

Leaching of Composts from Agricultural Wastes to Prepare Nursery Potting Media

C. Carrión, M. Abad,
F. Fornes and V. Noguera
Instituto Agroforestal Mediterráneo
Universidad Politécnica de Valencia
P.O. Box 22012, E46071 Valencia
Spain

Á. Maquieira and R. Puchades
Departamento de Química
Universidad Politécnica de Valencia
P.O. Box 22012, E46071 Valencia
Spain

Keywords: salt, mineral elements, leaching efficiency, vegetable crop wastes, container media, peat substitutes, waste utilization

Abstract

The leaching of salt and mineral elements from three composts prepared with residual vegetable crop biomass (melon, pepper or zucchini) and from one limed peat (control) was studied using methacrylate columns and distilled water. After 5 container capacities of effluent, both the electrical conductivity and the concentration of soluble elements in compost leachates decreased substantially and equalled those of peat. Composts reacted differently to the leaching of salt due to differences in the raw waste sources and the composting process and hence, in their physical and chemical characteristics, especially organic matter contents. At the end of the experiment, after pouring 8 container capacities of water, the leaching efficiency of the salts was 84%, 89% and 77% for melon, pepper and zucchini-based composts, respectively. Mineral elements differed in their ability to be removed from the composts; available N (NH_4^+ and NO_3^-), K^+ , Na^+ , Cl^- , and S were leached readily, whereas P, Ca^{2+} , and Mg^{2+} were removed hardly due to chemical binding or adsorption. Leached composts showed a range of physico-chemical and chemical parameters suitable for use as growing media constituents. Finally, special emphasis must be paid to the management of the effluents produced under commercial conditions to avoid environmental pollution.

INTRODUCTION

During the last two decades much attention has been paid to the reclamation of organic wastes and by-products for horticultural utilization. In this line of research composting is one of the most attractive organic waste management methods due to the further reutilization of the end product -compost- (Raviv, 1998; Hauke and Stöppler-Zimmer, 1999) in a number of useful applications such as soil amending, fertilization, or restoration, landfill covering, landscaping, containerized medium, and so forth.

In order to reduce the consumption of *Sphagnum* peat, the use of compost in the formulation of soilless growing media has become widespread in certain areas of commercial horticulture, especially in containerized ornamental plant production (Fitzpatrick et al., 1998; Abad et al., 2001; Raviv et al., 2002). There are composts which show physical and chemical characteristics similar to peat, making them suitable as peat substitutes. Nevertheless, most composts can not be used as such for horticultural purposes due to an excess of salts or nutrients that leads to substrates with high electrical conductivity (Abad et al., 2001; García-Gómez et al., 2002; Sánchez-Monedero et al., 2004). A high salt concentration constitutes a critical and significant limiting factor, particularly in nursery production, since the early growth stages of the plant are very sensitive to growing media salinity (Marschner, 1995).

These poor saline composts can be improved either by leaching with water (Chen et al., 1984; Lohr et al., 1984; Marfà et al., 1998) or by mixing with other non-saline materials (Eklind et al., 1998; Atiyeh et al., 2001).

This work investigated the leaching of salt and mineral elements from three composts prepared with the residual biomass of different vegetable crops and from one limed peat used as control.

MATERIALS AND METHODS

Composts and Peat

Three mature composts (C1, C2 and C3) prepared with different agricultural wastes - mainly residual vegetable crop biomass removed from the soil at the end of the growing season- were studied (composition expressed in % by volume):

C1 - melon (75 %) + yard trimmings (19 %) + almond husk (6 %)

C2 - pepper (75 %) + almond husk (15 %) + yard trimmings (10 %)

C3 - zucchini (70 %) + cucumber (15 %) + pepper (15 %)

To mixtures C1 and C2 dilute sulphuric acid and ligno-cellulolytic bacteria were added. These mixtures were composted in a pilot plant (University of Almería, Spain) using a combined system -Rutgers static pile, with forced aeration and controlled temperature, plus pile turning- for 45 days, and they were then left to mature for another 135 days. Mix C3 was added with urea and one enzyme formulae, and composted under commercial conditions (Ejido Medio Ambiente S.A.[®], Almería, Spain) using the open windrow system with periodical pile turning. Composting lasted 60 days and at that time the compost was allowed to mature for another 15 days.

