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Field-grown maize *(Zea mays* L.) with composted sewage sludge. Effects on soil and grain quality

G. Cuevas, F. Martínez and I. Walter*

Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA). Apdo. Correos 8111. 28080 Madrid. Spain

Abstract

Management of various biosolids rates on a corn silage (*Zea mays* L.) crop was studied to determine its effects on the main characteristics of soil and on corn grain yield and quality. Results obtained showed that both corn grain yields and corn grain quality harvested in the amended soil were similar to the results obtained with the traditional mineral fertiliser. There were no significant differences among treatments over the two years of study. The mean values of Cu and Zn in the grain (1.95 and 33.4 mg kg^{-1}, respectively) obtained in the amended plots were far below the tolerance threshold for livestock and the toxicity values for plants. Treatment T4 (60 Mg ha^{-1} applied once in seedbed) showed the highest values for both the electrical conductivity (0.330 dS m^{-1}) and the amount of NO_3-N (28.5 mg kg^{-1}). Although neither of these values was dangerous, this treatment is not recommended to avoid groundwater contamination risk. The available heavy metals extracted with diethylentriaminepentaacetic acid were not significantly different among treatments and a reduction in their availability over time was observed, mainly due to the physical and chemical soil properties.

Key words: yield, nutrients, trace elements, soil physico-chemical properties.

Resumen

Cultivo de maíz *(Zea mays* L.) con compost de lodo residual. Incidencias sobre el suelo y calidad del grano

Se han estudiado diferentes manejos de varias dosis de compost de lodo residual en un cultivo de maíz forrajero (*Zea mays* L.) para determinar el impacto potencial sobre las características del suelo y el estado nutritivo del grano. Los resultados de la producción y calidad de grano en los tratamientos con compost fueron equiparables a la fertilización mineral aplicada, no registrándose diferencias significativas entre los tratamientos. Las concentraciones medias de Cu y Zn en grano en las parcelas con compost (1,95 y 33,4 mg kg^{-1} respectivamente) alcanzaron valores inferiores a los considerados tóxicos para las plantas y para el consumo del ganado. No se detectaron metales pesados en ningún tratamiento. El valor más elevado de la conductividad eléctrica en el suelo (0,330 dS m^{-1}) correspondió a T4 (60 Mg ha^{-1} de compost en sementera), con el que también se observaron los valores más altos de N-NO_3 en diferentes profundidades del suelo. Aunque estos valores no son preocupantes, esta dosis no sería recomendable, ya que podría representar una fuente de contaminación para las aguas subterráneas. Los metales pesados extraídos con ácido dietilentriaminopentaacético no presentaron diferencias significativas entre los tratamientos, habiendo una tendencia a inmovilizarse debido a las características físico-químicas del suelo.

Palabras clave: producción, nutrientes, elementos traza, características físico-químicas del suelo.

Introduction

The use of biosolids in agricultural and forest soils have become a routine practice in recent years due to the need to diminish disposal costs, to recycle nutrient elements in the soil-crop system, and to offset the decreasing organic matter (OM) content of soils. Indeed, it can be an useful alternative to landfilling and incineration if their heavy metals contents are below the maximum level recommended by Spanish legislation (BOE, 1990). Application of this residue to the soil results in two environmental solutions: i) reduction of a potential source of contamination leading to reduced costs of building and maintaining controlled landfills and ii) use of an economical resource favouring increased soil productivity and reducing the requirement for synthetic fertilisers. The potential benefits of land-applying biowastes on soil characteristics and on agricultural production are well documented (Bidwell and

* Corresponding author: walter@inia.es
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Dowdy, 1987; García *et al*., 1991; Cripps *et al*., 1992; Hernández *et al*., 1992; Walter *et al*., 1994; Dowdy, 1995; Gigliotti *et al*., 1996; Logan *et al*., 1997; Binder *et al*., 2002).

