Agriculture, Ecosystems and Environment 141 (2011) 100–107

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Environmental and agronomic impact of fertilization with composted organic fraction from municipal solid waste: A case study in the region of Naples, Italy

Massimo Fagnano[a,*], Paola Adamo[b], Mariavittoria Zampella[b], Nunzio Fiorentino[a]

[a] *Dipartimento di Ingegneria agraria e Agronomia, Università di Napoli Federico II, Via Università 100, 80055 Portici, Italy*
[b] *Dipartimento di Scienze del Suolo, della Pianta, dell'Ambiente e delle Produzioni Animali, Università di Napoli Federico II, Via Università 100, 80055 Portici, Italy*

ARTICLE INFO

Article history:
Received 7 September 2010
Received in revised form 8 February 2011
Accepted 11 February 2011
Available online 5 March 2011

Key words:
Compost fertilization
Municipal solid waste
Heavy metal
Nitrate
Lettuce yield

ABSTRACT

In large urban agglomerations, composting of organic waste is a possible solution to the long-standing rubbish problem, limiting the amount of waste going to final disposal. Fertilization with composted waste from Naples city was studied with the aim to evaluate the possibility of recycling waste through its agricultural use after composting. The best agronomic (soil fertility, quantity and quality of lettuce yield) and environmental (C storage in stable SOM, low risk of potentially toxic metal and nitrate pollution) results were obtained using the 30 Mg ha^{-1} dose of compost. In compost and soil, total concentrations of Cu, Cr, Pb and Zn were always below European pollutant limits. However, after plant growth and compost fertilization at the highest dose (60 Mg ha^{-1}), the amounts of EDTA-extractable Pb and Zn in soil significantly increased, suggesting a role of composted organics and root exudates in metal bioavailability. Fertilization with composted waste could have positive agronomic and environmental effects if the doses are balanced against the N requirements of crops. However, further researches are needed to assess the long-term effect of repeated compost application to soil and the potential cumulative effects.

1. Introduction

Compost manure is frequently advocated as an inexpensive and simple solution for a wide variety of agronomic, environmental and socio-economic problems. In agricultural soils, compost addition increases porosity, structural stability, moisture and nutrient availability, biological activity, root aeration and protects soil from erosion (Pinamonti et al., 1997; Garcia-Gil et al., 2000; Aggelides and Londra, 2000; Ramos and Martınez-Casasnovas, 2006; Weber et al., 2007).

Compost fertilization increases the molecular diversity of soil organic matter (SOM), increasing the amounts of fatty acids, *n*-alkanes, and biopolyesters derivatives, thus indicating direct inputs of undecomposed lignin residues and hydrocarbon waxes (Spaccini et al., 2009). These hydrophobic compounds protect the biolabile soil carbon from mineralization thereby enhancing the carbon sink capacity of SOM and thus contributing to greenhouse gases mitigation (Spaccini et al., 2002; Piccolo et al., 2004; Forte et al., 2009). The effect of compost on SOM increase and stabilization could be particularly useful in Mediterranean areas, where the degradation of SOM is accelerated by the succession of dry-warm to humid-temperate seasons and by the high intensity and frequency of soil tillage in horticultural areas (Cala et al., 2005).

Nevertheless, the effect of compost on soil fertility and crop response can vary in relation to soil properties such as porosity and oxygen availability, pH, initial content of organic matter, clay and iron oxide (Courtney and Mullen, 2008; Forte et al., 2009).

Compost fertilization may have some negative effects on the environment, such as the increase of soil content of potentially toxic elements (PTEs) and nitrates (Jordao et al., 2003). PTEs include essential and nonessential elements, which at different levels can cause toxicity to both plants and animals. They are not biodegradable; therefore, if an excess of PTEs is introduced in soil with the application of low-quality compost, fertility may be adversely affected, ground-water quality threatened, and the food chain contaminated (Sims and Kline, 1991; McBride, 1995; Keller et al., 2002).

In southern Italy, the environmental waste problem has been festering for decades becoming the subject of recent campaigns in the media. In particular, the city of Naples, with its mean population density of about 2600 persons per square kilometre and its large agglomeration, produces more rubbish than its coping capacity. Areas for landfilling are limited, and the situation has generated illegal waste dumping and a diffuse management of hazardous waste (Basile et al., 2009). The composting of the organic fraction contained in municipal solid waste (MSW) could limit the amount of waste going to final disposal. Therefore, from the perspective of a recycling economy, the use in agriculture of compost from municipal waste, which is potentially a useful resource for soil organic

* Corresponding author. Tel.: +39 0812539129.
E-mail addresses: massimo.fagnano@unina.it (M. Fagnano), adamo@unina.it (P. Adamo), mvzampel@unina.it (M. Zampella), nunzio.fiorentino@unina.it (N. Fiorentino).

0167-8809/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2011.02.019

Table 1
Main physical and chemical features of the compost.

Feature	Unit		Notes
Humidity	%	60.0	On total compost mass
Non-compostable materials	%	12.4	Glass and plastic particles > 2 mm
Coarse organic materials	%	39.4	Wood particles > 2 mm
Organic matter	%	15.8	On <2 mm compost mass
Total organic matter	%	55.2	On total compostable dry matter
Total organic C	%	32.1	On total compostable dry matter
Total N	%	1.3	On total compostable dry matter
C/N		24.1	On total compostable dry matter
Organic N	%	1.3	On total compostable dry matter
NH_4-N	mg kg^{-1}	174.5	On total compostable dry matter
NO_3-N	mg kg^{-1}	6.8	On total compostable dry matter
K_2O	g kg^{-1}	9.5	On total compostable dry matter
P_2O_5	g kg^{-1}	0.2	On total compostable dry matter
$CaCO_3$	g kg^{-1}	114.7	On total compostable dry matter
Cu	mg kg^{-1}	41.7	On total compostable dry matter
Pb	mg kg^{-1}	81.1	On total compostable dry matter
Zn	mg kg^{-1}	77.2	On total compostable dry matter
Cr	mg kg^{-1}	8.3	On total compostable dry matter

fertility restoration, could also contribute to the solution of the rubbish problem in other densely urbanised areas, with both economical and environmental benefits. The beneficial aspects should be assessed together with the potentially detrimental ones and the introduction of PTEs to soils needs to be controlled and their transfer to crops studied (Weber et al., 2007).