The three composts reached an acceptable degree of maturity -being the total organic carbon to total nitrogen (C/N) ratio about 17, cation exchange capacity ranging from 34 (C3) to 59 cmol_c/kg (C1), and cress germination index greater than 60% of the control- and showed total organic matter contents of 67%, 70% and 26% for C1, C2 and C3, respectively.

For purposes of comparison, a light and weakly-decomposed Finnish *Sphagnum* moss peat (P) -H1 to H3 according to the Von Post scale- was included as control. The peat was limed with dolomite to raise pH from 3.50 to 5.57.

Compost and Peat Characterization

The composts and peat were characterized physically at the beginning of the leaching experiment as well as chemically at both the beginning and the end.

The geometric particle-size diameter was calculated following Shirazi and Boersma (1984). Dry bulk density, total pore space, air volume and water volume were determined following UNE-EN 13041 (2001). The water release curve was obtained in accordance with De Boodt et al. (1974). The relative hydraulic conductivity at 1 kPa tension -Kr (1 kPa)- was predicted by combining the hydraulic models proposed by Mualem (1976) and Van Genuchten (1980).

Both the electrical conductivity (EC) and the available mineral element concentrations were determined in the filtered water suspension 1:5 (v:v) as described in UNE-EN 13038 (2001) and UNE-EN 13652 (2002), respectively.

All determinations were replicated three times.

Column Preparation and Leaching

Methacrylate columns measuring 40 cm in height and 5.3 cm in diameter were filled with 883 ml of each material with a moisture content equivalent to container capacity (CC, determined at 2 kPa). The leaching experiment was performed in triplicate (3 columns per material). Loosely-packed cores were compacted by 10% of their height using a piston. Different volumes of distilled water, determined as multiples of container capacity (xCC), were poured through the materials to complete 8xCC. To collect the greatest volume of leachates, the time elapsed between two successive additions of water was 1 hour approximately.

The effluents -leachates- were collected continuously and analysed as such for EC and mineral N, P, K⁺, Ca²⁺, Mg²⁺, Cl⁻, S, Na⁺, and micronutrients determinations. Available N (NO₃⁻ and NH₄⁺) was determined by distillation, P, K⁺, Ca²⁺, Mg²⁺, S, Na⁺, and micronutrients by ICP-AES, and Cl⁻ by means of an automatic titrator.

A leaching efficiency index (LE, %) was calculated (adapted from Kerr and Hanan, 1985) using the equation:

$$LE = 100 \times \left(1 - \frac{X}{X_0}\right)$$

where X = EC (mS/m) or ion content (mg/L) in the material leached, and X_0 = EC (mS/m) or ion content (mg/L) in the material before leaching.

RESULTS AND DISCUSSION

The purpose of the leaching experiment carried out in plastic columns using distilled water was twofold. On the one hand, to investigate the leaching pattern of salts and mineral elements washed out from the four materials studied (composts C1, C2 and C3, and limed moss peat, P). On the other hand, to examine the changes with leaching in both the EC and the concentration of soluble elements in the aforementioned solid materials, and hence the removal efficiency of salts. This is of paramount importance for the composts studied, because their high salinity makes them unsuitable for growing ornamental plants in containers.

Leaching the composts with water decreased substantially the salinity and the concentration of soluble mineral elements both in the leachates and in the composts, with significant differences in the displacement efficiency of salts between the three composted materials. Moreover, water soluble elements differed in their ability to be removed from the composts.

Leaching Curves

Variations in the physico-chemical and chemical parameters determined in the effluents throughout the leaching experiment are shown in Figures 1 and 2. As stated before (see Materials and Methods), the volume of water applied with the various leaching fractions was different for each material since it depended on its CC.