The agricultural use of biosolids, whether directly or transformed into products with a high stabilised organic matter content (compost) has led to a better valoration of these materials, mainly in relation to their ability to improve the quality and quantity of soil organic matter (valuable as soil amendment) and as a source of nutrient contents (valuable as fertiliser) in intensively cultivated soils. It is well known that the organic matter input improve the physical, biological and chemical soil characteristics, and consequently, its capacity to store water, to control erosion and as a storage and a releaser of nutrients. The main advantages of composts over direct application of biosolids can be summarised in: effective reduction of pathogens, elimination of odour (therefore, reduction of vectors attraction), decrease of risk of polluting groundwater owing to the high stability of the organic matter and better acceptance by farmers and consumers.

Nevertheless, application of these wastes to the soil must be done in a controlled manner and with knowledge of all the variables that can affect the system. Proper management of cropland receiving compost by either high-rate single applications or repeated lower rate application depends on the initial mineral N concentration, the rate at which compost organic matter is decomposed and the type of crop grown. Environmental limitations, and the aptitude of the soils and crops should be taken into account to avoid undesired consequences. The potential environmental hazard most frequently associated with biosolids nutrients is excessive movement of NO_3 from soil to groundwater, or excessive accumulation of P and trace elements (Binder *et al*., 2002). More reliable predictions, especially for local soil and climatic conditions, of the overall nutrient value, the N-supplying capacity, and crop yield response of biowaste, are required. Also, the introduction of heavy metals to the soils should be controlled and their transfer to the crop must be studied.

The objectives of this work were to: (i) study the effects of composted biosolids applied, in different rates and by different application methods, on the yield, nutritive state and quality of corn (*Zea mays* L.) cv. Florencia, and (ii) assess the potential environmental impact on the soil as outcome to the compost application.

Material and methods

Study area and experimental design

A field experiment was carried out, in an agricultural plot belonging to the municipality of San Martín de la Vega (south-east of the Madrid Autonomous Region). Soils of the area are classified into *Fluvents* within the order of Entisols (Soil Survey Staff, 1998). The soils of the study area did not present any limitation for crops growth and irrigated herbaceous crops were predominant, being corn crop the one which covers the largest area. The Jarama river, by irrigation channels and canals, provides water for the whole region. The climate is semiarid continental mediterranean, with a mean annual rainfall of 400 to 500 mm, with very high evapotranspiration in the summer months.

The study plot was divided into four splits as homogeneous as possible, each of which representing a block. Every block was subdivided into six subplots (100 m^2) on which the treatments indicated in Table 1 were randomly applied.

To prevent possible contamination effects of neighbouring plots, wide corridors and furrows were made to separate the plots and blocks, respectively. The application of compost and mineral fertilisation to seedbed was done in the first week of June 1999 and in the middle of this month the corn 'Florencia' (short cycle) was sown. Organic and inorganic fertiliser on the surface was applied 20 days after germination. In the month of December, when the grain was completely mature, the corn was harvested and grain yields were obtained per treatment. In the second year, corn was cultivated without applying organic or inorganic fer-

Table 1. Treatments applied in the experiment

Treatment	Description
T1	Control, mineral fertilisation: 600 kg ha^{-1} (N, P, K: 8,15,15) applied in seedbed and 100 kg ha^{-1} (calcium ammonium nitrate, 27% N) applied on surface.
T2	30 Mg ha^{-1} compost (seedbed).
T3	15 Mg ha^{-1} compost (seedbed) and the same rate on surface.
T4	60 Mg ha^{-1} compost (seedbed).
T5	30 Mg ha^{-1} compost (seedbed) and the same rate on surface.
T6	30 Mg ha^{-1} compost (seedbed) and 100 kg ha^{-1} (calcium ammonium nitrate 27% N) applied on surface.

tiliser. Sowing and harvesting were carried out in approximately the same dates as the year before. Management practices were done in the farmer's typical way of the area and were dependent on climatic conditions.

Irrigation (surface type) was done during the summer months, taking water from the Jarama river. Each plot was watered individually to prevent possible contamination. The quality of the irrigation water according to the analyses carried out (mean value of 6 samples collected during the irrigation period) was classified as C2-S2 class, i.e. water with a mean salinity value and with an intermediate sodium contents, which can be used without problem in medium textured soils with high permeability, like the soil of this study (United States Salinity Laboratory Staff, 1954).