In the present paper, the potential effects of composted MSW on organic matter content, nutrient availability and lettuce yield were investigated in a Mediterranean agro-ecosystem. Potential environmental risks were evaluated by the analysis of nitrates and total and bioavailable (EDTA-extractable) Cu, Cr, Pb and Zn contents. For this purpose, the impact of fertilization with compost made from the organic fraction of Naples urban wastes was investigated in field conditions.

2. Materials and methods

2.1. Crop and experimental layout

The field experiment was carried out in a farm of Caivano municipality (40°56′N, 14°19′E), 12 km from Naples City. A randomized block design with 3 replicates was used to compare the following treatments: not fertilized control (NF), mineral fertilization (MF), compost fertilization with 10 (CF10), 30 (CF30) and 60 (CF60) Mg (fresh weight) ha^{-1} of compost from solid urban wastes.

Compost samples were gathered from a public composting plant that used as raw material lawn mower and pruning residues from public and private gardens and the organic fraction of MSW. In relation to Italian legislation regulating compost quality (L 784/94; DL 99/92) the main anomalies of this compost were the presence of non-compostable fraction (glasses and plastics) (12% *vs.* a legal threshold <0.66%) and the excessive humidity (60% *vs.* <50%) (Table 1). In order to bring the compost within legal limits, it was sieved to 2 mm and non-compostable fraction was excluded before application and chemical analyses.

The molecular characterization of the compost has been reported in a previous work (Spaccini et al., 2009) which found the presence of lignin components, aliphatic hydrocarbons, linear and branched fatty acids, cyclic lipid compounds and biopolyesters. A large part of these compounds consisted in plant biopolymers denoting the abundance of crop residues in compost raw material.

Considering the 3 doses applied in the experiment (10, 30 and 60 Mg ha^{-1}), the supplied amounts of nutrients respectively

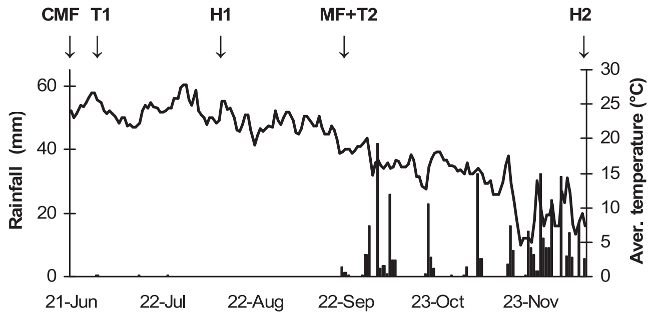

Fig. 1. Daily rainfall amount and average temperature during the two lettuce cycles (C, compost; M, mineral; F, fertilization; T, transplantation; H, harvest).

were: 1282, 3847 and 7694 kg C ha^{-1}; 53, 160 and 319 kg N ha^{-1}; 0.7, 2.0, and 4.0 kg P_2O_5 ha^{-1}; 38, 115 and 230 kg K_2O ha^{-1}. The supplied amounts of PTEs were 0.2, 0.5 and 1.0 kg Cu ha^{-1}; 0.3, 1.0 and 1.9 kg Pb ha^{-1}; 0.3, 0.9 and 1.9 kg Zn ha^{-1}; 0.03, 0.1 and 0.2 kg Cr ha^{-1}.

The compost was spread and buried with a rotary hoe on 2004 June 21. In the 1st cycle of lettuce, transplantation was made on July 2 and harvest on August 9 (38 days). In the 2nd cycle, transplantation was made on 2005 September 25 and harvest on December 12 (78 days). In both the periods 112 lettuce plants were transplanted in each 8.4 m^2 (4.0 m × 2.1 m) plot, according to a density of 13 plants m^{-2} (25 cm × 30 cm).

Two cultivars of iceberg lettuce (*L. sativa* var. *capitata* L.) were used, 'Audran' in the 1st cycle and 'Sagess' in the 2nd one, suitable to summer and winter cropping periods respectively.

Compost fertilization was made only before the 1st cycle, while mineral fertilization with 84 kg N ha^{-1} (ammonium nitrate) was made in MF plots at transplant of both lettuce cycles.

Soil was an Eutric Regosol, with a sandy loam texture (sand, 565 g kg^{-1}; silt, 285 g kg^{-1}; clay, 150 g kg^{-1}), low CEC (13.1 cmol kg^{-1}), subalkaline pH (8.1), and a medium water availability (field capacity, 21.5%; wilting point, 10.7%; available water, 10.8%), due to the high organic matter content (30 g kg^{-1}). Total carbonates were very high (520 g kg^{-1}), and contents of assimilable P_2O_5 (46 mg kg^{-1}), exchangeable K_2O (410 mg kg^{-1}) and NO_3-N (35 mg kg^{-1}) were high. The NH_4-N content (4 mg kg^{-1}) and the NH_4-N to NO_3-N ratio (0.11) were very low, which, together with the coarse soil texture, indicates a prevailing aerobic condition (Alluvione et al., 2008).

2.2. Weather, water balance and irrigation

Maximum evapotranspiration (ETm) was calculated as the product of the daily reference evapotranspiration (Hargreaves et al., 1985) and the crop coefficients (from 0.7 to 1.0), as suggested by Allen et al. (1998). During the 1st cycle of lettuce (July 2–August 9), there was no effective rainfall (Fig. 1), total ETm was 190 mm (4.9 mm day^{-1} on the average) and water deficit (ETm − rainfall) was reintegrated by irrigation. In the 2nd cycle of lettuce (September 25–December 12), rainfalls were frequent and much higher (412 mm) than ETm (112 mm).

2.3. Samplings

Soil samples were collected from the top layer (0–20 cm) on June 21 (before compost and mineral fertilization) and on July 12, 19, 26, August 2 and 9 (1st cycle harvest); September 24 (before mineral fertilization), October 20, November 18, December 1 and 12 (2nd cycle harvest).

Lettuce yield of each plot was measured from a 2.7 m^2 harvest area (about 35 plants) on August 9 and December 12. A two-plant sub-sample was collected from each plot for chemical analyses.

