorganisms under variably sized matrix (Hamelers, 2004).

As usual, a high negative statistical influence has been found in time (Whang and Meenaghan, 1980). Similar evo-lution has been found for 55% and 70% moisture content with respect 40% moisture content. Particle size has both positive and negative effects in the studied range. In that form, the lower values for organic mater (maximum degra-dation have been found for medium-to-low particle size (1–3 cm, 0 to −1 in the normalized value). The composting efficiency have been related to the effect of free air space (proportional to particle size) (El Kader et al., 2007) and an optimal free air space could be found at this particle size. Fig. 5 shows the lowest values organic matter content (OM = 82.3%) obtained at intermediate-to-low value of the particle size, 40% for moisture content and long com-posting time. The higher values (low degradation) at long composting time (OM = 91.8%) were yielded at high parti-cle size and 55% moisture content.

The organic matter losses found are similar to them found by other authors in similar agricultural residues (Nogueira et al., 1999; Nakasaki and Ohtaki, 2002; Grigat-ti et al., 2004.,).

Fig. 6 shows the C/N ratio evolution, as function of time and particle size at the three aeration levels. The C/N ratio of the initial mixtures (19.6) is slightly lower than the opti-mum C/N ratio of the initial mixtures is between 25 and 35 (Haug, 1993; Choi, 1999). The C/N ratio evolution was less markedly influenced by the particle size than by the aera-tion level. Also, this figure reveals that at high particle size similar evolution on C/N was found. As can be seen in Fig. 6, using high aeration level, a decrease on C/N ratio values have been found. Subsequently, to obtain lower C/N ratio, medium-to-high aeration levels could be used.
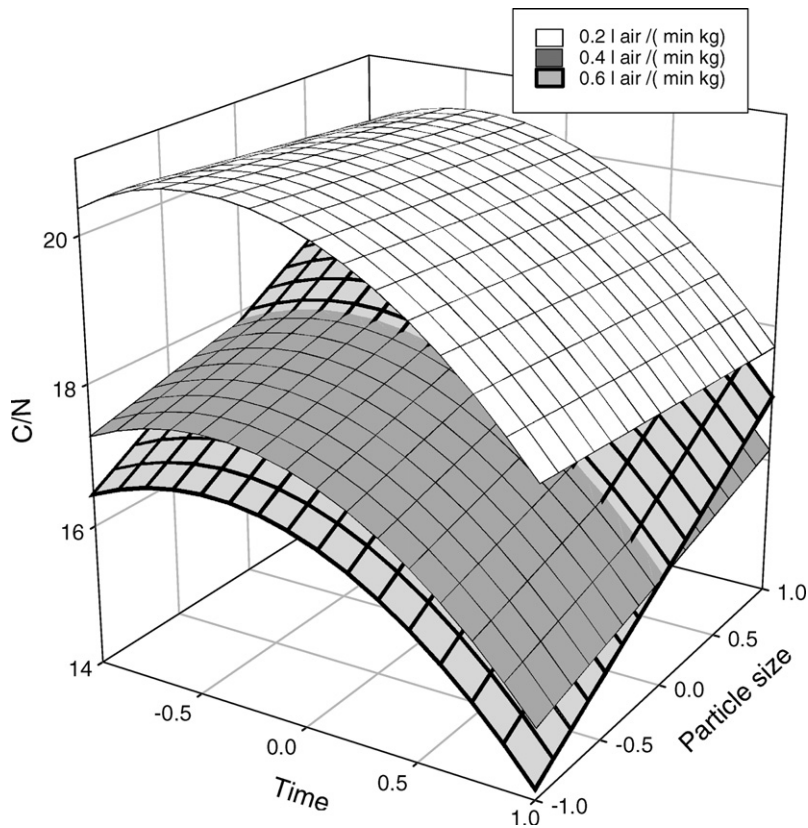
Fig. 6. C/N variation as a function of operation time and particle size.