Soil and compost

Soil samples were taken at different depths from the soil profile over the experimental period. The first sampling was done before applying the waste (year 0), the second after the first harvest (year 1) and the third after the second harvest (year 2). Twelve composite soil samples were taken manually from each plot at four depths (0–20 cm, 20-40 cm, 40-60 cm and 60-80 cm) using a 5 cm-diameter bucket auger. The samples were homogenised, air-dried and sieved through a 2 mm mesh before analysis. The determination of the main physico-chemical characteristics were carried out according to official analytical methods of MAPA (1994). The soil available trace elements concentration was determined by ICP, atomic emission spectrophotometer (Perkin Elmer AEE 400) after extracting the samples with diethylentriaminopentacetic acid, DTPA (Lindsay and Norvell, 1978).

The compost used came from a mixture of anaerobic sewage sludges generated by 5 wastewater treatment plants of Madrid municipality that had been composted and stabilised for more than three months and fulfilled criteria established by Spanish legislation concerning agricultural use of biosolids from wastewater treatment plants. The main agronomic parameters of this waste have been previously described by Walter *et al*. (1989).

Grain yield and analysis

Grain yield per treatment was determined. Only the central part of each plot was harvested to eliminate any possible border effect. The yield of dry grain was calculated in kg ha^{-1} (14% of humidity).

Twelve corn ears were also randomly collected for each treatment, washed with distilled water and oven-dried at 60ºC to constant weight. Grains were removed and ground in a stainless steel mill. The main macro and micronutrients and heavy metals were analysed. Nitrogen was determined by dry combustion with a LECO analyser (CHN-600 model) and P, K, Ca, Mg, Zn, Cu, Pb, Cd, Ni and Cr with an ICP-AES after wet digestion, with concentrated HNO_3 under pressure, in a microwave oven, and then diluting the extract obtained with distilled water.

Statistical analysis

All data were statistically evaluated by the one-way analysis of variance (ANOVA) and Duncan's multiple range test at $P \leq 0.05$ was used for comparison of means.

Results

Compost and soil characteristics

The average compositions of the compost applied are summarised in Table 2. It can be observed that this biowaste has a high organic matter content and acceptable amounts of N and P and, thus, it is an useful organic-mineral soil amendment. On the other hand, total heavy metals are well below the maximum recommended level for Spanish legislation (BOE, 1990).

The main characteristics of the soil before applying the compost and mineral fertiliser are presented in Table 3. As significant differences were not found among

Table 2. Characteristics of the compost used (all data, except pH and EC are expressed on dry weight)

Parameters		Trace elements (mg kg^{-1})		
			Total	Available
pH (soil:water 1:2.5)	7.7	Zn	1635	77.8
EC (dS m^{-1}) at 25ºC	5.25	Pb	385	6.70
Total organic matter (%)	14.4	Cd	3.97	0.30
Total N (%)	1.68	Ni	79.6	1.52
Total P (%)	2.6	Cr	468	0.20
Total K (%)	0.40	Cu	460	11.2
N-NH_4 (mg kg^{-1})	50			
N-NO_3 (mg kg^{-1})	227			

Table 3. Initial soil properties at different depths (n = 24)

Soil characteristics	Depth (cm)			
	0-20	20-40	40-60	60-80
pH	7.7	7.8	8.0	8.2
EC (dS m^{-1})	0.139	0.130	0.138	0.134
OM (%)	1.02	1.07	0.67	0.38
Available P (mg kg^{-1})	42.30	41.27	31.64	26.96
N-NH4 (mg kg^{-1})	0.54	0.58	1.06	1.14
N-NO3 (mg kg^{-1})	4.52	2.72	2.43	1.90
Available trace elements (mg kg^{-1}):				
Zn	3.49	3.61	2.48	0.78
Pb	1.55	1.56	1.05	0.47
Cd	0.08	0.08	0.06	0.03
Ni	0.42	0.44	0.28	0.09
Cr	nd	nd	nd	nd
Cu	1.23	1.26	0.88	0.37

OM: organic matter. nd: not detected.

plots the data correspond to average values of the 24 plots. The most relevant characteristic found in this soil is the presence of a large content of available phosphorus probably due to previous mineral fertilisations.

