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Use of Organic Compost Containing Waste from Small Ruminants in Corn Production

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ABSTRACT: Composting is a useful way of transforming livestock waste into organic fertilizer, which is proven to increase soil nutrient levels, and thus crop yield. Remains from production and slaughter of small ruminants can become a source of important elements for plant growth, such as N, after microorganism-driven decomposition.The aim of this investigation was to evaluate the effects of this compost on soil fertility and on the nutritional status and yield of the corn crop. The experiment was conducted in a Haplic Luvisol in a randomized block design with six treatments and five application rates of the organic compound in Mg ha^{-1}: 3 (half the standard rate), 6 (standard rate), 9 (one and a half times the standard rate), 12 (twice the standard rate), and 24 (four times the standard rate) and an additional treatment with mineral fertilizers (110, 50 e 30 kg ha^{-1} of N, P_2O_5 and K_2O, respectively), with four blocks. Evaluations were performed for two harvests of rainfed crops, measuring soil fertility, nutritional status, and grain yield. The compost increased P, K, Na and Zn values in the 0.00-0.20 m layer in relation of mineral fertilization in 616, 21, 114 and 90 % with rate 24 Mg ha^{-1} in second crop. Leaf N, Mg, and S contents, relative chlorophyll content, and the productivity of corn kernels increased in 27, 32, 36, 20 e 85 %, respectively, of low rate (3 Mg ha^{-1}) to high rate (24 Mg ha^{-1}) with of application of the compost. Corn yield was higher with application of organic compost in rate of 24 Mg ha^{-1} than mineral fertilizer combination in second crop.

Keywords: *Zea mays*, organic fertilizer, goats, sheep.

INTRODUCTION

Raising sheep and goats, like all stockbreeding activities, generates wastes (viscera, blood, or even entire carcasses), which have good potential for producing compost. Therefore, it is necessary for these materials, which contain satisfactory levels of nutrients, to be evaluated regarding their potential use as components of organic fertilizer.

Brazilian flocks of small ruminants increased markedly in the first decade of this century mainly due to greater domestic demand for dairy and meat products. This was accompanied by a rising number of studies on goats and sheep (Resende et al., 2010). Of Brazil's five geographic regions, the Northeast has the largest flocks of these animals (about 8 million goats and 9 million sheep), with a high percentage in each case belonging to smallholders. Based on an assumption that (i) 50 % of these animals are females, with a birth rate of 1.0 per year, or 8.5 million newborns, (ii) there is a natural mortality rate of about 10 %, where average carcass weight is 20 kg, and (iii) compost made from this material would contain 1.5 to 2.0 times that quantity in weight of structuring materials (plants and dung), the potential annual generation of compost in the region is approximately 47 thousand metric tons.

This region also stands out for low use of inputs in farming, mainly due to the prevailing semiarid conditions, with low rainfall and frequent winter hot spells. The consequence is soil degradation, mainly reduced fertility (Menezes et al., 2012).

The use of carcasses from slaughter of ruminants to produce meat and bone meal or animal feed was banned in Brazil by the Ministry of Agriculture in 2004, thus limiting the alternatives for allocation of this material. However, through composting, the byproducts from raising goats and sheep can be made into organic fertilizer, thus recycling nutrients in the farm productive chain and reducing environmental impacts.

Among the nutrients present in wastes, byproducts, and compost, N stands out (Chacón et al., 2011; Carneiro et al., 2013). Shortage of this macronutrient limits the development of most crops, and poses a particular problem for smallholders who cannot afford commercial fertilizers. Therefore, the use of organic materials can be a feasible option to substitute mineral fertilizers and to restore soil conditions in degraded areas.

In the state of Ceará, average corn yield is about 1,059 kg ha^{-1}, a value below the average of the Northeast region, which was 2,656 kg ha^{-1} for the 2013-2014 crop (Viana and Lima, 2013). According to the latest figures (year 2014), yearly corn consumption in Ceará is about 950 thousand tons while production is around 401 thousand tons, meaning the state needs to import at least 549 thousand tons to meet demand (Lima, 2014). Furthermore, farmers in Ceará use relatively small quantities of fertilizers: the state has the lowest consumption in the Northeast and ranks 23rd in the country (out of 26 states) (IPNI, 2014).

Therefore, the use of organic compounds derived from waste material from breeding small ruminants can increase crop production through recycling of nutrients. Considering the absence of research under field conditions, the aim of this study was to assess the effects on soil quality, plant nutritional status, and corn yield of different application rates of organic compost containing wastes from slaughter of small ruminants.

