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Plant and livestock waste compost compared with inorganic fertilizer: nutrient contribution to soil

Aporte nutricional al suelo mediante fertilizantes químicos y abonos orgánicos de residuos vegetales y pecuarios

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SUMMARY

The use of livestock and plant wastes, as sources of nutrients and organic material to the soil, is a viable alternative to chemical fertilizers, which eventually cause serious risks to agroecosystems. The present study was conducted in 2013 in a greenhouse at FACIATEC-UACH, Chihuahua, México. Four composts made with (a) cow manure, (b) hen manure, (c) sawdust and (d) maize stover were evaluated for their contribution of the soil macronutrients NO_3^-, $P^=$, K^+, Ca^{++}, Mg^{++} and Na^+ and compared with urea as a synthetic fertilizer and a control without fertilizer. The experiment was based on a completely randomized design; statistical analysis included an analysis of variance using the statistical package SAS (Statistical Analysis System) version 9.3.1 and comparison of means with the Tukey procedure (a = 0.05). Results suggest that five of the compost treatments increased the concentration of NO_3^-. Hen manure significantly outperformed cow manure in providing NO_3^- and $P^=$. Likewise, the sawdust-based compost significantly affected the content of NO_3^-, outperforming the treatment based on maize stover. The concentration of Ca^{++} and Mg^{++} in soils resulting from the applied composts was lower than in the treatment with inorganic fertilizer, but that of Na^+ was statistically higher than in the inorganic fertilizer treatment. This evidence suggests that the use of organic fertilizers, of either animal or plant origin, is a beneficial source of soil nutrients with high potential in sustainable agriculture.

Index words: *macronutrients, organic fertilizer, soil fertility.*

RESUMEN

El uso de desechos de ganado y residuos vegetales, como fuente de nutrientes y material orgánico para el suelo, puede representar una alternativa viable para evitar daños riesgosos para el agroecosistema, derivados del uso de fertilizantes químicos. El presente estudio fue conducido en 2013, en condiciones de invernadero en la FACIATEC-UACH, Chihuahua, México. Se evaluó la contribución al suelo de los macronutrientes NO_3^-, $P^=$, K^+, Ca^{++}, Mg^{++} y Na^+, a partir de cuatro compostas elaboradas de (a) estiércol de bovinos, (b) excremento de gallina, (c) aserrín y (d) esquilmo de maíz, los cuales fueron comparados con urea como fertilizante sintético y un control sin fertilizante. Se utilizó un diseño completamente aleatorizado y se realizó el análisis de varianza mediante el paquete estadístico SAS (Statistical Analysis System), versión 9.3.1; la comparación múltiple de medias se realizó mediante el procedimiento de Tukey (α = 0.05). Los resultados sugieren que cinco de los tratamientos de compostas incrementaron la concentración de NO_3^-, en los cuales el estiércol de gallina superó significativamente al de bovinos en su aportación de los macronutrientes NO_3^- y $P^=$; del mismo modo, las compostas elaboradas a partir de aserrín tuvieron un efecto significativo sobre el NO_3^- y superaron a los que contenían esquilmos de maíz. La concentración de Ca^{++} y Mg^{++} en los suelos donde se aplicó la composta, fue menor en comparación con aquellos tratados con urea, aunque el contenido de Na^+ en los tratamientos de composta superó estadísticamente a la de aquellos tratados con fertilizantes inorgánicos. Esta evidencia sugiere que el uso de fertilizantes orgánicos, ya sea de origen animal

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o vegetal, es una fuente benéfica para los nutrientes del suelo con alto potencial en la agricultura sostenible.

Palabras clave: *macronutrientes, fertilizante orgánico, fertilidad del suelo.*

INTRODUCTION

The actual practice of agriculture with the use of chemical fertilizers is one of the main causes of today's environmental diseases. Although technological packages have produced high increases in crop yields, they have also had collateral effects such as losses of thousands of hectares of fertile land, soil degradation and increases of more virulent pathogens (Cruse, 2012). This technology is also responsible for eutrophication of bodies of water, increases in nitrate levels in ground and surface water, and increments of pesticide residues in water, soils and food (Tarigo *et al*., 2004)[1].