Tables 4, 5 and 6 show the mean values obtained for electrical conductivity (EC), $N\text{-}NH_4$ and $N\text{-}NO_3$, respectively. The only EC significant increases were found in T4 and T5 (highest compost rate) compared to the other treatments and to the unamended soil, in the first 20 cm and over the first year (Table 4). In other depths studied no significant differences were observed among treatments.

The $N\text{-}NH_4$ contents (Table 5) were significantly higher in all the treated plots than in the unamended-soil. Values obtained for treatments T1, T4 and T6 (mineral treatment, high rate of compost and mixed organic compost and mineral fertilisation, respectively) were significantly higher than for other treatments in the first 20 cm of soil and in the first year of study, while in the second year significant differences were only observed with the unamended soil. Generally, significant differences were observed for the other depths studied with regard to unamended soil but not among the treatments applied.

The mean values of $N\text{-}NO_3$ (Table 6) in treatments T4 and T5 were significantly different than in other treatments applied and than in the unamended soil, in the first 20 cm of soil and in the first year. There were no significant differences for the second year. In the 20-40 cm soil depth there was a remarkable increase in this parameter, significant in T4 compared to other treatments, and significantly higher than the unamended soil. In general, this increase was also showed at depths of 40-60 cm and 60-80 cm, and in some cases differences were also observed in the second year.

The other parameters studied such as pH, oxidable organic matter and available P did not present significant differences among treatments or between treatments and the unamended soil. The pH increased with depth, ranging from 7.5-7.8 for the first 20 cm to 8.2-8.4 for a depth of 60-80 cm. The oxidable organic matter contents gradually decreased over the soil profile, ranging from 1.23-1.25 g kg^{-1} in the top layer to 0.24-0.34 g kg^{-1} in the deepest layer over the two years of study; no significant differences were found. In relation to available P (Olsen) it must be pointed out that the soil already had a significant amount with mean values ranging from 60.0 to 18 mg kg^{-1}.

Table 4. Mean values of electrical conductivity (dS m^{-1}) throughout the soil profile in the different treatments and for the three sampling dates

Treatments	Depth (cm)							
	0-20		20-40		40-60		60-80	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
T1	0.148 b	0.130 b	0.171 b	0.137 b	0.142 a	0.136 a	0.153 a	0.135 a
T2	0.157 b	0.147 b	0.161 b	0.141 b	0.157 a	0.138 a	0.152 a	0.158 a
T3	0.177 b	0.140 b	0.155 b	0.141 b	0.149 a	0.139 a	0.156 a	0.132 a
T4	0.330 a	0.155 b	0.208 a	0.182 b	0.162 a	0.146 a	0.157 a	0.161 a
T5	0.290 a	0.143 b	0.155 b	0.141 b	0.159 a	0.122 a	0.141 a	0.142 a
T6	0.137 b	0.150 b	0.170 b	0.156 b	0.180 a	0.146 a	0.145 a	0.154 a
Year 0	0.139 b		0.130 b		0.138 a		0.134 a	

Mean values followed by the same letters in the same column are not significantly different at P ≥ 0.05. Year 0: initial soil.

Table 5. Mean values of N-NH_4 (mg kg^{-1}) throughout the soil profile in the different treatments and for the three sampling dates

Treatments	Depth (cm)							
	0-20 cm		20-40 cm		40-60 cm		60-80 cm	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
T1	6.2 a	2.1 b	5.2 a	1.9 b	5.4 a	1.4 b	9.1 a	1.1 c
T2	3.1 b	2.9 b	3.5 a	2.4 b	2.0 a	2.8 a	3.6 b	1.7 c
T3	4.1 b	2.9 b	3.5 a	3.7 b	4.3 a	3.0 a	4.9 b	1.8 c
T4	7.0 a	3.2 b	4.8 a	3.1 b	4.0 a	3.2 a	7.2 a	2.1 c
T5	4.5 b	2.7 b	2.4 a	3.4 b	2.7 a	2.3 a	1.6 c	1.7 c
T6	7.3 a	3.4 b	3.7 a	2.0 b	4.6 a	2.1 a	3.0 b	1.4 c
Year 0	0.4 c		0.4 c		0.8 b		0.9 c	

Mean values followed by the same letters in the same column are not significantly different at $P \geq 0.05$. Year 0: initial soil.