MATERIALS AND METHODS

The study was conducted in the experimental fields of the Embrapa Goat and Sheep Research Unit (Embrapa Caprinos e Ovinos) in the Semiarid Coexistence Sector in a soil classified as *Luvissolo Háplico* (Santos et al., 2013) or Haplic Luvisol. The climate in the region is BShw (hot semiarid) according to the Köppen classification system, with the rainy season lasting from January to June. The average annual temperature is 28 °C and average historical rainfall is 759 mm yr^{-1}. The experiment was conducted on two corn crops, in 2013 and 2014 (sown on March 20, 2013 and March 17, 2014, and harvested on July 1, 2013 and June 20, 2014). The rainfall level in the wet season (January to May) was 638 mm in 2013 and 614 mm in 2014 (Figure 1).

Before starting the experiment, soil samples were collected in two layers (0.00-0.20 and 0.20-0.40 m) to assess soil fertility and soil particle size distribution (Table 1).

The results of soil analysis indicated that, according to the classification of Fernandes (1993), the pH was low-acidic and organic matter content was low, while nutrient concentrations were very high P, very high K, high Ca, high Mg, and low Al (Table 1). The soil was classified as sandy loam (Table 1).

The compost used was produced using the following materials: solid wastes from slaughter of goats and sheep, 1.5 to 2.0 times the quantity of the wastes of a mixture of 50 % dung from cleaning pens/corrals and 50 % uneaten feed (chopped elephant grass) and tree trimmings, with 50 % moisture. Approximately 120 days were needed to produce the organic compost (Souza et al., 2012; Oliveira et al., 2015).

The chemical characteristics of the compost utilized were determined according to Abreu et al. (2006) (Table 2). Moisture content after 120 days was approximately 10 %. According to Siqueira (2013), at the end of composting, the material should not contain thermotolerant coliforms, total bacteria, or *E. coli.* The material produced in this study was compliant with the regulations from the National Environmental Council (Conama), established in Resolution 375/2006, which "defines criteria and procedures for agricultural use of sewage sludge produced by sanitary waste treatment stations and its derived products..." We used this framework as a reference because of the lack of specific laws or regulations applicable to compost obtained from stockbreeding wastes.

Applications of the compost were established based on N content, a nutrient present in satisfactory levels, and the amount adequate for medium production of corn, considering the quantity of the nutrient necessary for sowing and topdressing, whose total value was 110 kg ha^{-1} for an expected corn yield of 8 Mg ha^{-1} (Alves et al., 1999). Five rates of compost were applied, with the following values in Mg ha^{-1}: 3 (half the standard rate), 6 (standard rate), 9 (one and a half times the standard rate), 12 (twice the standard rate), and 24 (four times the standard rate), and an additional treatment with mineral

