Fertilization of maize with compost from cattle manure supplemented with additional mineral nutrients

M.V. Gil, M.T. Carballo, L.F. Calvo*

Chemical Engineering, Institute of Natural Resources, University of León, Avda. Portugal, 41, 24071 León, Spain

Abstract

An alternative approach for cattle manure management on intensive livestock farms is the composting process. An industrial-scale composting plant has been set up in northwest Spain for producing compost from cattle manure. Manure composting involved an increase in pH, electrical conductivity (EC), cation exchange capacity (CEC) and NO_3^--N concentration, and a decrease in temperature, moisture content, organic matter (OM) content, NH_4^+-N concentration and C/N ratio. Cu, Zn and Ni concentrations increased due to the reduction of pile weight during the composting process. The resulting compost was applied to a field to study the viability of applying this compost combined with a nitrogen mineral fertilizer as a replacement for the mineral fertilization conventionally used for maize *(Zea mays* L.). The thermophilic phase of the composting process was very prolonged in the time, which may have slowed down the decomposition of the organic matter and reduced the nitrification process, leading to an over-short maturation phase. The humification and respirometric indexes, however, determined immediately after compost application to the soil, showed it to be stable. Compost application did not decrease the grain yield. A year later, soil pH, OM content and CEC were higher with the compost treatment. Total P, K, Ca and Na concentrations in compost-amended plots were higher than in mineral-fertilized ones, and no significant differences between treatments were found in soil concentrations of NH_4^+-N, NO_3^--N, available P, Mg and B. Compost caused no heavy metal pollution into the soil. Therefore, this compost would be a good substitute for the mineral fertilizers generally used for basal dressing in maize growing.

Keywords: Cattle manure; Compost; *Zea mays* L.; Soil chemical properties; Nutrients; Heavy metals

* Corresponding author. Tel.: +34 987 291 844; fax: +34 987 291 839.

E-mail address: dfqlcp@unileon.es (L.F. Calvo)

1. Introduction

Nowadays, the amount of organic wastes produced by the cattle on intensive livestock farms is significant; furthermore, they are produced at specific points and daily. In such conditions, farmers do not have enough available agricultural land on which to dispose of the produced manure in appropriate doses. Furthermore, there are many problems associated with the storage and use of raw manures, such as odour, emissions or leaching of hazardous compounds and health risks, loss of nutrients and difficulty of handling and application. The accumulation of manure can therefore cause problems of environmental pollution. On the other hand, the agricultural use of raw manure can produce nitrogen losses by volatilization or leaching into surface waters and groundwater. Indeed, Basso and Ritchie (2005) found that more nitrate was leached as a result of untreated manure use than from compost application. An alternative approach for manure management is composting, which implies organic matter stabilization, sanitization regarding weeds and pathogens, deodorization, improvement of handling of the product and possibility of safe storage and transportation (Parkinson et al., 2004).

This type of manure management is implemented in a company placed near the city of León in northwest Spain, which operates a livestock farm where 13,500 cows are fattened per year, generating approximately 247 m^3 day^{-1} of cow dung. A further two large-scale projects are now at the planning stage, and the plant may expand to 17,000 animals. As composting seemed to be the most suitable way of recycling this manure, the company has recently built a composting plant that processes about 90,000 cubic meters of cattle manure per year. It is hoped that the finished compost could be sold as organic fertilizer for agricultural or horticultural purposes and gardening. However, before the compost will be applied to soil for crop production, its nutritional value and possible negative effects need to be assessed (Zhang et al., 2006). Soumaré et al. (2003a) recommend the characterization of composts for use in agriculture with regard to their agronomic value (availability of elements) and heavy metal contents.

Manures and other organic wastes, such as municipal solid wastes and agricultural or forest residues, have long been used in Spain for fertilizing crops and maintaining soil fertility. With the advent of chemical fertilizers, organic wastes were gradually replaced by mineral products, because of their lower cost and easier transportation and application (Pomares and Canet, 2001). The massive use of chemical fertilizers in intensive agriculture has greatly increased concern for the declining fertility of soils. Soil nutrient depletion is the result of increasing pressure on agricultural land, resulting in higher nutrient outflows that are not compensated for (Wopereis et al., 2006). Organic inputs are required to ensure that intensive systems do not threaten the sustainability of land use. However, small farmers are reluctant to use organic wastes or composts through uncertainty as to their benefits and safety.

Several works have showed beneficial effects of compost application for crop production. In this regard, Aggelides and Londra (2000) assessed the effects of compost produced from Municipal Solid Waste (MSW) and sewage sludge on soil physical properties. Borken et al. (2002) studied the effects of compost from organic household waste on soil properties in degraded forests. The effects of composted cotton-gin trash and composted garden waste properties were examined by Bulluck III et al. (2002). Debosz et al. (2002) evaluated the effects of sewage sludge and household compost on the physical, chemical and microbiological properties of soil. Vagstad et al. (2001) studied the effects of paper sludge composted on barley and wheat crops. Cuevas et al. (2003) studied the effects of various composted sewage sludge rates on a maize crop. Stamatiadis et al. (1999) applied compost from green wastes, cow manure and spoiled hay to a broccoli field and Soumaré et al. (2003b) used municipal solid waste compost on soils with a ryegrass crop. Basso and Ritchie (2005) used dairy manure compost in maize crop.

Cattle manure compost was applied to the soil as a fertilizer for maize growing. Nevertheless, compost alone could not work as effectively as chemical fertilizers because its mineralization time is generally unknown and therefore the availability of nutrients to plants. Sometimes, compost application as a substitute for the conventional mineral fertilization is problematic because some crops have high nutrient needs or punctual needs throughout their growth cycle, and large quantities of compost would be necessary to satisfy the overall needs of the crop, and/or the compost would not supply sufficient quantities of nutrients in the right moment. Bazzoffi et al. (1998) found that urban refuse compost produced a lower maize grain yield than mineral fertilization, as did Businelli et al. (1990), who observed a decrease of maize yield with compost compared with mineral fertilization. A combination of compost application with a nitrogen mineral fertilizer meeting N needs was therefore proposed for maize, a high nutrient-demanding crop, to replace the conventional mineral fertilizer. Thus, the objective of this work was to prove the feasibility of using bovine manure compost instead of chemical basal fertilizer for maize grown under semiarid conditions, in order to launch this organic fertilizer commercially.