The available trace elements analysed in this study were cadmium, zinc, copper, nickel, lead and chromium. The values obtained, with the exception of Cr, for the different treatments throughout the soil profile and over the two years, are represented in Fig. 1.

Chromium was not detected in any of the treatments applied in the different depths studied since the values obtained were below detection limits to the analytical instrument used for their determination (0.08 mg kg^{-1}). There were no significant differences among treatments in the other DTPA extracted elements analysed.

Grain yield

The average corn yields obtained in the different plots over the two years of study are represented in Fig. 2. The results of the statistical analysis of the data obtained show a lack of significant differences among treatments in both years of the study. These results suggest that the different rates of compost applied do not present an adverse effect in corn yield and are in agreement with the results obtained by Parkinson *et al*. (1999) in a three year study growing fodder corn with 15, 30 and 60 Mg ha^{-1} rates of compost with and without application of mineral fertiliser.

Nutritive status of grain

Table 7 shows the nitrogen content of grain (g kg^{-1}) and grain N uptake in kg ha^{-1}, for the different treatments in both years of study. It can be observed that there were no significant differences among treatments in both years. Table 8 shows the mean values of grain phosphorus, potassium, calcium and magnesium ob-

Table 6. Mean values of N-NO_3 (mg kg^{-1}) throughout the soil profile in the different treatments and for the three sampling dates

Treatments	Depth (cm)							
	0-20 cm		20-40 cm		40-60 cm		60-80 cm	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
T1	2.0 c	1.9 c	2.9 b	1.6 b	2.4 b	1.5 c	0.7 c	1.6 b
T2	4.9 b	3.0 b	0.9 b	3.4 b	2.3 b	3.2 a	0.7 c	2.3 b
T3	1.0 c	2.8 b	3.5 b	2.6 b	2.7 b	2.7 b	1.5 b	1.5 b
T4	9.5 a	1.8 c	28.5 a	2.8 b	3.4 a	3.5 a	3.0 a	5.1 a
T5	10.0 a	2.1 c	8.9 b	2.7 b	2.5 b	3.7 a	1.1 b	1.7 b
T6	1.8 c	2.6 b	1.7 b	2.4 b	2.6 b	2.1 b	1.7 b	2.2 b
Year 0	1.0 c		0.6 c		0.5 c		0.4 c	

Mean values followed by the same letters in the same column are not significantly different at $P \geq 0.05$. Year 0: initial soil.