Changes with leaching in the EC of the leachates for the four materials studied - including the best fitted polynomial model equations and their coefficient of determination (R^2)- are shown in Figure 1. The EC of drainage waters of composts was too high at the beginning of the experiment (over 3000 mS/m), but it decreased rapidly, especially in C2. EC curves for C1 and C3 intersected at $2.5 \times \text{CC}$ volumes of water; from this point of intersection, the C1 curve -with higher initial levels- remained below that for C3 until the end of the experiment. After $5 \times \text{CC}$ of water, the EC of compost effluents was close to that of peat, particularly for C1 and C2.

The EC of peat leachates did not vary significantly throughout the experiment -in spite of the fact that the peat was previously limed- and it was remarkably lower (below 40 mS/m) than that of the composted materials.

With regard to the mineral element contents in the leachates (Fig. 2), the composts washed out great amounts of K^+ , Cl^- and S compared to all other components. Most of the N leached from the composted materials was in the NH_4^+ -N form since drainage waters contained negligible and non-detectable amounts of NO_3^- -N. Rapid leaching of NH_4^+ -N occurred in the three composts with no significant differences. P was removed slowly and in a slight amount -particularly in C3- probably because of chemical binding or adsorption processes in the composted materials. By contrast, K^+ was leached easily -despite its high initial levels- and with similar kinetics in C1 and C2 in comparison with C3. Changes of S, Mg^{2+} and Ca^{2+} concentrations in leachates were similar for the three composts; although the contents of these elements were higher in C1 throughout the study, after pouring $5 \times \text{CC}$ of water for S and Mg^{2+} or $7 \times \text{CC}$ for Ca^{2+} , they equalled those from C2 and C3. Leaching curves for Cl^- and Na^+ showed a trend of variation similar to that for EC, the effluents of the composts containing negligible amounts of these ions at $5 \times \text{CC}$ volumes of water. Fourth-power polynomial was the best model to which data for mineral element concentrations in leachates fitted, the coefficient of determination (R^2) being greater than 0.970 in most cases.

Limed peat moss contained small amounts of mineral elements -with the exception of Ca^{2+} and Mg^{2+} -, the leaching curves resting practically on the X-axis.

On the other hand, the microelements Fe, Cu, Zn, Mn, and Mo leached rapidly -after 2 to $3 \times \text{CC}$ of effluent-, whereas B was hardly removed. Moreover, the composts differed in the displacement efficiency of micronutrients, which were removed from C1 and C2 more easily than from C3 (data not shown).

Effects of Leaching on Composts and Peat

EC readings and mineral element concentrations of composts and peat -determined in the 1:5 (v:v) water extract and expressed as mg per liter material- at the beginning (B) and at the end (E, after 8xCC of effluent) of the leaching experiment are shown in Table 1.

The EC decreased sharply with leaching and finally reached acceptable levels (< 170 mS/m) despite the high initial value of this parameter in the composts (> 480 mS/m). This drop in the EC was parallel to that experienced in the contents of soluble mineral elements - mainly K^+ , Ca^{2+} , Cl^- , S, and Na^+ - especially in C1 and C2. Compost C3 reacted weakly to leaching since it exhibited in general higher levels of elements at the end of the experiment irrespective of their initial values.

The limed peat presented a low concentration of mineral elements from the beginning of the experiment; after leaching, some of them decreased either sharply (NH_4^+-N , K^+ , Ca^{2+} , and Mg^{2+}) or to non-detectable levels (P), whereas others washed out hardly (Cl^- , S, and Na^+) and remained close to the initial values.

The efficiency with which the salts were removed from the materials is shown in Table 2. The composts differed in the leaching efficiency index (LE): the highest reduction in EC values was found in C2 (LE = 89%) and in C1 (LE = 84%), whereas the lowest was observed in C3 (LE $< 78\%$).