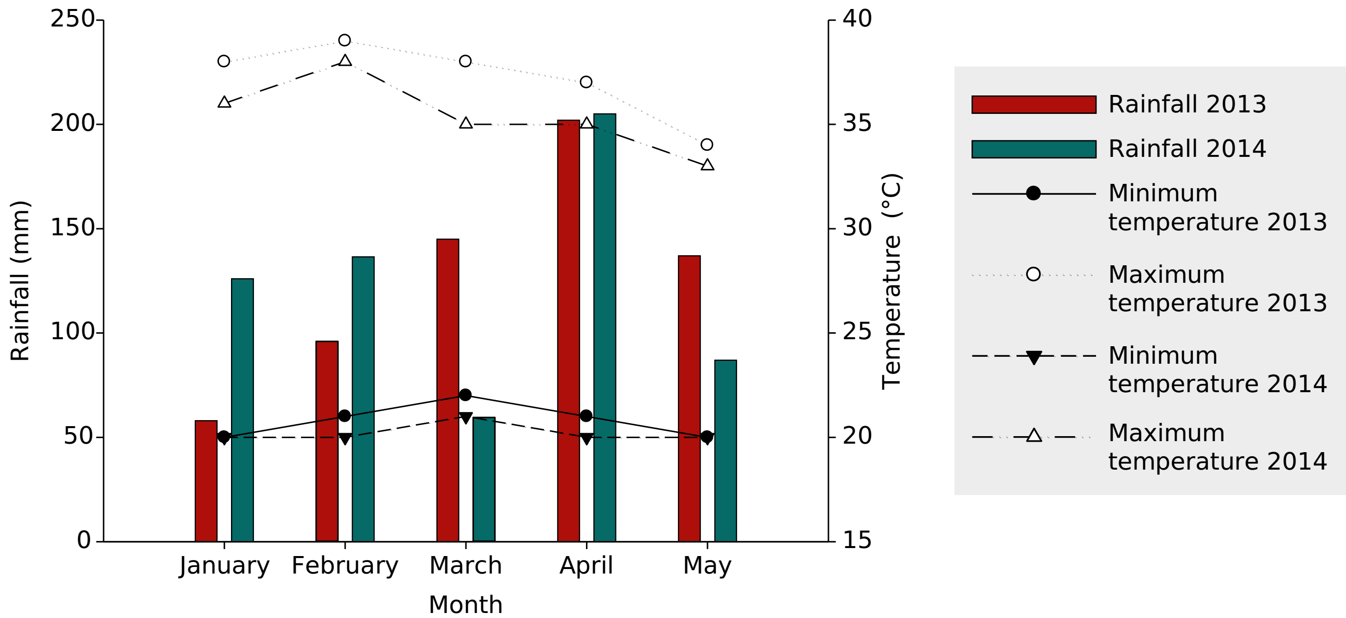

Figure 1. Rainfall and minimum and maximum air temperatures in each month of the rainy season in 2013 and 2014. Sobral, CE, Brazil.

Table1. Chemical and physical properties of the soil in the experimental area

Property	0.00-0.20 m	0.20-0.40 m
pH(H_2O)	6.1	6.0
Nt (g kg^{-1})	0.63	0.61
OM (g kg^{-1})	10.0	9.8
P (mg kg^{-1})	87	15
K (mg kg^{-1})	249	121
Na (mg kg^{-1})	14	21
Ca^{2+} ($mmol_c$ kg^{-1})	65	66
Mg^{2+} ($mmol_c$ kg^{-1})	60	51
Al^{3+} ($mmol_c$ kg^{-1})	1.0	1.0
H+Al ($mmol_c$ kg^{-1})	17	20
CEC ($mmol_c$ kg^{-1})	149	141
SB ($mmol_c$ kg^{-1})	132	121
V (%)	89	85
m (%)	1.0	1.0
ESP (%)	1.0	1.0
BD (Mg m^{-3})	1.6	1.5
PD (Mg m^{-3})	2.6	2.6
TP (m^3 m^{-3})	5.8	5.3
Coarse sandy (g kg^{-1})	335	231
Fine sandy (g kg^{-1})	373	348
Silt (g kg^{-1})	213	241
Clay (g kg^{-1})	79	180

pH in water, v/v; Nt: total nitrogen, Kdjedahl method; OM: organic matter, Walkley-Black method; P, K, Na: Mehlich-1 method; Ca, Mg Al: 1 mol L^{-1} KCl method; H+Al: potential acidity, calcium acetate 0.5 mol L^{-1} pH7 method; SB: sum of bases; CEC: cation exchange capacity; V: base saturation; m: aluminum saturation; ESP: exchangeable sodium percent; BD: soil bulk density; PD: particle density; TP: total porosity; Coarse sandy, fine sandy, silt, clay: pipette method.

Table 2. Chemical properties of the organic compost

Property	Value
N inorg (mg kg^{-1})	350
N-NO_3^- (mg kg^{-1})	250
N-NH_4^+ (mg kg^{-1})	105
Nt (g kg^{-1})	20.3
C (g kg^{-1})	150.6
P (g kg^{-1})	9.0
K (g kg^{-1})	15.7
Na (g kg^{-1})	2.1
Ca (g kg^{-1})	21.9
Mg (g kg^{-1})	5.5
S (g kg^{-1})	2.8
B (mg kg^{-1})	20
Cu (mg kg^{-1})	30
Fe (mg kg^{-1})	2051
Mn (mg kg^{-1})	175
Zn (mg kg^{-1})	138
C/N	7.4
pH($CaCl_2$)	6.7

N inorg: inorganic nitrogen; NO_3^--N: nitrate; NH_4^+-N: ammonium; Nt: total nitrogen; C: carbon; pH in $CaCl_2$ solution.

fertilizers. The treatments with compost did not receive mineral fertilization. The additional treatment received 110 kg ha^{-1} of N (30 kg at sowing and 80 kg as topdressing) in the form of urea, 50 kg ha^{-1} of P_2O_5 in the form of triple superphosphate (2013 crop) and single superphosphate (2014 crop - the change in P fertilizer occurred because no source of S had been applied the previous year), and 30 kg ha^{-1} of K_2O in the form of potassium chloride. The experimental design was randomized blocks with five application rates of compost plus one additional treatment, with four replications, for a total of 24 plots. No acidity correction was necessary (Table 1), according to Alves et al. (1999).