Moreover, huge amounts of organic residues produced by agricultural activities have become environmental pollutants since they increase salinity levels, nitrate lixiviation rate into underground and drain water as well as phosphate concentration in surface water (Flotats and Sole, 2008). In addition, organic residues are associated with accumulation of lignin, aromatic oils and resins (Obied *et al*., 2005), and several pests, weeds and diseases have been disseminated (Baffi *et al*., 2007) and cases of toxicity in cultivated plants have increased (Zucconi *et al*., 1981). As a result, the use of organic residues has become increasingly important as an efficient way to recycle nutrients and stimulate plant growth as well as to incorporate nutrients to degraded soils (Cerrato *et al*., 2007). Hence, controlled degradation processes have been considered necessary to minimize environmental risks caused by organic residues as in the case of manure and urine (Lüebka and Lüebka, 2007)[2].

Composting and biodegradation is an effective way to manage organic residues to obtain a healthier, safer, more economically profitable product while improving soil fertility (Bernal *et al*., 2008; Szabová *et al*., 2010). The factors involved in the composting process, such as aeration, initial C/N relationship and moisture content, influence nutrient conservation, which are important in improving the potential of compost as organic fertilizer and its agronomical value (Guo *et al.,* 2012). Application of organic fertilizers to agricultural soils is an important practice for increasing crop yield (Saldaña *et al.,* 2014), and composts can improve physical, chemical and biological soil attributes (Soto and Melendez, 2003). The objective of this study was to evaluate the contribution of soil macronutrients by composts made from organic residues (plant and livestock wastes) as compared with inorganic fertilizers.

MATERIALS AND METHODS

Experiment Location

The experiment was conducted at the School of Agrotechnological Sciences (FACIATEC) of the Autonomous University of Chihuahua (UACH), Chihuahua, México, in a chapel-type greenhouse, 16 m wide × 45 m long, with galvanized iron structure and covered with fiberglass.

Experimental Design

The experimental design was completely randomized with ten fertilization treatments and five replications. The experimental unit was defined as a 6 L capacity pot. Treatments were set up with eight fertilizers based on four composts in two doses, a synthetic fertilizer (urea) and a control (no fertilizer). Composts were prepared from animal waste and plant residues and allowed to transform naturally for 25 weeks. For this purpose, we used hen manure (H) and cow manure (C) as animal source; sawdust (S) and maize stover (M) were used as plant residues. The characteristics of the applied composts are shown in Table 1. Compost doses were 35 and 75 Mg ha^{-1}, as recommended by Castellanos *et al*. (2000), to achieve an experimental soil with medium and high organic matter (OM) content, 2 and 3% respectively, in this case based on an original content of 1.14% of OM and a sandy loam texture. The dose of urea (U) was 200 kg ha^{-1}. Treatments and doses are shown in Table 2. Composts and fertilizer were applied at the time of planting blue corn. Harvest took place 130 days after planting, when the soil sampling was performed.

[1] Tarigo, A., C. Repetto y D. Acosta. 2004. Evaluación agronómica de biofertilizantes en la producción de lechuga (*Lactuca sativa*) a campo. Tesis de Licenciatura Universidad de la Republica Facultad de Agronomía. Montevideo, Uruguay.

[2] Lüebka, U. y S. Lüebka. 2008. Materia orgánica como un recurso para la fertilidad. pp. 309-16. *In*: II Conferencia Internacional sobre eco-biología del suelo y el compost, 26-29 de noviembre 2008. SoilAce. Puerto de la Cruz, Tenerife, España.

Table 1. Characteristics of four composts used as a source of organic fertilization.

Compost	C	N	C/N	P	K	Ca	Mg	Na	NO_3	Cu	Fe	Zn	Mn	pH
	- - - - - % - - - - -			- - - - - - - - - - - - - - - - - - mg kg^{-1} - - - - - - - - - - - - - - - - - -										
HS	10.9	2.3	4.9	0.11	1.4	6.1	0.72	0.42	1190	56	1633	277	378	7.8
CS	17.8	1.4	12.9	0.02	0.5	2	0.3	0.21	1421	87	1326	67	192	8.1
HM	13.4	2.1	6.5	0.11	2.3	1.1	0.6	0.34	1473	48	1662	244	381	7.9
CM	14	1.6	8.6	0.02	1.9	5.3	0.89	0.44	1279	93	1640	96	243	9.7

HS = hen manure and sawdust; CS = cow manure and sawdust; HM = hen manure and maize stover; CM = cow manure and maize stover.