It is known that the control of the leaching efficiency depends on certain physical characteristics of the material. In the present study, composts C1 and C2 -with a relatively high efficiency of salt removal- are characterized by their smaller particle size and lower bulk density, total water-holding capacity, and relative hydraulic conductivity, together with higher total porosity and air content, than compost C3 (Table 3). The poor physical properties of compost C3 resulting from its lower organic matter content (26% vs. 67% and 70% for C1 and C2, respectively) prevented water from percolating appropriately through the compost and hence, leaching was quite inefficient.

From among the most abundant elements in the composts, S, K^+ , Cl^- and Na^+ showed the maximum efficiency in salt removal (average LE $\approx 90\%$), whereas P yielded the minimum one (average LE $< 35\%$) probably because of chemical binding or adsorption as indicated in the previous section (Leaching Curves); Mg^{2+} and Ca^{2+} ions exhibited an intermediate leaching efficiency (around 65% and 80%, respectively) (Table 2).

CONCLUSIONS

The composts prepared with residual vegetable crop biomass showed an excess of salt and nutrients that leads to growing media with high EC.

These poor saline composts were improved significantly by leaching; most of the salt content was removed by applying 5 times the amount of water held in the material at CC. Composts differed in the efficiency with which the salts were removed. In addition, mineral elements differed in their ability to be leached. As soluble nutrients in compost will also be lost in drainage water, the main objective of leaching is to wash out as few nutrients as necessary to reduce EC; the best guide for controlling this will be to leach according to EC measurements.

To avoid environmental pollution, special emphasis must be paid to the management and treatment of effluents produced when leaching saline composts under commercial conditions. Nevertheless, the low levels of available nitrogen and the chemical binding or adsorption of phosphorus found in the composts studied will reduce N and P concentrations in leachates.

Since leaching is fresh water and time consuming as well as a potential source of pollution, the use of unleached compost mixed with other non-saline, nutrient-poor materials should be tested and horticulturally evaluated under commercial growing conditions.

ACKNOWLEDGEMENTS

This research was financially supported by the Spanish Ministry of Science and Technology (MCyT) through the Project AGL 2001-2815 AGR. The authors would like to thank Dr. Debra Westall for her revision of the English in this text.