The experimental plots were composed of six rows at a spacing of 0.80 m and length of 5 m, with a 0.5 m boundary at each end. Only the plants in the four central rows were considered in the measurements. The compost was applied manually just after sowing of each crop (2013 and 2014) across the total area of each plot, according to the respective treatment. The mineral fertilizer mixture was applied at sowing 0.05 m below the seeds and as topdressing at the side of each row. The corn variety planted was BRS Gorutuba.

To assess the chemical properties of the soil, samples were collected at two depths (0.00-0.20 and 0.20-0.40 m) at three points in each plot with a Dutch auger and mattock. These samples were then mixed to form a representative sample from each layer. The samples were air-dried and sifted (2 mm mesh), and the chemical properties were measured according to Silva et al. (2009). Additionally, in the samples from the top layer (0.00-0.20 m), the inorganic N content was measured according to the procedure described by Cantarella and Trivelin (2001), with correction of the values obtained to dry basis. Sampling was performed one week after the harvest of each crop.

The nutritional state of the plants was determined by sampling the middle third of the ear leaf during the tasseling phase (50 % of the plants with tassels), according to Cantarella et al. (1997). The same diagnostic leaves were used, in the middle of the blade and avoiding the central nervure, to measure the relative chlorophyll content (RCC) by the SPAD (soil plant analysis development) index using a chlorophyll meter (Minolta SPAD 502), as previously done by Argenta et al. (2004). The concentrations of macro- and micronutrients were measured according to the procedures described in Bataglia et al. (1983).

Corn ears were harvested when plants were in the R6 stage (phenological maturity) and grain moisture was adjusted to 13 %. Because of the lack of uniformity of the plants in some plots, grain yield was estimated by the formula of Zuber (Schimidt et al., 2001; Nascimento et al., 2003).

The data were subjected to analysis of variance (F-test; $p<0.05$), and when significant, regression analysis was performed for the application rates. Orthogonal contrast analysis (F-test, $p<0.05$) was performed on the data from the additional treatment group. Sisvar software was used for all the statistical tests (Ferreira, 2011).

RESULTS AND DISCUSSION

For soil chemical properties, we found significant results for the variables inorganic N and K in 2013 in the 0.00-0.20 m layer (Table 3). In other words, the organic compost application rates promoted changes in the concentrations of these nutrients in the soil. Contrast analysis did not reveal a significant difference between organic and mineral sources.

In the subsurface layer (0.20-0.40 m), no significant difference was found in routine soil analysis or for micronutrients, S, and Na as a function of the application rates of compost (Table 3). The same situation occurred for contrast analysis.

For the 2014 crop, routine soil analysis showed significant differences for the variables NO_3^--N, P, and K: the concentrations of these nutrients increased along with an increase in compost rates. For K, the same behavior was observed in the 2013 crop (Table 4). Contrast analysis revealed significant differences for inorganic N and P, i.e., organic

Table 3. Chemical properties of a Haplic Luvisol at 0.00-0.20 and 0.20-0.40 m depths, in 2013, and analysis of variance