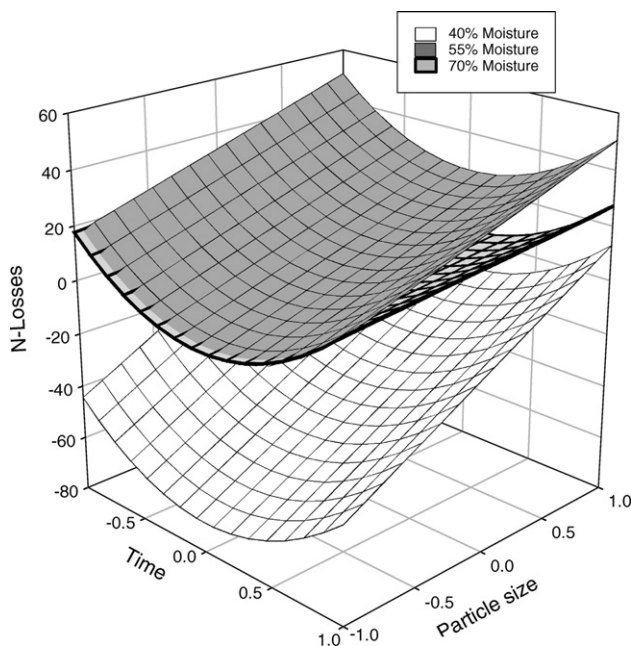## 3.4. Nitrogen and N-losses evolution

Fig. 7. Kjeldahl-N losses variation as a function of operation time and particle size.

That decrease is higher for low particle size and, naturally, higher composting time. The C/N ratio of finished compost typically close to 10–15 (Poincelot, 1974; Díaz et al., 2002).

The Kjeldahl-N content evolution was thus much more sensitive to changes in the aeration and time than in the others independent variables. A similar behaviour was found by Szanto et al. (2007) in straw-rich pig manure composting. A positive influence (better nitrogen content in composts) of almost all the dependent variables, with except particle size, has been found (Eq. (8)). And then, to produce composts with high nitrogen content (>3%), it is advisable to use a high aeration level and long time and a low particle size.

Eq. (9) can be used to estimate the variation of the N-losses in the independent variables over the ranges considered, in that form, the main parameter on variation is moisture. Particle size has a positive effect on N-losses, using high particle size, high contents of nitrogen could be losses. El Kader et al. (2007) found an empirical relationship between free air space (related with te particle size) and the ammonium emissions. This fact could explain the higher nitrogen losses under high particle size. Therefore, to improve nitrogen contents in final composts, medium-to-low particle size could be used. For analogous reasons to that found for organic matter evolution, from Fig. 6, which show the variation of N-losses as a function of time and particle size at the three moisture levels studied. In that figure a similar evolution on N-losses for 55% and 70% of moisture content with respect to 40% have been found among the

different particle size used (Fig. 7). Under those conditions a positive N-losses are found. Lower N-losses have been found at intermediate time (mesophilic phase) with respect to initial and final composting time. The minimum N-losses (-70%) was obtained at medium values of composting time (55 days) and low values of particle size (1 cm) and moisture content (40%). An increment on total-N could be obtained at high values of moisture and medium values of aeration. On the other hand, the operation time accuses a negative influence on the N-losses variation, thereby, ensuring a low N-losses ($>-40\%$) using lower values of the composting variables (particle size and moisture) and medium composting time, lower N-losses could be obtained. This fact could be due to the higher degradation experimented by the organic matter with respect to the nitrogen losses. Therefore, it gives rise to a higher nitrogen concentration in final with respects to initial composts.

The Kjeldahl-N losses found are similar to them found by other authors in similar agroindustrial residues (Mahimairaja et al., 1994; Tiquia and Tam, 2000).

In all cases, the content of NH_4^+-N in the final products (Table 1) was lower than the value advised for matures compost (40 mg/kg) (Zucconi et al., 1985; Mathur et al., 1993).

4. Conclusions

The results of experiments indicated that the composting process of leucaenas trimming residues is technically feasible in in-vessel systems and could be considered as an ecological way to recycle these wastes from soil restoration.

The chemical values found for the products obtained from leucaenas trimming residues are similar (same magnitude order) to other agricultural residues.

Results of the experiment showed that compost with acceptably chemical properties (OM 85%, Kjeldahl -N 3.2%), high degradation and no N-losses entails operating at high operation time (78 days) and low particle size (1 cm) and moisture content (40%) and medium aeration level (0.4 l air/min kg).

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References

Aknazarova, S., Kafarov, V., 1982. Experiment optimization in chemistry and chemical engineering. Mir Publisher, Moscow.

Allison, L.E., 1965. Organic carbon. In: Black, C.A., Evans, D.D., White, J.L., Ensiminger, L.E., Clark, F.E., Dinauer, R.C. (Eds.), Methods of Soil Analysis, vol. II. SSSA, Madison, WI, pp. 367–378.