Literature Cited

- Abad, M., Noguera, P. and Burés, S. 2001. National inventory of organic wastes for use as growing media for ornamental potted plant production: case study in Spain. *Bioresource Technol.* 77: 197-200.
- Atiyeh, R.M., Edwards, C.A., Subler, S. and Metzger, J.D. 2001. Pig manure vermicompost as a component of a horticultural bedding plant medium: effects on physicochemical properties and plant growth. *Bioresource Technol.* 78: 11-20.
- Chen, Y., Inbar, Y., Raviv, M. and Dovrat, A. 1984. The use of slurry produced by methanogenic fermentation of cow manure as a peat substitute in horticulture - physical and chemical characteristics. *Acta Hort.* 150: 553-561.
- De Boodt, M., Verdonck, O. and Cappaert, I. 1974. Method for measuring the water release curve of organic substrates. *Acta Hort.* 37: 2054-2062.
- Eklind, Y., Salomonsson, L., Wivstad, M. and Rämert, B. 1998. Use of herbage compost as horticultural substrate and source of plant nutrients. *Biol. Agri. Hort.* 16: 269-290.
- Fitzpatrick, G.E., Duke, E.R. and Klock-Moore, K.A. 1998. Use of compost products for ornamental crop production: research and grower experiences. *HortScience* 33: 941-944.
- García-Gómez, A., Bernal, M.P. and Roig, A. 2002. Growth of ornamental plants in two composts prepared from agro-industrial wastes. *Bioresource Technol.* 83: 81-87.
- Hauke, H. and Stöppler-Zimmer, H. 1999. Compost based products: history, recent activities, chances. p. 363-369. In: W. Bidlingmaier, M. de Bertoldi, L.F. Diaz and E.K. Papadimitriou (eds.), *Orbit 99: Organic Recovery and Biological Treatment*. Rhombos Verlag, Berlin.
- Kerr, G.P. and Hanan, J.J. 1985. Leaching of container media. *J. Amer. Soc. Hort. Sci.* 110: 474-480.
- Lohr, V.I., Wang, S.H. and Wolt, J.D. 1984. Physical and chemical characteristics of fresh and aged spent mushroom compost. *HortScience* 19: 681-683.
- Marfà, O., Tort, J.M., Olivella, C., Cáceres, R. and Martínez, F.X. 1998. Cattle manure compost as substrate. II - Conditioning and formulation of growing media for cut flower cultures. *Acta Hort.* 469: 305-312.
- Marschner, H. 1995. *Mineral Nutrition of Higher Plants*, 2nd ed. Academic Press, London.
- Mualem, Y. 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media. *Water Resources Res.* 12: 513-522.
- Raviv, M. 1998. Horticultural uses of composted material. *Acta Hort.* 469: 225-234.
- Raviv, M., Wallach, R., Silber, A. and Bar-Tal, A. 2002. Substrates and their analysis. p. 25-101. In: D. Savvas and H. Passam (eds.), *Hydroponic Production of Vegetables and Ornamentals*. Embryo Publ., Athens.
- Sánchez-Monedero, M.A., Roig, A., Cegarra, J., Bernal, M.P., Noguera, P., Abad, M. and Antón, A. 2004. Composts as media constituents for vegetable transplant production. *Compost Science and Utilization* 12: 161-168.
- Shirazi, M.A. and Boersma, L. 1984. A unifying quantitative analysis of soil texture. *Soil Sci. Soc. Amer. J.* 48: 142-147.
- UNE-EN 13038. 2001. Mejoradores de suelo y sustratos de cultivo. Determinación de la conductividad eléctrica. AENOR, Madrid.
- UNE-EN 13041. 2001. Mejoradores de suelo y sustratos de cultivo. Determinación de las propiedades físicas. Densidad aparente seca, volumen de aire, volumen de agua, valor de contracción y porosidad total. AENOR, Madrid.
- UNE-EN 13652. 2002. Mejoradores de suelo y sustratos de cultivo. Extracción de nutrientes y elementos solubles en agua. AENOR, Madrid.
- Van Genuchten, M.T. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Amer. J.* 49: 12-19.

Tables

Table 1. Electrical conductivity (EC) values and available element concentrations of composts (C1, C2 and C3) and peat (P) at the beginning (B) and at the end (E) of the leaching experiment.

Parameter	C1		C2		C3		P	
	B	E	B	E	B	E	B	E
EC (mS/m)	870	141	482	55	719	168	99	69
Available elements (mg/L material)								
(NO ₃ ⁻ +NH ₄ ⁺)-N	97.5	2.33	232	6.90	145	45.8	4.71	1.40
P	21.8	11.5	26.0	15.6	218	183	0.46	nd
K ⁺	8725	412	3409	219	13927	2624	5.80	2.97
Ca ²⁺	1615	527	202	44.8	286	8.54	16.8	2.40
Mg ²⁺	549	116	221	58.0	147	80.7	6.81	2.14
Cl ⁻	6483	189	997	28.9	3959	298	95.0	85.0
S	7848	800	1460	62.7	2338	220	16.6	12.3
Na ⁺	1314	104	340	6.40	429	173	60.2	54.5

nd = non-detectable.

In any case, paired values (B and E) differed significantly at $P \leq 0.01$ (at least).

Table 2. Leaching efficiency index (LE) of salts and mineral elements for composts (C1, C2 and C3) and peat (P).

Parameter	LE (%)			
	C1	C2	C3	P
EC	84b	89a	77c	30d
(NO ₃ ⁻ +NH ₄ ⁺)-N	98a	97a	69b	70b
P	47a	40b	16c	--
K ⁺	95a	94a	81b	49c
Ca ²⁺	67d	78c	97a	86b
Mg ²⁺	79a	74b	45d	69c
Cl ⁻	97a	97a	92b	11c
S	90b	96a	91b	26c
Na ⁺	92b	98a	60c	9d

EC - electrical conductivity.