Rate (R)	NH_4^+-N	NO_3^--N	N inorg	pH	OM	P	K	Ca^{2+}	Mg^{2+}	H+Al	SB	CEC	V	SO_4^{2-}-S	Na	ESP	B	Cu	Fe	Mn	Zn
Mg ha^{-1}	mg kg^{-1}				g kg^{-1}	mg dm^{-3}		mmol$_c$ dm^{-3}					%	mg dm^{-3}		%	mg dm^{-3}				
0.00-0.20 m																					
3	9.9	22.9	32.9	6.6	8.0	7	69	37	17	16	56.5	72.5	78	7	15.9	1.0	0.34	0.63	44	27	0.6
6	9.3	23.5	31.5	6.6	9.7	11	79	39	12	16	53.3	69.3	77	7	7.0	0.4	0.25	0.66	36	34	1.0
9	11.5	24.5	35.9	6.4	10.5	10	60	39	19	17	60.8	77.8	78	5	28.7	1.6	0.31	0.75	52	31	0.7
12	12.2	23.8	36.1	6.6	10.5	23	100	47	22	16	72.4	88.4	82	8	19.1	0.9	0.3	0.84	44	41	0.8
24	8.6	23.2	31.8	6.6	15.5	26	126	47	22	17	73.7	90.7	81	7	32.9	1.6	0.26	0.81	45	48	1.1
F-test	1.44^{ns}	0.82^{ns}	2.70*	0.68^{ns}	2.57^{ns}	1.51^{ns}	15.69**	0.42^{ns}	0.44^{ns}	0.15^{ns}	0.44^{ns}	0.73^{ns}	0.36^{ns}	0.90^{ns}	2.17^{ns}	1.73^{ns}	2.11^{ns}	0.30^{ns}	0.40^{ns}	1.48^{ns}	1.57^{ns}
CV (%)	24.6	5.6	8.1	3.8	32.3	15.5	15.3	37.2	33.6	15.6	42.6	34.5	7.8	37.6	37.7	37.5	16.7	35.0	39.3	37.7	38.9
Contrast																					
Rate (mean)	14.2	19.3	28.0	6.6	10.8	15	87	42	18	13	63.3	76.7	83	7	20.7	1.1	0.29	0.74	44	36	0.8
Min. Fert.	9.5	24.6	34.2	6.5	14.8	11	97	56	27	18	86.1	103.9	82	9	15.0	0.6	0.32	0.87	32	35	1.0
F-test	0.25^{ns}	1.51^{ns}	0.07^{ns}	0.34^{ns}	3.78^{ns}	0.43^{ns}	0.85^{ns}	3.07^{ns}	2.31^{ns}	1.40^{ns}	2.78^{ns}	3.07^{ns}	1.49^{ns}	3.40^{ns}	0.67^{ns}	1.71^{ns}	0.83^{ns}	0.56^{ns}	1.82^{ns}	0.04^{ns}	0.94^{ns}
0.20-0.40 m																					
3	-	-	-	6.4	8.0	8	62	46	29	17.5	79.0	96.5	82	8	56.5	2.5	0.30	0.60	38	31	1.1
6	-	-	-	6.3	9.3	8	69	49	23	17.5	74.8	92.3	81	8	24.0	1.1	0.27	0.75	26	23	0.7
9	-	-	-	6.4	8.8	10	60	55	33	18.5	92.0	110.5	83	7	56.5	2.2	0.24	0.81	39	29	0.8
12	-	-	-	6.4	8.0	15	72	64	39	17.5	107.3	124.8	86	8	55.5	1.9	0.28	0.87	39	37	0.7
24	-	-	-	6.5	12.0	18	88	55	33	16.3	92.5	108.8	85	8	50.5	2.0	0.30	0.75	39	41	1.3
F-test	-	-	-	0.36^{ns}	0.91^{ns}	2.36^{ns}	2.41^{ns}	0.32^{ns}	0.31^{ns}	0.76^{ns}	0.32^{ns}	0.30^{ns}	0.37^{ns}	0.17^{ns}	0.35^{ns}	0.32^{ns}	1.44^{ns}	0.45^{ns}	0.55^{ns}	1.93^{ns}	0.88^{ns}
CV (%)	-	-	-	4.3	37.7	29.5	20.4	26.3	36.3	10.5	31.0	30.7	7.8	21.0	30.2	28.9	14.8	39.6	42.7	32.2	29.3
Contrast																					
Rate (mean)	-	-	-	6.4	9.2	12	70	54	31	17	89.1	106.6	83	8	48.6	2.0	0.28	0.76	36	32	0.9
Min. Fert.	-	-	-	6.4	9.3	9	80	46	33	17	81.7	99.0	82	7	33.3	1.2	0.30	0.93	21	26	0.9
F-test	-	-	-	0.02^{ns}	0.01^{ns}	0.35^{ns}	0.86^{ns}	0.04^{ns}	0.01^{ns}	0.04^{ns}	0.09^{ns}	0.10^{ns}	0.01^{ns}	1.21^{ns}	0.43^{ns}	0.63^{ns}	5.76*	1.04^{ns}	3.86^{ns}	1.30^{ns}	0.01^{ns}

^{ns}, *, and **: no significant, significant at 5 and 1 % probability, respectively. Min. Fert.: mineral fertilization. N inorg: NH_4^+-N + NO_3^--N.

compost application promoted higher N and P concentrations in the soil than mineral fertilization did (Table 4). Souza et al. (2012), studying the same type of compost under controlled conditions, found increases in P and K concentrations in a *Latossolo* (Oxisol).