Response Variables

Soil samples were dried at room temperature from 34 to 40 °C. The variables evaluated in soil were concentration of NO_3^- by the Brucine method and UV-visible spectrophotometry (HACH DR 5000-UV-visible) (Uvalle-Bueno, 1993) and the major elements K^+, Ca^{++}, Mg^{++} and Na^+, through ammonium acetate and atomic absorption spectrophotometry (Perkin Elmer Analyst 100, New Jersey, US), $P^=$ with the ammonium molybdenum vanadate method and UV-visible spectrophotometry analysis (HACH DR 5000-UV-visible) (Nogales *et al.,* 2005).

Statistical Analysis and Hypothesis Testing

The first stage of the ANOVA was applied in a Completely Randomized Design (CRD). Since H_o was rejected, we proceeded to perform the hypothesis test for each of the contrasts and response variables, using 1 degree of freedom in each (H_o: σ^2_t/σ^2_e = 1; H_a: σ^2_t σ^2_e > 1). Nine hypotheses were tested, corresponding to each contrast (λ_i), as follows: H_o: λ_i=0; H_a: $\lambda_i \neq 0$.

Orthogonal Contrasts

A set of orthogonal contrasts was defined *a priori* under the requirements of orthogonality (independence) explained as follows: (1) all treatments vs control, (2) organic vs inorganic fertilizers, (3) composting based on hen manure (H) vs fertilizers based on cow manure (C), (4) compost based on sawdust (S) vs compost based on maize stover (M), (5) fertilization with 35 Mg ha^{-1} of hen manure + sawdust compost (HS) vs 75 Mg ha^{-1} of the same mixture; (6) fertilization with 35 Mg ha^{-1} of hen manure + maize stover (HM) compost vs 75 Mg ha^{-1} of the same mixture; (7) fertilization with 35 Mg ha^{-1} of cow manure + sawdust compost (CS) vs 75 Mg ha^{-1} of the same mixture; (8) fertilization with 35 Mg ha^{-1} of cow manure + maize stover compost (CM) vs 75 Mg ha^{-1} of the same mixture, and (9) interaction manure*crop residues. Statistical analysis was performed using PROC GLM of SAS version 9.1.3.

RESULTS AND DISCUSSION

The analysis of soil macronutrients revealed significant changes in their concentrations in the different treatments (Table 3). Results of nine independent comparisons selected *a priori* reveal that only orthogonal contrast of all (all types of fertilizers) vs control (no fertilizer) significantly affected the concentration of six nutrients, while the HS-35 Mg ha^{-1} vs HS-75 Mg ha^{-1} contrast had no effect on the levels of the macronutrients.

These findings agree with those observed by other researchers. Bernal *et al.* (2008), for example, mentioned that bulking agents such as cereal straw

Table 2. Treatments with organic and inorganic fertilization.

Treatment	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
Ky	HS-35	HS-75	CS-35	CS-75	HM-35	HM-75	CM-35	CM-75	U-200	C
Dose (Mg ha^{-1})	35	75	35	75	35	75	35	75	0,2	0

HS = hen manure and sawdust; CS = cow manure and sawdust; HM = hen manure and maize stover; CM = cow manure and maize stover.

Table 3. Mean squares and statistical significance of six macronutrients associated with application of different fertilizers (organic and inorganic).