2.4. Macronutrients

Analyses, such as the treatments, were made on the combined organic coarse fraction and fine fraction of compost. NO_3-N, NH_4-N, K and P were determined using the DR/2000 Hatch® spectrophotometer, while the Kjeldhal and Walkley Black methods were used for total N and organic C respectively. Organic N was calculated as Kjeldhal N minus NH_4-N.

N balance (kg N ha^{-1}) was calculated with respect to supply and uptake of total N (Kjeldhal N plus NO_3-N).

N from mineralization was estimated as the sum of N uptake in control plots and the increase of mineral N (NO_3-N plus NH_4-N) from transplanting to harvest in a 20 cm soil layer. Thus, N uptake by the control plant and mineral N increase in the root layer derived from soil organic N mineralization (Meisinger, 1984; Alluvione et al., 2008) were considered.

N and C mass content (Mg ha^{-1}) of the soil top layer (0–20 cm) was calculated by multiplying the measured concentrations by the volume of soil layer (2000 m^3 ha^{-1}) by the bulk density measured in this soil layer (1.35 Mg m^{-3}).

2.5. Potentially toxic elements

Potentially toxic elements (PTE: Cu, Cr, Pb and Zn) were investigated in compost, in soil before the 21 June fertilization, and in soil and plants from NF and CF60 treatments after the harvest of the 2nd lettuce cycle. For the determination of PTEs total content, soil, compost and plant samples were dried and crushed with a mortar and pestle prior to acid digestion in a Milestone 900 microwave oven. The digestion procedure for soil employed a H_2O_2 and HCl:HNO_3 3:1 solution at 250–650 W for 24 min. The digestion procedure for compost and plants employed a H_2O_2:HNO_3 1:3 solution at 250–600 W for 20 min. Accuracy of element determination was controlled by analyzing the certified reference materials BCR-CRM-141R for soil and CTA-VTL-2 for plant material.

The bioavailable fraction of Cu, Cr, Pb and Zn was extracted from soil by 0.05 M EDTA, according with the EC-BCR procedure (soil to extractant 1:10, end-over-end shaker for 60 min). Accuracy was controlled by analyzing BCR-700 (organic-rich soil) certified reference material. The element concentration in all extracts was determined by a PerkinElmer Analyst 700 atomic absorption spectrometer.

2.6. Data analysis

All the data were subjected to ANOVA, using the MSTAT-C software (Crop and Soil Science Department, Michigan State University, Version 2.0). The experimental design was a randomized block with 3 replicates and 5 treatments (NF, MF, CF10, CF30, CF60). Multiple comparisons of means were made calculating the LSD ($P \leq 0.05$).

3. Results

3.1. Lettuce yield and nitrate content

In both the growth cycles, total yield of lettuce was higher with MF and with the two highest compost doses (Table 2). The non-marketable yield (unformed heads or average weight lower than 200 g per head) in the 1st cycle was low in MF, CF30 and CF60, whereas in the 2nd cycle was low only in MF and CF60. In both cycles, the average weight of lettuce heads from all fertilized plots was higher than that from the control plots. Lettuce yield was lower in the winter than in the summer cycle for all treatments

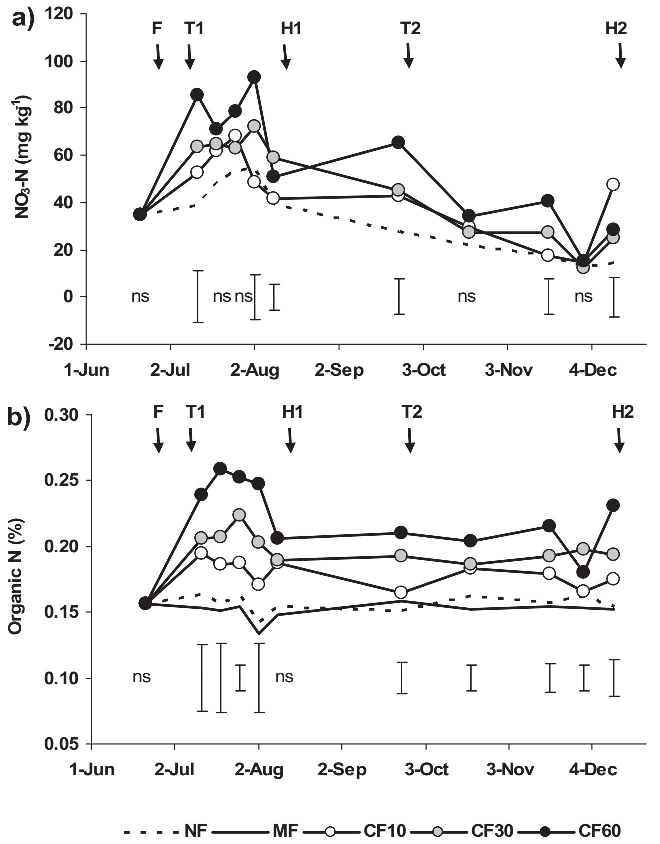

Fig. 2. Nitrate-N (a) and Organic N (b) content of the top soil (0–20 cm): average values and LSD (bars) per $P \leq 0.05$ in the different sampling dates; ns, not significant. Fertilization, F; transplanting of lettuce in the two cycles (T1, T2), harvests of lettuce (H1, H2). Not fertilized control (NF), mineral fertilization (MF), fertilization with 10 (CF10), 30 (CF30) and 60 (CF60) Mg ha^{-1} of compost.

(39.8 Mg ha^{-1} *vs.* 45.8 Mg ha^{-1} on average), whereas the nitrate content of lettuce showed an opposite trend (624 mg NO_3 kg^{-1} f.w. *vs.* 363 mg NO_3 kg^{-1} f.w. on average). Nevertheless, all nitrate values, with no significant differences among treatments, were much lower than the threshold values laid down in 466/01 European Directive (4500 mg NO_3 kg^{-1} of fresh weight).

As regards the NO_3-N content of lettuce plants during the two growth cycles (data not shown), the differences among the treatments were significant in the first sampling date. It is interesting that on July 12 (21 days after the compost distribution), nitrate contents of plants fertilized with compost (0.3, 0.2 and 0.2% in CF10, CF20 and CF30, respectively) were significantly lower than the one of the non-fertilized plots (0.5%) and of MF (0.5%). This may be likely due to the large amount of C supply to the soil that could have caused a short-term immobilization of mineral nitrogen by the soil microflora.