The analysis of variance (ANOVA) was significant at $P \leq 0.001$ for the parameters studied.

Mean separation within rows by Student-Newman-Keuls multiple range test ($P \leq 0.05$).

Table 3. Selected physical properties of composts (C1, C2 and C3) and peat (P).

Property	C1	C2	C3	P
Geometric particle-size diameter (mm)	1.12c	1.27b	1.49a	0.82d
Bulk density (kg/m³)	331b	258c	642a	86d
Total pore space (% v/v)	80.6c	84.6b	69.7d	94.2a
Air volume (% v/v)	31.5b	45.1a	13.4d	19.8c
Water volume (% v/v)	49.1c	39.5d	56.3b	74.4a
Kr (1 kPa)	1.27x10 ⁻³ c	2.26x10 ⁻⁷ d	2.54x10 ⁻¹ a	8.45x10 ⁻² b

The analysis of variance (ANOVA) was significant at $P \leq 0.001$ for the properties studied. Mean separation within rows by Student-Newman-Keuls multiple range test ($P \leq 0.05$).

Figures

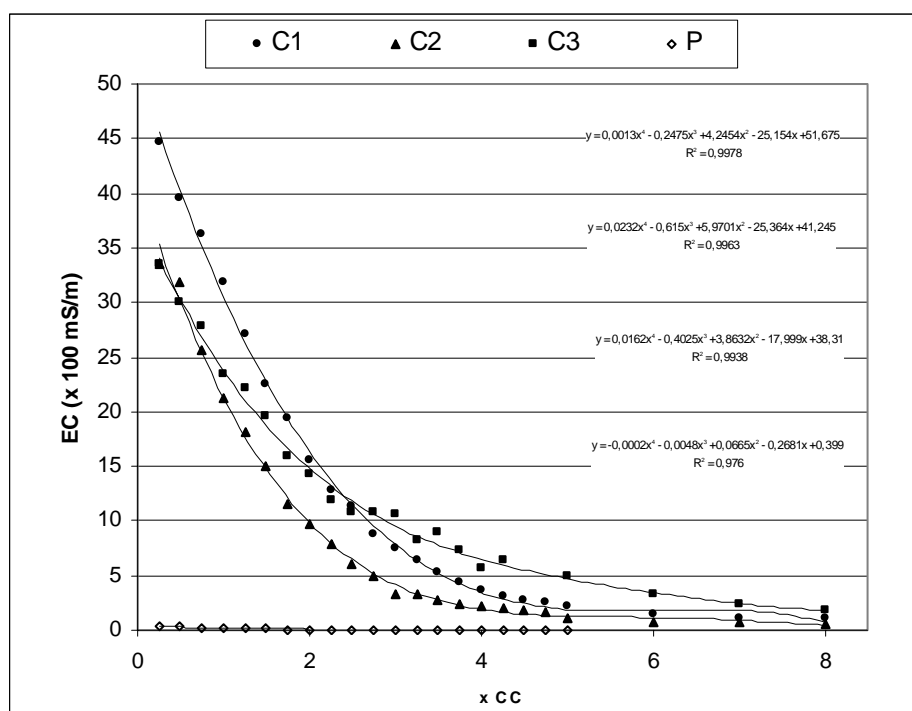


Fig. 1. Leaching curves of 40 cm deep columns of composts (C1, C2 and C3) and peat (P). Points shown are averages of 3 values each. Model equations are arranged from top to bottom for C1, C2, C3 and P, respectively. EC - electrical conductivity; CC - container capacity.