Source of variation	df	Soil macronutrients					
		NO_3-	$P^=$	K^+	Ca^{++}	Mg^{++}	Na^+
Treatments	9	2.46*	6848*	148555*	10711398*	6576*	0.0421*
All vs control	1	10.15*	12792*	611433*	24041333*	10396*	0.0645*
Org vs inorg	1	5.56*	13197*	527085	27569835*	8146*	0.0538
Hen manure vs cow manure	1	0.412*	28585*	140	6460140*	316	0.0109
Sawdust vs maize stover	1	0.533*	1296	6250	4709390*	472	0.0194
HS-35 vs HS-75	1	0.004	1638	1890	4000	62	0.0012
HM-35 vs HM-75	1	0.007	3546*	74390	5062	765	0.0774*
CS-35 vs CS-75	1	0	555	1562	6250	3062*	0.0980*
CM-35 vs CM-75	1	3.624*	1	4000	25840562*	25000*	0.0436
Interaction M*V	1	1.857*	22	110250	7766015*	10972*	0.0109
Error	40	0.057	787	29870	78750	440	0.0132
Mean		2.61	66.2	1109	2134.75	209.2	7.18
CV(%)		9.18	42.4	15.58	13.14	10.03	1.6
$R = r^2$		0.906	0.662	0.662	0.968	0.77	0.42

M = manure; V = plant residues; (*) significant at 5%.

and sawdust have high organic-C contents and high C/N ratios (above 50). Moreover, mature composts produced from cattle and poultry manure mixed with agricultural and forestry by-products provide beneficial effects on soil physical, chemical and biological properties as well as nutrient content. It has also been mentioned that bovine manure, being a rich source of carbon and nitrogen, increased microbial activity, and consequently led to increased availability of nutrients for the plant (Lincoff, 1981).

The contrast all vs control, significantly affected all nutrients. Some contrasts (CS-35 vs CS-75; HM-35 vs HM-75), however, had significant effect on at least one of the nutrients. The concentrations of NO_3^- and Ca^{++} were affected significantly by six of the nine contrasts, while the level of K^+ responded only to the contrast all vs control, probably because most of the soils in temperate zones in Mexico are rich in this macronutrient, the reason that potassium fertilizers are usually not applied or the required doses are low. The interaction M*V had a significant effect on macronutrients NO_3^-, Ca^{++} and Mg^{++}.

The coefficients of variation (CV) observed were 1.6 and 42.4% for Na^+ and $P^=$, respectively. This suggests that the concentration of the first was relatively constant. The second, on the contrary, was more affected by the application of organic and inorganic fertilizers, particularly by the composts prepared in this study.

The highest coefficient of determination (R^2) was estimated for Ca^{++} (0.968). At the other extreme, the macronutrient Na^+ exhibited the lowest (0.42). For Ca^{++}, the percentage of the total variation (96.8%) explained by the experimental design was close to 100%, while the value of 42% for Na^+, indicated that the error component (random causes) was proportionally higher than that, due to the effect of the treatments. The coefficients of determination of the rest of macronutrients ranged between 0.662 and 0.906. All of these values were higher than 0.5; that is, more than 50% of the variation was explained by the statistical model used in the study.

By comparing the concentrations of nutrients NO_3, $P^=$ and K^+ (Table 4), it was found that the control had the lowest means 75.4, 5 and 777.5 mg kg^{-1}, respectively, while the highest means, 268.2, 33.8 and 1267.5 mg kg^{-1}, were recorded for treatments CS-75, HS-75 and CM-75, respectively, in all three cases with the highest dose of compost (75 Mg ha^{-1}).

Table 4. Means comparison and significant groups of six soil macronutrients (mg kg^{-1}) from organic and inorganic sources.

Treatments		NO_3^-	$P^=$	K^+	Ca^{++}	Mg^{++}	Na^+
T_1	HS-35	209.2 ab†	26.8 abc	1212.5 a	1342.5 b	212.5 bcd	2.87 a
T_2	HS-75	238.3 a	33.8 a	1240 a	1302.5 b	207.5 abc	2.91 a
T_3	CS-35	234.2 a	13.2 cde	1105 ab	1220.0 b	165.0e	3.11 a
T_4	CS-75	268.2 a	17.3 abcd	1130 ab	1270.0 b	200.0 cde	3.12 a
T_5	HM-35	195.2 abc	21.6 ab	1060 ab	1150.0 b	175.0 de	3.11 a
T_6	HM-75	112.6 cd	31.9 ab	1232.5 a	1105.0 b	192.5 de	3.06 a
T_7	CM-35	85.4 d	12.4 cde	1227.5 a	1205.0 b	172.5 de	3.05 a
T_8	CM-75	131.2 bcd	12.6 cde	1267.5 a	4420.0 a	272.5 a	1.85 b
T_9	U-200	132.9 bcd	6.33 de	840 b	4117.0 a	242.5 abc	1.77 b
T_{10}	C	75.4 d	5.0 e	777.5 b	4215.0 a	252.5 ab	1.26 c

† In each column the same letters indicate the same group of significance. Tukey Test ($\alpha = 0.05$).