The aim of this study is to ascertain whether the composting of cattle manure on an industrial scale is an appropriate way of managing manure on intensive livestock farms and if the final product can be sold and applied to the soil as a fertilizer and/or amendment without risks. For answering this question the following objectives were solved: (i) to establish whether the composting process produced an agronomically valuable compost, with chemical characteristics fulfilling the requirements of Spanish and European legislation and (ii) to assess the agronomic potential of the cattle manure compost thus obtained for growing maize, comparing the effect of this compost supplemented with mineral fertilizer with the conventional mineral fertilization on maize yield and on soil chemical properties and nutrient and heavy metal concentrations in soil.

2. Materials and methods

2.1. Composting process

The compost used was produced from bovine manure (faeces and straw bed) in the composting plant mentioned above. Here, the average temperature is 1.82ºC in January and 19.92ºC in July, with an average daily minimum of -1.66ºC in January and an average daily maximum of 23.78ºC in June (Spanish National Meteorological Service).

The cow dung is collected daily from the sheds and transported to the compost plant in trailers. The manure is scraped up from the slightly sloping concrete floor with a shovel-loader hitched to a small tractor. The composting process consists of two stages. The first phase of intensive decomposition is performed by means of mechanical turnings and forced aeration, in a completely roofed silo (45 x 60 m) with eight silo units (each 4.5 m wide and 49 m long). The dung is dumped from the transport vehicle directly into the silos, which are filled up to a height of 2.1 m. Daily turning is carried out with a diesel-driven Backhus 9.45 mobile silo turning machine, specially designed for composting biological waste and sludge in linear or tunnel plants. It is equipped with a crawler drive fitted with rubber chains, and runs along the silo walls, which are 2.3 m high and 30 cm thick, and made of concrete. The rotor, which is mounted horizontally, is equipped with throwing racks and tearing blades and the rotor drive is effected hydraulically via the rotor sword. During the turning process the rotting material is transported in a longitudinal direction and thrown backwards via the rotor and deposited loosely. When the linear turner arrives at the input side the rotor is brought into transport position by using special retraction kinematics.

The machine drives without an additional transport alliance manually from silo to silo via ramps. Forced aeration accelerates the decomposition and works with a feedback control in order to maintain temperature below 80ºC and oxygen content above 5-10%. The forced aeration system consists of fans to pull air through the composting mass from perforated piping, connected to the fans, which deliver the air. The pipes are installed along the ground of the silos. This system makes possible the removal of excess heat and the use of biofilters to treat the air. After the first phase of composting inside the silo, about two weeks, the material leaves the silo. In another roofed area, measuring 200 m x 55 m, the compost is maintained in trapezoidal piles (2.0 m high with a 3 m x 4 m base) and turned daily with a turning machine during the maturation phase for an additional eight weeks. The turning improved both the homogeneity of the composting substrate and the oxygen supply. Water was added regularly by aspersion to avoid moisture level dropping below 35-40%.

Three windrows were processed simultaneously and monitored. Temperature was monitored at three depths: 0.25, 0.5 and 1.0 m. The organic material in the three windrows was processed in the silo for the first 20 days and then moved to the trapezoidal piles, where it was kept until day 75. After that, the composted material was stored for about fifteen days without turning until sieved (< 5 mm mesh) in the composting plant. Representative samples were taken approximately every two weeks by mixing ten subsamples taken from the whole profile of the silo or pile. A part of each sample was immediately frozen (-20ºC) and kept for NH_4^+-N analysis and the other part was air dried and ground to 2 mm for other analyses.

2.2. Field experimental set-up

The end product was used for land application. Characteristics of this compost are shown in Table 1. The heavy metal concentrations were within the levels set out in the legislation in force (Royal Decree 824/2005 of the 8th July concerning fertilizers in Spain, and the European Commission's Working Document about Biological Treatment of Biowaste, Second Draft, of 2001). The field experiment was conducted in collaboration with a farmer in the province of León in northwest Spain. The experimental field was established on a sandy clay loam soil near Quintana de Rueda at 42º34'51''N and 5º15'24''W, where the crop grown was maize *(Zea mays* L.). The climate is continental, characterised by cold winters and hot summers, with considerable seasonal thermic oscillations. The mean annual rainfall is about

556 mm. The average annual temperature is 10.9ºC, with an average daily minimum of -0.8ºC in January and an average daily maximum of 27.2ºC in July (Spanish National Meteorological Service).

Table 1
Main characteristics of the compost used in the field experiment (means of three replicates) (dry weight)

Parameter	Compost
Moisture content (% f. w)	29.1
pH, H_2O	9.6
Electrical conductivity (dS m^{-1})	3.35
Organic matter (%)	56.96
Total nitrogen (Kjeldahl) (g kg^{-1})	21.3
NH_4^+-N (g kg^{-1})	0.8
NO_3^--N (g kg^{-1})	1.1
Total phosphorus (mg kg^{-1})	10400
K (mg kg^{-1})	21700
Ca (mg kg^{-1})	23700
Mg (mg kg^{-1})	5680
Na (mg kg^{-1})	4480
B (mg kg^{-1})	21
Fe (mg kg^{-1})	1030
Mn (mg kg^{-1})	176
Cu (mg kg^{-1})	53.8
Zn (mg kg^{-1})	82
Cr (mg kg^{-1})	2.6
Ni (mg kg^{-1})	<5
Pb (mg kg^{-1})	1.5
Cd (µg kg^{-1})	88
Hg (µg kg^{-1})	<100