Ayers, V., 1997. Farmer composting of cotton gin trash. In: Proceedings Beltwide cotton conferences, vol. II. New Orleans. pp. 1615–16.

Barnhisel, R., Bertsch, P.M., 1982. Digestion with perchloric-nitric acids, 2nd ed.. In: Page, A.L. (Ed.), Methods of Soil Analysis, Part 2. Chemical and Microbial Properties. Monograph Agronomy ASA, vol. 9 SSA, Madison, WI, USA, pp. 279–280.

Bernal, M., Paredes, C., Sánchez-Mondero, M., Cegarra, J., 1997. Maturity and stability parameters of composts prepared with a wide range of organic wastes. Biores. Technol. 63 (1), 91–99.

Bertoldi De, M., Vallini, G., Pera, A., 1985. Technological Aspects of composting including modelling and microbiology. In: Gasser, J.K.R. (Ed.), Composting of Agricultural and Other Wastes. Elsevier Applied Science Publishers, London, UK, pp. 27–40.

Bremnen, J.M., 1996. Nitrogen-Total. In: Sparks, D.L. (Ed.), Methods of Soil Analysis, vol. III. SSSA, Madison, WI, pp. 1085–1121.

Choi, K., 1999. Optimal operating parameters in the composting of swine manure with wastepaper. J. Environ. Sci. Health, B. 34 (6), 975–987.

Das, K., Keener, H.M., 1996. Process control based on dynamic properties in composting, moisture and compaction considerations. In: De Bertoldi, M., Sequi, P., Lemmes, B., Papi, T. (Eds.), The Science of Composting, vol. I. Blackie Academic & Professional, London, pp. 116–125.

Díaz, M.J., Madejón, E., López, F., López, R., Cabrera, F., 2002. Optimization of the rate vinasse/grape marc for co-composting process. Process Biochem. 37 (1), 1143–1150.

Díaz, M.J., Eugenio, M.E., Jimenez, L., Madejón, E., Cabrera, F., 2003. Modelling vinasse/cotton waste ratio incubation for optimum composting. Chem. Eng. J. 93 (3), 233–240.

Ekinci, K., Keener, H.M., Elwell, D.L., 2000. Composting short paper fiber with broiler litter and additives. Part I: effects of initial pH and carbon/nitrogen ratio on ammonia emission. Compost Science & Utilization. 8 (2), 160–172.

Ekinci, K., Keener, H.M., Elwell, D.L., Michel, F.C., 2004. Effects of aeration strategies on the composting process: Part I. Experimental studies. Trans.ASAE 47 (5), 1697–1708.

El Kader, N.A., Robin, P., Paillat, J.M., Leterme, P., 2007. Turning, compacting and the addition of water as factors affecting gaseous emissions in farm manure composting. Biores. Technol. 98, 2619–2628.

Gray, K.R., Sherman, K., Biddlestone, A.J., 1971. Review of Composting II. The Practical. Process Biochem. 6, 22–28.

Grigatti, M., Ciavatta, C., Gessa, C., 2004. Evolution of organic matter from sewage sludge and garden trimming during composting. Biores. Technol. 91 (2), 163–169.

Hamelers, H., 2004. Modeling composting kinetics: A review of approaches. Rev.Environ. Sci. Biotechnol. 3 (4), 331–342.

Hansen, R.C., Keener, H.M., Hoitink, H.A.J., 1989. Poultry manure composting-An exploratory study. Trans. ASAE 36, 2151–2157.

Haug, R.T., 1993. The Practical Handbook of Compost Engineering. Lewis Publishers, Boca Raton, Florida, USA.

Hong, J.H., Park, K.J., 2005. Compost biofiltration of ammonia gas from bin composting. Biores. Technol. 96 (6), 741–745.

Jeong, Y.K., Kim, J.S., 2001. A new method for conservation of nitrogen in aerobic composting processes. Biores. Technol. 79 (2), 129–133.

Jeris, J.S., Regan, R.W., 1973. Controlling Environmental Parameters for Optimum Composting. Part I. Compos. Sci. 14 (Jan-Feb), 10–15.

Kirchmann, H., Witter, E., 1989a. Ammonia volatilization during aerobic and anaerobic manure decomposition. Plant Soil 115, 35–41.

Kirchmann, H., Witter, E., 1989b. Ammonia volatilization during aerobic and anaerobic manure decomposition. Plant Soil 115 (1), 35–41.