For nutrients Ca^{++} and Mg^{++}, the means of the control (4215 and 252 mg kg^{-1}) were among the top three, although they were statistically equal (Table 4), while treatments CM-75 and U-200 were, respectively, first and second with the means 4420 and 4117 mg kg^{-1}for the element Ca^{++}; 272.5 and 245.5 mg kg^{-1} for the nutrient Mg^{++}. These results clearly demonstrate a substantial improvement in the concentration of the above mentioned nutrients, in response to the application of compost obtained by mixing manure and plant residues, as has been pointed out by several researchers (Fox *et al.,* 1989; Magdoff, 1991; Blackmer, 1992).

The comparison of means test of the control (Table 4) revealed the presence of at least two significance groups for K^+ and Ca^{++} and up to five groups for $P^=$ and Mg^{++} averages. As mentioned above, the control group had the lowest average for nutrients NO_3^-, $P^=$, K^+ and Na^+; however, it can be seen that in five of the six nutrients, the control was statistically equal to at least one other treatment, as with the element K^+, 777.5 and 840 mg kg^{-1}, for the control and inorganic fertilization, respectively. When analyzing the Na^+ element, the presence of three groups of significance is remarkable: group a, formed by treatments T_1 to T_7 (means varied from 2.87 to 3.12 mg kg^{-1}), group b, formed by treatments T_8 and T_9 (1.85 and 1.77 mg kg^{-1}); group c, the control (T_{10}), with the lowest mean (1.26 mg kg^{-1}).

The responses observed in the present study agreed with other studies carried out by several researchers, who reported significant increases in the concentration of nutrients. For instance, López *et al.* (2001) reported values of N of 2.18 and 1.80%, when organic fertilizer made from hen manure and cow manure were applied. In a critical review, Bernal *et al.* (2008) discussed the important role of bulking agents such as cereal straw and wood by-products (sawdust), which have high organic-C contents and high C/N ratios, on maturity index of compost produced when they are mixed with cattle manure and poultry manure. This also supports the idea of the effect of the interaction manure × plant residues on soil mineral content. These results have also been observed in other studies, where responses to compost application were evaluated in the stages of growth and fruit development (Ortega *et al.,* 2010). Similar results have been reported by Apolinar (2006)[3], who applied a mixture of sawdust-compost to a soil cultivated with tomato, demonstrating the benefits of sawdust as a bulking agent used to produce composts. In addition, this researcher reported improvement in physical-chemical properties of the soil fertilized with compost mixed with sawdust.

Millaleo *et al.* (2006) reported increases in the concentration and availability of $P^=$ when high doses of organic fertilizers made from livestock manure and crop residues were applied. The same authors observed

[3] Apolinar, S. 2006. Índices fisiotécnicos en la productividad de seis híbridos de tomate (*Lycopersicum esculetum* Mill) en cultivos sin suelo en invernadero. Tesis de Licenciatura. Instituto Tecnológico del Valle de Oaxaca, Ex Hacienda de Nazareno, Xoxocotlan, Oaxaca México. 107 p.

a significant increase in crop foliage biomass and availability of several nutrients. Other authors (Laboski and Lamb, 2003) observed an increase in the availability of $P^{=}$ when livestock manure was applied because its concentration in the organic amendment can be equal to or greater than. Another factor that may explain the results reported in this research is the production of organic acids during microbial degradation of organic fertilizer applied to soil, as they can increase nutrient availability to plants (Gale *et al.*, 2000). Beneficial effects on soil-plant system properties, such as improved physical characteristics, increased nutrient contents, soil fertility, higher biological and enzymatic activity, have been observed after applying composts (Roca *et al.*, 2008).