The purpose of the experiment was to study the possibility of using bovine manure compost as a substitute for the usual basal dressing in maize growing. Two treatments were used: compost plus mineral application and conventional mineral fertilization as a control. The total surface of soil used in this experiment was 5200 m^2. The experimental set-up was a completely randomized design with three replicates per treatment, i.e. six subplots of 23 m x 28 m were used. The plantation frame consisted of 0.8 m between lines with a distance of 0.4 m between plants. The compost dose was determined by its nitrogen content, on the basis that it only releases 50% of its organic N in the first year of cultivation (Urbano, 1995; Zublena, 1996), which resulted in the application of 8.94 t ha^{-1} of compost (dry basis) as a basal dressing plus 650 kg ha^{-1} of calcium ammonium nitrate (27% of N) top dressing. Likewise, mineral fertilizer was applied according to the usual practice of the grower, 750 kg ha^{-1} of N, P, K (N, P_2O_5, K_2O): 6, 11, 22 fertilizer as a basal dressing plus 650 kg ha^{-1} of calcium ammonium nitrate (27% of N) top dressing. Both basal treatments were effected in April 2002, compost being spread on the soil surface and immediately raked evenly for each subplot and then rototilled into the soil to a depth of about 20 cm. The top fertilization was applied in June 2002. The grain was harvested in April 2003, and the top 15-20 cm of soil were sampled and analysed at the beginning of May 2003.

Maize plants in the middle 20 rows in each subplot were harvested separately to estimate the grain yield. A random subsample of each fraction was oven-dried at 60ºC (Wopereis et al., 2006), ground to pass through a 0.5 mm mesh and then analysed. Soil samples were also taken from the 20 inner rows of each treatment subplot. Each sample consisted of a mixture of ten cores randomly collected with an auger from each subplot. They were taken from the top 15-20 cm of soil, allowed to air dry and sieved through a 2 mm mesh before analysis.

2.3. Analytical methods

The protein content of the maize was determined by acid digestion (Kjeldahl method), followed by titration. Temperature during composting process was measured with a temperature probe. Bouyoucos' densimeter method was used to determine soil texture, which was obtained by fitting the percentages of sand, silt and clay fractions to the U.S.D.A. soil texture classification triangle (MAPA, 1994). The moisture content was determined by drying a sample at 105ºC until constant weight was reached (MAPA, 1994). The pH was measured in ratios of 1:2.5 soil/water and 1:25 compost/water (MAPA, 1994). Electrical conductivity (EC) was measured in ratios of 1:25 compost/water (MAPA, 1994). The organic matter (OM) content of the composting samples was analysed by loss on ignition at 430ºC for 24h (Navarro et al., 1993). Soil organic matter content was determined by the Walkley-Black wet digestion method (Walkley and Black, 1934). The cation exchange capacity (CEC) was determined in $BaCl_2$ extracts by ICP-AES spectrophotometry, according to Hendershot and Duquette (1986). Total nitrogen concentrations were determined according to the Kjeldahl method (MAPA, 1994). Ammonium-N concentrations were determined in KCl extracts using a pH ion-meter coupled with an ammonium ion selective electrode (APHA et al., 1992). Nitrate-N concentrations were determined in $CaSO_4$ extracts using a UV-visible spectrophotometer, according to the method described by Sempere et al. (1993). Available phosphorus was determined in HCO_3Na extracts using a UV-visible spectrophotometer (Olsen method). Concentration of total P was determined by ICP-AES spectrophotometry after digestion in HNO_3 65% in pressurized microwave. Concentrations of Ca, Mg, K and Na were determined in ammonium acetate extracts by atomic absorption spectrometry. Concentrations of Fe, B, Zn, Cu and Mn were determined in DTPA and CaCl by ICP-AES spectrophotometry. Concentration of B was determined by ICP-AES in water extracts. Concentrations of Ni, Cr, Pb, Cd and Hg were determined by ICP-MS spectrophotometry after digestion in HNO_3 65% in pressurized microwave. The humification index in the final compost was determined in NaOH extracts by means of measuring the absorbance at $\lambda = 472$ nm (A_{472}) and 664 nm (A_{664}) (Sapek and Sapek, 1999). The following absorbance ratio indicating the degree of humification was calculated: $Q_{4/6}=A_{472}/A_{664}$, which is often called the humification index. The respiration rate of the final compost was determined with the Oxitop® measuring system (Veeken et al., 2003), which measures the drop of oxygen pressure in a closed system while the carbon dioxide produced by the respiration is trapped in a NaOH solution. The oxygen consumption is directly related to the measured pressure drop. Thus, cumulative oxygen uptake (COU) during 96 h and the oxygen uptake rate or respiration rate (OUR) were calculated.

2.4. Statistical analyses

Data were evaluated by one-way ANOVA. Tukey's test was used for means comparison and statistical significance of hypotheses was assessed at $\alpha = 0.05$. All statistical analyses were performed using SPSS v. 11.0 software.

3. Results and discussion

3.1. Evolution of the composting process

The temperature was measured at depths of 0.25, 0.5 and 1.0 m. The temperatures reached about 70ºC after 20 days of composting, and they decreased over time (Fig. 1a). It was kept at 55ºC or above for a minimum of two weeks, which contributed to the hygienization and sanitization of the end-product through pathogen, weed and seed reduction (Paredes et al., 2005). The high temperatures of composting indicate that further research could be made about composting as detoxification process, which is outside the scope of this paper. During the process, temperatures were higher at depths of 0.5 and 1.0 m than at 0.25 m, because the heat loss through diffusion is greater at lower depths. From day 20 to day 40, higher temperatures were recorded at 0.5 m than at 1.0 m depth, but the difference disappeared around the middle of the process. This can be explained considering that 0.5 m is the most active zone since the concentration of oxygen is usually lower at the bottom of the pile due to the higher compaction of the material (Cayuela et al., 2004). A temperature of 80ºC as a control value for the forced aeration system may be too high because it can reduce the microbial activity, the waste being decomposed slowly, although thermal organisms may be also present. Thus, a good threshold temperature would be 65ºC, but, however, 80ºC was the temperature used in the composting plant to control aeration. The thermophilic phase was very long, with temperatures around 50ºC up to day 60 of the process, perhaps owing to the high initial temperatures, which slowed down the decomposition of the organic matter. It could mean that an insufficient maturation phase occurred. Finally, the temperature of the pile decreased to about 38ºC and was homogeneous. The moisture content of the pile (Fig. 1a) tended to decrease throughout the composting process, reaching about 30% in the final compost.