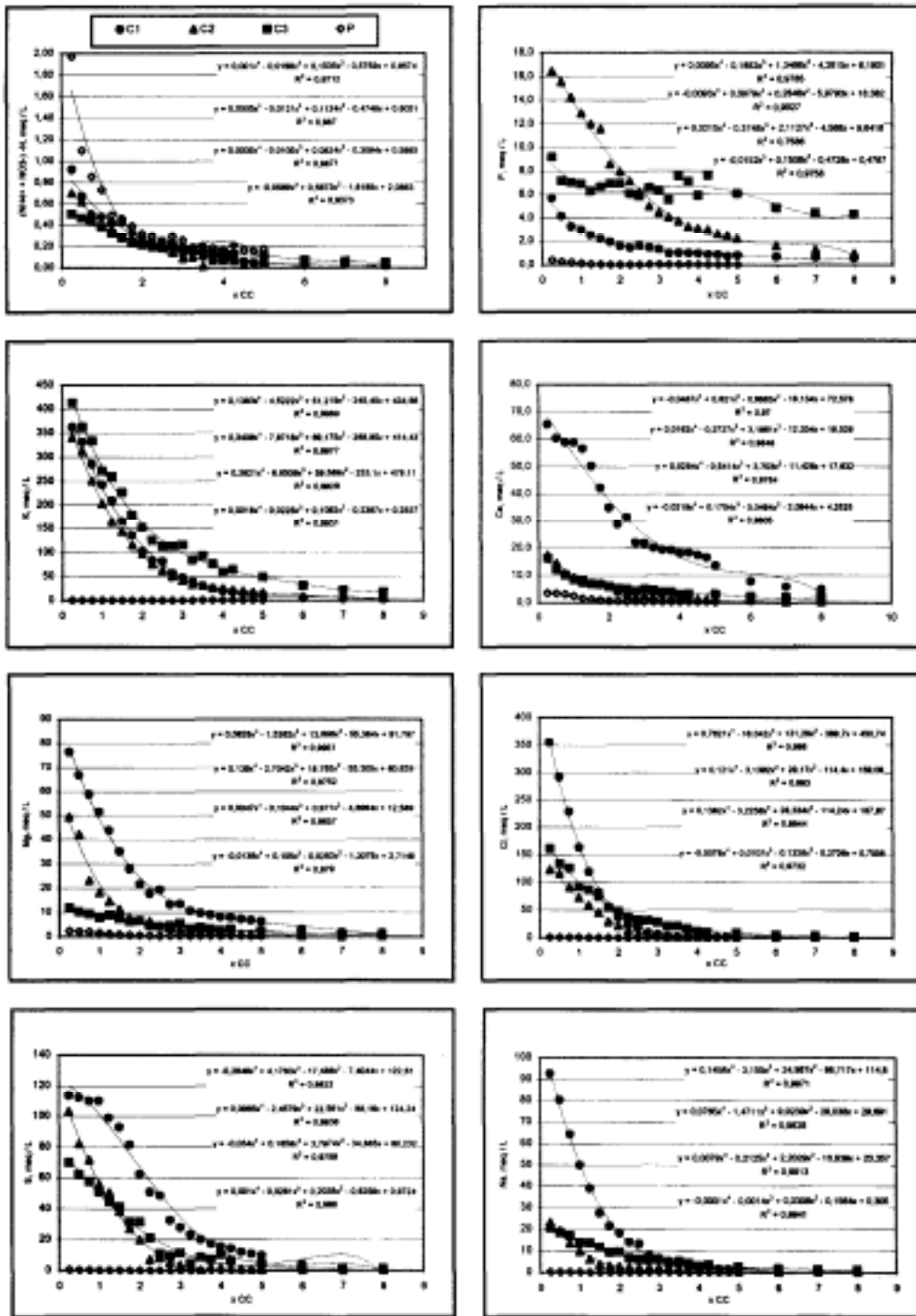


Fig. 2. Evolution of the concentration of mineral elements (in me/L leachate) with leaching of composts (C1, C2 and C3) and peat (P). Points shown are averages of 3 values each. In any case, model equations are arranged from top to bottom for C1, C2, C3 and P, respectively. CC - container capacity.