3.2. Soil NO_3-N content

NO_3-N content in the top soil layer (0–20 cm) was significantly different among the treatments on July 12, August 2 and 9 (1st lettuce cycle) and on September 24, November 18 and December 12 (Fig. 2a). It increased after fertilization reaching the highest values in MF and CF60. During the 1st cycle of lettuce, nitrate content decreased in MF as a result of lettuce uptake, while it remained higher also in the post-harvest period in the compost-fertilized plots, thus indicating a slow and prolonged nitrification of organic N. During the autumn–winter period the nitrate values were lower than in the previous period in all treatments because of

Table 2
Yield and quality of lettuce in the two growing periods.

Treatment	Total yield ($Mg\,ha^{-1}$)	Not marketable (%)	Marketable yield ($Mg\,ha^{-1}$)	Average weight of heads ($g\,head^{-1}$)	Nitrate content ($mg\,kg^{-1}$ f.w.)
1st cycle (July 2–August 9)					
NF	38.9 c	8.6 a	35.6 c	328 c	306
CF10	44.0 b	6.1 b	41.3 b	352 b	349
CF30	48.1 a	3.7 c	46.4 a	375 a	396
CF60	49.5 a	1.4 d	48.9 a	384 a	375
MF	48.3 a	1.5 d	47.6 a	382 a	390
2nd cycle (September 25–December 12)					
NF	30.7 c	32.1 a	21.0 d	279 b	679
CF10	39.7 b	18.2 b	32.5 c	353 a	543
CF30	42.3 ab	17.6 b	35.0 bc	365 a	500
CF60	44.5 a	8.4 c	40.8 a	385 a	552
MF	41.6 ab	8.6 c	38.0 ab	355 a	845

Note: Values of the two cropping cycles followed by the same letter are not significantly different, according to LSD test at $P \leq 0.05$ level of significance.

both lettuce uptake and rain leaching effect. Only with the highest compost dose, soil nitrate content was significantly higher until mid-November, thus showing that it supplies an excessive N amount as compared with the lettuce needs. In the subsequent samples, corresponding to the most rainy periods, nitrate values were lower and consistent among the treatments confirming the leaching effect of rainfalls in this period.

3.3. Short-term and medium-term variations of some soil characteristics

In the soil samples collected 20 days after fertilization, organic C increased with compost doses (Table 3), while no significant variation was evident for NF, MF and CF10.

The mineral N content in MF also increased in the short term, while no significant variation was observed for P_2O_5 and K_2O, even if higher values were associated with the highest compost dose.

Comparing the values measured at the end of the experimental period (December) with the start-up values, organic C increased with compost doses in the medium term. In contrast, it decreased in NF and MF plots, because SOM degradation due to soil tillage was not balanced by the supply of stable organic matter.

Organic N content of the top layer of soil (0–20 cm) was significantly different among the treatments on July 12, 19, 26 and August 2 (1st lettuce cycle) and on all the sampling dates on the 2nd cycle. It showed no changes during the trial period (July–December) in NF and MF, while it increased with the increase of dose in the compost-fertilized plots (Fig. 2b). In the compost-fertilized plots, higher organic N values were maintained for six months after the compost addition, indicating that compost fertilization can supply organic matter more stable to degradation.

In all the fertilized plots, mineral N was also higher in the December samplings, but in CF30, CF60 and MF these surpluses were lower than those measured in July, probably as a result of plant uptake and rain leaching.

Assimilable P_2O_5 soil content in December showed the same differences from the starting values already observed in July, thus suggesting that it did not change during the lettuce growth periods, remaining higher in all the compost-fertilized plots when compared both with NF and MF.

K_2O soil contents were lower in December sampling, thus indicating a decrease during the two lettuce cycles. This difference may be due in part to the lettuce uptake (252 and 219 $kg\,N\,ha^{-1}$ on the average in the two cycles on the basis of an unitary uptake of 5.5 $kg\,N\,Mg^{-1}$), but also to the very high soil Ca content that saturated the cation exchange capacity, thus moving other cations into the soil circulating solution.

Table 3
Short term (July 12 *vs.* June 21) and medium term (December 12 *vs.* June 21) effects on some soil chemical features: variations respect to the starting values.

	Organic C (%)	Mineral N ($mg\,kg^{-1}$)	Assimilable P_2O_5 ($mg\,kg^{-1}$)	Exchangeable K_2O ($mg\,kg^{-1}$)
Starting values	1.89	39.3	46.1	410
Variations July 12 *vs.* June 21				
NF	−0.03 b	6.7 d	−0.1	−0
CF10	−0.02 b	17.7 cd	8.6	39
CF30	0.06 ab	33.3 bc	2.8	57
CF60	0.47 a	59.0 a	12.1	129
MF	−0.13 b	42.0 ab	−2.5	49
Significance	*0.05*	*0.01*	*n.s.*	*n.s.*
Variations December 12 *vs.* June 21				
NF	−0.24 c	1.8 b	−9.7 c	−59 b
CF10	0.07 b	18.5 a	1.6 bc	−63 b
CF30	0.10 b	15.2 a	17.7 a	−92 b
CF60	0.41 a	26.2 a	8.6 ab	119 a
MF	−0.23 c	19.5 a	−10.5 c	−89 b
Significance	*0.01*	*0.02*	*0.01*	*0.01*

Note: Values followed by the same letter are not significantly different, according to LSD test at $P \leq 0.05$ level of significance.

Table 4
N balance of the two lettuce cycles.

Treatment	N input ($kg\,N\,ha^{-1}$)	Net N uptake[a] ($kg\,N\,ha^{-1}$)		N balance ($kg\,N\,ha^{-1}$)
		1st cycle (Jul. 2–Aug. 9)	2nd cycle (Sept. 25–Dec. 12)	
NF	0.0	69.4	41.8 b	−111.2 c
CF10	53.2	71.4	62.9 ab	−81.1 c
CF30	159.6	75.8	62.0 ab	21.8 b
CF60	319.3	79.2	86.8 a	153.3 a
MF	168.0[b]	81.4	76.0 a	10.6 b
Significance	–	*n.s.*	*0.05*	*0.01*

Note: Values followed by the same letter are not significantly different, according to LSD test at $P \leq 0.05$ level of significance.
[a] Excluded the not-marketable (not formed or underweight) heads that normally remain in field and return to the soil.
[b] 2 fertilizations of $84\,kg\,N\,ha^{-1}$ (from ammonium nitrate).