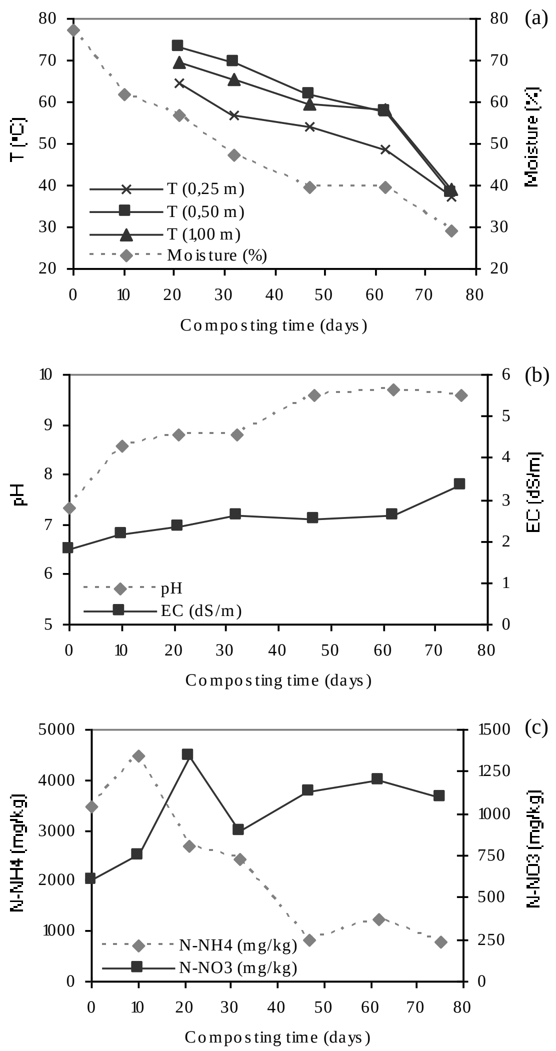

Fig. 1. Evolution of main parameters during composting of cattle manure: (a) temperature and moisture content, (b) pH and electrical conductivity (EC) and (c) NH_4^+-N and NO_3^--N concentrations.

On the other hand, odours were not a major problem during the process, probably owing to the relatively high initial composting temperatures and also to the biofilter located in the ventilation system. When composting temperatures are high, microbes probably utilize the bound oxygen from the biomass more effectively, which reduces the need of atmospheric oxygen and keeps the level of odorous compounds down.

There were an increase in pH from 7.3 to 9.6 (Fig. 1b), mainly during the first half of the process. This could be an advantage in acidic soils, although the high pH could also cause a reduction in the availability of some nutrients in other soils. The increase in pH is due to complex chemical and biological reactions occurring during the mineralization of organic matter (Cayuela et al., 2004), such as the degradation of acid-type compounds like carboxylic and phenolic groups or the mineralization of compounds, such as proteins, amino acids and peptides, to ammonia. The solubilization of the ammonia led to the formation of ammonium and an increase in pH.

EC also increased during the process (Fig. 1b), as reported by other authors (Sánchez-Monedero et al., 2001), who stated that EC increases during composting, owing to the concentration of ions as the weight of a pile decreases and also because of the increased concentration of nutrients, such as nitrate. A decrease in EC, instead, could have been explained by losses due to leaching. The addition of water to the pile was well controlled and the loss of soluble salts by leaching seemed to be avoided. On the other hand, EC values were not too high and no problems of soil salinization were foreseen.

There was a major decrease in OM content during the first stage of composting (Table 2), after which it remained practically constant until the end of the process. This may be due to the mineralization of labile organic compounds which mainly occurs during the thermophilic phase, whereas humification prevails over mineralization during the maturation stage. The OM content of the final compost was higher than the minimum value of 35 % established by the Spanish compost legislation. The CEC value (Table 2) increased slightly during the composting process, during the OM humification.

Table 2
Evolution of main parameters during composting (dry weight)

Composting time (days)	OM (%)	CEC (meq/100 g)	Total N (g kg^{-1})	C/N	Total P (mg kg^{-1})	K (mg kg^{-1})
0	71.36c	103.70a	25.5b	16.27b	9310a	21621a
10	59.32b	101.89a	21.3a	16.19b	11600ab	23959a
21	59.19b	111.09b	20.1a	17.12b	11300ab	26817ab
32	50.49a	105.80ab	22.0a	13.34a	13800ab	27799ab
47	50.26a	111.30b	22.3a	13.10a	16750b	32490b
62	55.29ab	107.20b	21.5a	14.95a	15500b	29988b
75	56.96ab	109.30b	22.3a	14.85a	10400a	21700a

OM: organic matter, CEC: cation exchange capacity.
Values followed by the same letter in the same column are not statistically different according to the Tukey’s test at 5% probability level.

Total N concentration decreased during the high temperature phase (Table 2), owing to the mineralization of the organic N, to remain constant thereafter. The NH_4^+-N concentration increased at the beginning of the process (Fig. 1c), when OM degradation was more intense and ammonium was produced through the organic N mineralization, but decreased later, because of either volatilisation losses or nitrate formation. In this experiment, the very high initial ammonium concentration fell during the composting process, but the final NH_4^+-N concentration was double than the 400 mg kg^{-1} value established as a compost maturity index (Zucconi and Bertoldi, 1987). It is therefore of major importance to ascertain the behaviour of this compost into the soil.