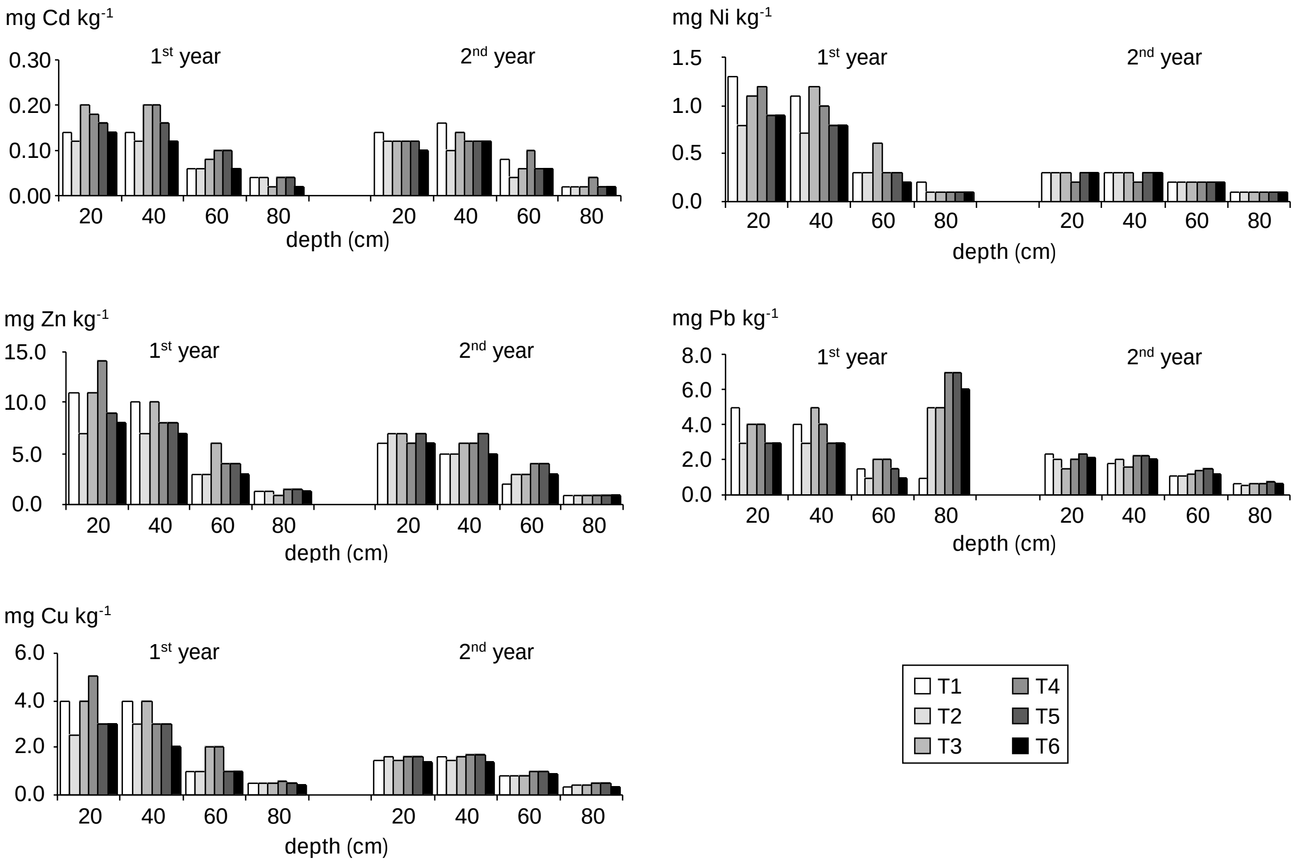

Figure 1. Available heavy metal contents in the different treatments, for the different soil depths studied over the two years of study.

tained (g kg^{-1}) for the treatments applied in the two years of study and the average value obtained with the compost treatments. It shows that the mean values obtained for phosphorus in all the treatments with compost are usually higher than the mineral treatment, although this difference was not significant. A similar pattern was found in the second year but a decrease of this element concentration was observed in all the treatments.

Mean values of K, P, Ca and Mg in corn grain did not present significant differences among treatments in the two years of study. In general, a clear difference can be observed in the values obtained of these macronutrients contents in the two years studied.

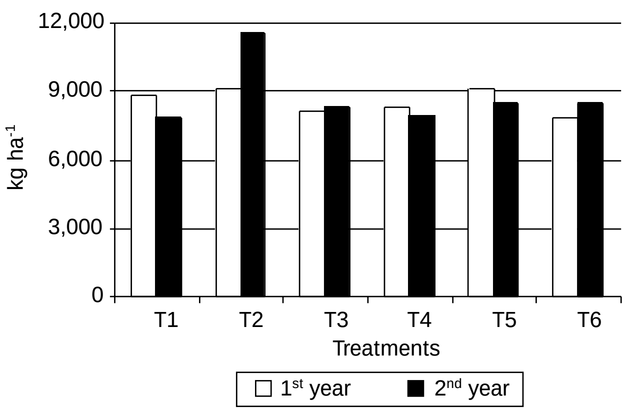

Figure 2. Grain yield (kg ha^{-1}) in the different treatments for the two years of study (at 14% humidity).