3.4. Nitrogen balance

The nitrogen balance, calculated considering only input and uptake (Table 4), clearly shows N deficit in control plots and CF10, and a surplus in CF60, whereas values not different from zero were measured in CF30 and MF.

The contribution of N from SOM mineralization, calculated as the sum of N uptake in control plots (75.7 and $54\,kg\,N\,ha^{-1}$ in the 2 cycles, respectively) and the variation of mineral N from transplanting to harvest in a 20 cm soil layer (+38 and $-8\,kg\,N\,ha^{-1}$ in the two cycles), were 107 and $46\,kg\,N\,ha^{-1}$ in the two cycles despite the greater length of the second growth period (38 days in the 1st cycle and 78 in the 2nd one). The reduction of N mineralization in the autumn–winter cycle may be due to the effect of the lower temperatures on nitrification or to leaching of nitrates during the frequent rainfall. In the 6 months of this experiment the contribution of SOM was estimated in $156\,kg\,N\,ha^{-1}$ that corresponded to 3.7% of the starting organic N. Adding the value of mineral N from SOM mineralization to the calculation of N balance results in strong N surplus for all treatments.

3.5. Potentially toxic elements in compost, soil and plant

The total contents of Cu, Cr, Pb and Zn in compost mass, in soil before fertilization and in soil and plants after the 2nd lettuce cycle from NF and CF60 treatments are given in Table 5.

In comparison with the starting values, no significant increment in soil PTEs was measured after compost addition and after the harvest of the 2nd cycle lettuce.

Values for EDTA-extractable Cu, Cr, Pb and Zn in soil before and after the 2nd cycle of lettuce cultivation ranged from 8% (for Cr) to 44% (for Cu) of total PTEs. In the soil amended with $60\,Mg\,ha^{-1}$ of compost (CF60), after the 2nd cycle of lettuce cultivation, EDTA-extractable Pb and Zn were significantly higher than the respective soil contents before fertilization. When PTEs concentrations in plants were expressed as $mg\,kg^{-1}$ of dry biomass, Cu and Pb values for plants harvested from NF soil were slightly higher than those for plants grown on compost-amended (CF60) soil (Table 5) and significant differences in Cu content were found by one-way ANOVA ($P < 0.05$). This is due to the higher dry mass of lettuce plants from CF60 soil ($30.6\,g\,plant^{-1}$) compared with that of plants from NF soil ($25.9\,g\,plant^{-1}$). Indeed, when the PTEs concentrations were expressed as $mg\,plant^{-1}$, the amounts of PTEs absorbed by plants grown on NF and CF60 soils were very similar, with only Zn showing higher values in plants grown on CF60 soil.

4. Discussion

4.1. Compost quality

The compost used in this experiment was produced by a composting plant linked to the public MSW management system of Naples city. It was collected at the platform of the plant directly from the heap ready to be distributed.

From our analyses, its main anomaly was the excessive inorganic coarse fraction (12%) represented by non-compostable glasses and plastics, which were easily removed by sieving. From the chemical standpoint, it showed a number of interesting features. It had a prevailing N organic fraction, a good K and C content, the latter mainly represented by ligninic and lipidic compounds effective for humification, and a trace metal content below the legal threshold.

Table 5
Content ($mg\,kg^{-1}$; mean ± SD; $n = 9$) of potentially toxic elements in compost, in soil before fertilization (starting value) and in soil and lettuce plants after the 2nd lettuce cycle from NF and CF60 treatments.

	Cu	Cr	Pb	Zn
Compost	41.7	8.3	81.1	77.2
Soil				
Total				
Starting value	49.7 ± 1.7	28.6 ± 4.9	102.6 ± 6.2	72.1 ± 3.0
NF	50.4 ± 7.4	29.4 ± 0.6	103.3 ± 9.4	74.1 ± 7.8
CF60	50.0 ± 7.5	29.7 ± 2.0	105.5 ± 8.4	77.5 ± 6.1
Bioavailable fraction[a]				
Starting value	21.7 ± 0.1	2.1 ± 0.18	11.0 ± 1.1	10.0 ± 0.3
NF	22.8 ± 3.3	2.3 ± 0.03	12.2 ± 3.1	12.0 ± 3.7
CF60	21.8 ± 2.3	2.3 ± 0.02	16.5 ± 1.4	17.4 ± 0.8
Plant				
NF ($mg\,plant^{-1}$)	28.4 ± 2.1 (0.73 ± 0.03)	18.5 ± 1.1 (0.48 ± 0.04)	44.7 ± 5.2 (1.15 ± 0.09)	63.4 ± 1.0 (1.64 ± 0.06)
CF60 ($mg\,plant^{-1}$)	24.2 ± 0.8 (0.74 ± 0.12)	17.8 ± 1.8 (0.55 ± 0.14)	38.4 ± 8.5 (1.15 ± 0.16)	70.5 ± 7.3 (2.17 ± 0.54)

[a] As assessed by 0.05 M EDTA.

4.2. Soil fertility

The soil used in this experiment, had very good fertility levels and the contribution of mineralization to N availability to crops was estimated as 156 kg N ha^{-1} corresponding to 3.7% of the starting organic N, a much higher rate than that (1.6%) calculated applying the formula proposed by Remy and Marin-Laflèche (1974). This corroborates the hypothesis of Alluvione et al. (2008) that in Mediterranean climates intensively cropped sandy soils can undergo SOM mineralization rates higher than those reported in literature. In the calculation of N balance, a strong N surplus was found for all treatments if the mineral N value from SOM mineralization was included. This means that in the Mediterranean fertile soils a risk of excessive levels of mineral N than crop uptake capacity exists. Thus, during the autumn–winter period the nitrate pollution hazard may be high also with organic fertilization.

Furthermore, as observed by Kolahchi and Jalali (2007) in calcareous soils of Iran, the water surplus in November–December (+300 mm) coupled with the good soil drainage (sand = 57%) might have leached K_2O too. Among the treatments, only CF60 increased K_2O soil content thanks to the highest supply from the compost (see Section 2.1). Therefore, for soils with comparable features (well drained and high Ca content) the possibility of cation leaching must also be taken into consideration.