The NO_3^--N concentration also increased up to about day 50 of composting (Fig. 1c), to remain constant thereafter, when there was less ammonium available to the nitrifying bacteria. Therefore, nitrification occurred during most of the composting process, which is significant from an agricultural point of view. An inexplicable peak in the NO_3^--N concentration occurred on the 20th day of the process. Usually, during the nitrification process in the final stages of composting, nitrifying bacteria lower the pH owing to the liberation of hydrogen ions. In this experiment, in the final days of composting the nitrification process was reduced, with no noticeable effect on pH. On the other hand, nitrification occurs mainly under mesophilic conditions (Mathur et al., 1993), and therefore, an inadequate maturation-mesophilic phase, indicated by the high temperatures, could explain the reduction of the nitrification process and the high pH value. Despite possible insufficient maturation by day 75 of the process, the company finished the composting, probably because it works in a continuous process and the material of the next group of silos had to be processed. They stored the final compost in order to sieve it and further maturation could, however, have occurred during storage.

The C/N ratio is an index of the degree of OM stability. In this experiment, it decreased (Table 2), to remain constant in the final stage of the composting process, indicating the stabilization of the OM. The C/N ratio of the final compost was slightly higher than the value established as a maturation index (Bernal et al., 1998), as Cayuela et al. (2004) also found in their olive mill waste composts. However, according to Allison (1973), materials with C/N<15 do not alter the microbiological equilibrium of the soil. The maximum limit of C/N ratio established by the Spanish legislation for compost is 20.

The humification index, $Q_{4/6}$ ratio, was calculated in the final sieved compost and its value was 3.92. Typical values of the $Q_{4/6}$ ratio for humified material are usually <5 (Gieguzyńska et al., 1998), which shows that, according to this stability index, the compost can be considered stable. COU can be assumed to be equivalent to the AT_4 (Respiration Activity after 4 days) and its value was 6.5 mg O_2 kg^{-1}. The European Commission's Working Document mentioned above establishes the maximum value of AT_4 as 10 mg O_2 kg^{-1} for a stabilized material. The maximum OUR was 5.3 mmol O_2 kg^{-1} VS h^{-1}, which was lower than the 15 mmol O_2 kg^{-1} VS h^{-1} value proposed for stable composts by Veeken et al. (2003). Moreover, the OUR can be assumed to be the Dynamic Respiration Index (DRI), proposed by the Working Document mentioned above. Its value was 168 mg O_2 kg^{-1} VS h^{-1}, which was lower than the 1000 mg O_2 kg^{-1} VS h^{-1} established in that document for stable biowastes. Therefore, the compost can also be considered stable according to the respirometric indexes. These results can be due to the fact that the respirometric measurements were realized immediately after the application of compost to the soil, which was carried out approximately one month after the end of the monitoring of the composting process, after it had been sieved at the composting plant.

In relation to the total P and K concentrations (Table 2), there is a limited increase both of total P and K from the beginning to day 47, followed by a decrease to levels slightly higher than the initial ones by day 75, although not significantly different from them. This slight increase can probably be explained by the concentration of P and K due to the reduction in pile weight.

No major change occurred in the concentrations of Cr, Pb, Cd and Hg over time (Table 3). The concentrations of Cu, Zn and Ni seemed to increase during the process (Table 3), also perhaps because of the concentration effect caused by the reduction in pile weight. However, final heavy metal values were within the safe levels for plant growth, as set out in the legislation (the Royal Decree and the EC working document mentioned earlier).

Table 3
Evolution of heavy metal concentrations during composting (dry weight)

Composting time (days)	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Cr (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})	Cd (µg kg^{-1})	Hg (µg kg^{-1})
0	8.2a	56.0a	5.36ab	15.2a	2.0	79.1a	<100
10	10.9a	61.2a	9.27b	17.7a	2.0	108.2b	<100
21	11.7a	60.5a	3.45a	14.8a	2.0	80.5a	<100
32	10.7a	63.5a	4.85ab	19.1a	1.1	103.0b	<100
47	11.2a	96.0b	5.37ab	27.7b	2.6	120.9b	<100
62	27.9b	94.9b	2.70a	22.6b	1.5	109.3b	<100
75	53.8c	82.0b	2.60a	---	1.5	88a	<100

Values followed by the same letter in the same column are not statistically different according to the Tukey's test at 5% probability level.

The compost obtained had a high OM content and total N, total P, K, Ca and Mg concentrations compared with those found by Soumaré et al. (2003a) in farm and MSW composts. Total N, NH_4^+-N,

NO_3^--N, K, Mg, Fe, Cu and Zn concentrations in the final compost were higher than those found by Guerrero et al. (2001) in MSW compost. Also the final compost had a higher OM content and total N, K, NH_4^+-N, NO_3^--N concentrations, and a similar P content, than those found by Bar-Tal et al. (2004) in cattle manure compost, which was also applied to the soil.

3.2. Field experiment

The grain yield was not significantly different between treatments, since the maize grain harvested was 7580 kg ha^{-1} on the plots treated with mineral fertilizer and 7700 kg ha^{-1} on those treated with compost plus mineral. The Ca, Mg, Fe, Mn, Cu, Zn and B concentrations were analysed in the grain (data not shown), but no significant differences were observed between the two treatments except in Fe concentration, which was higher when compost plus mineral was applied (36.0 mg kg^{-1} as opposed to 22.6 mg kg^{-1} for mineral fertilization). Significant differences were also observed in the protein content of the grain for both treatments and it was higher with the application of compost, 7.7% as opposed to 6.8% for mineral fertilization. Analysis of the heavy metal (Cr, Ni, Pb, Cd and Hg) concentrations of the maize grain showed these elements to be below the analytical detection limit.