Table 7. Mean concentration of nitrogen in grain (g kg^{-1}) and mean value of nitrogen uptake (kg) per hectare for the different treatments over the two years of study

Treatments	N in grain (g kg^{-1})		N uptake (kg ha^{-1})	
	1st year	2nd year	1st year	2nd year
T1	14.64	14.38	129	113
T2	14.06	13.31	128	154
T3	14.77	13.62	120	113
T4	14.62	13.86	121	111
T5	14.94	13.86	136	117
T6	14.70	17.72	116	150
Mean values of compost	14.62	14.47	125	130

Table 8. Mean values of grain P, K, Ca and Mg (g kg^{-1}) for the different treatments over the two years of study

Nutrient	Year	Treatments						Mean values of compost
		T1	T2	T3	T4	T5	T6	
Phosphorus	1	2.98	3.47	3.41	2.98	3.40	3.14	3.28
	2	1.10	1.56	1.62	1.01	1.35	1.65	1.44
Potassium	1	3.45	3.62	3.62	3.27	3.76	3.37	3.53
	2	9.19	12.16	8.70	9.50	7.98	6.71	9.01
Calcium	1	2.33	2.35	2.46	2.62	2.31	2.28	2.40
	2	2.51	2.19	2.37	2.37	2.49	2.10	2.30
Magnesium	1	1.21	1.46	1.34	1.29	1.39	1.27	1.35
	2	5.68	5.17	5.99	5.74	7.33	6.79	6.20

The heavy metals cadmium, nickel, chromium and lead in grain were not detected in any of the treatments applied in the two harvests analysed. Their values were below the detection limits (0.1 mg kg^{-1}; 0.16 mg kg^{-1}; 0.08 mg kg^{-1}; 0.32 mg kg^{-1}, for Cd, Ni, Cr and Pb, respectively). The concentration of the two micronutrients determined, Cu and Zn, are shown in Table 9. There were no significant differences among treatments in the two years of study.

Discussion

The maximum value of EC found (0.330 dS m^{-1}) (Table 4) did not constitute a risk for crops development in general. Soil EC levels obtained with the compost treatments showed that soluble salts were not sufficiently concentrated to inhibit corn growth (Porta *et al.*, 1999). In the second year there was a decrease in salt levels compared to the first year for most treatments and depths studied, mainly due to the leaching of soluble salts during irrigated time.

As expected, the differences in N-NH_4 concentrations among the different treatments were found in the first 20 cm of soil. Similar results were obtained by Magdoff and Amadon (1980) and Soler (1998).

Nitrate is the nitrogenated compound that the plant assimilates directly and owing to its high water solubility is very mobile in the soil. Therefore, NO_3 is an important compound, not only because it supplies the plant's immediate requirements but also because of its possible environmental impact on soil-water system. The N-NO_3 concentration (Table 6) decreases markedly in the 80 cm of soil, suggesting that there was not large amounts of NO_3 leaching that reach to groundwater. According to the results obtained, T4 (high rate of composts once-applied in seedbed) is not recommendable, since a very high quantity of nitrate is in soil that is not uptaken by the plants and therefore, increase soil NO_3 leaching to the different layers polluting the groundwater. The N-NO_3 values obtained in treatment T5, also equivalent to 60 Mg ha^{-1}, but applied at two different times, were lower than the values obtained in T4. It is especially important since this compost management showed a small NO_3 accumulation. There are less N-NO_3 losses from leaching which suggest a better agreement between the plant's requirements and the amount of composts applied in the soil.

Table 9. Mean values of the micronutrients (mg kg^{-1}) in grain for the different treatments in the two years of study

Nutrient	Year	Treatments						Mean values of compost
		T1	T2	T3	T4	T5	T6	
Zn	1	26.70	29.80	22.47	21.30	25.30	23.20	24.40
	2	24.73	31.59	37.05	26.03	44.97	27.11	33.35
Cu	1	1.43	1.82	2.43	2.43	1.24	1.83	1.95
	2	1.87	1.60	1.97	1.78	1.81	1.48	1.73

In spite of a large amount of organic matter input, there were no significant differences among treatments, probably because soils often respond to nitrogen additions with further increases in the mineralization of indigenous soil organic matter. In a short term, this results in soil organic matter decrease. It takes three to four years to observe any positive effects of compost applications on soil organic matter (White *et al*., 1997).

Although treatments T2, T3, T4 and T5 incorporate large amounts of P to the soil, this input does not produce any significant difference. This can be explained mainly due to the soil physico-chemical characteristics. This soil has a high capacity of P retention, resulting in this element becoming strongly fixed. Consequently, this property may minimize the effects of excessive P rates with compost applied.