Average $P^{=}$ content in hen manure-sawdust mixture composts was HS-35 (26.8 mg kg^{-1}) and HS-75 (33.8 mg kg^{-1}); in cow manure-sawdust composts it was CS-35 (13.2 mg kg^{-1}) and CS-75 (17.3 mg kg^{-1}). It was observed that in the first group the means were almost double the value of the second group (Table 4). Similar studies (Jiménez *et al.*, 2004), where cattle manure was used without mixing with sawdust, reported concentrations of $P^{=}$ between 16.54 mg kg^{-1} and 38.10 mg kg^{-1}, far below the values observed here. This suggests a positive significant effect of the interaction manure x sawdust. Pérez *et al*. (2008) recorded a concentration of 247.45 Mg ha^{-1} $P^{=}$ in response to compost made from mixtures of hen droppings and cow manure. These values exceed the results presented in our paper by nearly 60%.

For K^{+}, averages from 777.5 mg kg^{-1} (control) to 1267.5 mg kg^{-1} (BE-75) were reported in our work. However, eight of the 10 treatments compared were part of the group of significance, which includes the highest average (Table 4). Arrieche (2008)[4] reported a K^{+} concentration average of 278.8 mg kg^{-1}, contribution achieved with composts were made with chicken manure and cachaza. The composts were applied to improve soil properties; however, these values were lower than those reported in our study.

Two groups of significance for the nutrient Ca^{++} were observed, fluctuating between the treatment means of 1105 and 4420 mg kg^{-1} (Table 4). Other researchers (Olivares *et al.*, 2012) have reported values close to 4800 mg kg^{-1} in soils fertilized with compost made from cattle manure; this is greater than the average of the treatments compared in our study. Similarly, the results of this study agree with those reported by Carmo *et al.* (2016), who observed that only chicken and quail manures, substrate and compost, had a significant effect on Ca^{++} concentration. Also, Olivares *et al.* (2012), using cattle manure mixed with sawdust, reported an average contribution to soil of Ca^{++} of 4500 mg kg^{-1}, similar to those of some of the treatments analyzed in our work.

The average concentrations of Mg^{++} in treatments varied between 165 and 252 mg kg^{-1}. These results differ from Olivares *et al*., 2012, who reported an average of 5200 mg kg^{-1} when manure-based compost and sawdust were applied. This value was higher than the best treatment of our study. Cortés *et al.* (2008) reported values of 604 to 797 mg kg^{-1} with fertilizers based on cattle manure; these values were also higher than the results presented in Table 4. Arrieche and Ramírez (1997), Lora (1998) and Brito *et al.* (2004) noted that values between 100 and 150 mg kg^{-1} Mg^{++} are suitable for a sandy loam soil, such as that used in this study; thus, the values obtained in this study can be considered acceptable.

The average concentration of Na^{+} varied from 1.26 to 3.12 mg kg^{-1} (Table 4), values that differ from those observed in other studies (Olivares *et al*., 2012), where a combination of manure and sawdust was applied, yielding an average of 900 mg kg^{-1}, much higher than the value found in our study. Canet *et al.* (1998) reported lower concentrations than those observed here (0.22 mg kg^{-1}) when they applied ovine manure. It is important to avoid high values of Na^{+} because the osmotic pressure generated in the groundwater interferes with the growth of most crops.

CONCLUSIONS

Five treatments of compost applied to soils significantly increased concentrations of NO_3^- compared with inorganic fertilization and the control. Compost produced from hen manure provided a more consistent effect on the concentration of NO_3^- and $P^{=}$ in soil, relative to cow manure. Sawdust-based composts had a greater effect on the content of NO_3^-, compared with maize stover-based compost. The average

[4] Arrieche, L. I. 2008. Efecto de la fertilización orgánica y química en suelos degradados cultivados con Maíz (*Zea mays* L.) en el estado Yaracuy, Venezuela. Tesis Doctoral. Universidad de Valladolid. Departamento de Agrociencias Forestales. p 71.

concentration of Ca^{++} and Mg^{++} in soils with organic fertilizers was lower than those caused by inorganic fertilization. The average concentration of Na in soils with organic fertilizers was higher than that observed with inorganic fertilization.

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