Both treatments significantly increased the soil pH, but this increase was greater with the application of compost (Fig. 2). The increase of soil pH with compost shows that it could be useful for increasing the pH of acid soils and it could also avoid the decrease that sometimes happens after successive applications of mineral fertilizers. Paino et al. (1996) also reported that soil pH rose when compost was used.

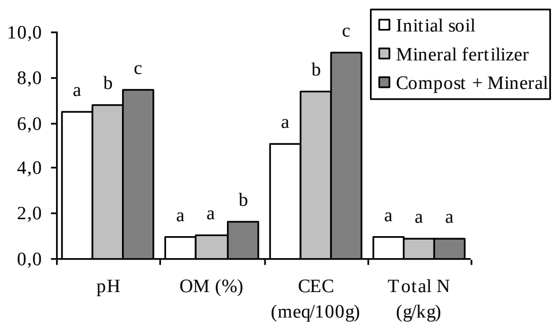

Fig. 2. Chemical properties of Maize soil initially and after the first harvest. Values followed by the same letter in the same parameter are not statistically different according to the Tukey's test at 5% probability level (n = 3).

The organic matter content into the soil significantly increased after compost application in relation to initial value (Fig. 2), and was finally significantly higher in plots treated with compost than in mineral fertilized soils. Increased soil OM improves the physical characteristics of soil, such as soil water retention and movement, soil structure and porosity (Adegbidi et al., 2003). The compost increases the humus content of the soil, which is particularly important for the establishment of the carbon cycle (Leiros et al., 1993). The increase of organic matter content into the soil by compost application is a positive effect, although it does not change much over such a short period and the impact of the compost should be assessed over more than one year after successive applications of organic materials. Both treatments also increased the CEC of the soil, but the final value was higher with compost (Fig. 2). The results are also in agreement with Bulluck III et al. (2002), who found higher CEC values in the soil after the application of organic amendments, in comparison with mineral fertilization.

Neither treatment significantly changed the total N concentration (Fig. 2), but both treatments reduced concentrations of NH_4^+-N and NO_3^--N to similar values (Fig. 3). Thus, the inorganic N concentration into the soil after harvest was similar after both treatments, which would not indicate a deficiency in this nutrient with compost fertilization in relation to mineral fertilization. It is thought, however, that it would be useful to measure the plant's N uptake to lend more validity to the conclusions.

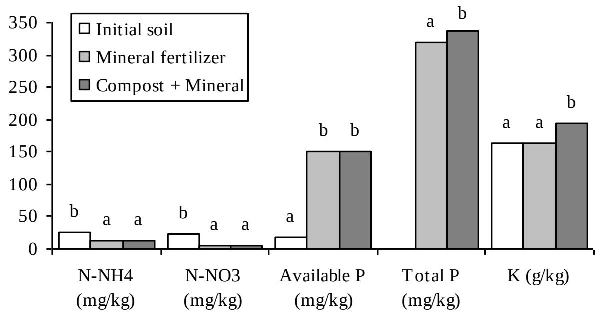

Fig. 3. Nutrient concentrations of Maize soil initially and after the first harvest. Values followed by the same letter in the same parameter are not statistically different according to the Tukey's test at 5% probability level (n = 3).

The available P concentration significantly increased to the same extent with both treatments (Fig. 3). Total P concentration at the end of the experiment was higher with the application of compost plus mineral (Fig. 3), revealing a greater amount of organic P in the soil after this treatment. Available K significantly increased with the compost, whereas its concentration did not change with mineral fertilization (Fig. 3).

Compost increased Ca concentration in the soil more significantly than mineral fertilization did (Table 4). Na concentration also significantly increased with compost application, but did not change with mineral fertilization (Table 4). Mg, Cu and Zn concentrations, on the other hand, did not change significantly with either treatment (Table 4). Nor is there any clear variation in the concentration of B in the soil after the application of compost, and in any event, concentration did not differ significantly from when mineral fertilization was used (Table 4).

Table 4
Properties of Maize soil initially and after the first harvest (means of three replicates) (dry weight)

Parameter	Initial soil	Mineral fertilizer	Compost + Mineral
Ca (mg/kg)	1002a	1293b	1707c
Mg (mg/kg)	63a	88a	84a
Na (mg/kg))	9a	9a	14b
B (mg/kg)	0.3a	0.9b	0.7ab
Fe (mg/kg)	45.3b	43.7b	36.0a
Mn (mg/kg)	22.4c	10.5b	6.6a
Cu (mg/kg)	0.6a	0.7a	0.6a
Zn (mg/kg)	0.7a	0.5a	0.5a
Hg (µg/kg)	<100	<100	<100

Values followed by the same letter in the same row are not statistically different according to the Tukey's test at 5% probability level.

Soil concentrations of Fe and Mn were lower after compost application than with mineral fertilization (Table 4). The lower Fe and Mn concentrations with the application of compost may be due to the higher pH and organic matter content reached when compost was applied, as the solubility of these elements greatly depends on pH and organic matter content decreasing as they increase (Domínguez, 1997), although perhaps these elements may be less abundant in the soil also because of partial absorption by maize plants.

Higher concentrations of K, total P, Ca and Na were found after compost application than after mineral fertilization, which showed that the compost contributed more of these nutrients than the mineral fertilizer. Bulluck III et al. (2002) found higher concentrations of Ca and K, as Soumaré et al. (2003b) did of K and P after the application of organic amendments in comparison with mineral fertilizers. Adegbidi et al. (2003) also found higher concentrations in the soil of P, Ca and K after the application of organic fertilizers than after that of slow-release mineral fertilizers.

On the other hand, final concentrations of NH_4^+-N, NO_3^--N, total N, available P, Mg and B were similar after both treatments, which showed that there was no deficiency in these nutrients after the compost application with regard to the mineral fertilization.

Cr, Ni, Pb and Cd concentrations in the soil were similar after both treatments and they were not significantly different from the initial values (Fig. 4). Soil Hg concentration after the experiment was below the detection limit (Table 4). Therefore, heavy metal concentrations in the soil did not increase over dangerous levels for plant growth.