Even though concentrations of total heavy metals in the applied compost are within legal limits, an important amount of metals is incorporated into the soil (Table 2). Knowledge of a soil's composition in term of total trace elements normally, is not useful when it comes to understand the processes and dynamics of element mobility and availability. Nevertheless, if total concentration is greatly in excess of that expected for a particular soil type, this may be a sign of pollution. A measure more useful than total element content for most purposes is an estimation of element availability, since this can be related to mobility and uptake by plants and extractability by chemical reagents (Hue and Ranjith, 1994; McBride, 1995); thus, in the present study trace elements were analyzed extracting them with DTPA solution (Lindsay and Norvell, 1978). Figure 1 shows that the contents of available heavy metals determined in all cases decreased over time (second year). Probably due to adsorption/precipitation processes, metals are strongly fixed in the organic and inorganic fractions of the soil, becoming more insoluble, i.e. less available. In spite of the high mobility of some heavy metals and the high rates of compost applied in an irrigated system, no risk of soil and groundwater pollution is expected due to leaching of trace elements.

Grain yield obtained with composts treatments (Fig. 2) was the same as that obtained with mineral fertilization and similar to the mean value obtained by farmers in the same area and year. The mean values obtained for all treatments with compost during the first year were slightly lower than those obtained with mineral fertilization (T1) (an average difference of 300 kg ha^{-1}), while in the second year the mean for compost treatments was higher (8960 kg ha^{-1}) than the yield obtained with the mineral fertilization (7870 kg ha^{-1}). This indicates a clear residual effect of the compost used. Every treatment applied, at different rates and methods, can release enough nutrients to give a second profitable corn yield.

The amounts of grain nitrogen obtained during the second year were slightly lower than values obtained in the first year. Nevertheless, nitrogen concentrations in both years were within recommended limits for corn grain (Table 7). These results agree with those obtained by Dumitru *et al*. (1997), who did not observe significant differences among the different treatments, and values reported for nitrogen grain contents ranged from 14 to 17 g kg^{-1}. The average values obtained for all compost treatments in the first year were very similar to that found by the mineral fertilizer. However, in the second year the N uptake was 17 kg ha^{-1} higher than the value obtained with the mineral fertilizer and higher than the average value obtained in the first year. This demonstrates that the amount of compost added in any of the treatments applied gives enough nitrogen for a second harvest. The range of grain N uptake obtained was similar to that reported by Hormann *et al*. (1995) for corn that applied 20 Mg ha^{-1} of lime stabilized sewage sludge.

Heavy metals were not detected in any case. This is very important since all the metals studied here are considered to be highly toxic and there is a strict legislation concerning their contents in grain used for animal feed (Madejón *et al*., 2001). The ranges obtained for the two microelements studied were similar to those obtained by Jarausch–Wehrheim *et al.* (1996) that applied 10 and 100 Mg ha^{-1} of compost to an acid sandy soil, and to those obtained by Hormann *et al*. (1995) for a fodder corn crop amended with different rates of lime stabilized sludges (20 to 60 Mg ha^{-1}) in a long time experiment. The values for both microelements were much lower than those considered to be phytotoxic or maximum mean levels tolerated by cattle (25-40 mg kg^{-1} and 100-300 mg kg^{-1}dry matter, respectively for Cu, and 500-1500 mg kg^{-1} and 500-1000 mg kg^{-1} dry matter, respectively for Zn), according to Macnicol and Beckett (1985) and Madejón *et al.* (2001).

The yield and quality of corn grain (macro and micronutrients) in the compost treatments were similar to or exceeded those in mineral fertilizer treatment (control). It suggests that large amounts of compost-N were plant available in the two years and that the yields values obtained were within normal limits for this corn variety in both climatic and soil conditions. Heavy metal levels in corn grain were not detected, mainly due to these being strongly retained in the soil.

However, further studies should be done to evaluate the possible changes in soil available trace elements in the medium and long term.

It can therefore be concluded that, with the exception of T4 treatment (compost by high-rate single application), all the other treatments are appropriate for the corn crop. The use of compost in appropriate rates provide a good quality and quantity corn yield for two consecutive years, without producing any appreciable environmental damage.

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