Plant available phosphorous was higher in all the compost treatments without differences between the two lettuce cycles. This result is in accordance with Odlare et al. (2008), who found that plant-available phosphorous increased in plots amended with compost. In soils amended with biologically active compost, organic P compounds mineralization and orthophosphate ions production may enhance soil P availability thanks to the increase of microbial biomass, enzymatic activity and production of organic acids (Mkhabela and Warman, 2005). Moreover, the addition of organic matter to soil may enhance its potential P storage providing new sites for capture of the nutrient (Speir et al., 2004).

4.3. C storage in the soil

Compost fertilization compensated the SOM degradation due to cultivation (2 soil tillages with rotary hoeing for fertilizer burying, and 7 with inter-row cultivator for mechanical weed control), also increasing soil organic C content. This increase remained stable even after six months of intense cultivation confirming that composting of fresh organic matter slows its degradability (Albiach et al., 2001) due to the formation of humic substances and the subsequent increase of hydrophobic protection (Piccolo and Mbagwu, 1999). Nevertheless, repeated compost application to soil could be necessary to extend these results in the long-term.

The quantification of C variation on mass basis showed a decrease of 6.6 ± 1.1 and 6.2 ± 4.6 Mg C ha^{-1} in the plots that did not receive organic matter inputs (NF and MF, respectively). This indicates that in Mediterranean sandy soils the degradation of SOM could determine a CO_2 flux value close to 20 Mg ha^{-1}. In contrast, the increase of soil C content following compost fertilization (1.9 ± 1.0, 2.7 ± 2.1 and 11.0 ± 4.5 Mg ha^{-1} in CF10, CF30 and CF60, respectively) can be quantified as approximately 7, 10 and 40 Mg CO_2 ha^{-1}, thus confirming that continued compost application can be an effective tool to compensate SOM degradation due to soil tillage (Fagnano and Quaglietta Chiarandà, 2009; Spaccini et al., 2009) and to reduce greenhouse gases in the atmosphere through C fixation in stable soil organic matter under soil and climate conditions of this study (Spaccini et al., 2002; Piccolo et al., 2004; Forte et al., 2009).

The effects of compost fertilization on the molecular changes in soil organic C were reported in a previous paper (Spaccini et al., 2009) which confirmed the formation of more stable C compounds, such as fatty acids, *n*-alkanes, and various biopolyesters derivatives.

4.4. Lettuce yield and nitrate content

The different yield of lettuce in the 2 cycles may be appointed to the lower nitrogen availability in the second cycle, which may in turn be related to the lower contribution of N mineralization from the soil reserve or to nitrate leaching caused by frequent rainfalls. This is confirmed by the yield losses of control plots in comparison with the ones of mineral fertilization plots which increased from 25% in the first cycle to 45% in the second one.

The lower compost dose (10 Mg ha^{-1}), corresponding to a N supply of 47 kg N ha^{-1}, was not adequate to satisfy the N requirements of lettuce, while the dose of 30 Mg ha^{-1}, corresponding to a N supply of 141 kg N ha^{-1}, was sufficient for both cycles. The highest dose (60 Mg ha^{-1}) corresponding to a N supply of 282 kg N ha^{-1} caused a nitrate peak in the month following the fertilization and did not increase the yield, but showed a post-harvest N surplus that could be dangerous for watertable pollution during the rainy period. Therefore, it is confirmed that also organic fertilization is able to increase the nitrate pollution of groundwaters (Fagnano et al., 2008; Fiorentino et al., 2008), if other mitigation techniques, such as catch crops, are not adopted in the cropping system (Rodrigues et al., 2002).

The nitrate content of lettuce was higher in the winter cycle, confirming that the decrease in photosynthetic rate, due to the lowering of temperatures, is related to a lowering of nitrate-reductase activity, which in turn causes the accumulation of nitric N in plant tissues (Kaiser and Brendle-Behnisch, 2001; Larios et al., 2001). In any case, all the values were much lower than the threshold laid down in the 466/01 European Directive (4500 mg NO_3 kg^{-1} of fresh weight), confirming that vegetable production in the Mediterranean area does not have problems of nitrate accumulation in leaves (De Pascale et al., 2007).

4.5. Potentially toxic metals

Compost, to be allowed for agricultural use, must be conform to regulatory limits for its total metal concentrations and for the total metal concentrations in receiving soils. The compost used in the present study showed trace element concentrations within the regulatory limits for agricultural use established by the European Union (Cu: 1000–1750; Pb: 750–1200; Zn: 2500–4000 mg kg^{-1} of dry matter; European Communities Council Directive, 1986) and Italian law (Cu ≤ 230; Pb ≤ 140; Zn ≤ 500 mg kg^{-1} of dry matter; Legislative Decree 217, 29 April 2006). In soil, Cu, Cr, Pb and Zn total concentrations were higher than the maximum values reported by Salminen (2005) for Campania Region natural soils (38.0, 15.0, 42.0, 83.0 mg kg^{-1} d.w., respectively), but similar or lower than the average concentrations reported by De Vivo et al. (2005) for surface soils of Naples municipality (Cu, 163; Cr, 12.5; Pb, 100; Zn, 142 mg kg^{-1}). Considering the depth of compost incorporation and the bulk density of the soil, the highest rate of compost amendment (60 Mg ha^{-1}) added to the soil 1.0 kg Cu ha^{-1}, 0.2 kg Cr ha^{-1}, 1.9 kg Pb ha^{-1} and 1.9 kg Zn ha^{-1}. Even after compost use, the European maximum permissible limits for soil (Cu: 50–140; Pb: 50–300; Zn: 150–300 mg kg^{-1} of dry matter; European Communities Council Directive, 1986) were not exceeded in the short term of this experiment. However the long-term effect of repeated compost application to soil and the potential cumulative effects have to be assessed.