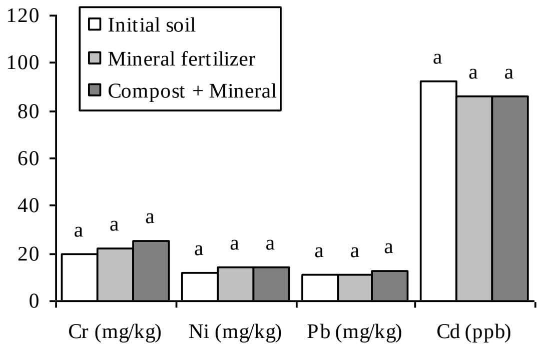

Fig. 4. Heavy metal concentrations of Maize soil initially and after the first harvest. Values followed by the same letter in the same parameter are not statistically different according to the Tukey's test at 5% probability level (n = 3).

5. Conclusions

Composting is a good alternative method for cattle manure management on intensive livestock farms, and a safe and agronomically useful product is obtained. Answering to the first objective, the compost studied had higher organic matter content and lower C/N ratio and heavy metal concentrations than the values established by Spanish and European legislation for compost or stabilized biowaste. The manure composting process involved an increase in pH, EC and NO_3^--N concentration and a decrease in OM content, NH_4^+-N concentration and C/N ratio, giving a final product with characteristics similar to those of other composts used for soil application by other authors. The humification (A_{472}/A_{664}) and respirometric indexes (COU, OUR), determined after the application of the compost to soil, indicated that the compost was stable. Moreover, the results confirmed that this compost would be a good substitute for the conventionally used basal fertilization for maize, because it was successfully applied as a fertilizer combined with additional nitrogen mineral fertilizers to complete the overall needs for crops with high requirements, in this case maize. There were no phytotoxicity symptoms in the plants treated with compost. The grain yield after compost application did not decrease in relation to conventional fertilization, while there was an increase in the protein and Fe contents of the harvested grain, indicating the fertilising value of the compost. This compost is therefore a good basal fertilizer for maize growing.

Its application improved the chemical properties and nutrient status of the soil in relation to the mineral fertilization and it did not increase the soil levels of heavy metals over dangerous limits. The application of compost could also be a means of correcting the low organic matter content of most Spanish agricultural soils, which would mean an improvement in their fertility. In this way, there are soil benefits from an organic amendment, while at the same time, useless and sometimes dangerous wastes are recycled with no decrease in crop yield or grain quality.

References

Adegbidi, H.G., Briggs, R.D., Volk, T.A., White, E.H., Abrahamson, L.P., 2003. Effect of organic amendments and slow-release nitrogen fertilizer on willow biomass production and soil chemical characteristics. Biomass and Bioenergy 25, 389-398.

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.

Allison, F.E., 1973. Soil organic matter and its role in crop production. Elsevier, New York.

APHA, AWWA, WPCF, 1992. Métodos normalizados para el análisis de aguas potables y residuales (Standard Methods for the Examination of Water and Wastewater). American Public Health Association, American Water Works Association and Water Pollution Control Federation. Ediciones Díaz de Santos, S. A., Madrid.

Bar-Tal, A., Yermiyahu, U., Beraud, J., Keinan, M., Rosenberg, R., Zohar, D., Rosen, V., Fine P., 2004. Nitrogen, Phosphorus, and Potassium Uptake by Wheat and Their Distribution in Soil following Successive, Annual Compost Applications. Journal of Environmental Quality 33,1855-1865.

Basso, B., Ritchie, J.T., 2005. Impact of compost, manure and inorganic fertilizer on nitrate leaching and yield for a 6-year maize-alfalfa rotation in Michigan. Agriculture, Ecosystems and Environment 108, 329-341.

Bazzoffi, P., Pellegrini, S., Rocchini, A., Morandi, M., Grasselli, O., 1998. The effect of urban refuse compost and different tractors tyres on soil physical properties, soil erosion and maize yield. Soil and Tillage Research 48, 275-286.

Bernal, M.P., Paredes, C., Sánchez-Monedero, M.A., Cegarra, J., 1998. Maturity and stability parameters of composts prepared with a wide range of organic wastes. Bioresource Technology 63, 91-99.

Borken, W., Muhs, A., Neese, F., 2002. Changes in microbial and soil properties following compost treatment of degraded temperate forest soils. Soil Biology and Biochemistry 34, 403-412.

Bulluck III, L.R., Brosius, M., Evanylo, G.K., Ristaino, J.B., 2002. Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties on organic and conventional farms. Applied Soil Ecology 19, 147-160.

Businelli, M., Gigliotti, G., Giusquiani, P.L., 1990. Applicazione contribute del compost da RSU in agricoltura. I: effetto sulla produttività del mais e destino dei nutrienti e dei metalli pesanti nel vegetale (Application of Urban Refuse compost in agriculture. I: effect on maize productivity, nutrient and heavy metal location in plants). Agrochimica 34, 454-466.

Cayuela, M.L., Bernal, M.P., Roig, A., 2004. Composting Olive Mill Waste and Sheep Manure For Orchard Use. Compost Science and Utilization 12, 130-136.

Cuevas, G., Martínez, F., Walter, I., 2003. Field-grown maize *(Zea mays* L.) with composted sewage sludge. Effects on soil and grain quality. Spanish Journal of Agricultural Research 1, 111-119.

Debosz, K., Petersen, S.O., Kure, L.K., Ambus, P., 2002. Evaluating effects of sewage sludge and household compost on soil physical, chemical and microbiological properties. Applied Soil Ecology 19, 237-248.

Domínguez, A., 1997. Tratado de fertilización (Treatise of Fertilization). Ediciones Mundi-prensa, Madrid.

Gieguzyńska, E., Koćmit, A, Gołębiewska, D., 1998. Studies on humic acids in eroded soils of Western Pomerania. In: Zaujec, A., Bielek, P., Gonet, S.S. (Eds.), Humic Substances in Ecosystems. Slovak Agricultural University, Nitra, pp. 35–41.