Kithome, M., Paul, J.W., Bomke, A.A., 1999. Reducing nitrogen losses during simulated composting of poultry manure using adsorbents or chemical amendments. J. Environ. Qual. 28, 194–201.

Kulcu, R., Yaldiz, O., 2004. Determination of aeration rate and kinetics of composting some agricultural wastes. Biores. Technol. 93 (1), 49–57.

Kuroda, K., Hanajima, D., Fukumoto, Y., Suzuki, K., Kawamoto, S., Shima, J., Haga, K., 2004. Isolation of thermophilic ammonium-tolerant bacterium and its application to reduce ammonia emission

during composting of animal wastes. Biosci. Biotechnol. Biochem. 68 (2), 286–292.

Madejon, E., Diaz, M.J., Lopez, R., Cabrera, F., 2002. New approaches to establish optimum moisture content for compostable materials. Biores. Technol. 85 (1), 73–78.

Mahimairaja, S., Bolan, N.S., Hedley, M.J., McGregor, A.N., 1994. Losses and transformations of nitrogen during composting of poultry manure with different amendments: an incubation experiment. Biores. Technol. 47, 265–273.

Mathur, S.P., Owen, G., Dinel, H., Schnitzer, M., 1993. Determination of compost biomaturity. I. Literature review. Biol. Agr. Hortic. 10, 65–85.

Montgomery, D.C., 1991. In: Diseño y análisis de experimentos. Ibero-americana, México.

Morisaki, N., Phae, C.G., Nakasaki, K., Shoda, M., Kubota, H., 1989. Nitrogen transformation during thermophilic composting. J. Ferm. Bioeng. 67, 57–61.

Mulvaney, R.L., 1996. Nitrogen-inorganic forms. In: Sparks, D.L. (Ed.), Methods of Soil Analysis, vol. III. SSSA, Madison, WI, pp. 1123–1184.

Nakasaki, K., Ohtaki, A., 2002. A simple numerical model for predicting organic matter decomposition in a fed-batch composting operation. J. Environ. Qual. 31 (3), 997–1003.

Nakasaki, K., Yaguchi, H., Sasaki, Y., Kubota, H., 1993. Effect of pH control composting of garbage. Waste Manag. Res. 11 (2), 117–125.

Nogueira, W.A., Nogueira, F.N., Devens, D.C., 1999. Temperature and pH control in composting of coffee and agricultural wastes. Wat. Sci. Technol. 40 (1), 113–119.

Poincelot, R.P., 1974. A Scientific Examination of the Principles and Practice of Composting. Compos. Sci. 15 (Summer), 24–31.

Reddy, K.R., Khaleel, R., Overcash, M.R., Westerman, P.W., 1979. A non-point source model for land areas receiving animal wastes: II. Ammonia volatilization. Trans. ASAE 22, 1398–1405.

Richard, T.L., 1992. Municipal solid waste composting: physical and biological processing. Biomass Bioenergy 3 (3–4), 163–180.

Szanto, G.L., Hamelers, H.V., Rulkens, W.H., Veeken, A.H., 2007. NH_3, N_2O and CH_4 emissions during passively aerated composting of straw-rich pig manure. Biores. Technol. 98, 2659–2670.

Tiquia, S.M., Tam, N.F.Y., 2000. Fate of nitrogen during composting of chicken litter. Environ. Pollut. 110, 535–541.

Whang, D.S., Meenaghan, G.F., 1980. Kinetic model of composting process. Compos. Sci. (May/June), 44–46.

Yamada, Y., Kawase, Y., 2006. Aerobic composting of waste activated sludge: Kinetic analysis for microbiological reaction and oxygen consumption. Waste Manag. 26 (1), 49–61.

Zavala, M.A.L., Funamizu, N., 2005. Effect of moisture content on the composting process in a biotoilet system. Compos. Sci. Util. 13 (3), 208–216.

Zucconi, F., De Bertoldi, M., 1987. Compost specifications for the production and characterization of compost from municipal waste. In: De Bertoldi, M., Ferranti, M., L'Hermite, P., Zucconi, F. (Eds.), Compost: Production, Quality and Use. Elsevier Applied Science, London, UK, pp. 30–50.

Zucconi, F., Monaco, A., Forte, M., 1985. Phytotoxins during the stabilisation of organic matter. In: Gasser, J.K.R. (Ed.), Composting of Agricultural and other Wastes. Elsevier Applied Science Publications, London, UK, pp. 73–85.