The bioavailable fractions of Cu, Cr, Pb and Zn were very low (in absolute amount and as a percentage of the PTEs total content) both before fertilization and after the 2nd cycle of lettuce cultivation. Anyway, an increase of bioavailable Pb and Zn forms was observed in the CF60 soil after the 2nd cycle of lettuce, likely as consequence of the combined effect of compost amendment and lettuce exudates, confirming the findings obtained from a recent work (Baldantoni et al., 2010) carried out in similar conditions (compost quality and pedoclimatic conditions). The addition of 60 Mg ha^{-1} compost to soil did not show a relevant impact on metal content in harvested lettuce plants, with the exception of Pb, whose concentration was not in the range of normal concentrations for plants leaves (Cu: 5–30; Pb: 5–10; Zn: 27–150 mg kg^{-1} DM) and was above the maximum toxic levels (Cu, 20; Pb, 30; Zn, 100 mg kg^{-1} DM) indicated by Kabata-Pendias, 2001, and considered as reference values.

Contradictory findings on the impact of compost amendment on bioavailability of potentially toxic elements are reported in literature depending on soil properties and on the origin of organic matter and metals (Düring et al., 2003; Clemente et al., 2006; Baldantoni et al., 2010). Nevertheless, as observed in this study, an increase in metal bioavailability may also occur when fragments of humic acids or low molecular weight organic compounds form metal chelates (Christensen and Christensen, 1999; Strobel et al., 2005).

The results of our work may therefore encourage the application of biosolids from the waste management system of Naples city not only to the studied agricultural soil from Caivano commune, but also more generally to sandy-loam carbonaceous soils whose concentrations of potentially toxic elements do not exceed the EC mandatory limits. However, in harmony with the European Directive 278/86 it will always be necessary to monitor the quality of both the MSW-compost and the soil on which it will be used. This procedure will ensure a better protection of soil and environment, preventing long-term changes of metal availability with harmful effects on soil, vegetation, animals and man.

5. Conclusions

In the studied environment, composting may reliably contribute to both restore soil organic fertility and solve the Naples waste problem within the perspective of a recycling economy. Annually, Naples city produces 1,500,000 tonnes of MSW with a 30% organic fraction; this would produce about 500,000 tonnes $year^{-1}$ of compost. At a maximum rate of 30 tonnes of compost ha^{-1} it would be possible to amend about 16,000 ha of agricultural areas, out of 42,000 in the Naples province and of 400,000 ha in the Campania Region, available for compost amendment (arable land, fruit crops, abandoned areas).

The results of this study showed positive effects of soil fertilization with compost made from the organic fraction of urban wastes from Naples city on C fixation in stable soil organic matter and on quantity and quality of lettuce yield, but the doses have to be balanced against the N requirements of the cropping systems, in order to reduce risks of nitrate leaching during the rainy season.

MSW-compost containing relatively low amounts of metals, such as that of this case study, may be used on agricultural crops as a soil fertilizer without any risk of phytotoxicity or increasing crop tissue concentrations of Cu, Cr, Pb and Zn beyond the normal range.

Further research under field conditions are needed to confirm the results obtained in this study and to assess the long-term effect of repeated compost application to soil. Indeed, a cumulative effect of compost application over several years cannot be excluded *a priori*.

Acknowledgement

The authors are grateful to Carmel Hennessy who checked the language of the text.

References

Aggelides, S.M., Londra, P.A., 2000. Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil. Bioresource Technology 71, 253–259.

Albiach, R., Canet, R., Pomares, F., Ingelmo, F., 2001. Organic matter components and aggregate stability after the application of different amendments to a horticultural soil. Bioresource Technology 76, 125–129.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation Drainage Paper No. 56, FAO, Rome, Italy.

Alluvione, F., Fagnano, M., Fiorentino, N., Grignani, C., Quaglietta Chiarandà, F., Zavattaro, L., 2008. Maize response to repeated compost additions in two contrasting environments in Italy. Italian Journal of Agronomy 3, 171–172.

Baldantoni, D., Leone, A., Iovieno, P., Morra, L., Zaccardelli, M., Alfani, A., 2010. Total and available soil trace element concentrations in two Mediterranean agricultural systems treated with municipal waste compost or conventional mineral fertilizers. Chemosphere 80, 1006–1013.

Basile, A., Sorbo, S., Aprile, G., Conte, B., Castaldo Cobianchi, R., Pisani, T., Loppi, S., 2009. Heavy metal deposition in the Italian "triangle of death" determined with the moss Scorpiurum circinatum. Environmental Pollution 157, 2255–2260.

Cala, V., Cases, M.A., Walter, I., 2005. Biomass production and heavy metal content of Rosmarinus officinalis grown on organic waste-amended soil. Journal of Arid Environments 62, 401–412.

Christensen, J.B., Christensen, T.H., 1999. Complexation of Cd, Ni, and Zn by DOC in polluted groundwater: a comparison of approaches using resin exchange, aquifer material sorption, and computer speciation models—WHAM and MINTEQA2. Environmental Science Technology 33, 3857–3863.

Clemente, R., Secular, Á., Bernal, M.P., 2006. Heavy metals fractionation and organic matter mineralization in contaminated calcareous soil amended with organic materials. Bioresource Technology 97, 1894–1901.

Courtney, R.G., Mullen, G.J., 2008. Soil quality and barley growth as influenced by the land application of two compost types. Bioresource Technology 99, 2913–2918.

De Pascale, S., Maggio, A., Pernice, R., Fogliano, V., Barbieri, G., 2007. Sulphur fertilization may improve the nutritional value of *Brassica rapa* L. subsp. *sylvestris*. European Journal of Agronomy 26, 418–424.

De Vivo, B., Cicchella, D., Lima, A., Albanese, S., 2005. Atlante geochimico-ambientale dei suoli dell'area urbana e della Provincia di Napoli. Dipartimento di Geofisica e Vulcanologia, Universita' Federico II, Napoli.

Düring, R.A., Hoss, T., Gäth, S., 2003. Sorption and bioavailability of heavy metals in long-term differently tilled soils amended with organic wastes. Science of Total Environment 313, 227–234.

European Communities Council Directive, 1986. European Communities Council Directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture (86/278/EEC). Official Journal of the European Communities L181/, 6–12.

Fagnano, M., Fiorentino, N., Caputo, R., Donatiello, S., 2008. Effects of different techniques of green manure on N balance of the rotation tomato-melon. Italian Journal of Agronomy 3, 203–204.