Guerrero, C., Gómez, I., Moral, R., Mataix-Solera, J., Mataix-Beneyto, J., Hernández, T., 2001. Reclamation of a burned forest soil with municipal waste compost: macronutrient dynamic and improved vegetation cover recovery. Bioresource Technology 76, 221-227.

Hendershot, W.H., Duquette, M., 1986. A simple barium chloride method for determining cation exchange capacity and exchangeable cations. Soil Science Society of America Journal 50, 605-608.

Leirós, M.C., Gil-Sotres, F., Ceccanti, B., Trasar-Cepeda, M.C., González-Sangregorio, M.V., 1993. Humification processes in reclaimed open-cast lignite mine soils. Soil Biology and Biochemistry 25, 1391-1397.

MAPA, 1994. Métodos oficiales de análisis (Tomo III) (Official Analytical Methods, Volume III). Ministerio de Agricultura, Pesca y Alimentación. Dirección General de Política Alimentaria (Ministry of Agriculture, Fisheries and Food. General Food Policy Directorate), Madrid.

Mathur, S.P., Owen, G., Dinel, H., Schnitzer, M., 1993. Determination of compost biomaturity: I. Literature review. Biological Agriculture and Horticulture 10, 65-85.

Navarro, A.F., Cegarra, J., Roig, A., García, D, 1993. Relationships between organic matter and carbon contents of organic waste. Bioresource Technology 44, 203-207.

Paino, V., Peillex, J.P., Montlahuc, O., Cambon, A., Bianchini, J.P., 1996. Municipal tropical compost: Effect on crops and soil properties. Compost Science and Utilization 4, 62-69.

Paredes, C., Cegarra, J., Bernal, M.P., Roig, A. 2005. Influence of olive mill wastewater in composting and impacto f the compost on a Swiss chard crop and soil properties. Environment International 31, 305-312.

Parkinson, R., Gibbs, P., Burchett, S., Misselbrook, T., 2004. Effect of turning regime and seasonal weather conditions on nitrogen and phosphorus losses during aerobic composting of cattle manure. Bioresource Technology 91, 171-178.

Pomares, F., Canet, R., 2001. Los residuos orgánicos utilizables en agricultura: origen, composición y características (The organic wastes in agriculture: origin, composition and characteristics). In: Boixadera, J., Teira, M.R. (Eds.), Aplicación agrícola de residuos orgánicos (Land application of organic wastes). 5º Curso de Ingeniería Ambiental. Universitat de Lleida, 23-25 de Abril de 2001, Lleida, pp. 1-15.

Sánchez-Monedero, M.A., Roig, A., Paredes, C., Bernal, M.P., 2001. Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixtures. Bioresource Technology 78, 301-308.

Sapek, B., Sapek, A., 1999. Determination of optical properties in weakly humified samples. In: Dziadowiec, H., Gonet, S.S. (Eds.), The Study of Soil Organic Matter – the Methodical Guide. Warszawa, Poland (in polish).

Sempere, A., Oliver, J., Ramos, C., 1993. Simple determination of nitrate in soils by second-derivative spectroscopy. Journal of Soil Science 44, 633-639.

Soumaré, M., Tack, F.M.G., Verloo, M.G., 2003a. Characterisation of Malian and Belgian solid waste composts with respect to fertility and suitability for land application. Waste Management 23, 217-522.

Soumaré, M., Tack, F.M.G., Verloo, M.G., 2003b. Effects of a municipal solid waste compost and mineral fertilization on plant growth in two tropical agricultural soils of Mali. Bioresource Technology 86, 15-20.

Stamatiadis, S., Werner, M., Buchanan, M., 1999. Field assessment of soil quality as affected by compost and fertilizer application in a broccoli field (San Benito County, California). Applied Soil Ecology 12, 217-225.

Urbano, P., 1995. Tratado de fitotecnia general (General Treatise on Plant Science), 2ª edición. Ediciones Mundi-prensa, Madrid.

Vagstad, N., Broch-Due, A., Lyngstad, I., 2001. Direct and residual effects of pulp and paper mill sludge on crop yield and soil mineral N. Soil Use and Management 17, 173-178.

Veeken, A.H.M., de Wilde, V., Hamelers, H.V.M., 2003. OxiTop® measuring system for standardised determination of the respiration rate and N-mineralisation rate of organic matter in waste material, compost and soil. Department of Environmental Technology, Wageningen University. The Netherlands. (http://www.nmi-agro.nl/_public/artikel/oxitop/Oxitop.pdf).

Walkley, A., Black, I.A., 1934. An examination of the Degtjareff method for determining soil O.M. and a proposed modification of the chromic acid titration method. Soil Science 37, 29-38.

Wopereis, M.C.S., Tamélokpo, A., Ezui, K., Gnakpénou, D., Fofana, B., Breman, H., 2006. Mineral fertilizer management of maize on farmer fields differing in organic inputs in the West African savanna. Field Crops Research 96, 355-362.

Zhang, M., Heaney, D., Henriquez, B., Solberg, E., Bittner, E., 2006. A Four-Year Study on Influence of Biosolids/MSW Cocompost Application in Less Productive Soils In Alberta: Nutrient Dynamics. Compost Science and Utilization 14, 68-80.

Zublena, J.P., Barker, J.C., Wessen, D.P., 1996. SoilFacts, Dairy Manure as a Fertilizer Source. North Carolina Cooperative Extension Service. Publication AG-439-28. March 1996. (http://www.soil.ncsu.edu/publications/Soilfacts/AG-439-28/AG-439-28.pdf).

Zucconi, F., de Bertoldi, M., 1987. Compost specification for the production and characterisation of compost from municipal solid waste. In: de Bertoldi, M., Ferranti, M., L'Hermite, P., Zucconi, F. (Eds.), Compost, Production, Quality and Use. Elsevier, London, pp. 30-50.