Fagnano, M., Quaglietta Chiarandà, F., 2009. Environmental effects of soil tillage. In: Formato, A. (Ed.), Advances in Soil & Tillage Research. Transworld Research Network, Kerala, India, pp. 203–217.

Fiorentino, N., Fagnano, M., Caputo, R., Donatiello, S., Quaglietta Chiarandà, F., 2008. Green manure as a tool for improving C and N balance of Mediterranean cropping systems. Italian Journal of Agronomy 3, 327–328.

Forte, A., Riondino, M., Fierro, A., Virzo, A., Fagnano, M., Fiorentino, N., Spaccini, R., Piccolo, A., Bertora, C., Alluvione, F., Zavattaro, L., Curtaz, A., Mendes da Silva, W., Grignani, C., 2009. GHGs-saving effects of minimum tillage, green manure and compost application on maize cropped soils in Northern and Southern Italy. In: Grignani, C., Acutis, M., Zavattaro, L., Bechini, L., Bertora, C., Marino Gallina, P., Sacco, D. (Eds.), Connecting different scales of N use in agriculture. Proceed. 16th Nitrogen workshop, 28th June–1st July 2009, Turin, Italy, pp. 155–156 (ISBN978-88-902754-2-5).

Garcia-Gil, J.C., Plaza, C., Soler-Rovira, P., Polo, A., 2000. Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. Soil Biology and Biochemistry 32, 1907–1913.

Hargreaves, G.L., Hargreaves, G.H., Riley, J.P., 1985. Agricultural benefits for Senegal River basin. Journal of Irrigation and Drainage Engineering, ASCE 111, 113–124.

Jordao, C.P., Cecon, P.R., Pereira, J.L., 2003. Evaluation of metal concentrations in edible vegetables grown in compost amended soil. International Journal of Environmental Studies 60, 547–562.

Kabata-Pendias, A., 2001. Trace Elements in Soils and Plants, 3rd Edition. CRC Press, Boca Raton, FL.

Kaiser, W.M., Brendle-Behnisch, E., 2001. Rapid modulation of spinach leaf nitrate reductase activity by photosynthesis. I. Modulation in vivo by CO_2 availability. Plant Physiology 96, 363–367.

Keller, C., McGrath, S.P., Dunham, S.J., 2002. Trace metal leaching through a soil-grassland system after sewage sludge application. Journal of Environmental Quality 31, 1550–1560.

Kolahchi, Z., Jalali, M., 2007. Effect of water quality on the leaching of potassium from sandy soil. Journal of Arid Environments 68, 624–639.

Larios, B., Aguera, E., De la Haba, P., Perez-Vincente, R., Maldonado, J.M., 2001. A short term exposure of cucumber plants to rising atmospheric CO_2 increases leaf carbohydrate content and enhances nitrate reductase expression and activity. Planta 212, 305–312.

McBride, M.B., 1995. Toxic metal accumulation from agricultural use of sludge: are USEPA regulations protective? Journal of Environmental Quality 24, 5–18.

Meisinger, J.J., 1984. Evaluating plant available nitrogen in soil-crop systems. In: Hauck, R.D. (Ed.), Nitrogen in Crop Production. ASA-CSSA-SSSA, Madison, USA, pp. 391–416.

Mkhabela, M.S., Warman, P.R., 2005. The influence of municipal solid waste compost on yield, soil phosphorous availability and uptake by two vegetable crops grown in a Pugwash sandy loam soil in Nova Scotia. Agriculture Ecosystem Environment 106, 57–67.

Odlare, M., Pell, M., Svensson, K., 2008. Changes in soil chemical and microbiological properties during 4 years of application of various organic residues. Waste Management 28, 1246–1253.

Piccolo, A., Mbagwu, J.S.C., 1999. Role of hydrophobic components of soil organic matter in soil aggregate stability. Soil Science Society American Journal 63, 1801–1810.

Piccolo, A., Spaccini, R., Nieder, R., Richter, J., 2004. Sequestration of a biologically labile organic carbon in soils by humified organic matter. Climatic Change 67, 329–343.

Pinamonti, F., Stringari, G., Zorzi, G., 1997. Use of compost in soilless cultivation. Compost Science and Utilization 5, 38–46.

Ramos, M.C., Martınez-Casasnovas, J.A., 2006. Erosion rates and nutrient losses affected by composted cattle manure application in vineyard soils of NE Spain. Catena 68, 177–185.

Remy, J.C., Marin-Laflèche, A., 1974. L'analyse de terre: Réalisation d'un programme d'interprétation automatique.(In French). Annales Agronomique 25, 607–632.

Rodrigues, A.M., Coutinho, J., Martins, F., 2002. Efficacy and limitations of Triticale as a nitrogen catch crop in a mediterranean environment. European Journal of Agronomy 17, 155–160.

Salminen, R., 2005. Geochemical atlas of Europe. Part I. Background Information, Methodology and Maps. Geological Survey of Finland, Espoo.

Sims, J.T., Kline, J.S., 1991. Chemical fractionation and plant uptake of heavy-metals in soils amended with co-composted sewage-sludge. Journal of Environmental Quality 20, 387–395.

Spaccini, R., Sannino, D., Piccolo, A., Fagnano, M., 2009. Molecular changes in organic matter of a compost-amended soil. European Journal Soil Science 60, 287–296.

Spaccini, R., Conte, P., Piccolo, A., Haberhauer, G., Gerzabek, M.H., 2002. Increased soil organic carbon sequestration through hydrophobic protection by humic substances. Soil Biology Biochemistry 34, 1839–1851.

Speir, T.W., Horswell, J., van Schaik, A.P., Mclaren, R.G., Fietje, G., 2004. Composted biosolids enhance fertility on a sandy loam soil under diary pasture. Biology and Fertility of Soils 40, 349–358.

Strobel, B.W., Borggaard, O.K., Hansen, H.C.B., Andersen, M.K., Raulund-Rasmussen, K., 2005. Dissolved organic carbon and decreasing pH mobilize cadmium and copper in soil. European Journal of Soil Science 56, 189–196.

Weber, J., Karczewska, A., Drozd, J., Licznar, M., Licznar, S., Jamroz, E., Kocowicz, A., 2007. Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts. Soil Biology Biochemistry 39, 1294–1302.