The average concentrations of nitrate and ammonium (Tables 3 and 4 for the 2013 and 2014 crops, respectively) showed higher values for nitrate than for ammonium, indicating the occurrence of a nitrification process.

With respect to micronutrients (B, Cu, Fe, Mn and Zn), S, and Na (2014 crop), significant differences were observed as a function of compost application rates for Na, percentage of exchangeable Na, and Zn. Contrast analysis revealed significant differences for Na, Cu, and Zn. For Na and Zn, compost application led to higher concentrations compared to mineral fertilization, with the opposite happening for Cu (Table 4). For the Na variable, this result indicates the need to monitor application of the compost to avoid a possible increase in sodicity in the area, even though the exchangeable sodium percent (ESP) result indicated a value below the critical values for saline soils (ESP >7 % for slightly sodic soils). Hence, this is a possible limiting factor for use of this organic fertilizer. In the composition of animal bodies, Na and K are considered macroelements, even though neither is a structural element (Barioni et al., 2001; Oliveira et al., 2014), so that the composting conditions to which the carcasses and slaughter wastes were subjected in this study may have led to greater release of these elements and their consequent availability in the compost.

The reduction in the concentration of Cu in comparison to the plot that received mineral fertilization may be related to complexation of this element by organic matter

Table 4. Chemical properties of a Haplic Luvisol at 0.00-0.20 and 0.20-0.40 m depths, in 2014, and analysis of variance

Rate	NH_4^+-N	NO_3^--N	N inorg	pH	OM	P	K	Ca^{2+}	Mg^{2+}	H+Al	SB	CEC	V	SO_4^{2-}-S	Na	ESP	B	Cu	Fe	Mn	Zn
Mg ha^{-1}	mg kg^{-1}				g kg^{-1}	mg dm^{-3}		mmol$_c$ dm^{-3}					%	mg dm^{-3}		%	mg dm^{-3}				
										0.00-0.20 m											
3	4.1	6.0	10.1	6.9	11.8	8	77	40	14	16	56.4	72.4	78	14	9.0	0.5	0.17	0.43	38	44	1.4
6	5.7	6.9	12.6	6.7	14.5	17	101	38	13	17	54.1	71.1	76	12	11.6	0.7	0.20	0.53	32	41	1.4
9	6.2	7.5	13.8	6.6	12.0	27	83	40	15	18	57.9	75.9	76	15	17.7	1.0	0.20	0.58	50	40	1.6
12	8.1	6.7	14.8	6.9	15.3	41	105	51	22	17	76.9	93.9	82	18	26.7	1.2	0.17	0.79	47	47	1.8
24	5.3	4.9	10.3	7.1	18.3	87	130	52	23	16	79.7	95.7	83	16	31.7	1.4	0.25	0.53	42	56	2.3
F-test	0.73^{ns}	3.83*	1.50^{ns}	2.10^{ns}	2.17^{ns}	7.39**	2.98*	0.87^{ns}	1.13^{ns}	0.52^{ns}	1.08^{ns}	0.98^{ns}	1.56^{ns}	2.45^{ns}	51.91**	4.66*	0.91^{ns}	0.46^{ns}	0.55^{ns}	2.12^{ns}	4.66*
CV (%)	30.5	15.4	27.4	3.7	25.2	29.1	24.2	32.9	20.6	11.7	36.3	29.7	6.4	16.5	13.9	32.4	35.3	27.6	45.3	19.7	20.6
Contrast																					
Rate $_{(mean)}$	5.9	6.4	12.3	6.8	14.4	36	99	44	17	17	65	81.8	79	15	19.3	1.0	0.2	0.57	42	46	1.7
Min. Fert.	4.6	1.4	6.0	6.6	12.3	12	106	57	24	18	84.1	102.1	82	16	15	0.6	0.2	0.98	33	39	1.2
F-test	0.55^{ns}	52.90**	13.63**	1.58^{ns}	1.31^{ns}	4.38*	0.19^{ns}	2.19^{ns}	1.53^{ns}	1.79^{ns}	1.93^{ns}	2.09^{ns}	1.00^{ns}	0.52^{ns}	3.91*	3.08^{ns}	0.01^{ns}	4.47*	0.88^{ns}	10.05^{ns}	7.39*
										0.20-0.40 m											
3	-	-	-	6.6	8.5	7	70	41	19	19	63.1	82.1	77	16	30.7	1.6	0.22	0.63	57	36	1.1
6	-	-	-	6.6	8.0	14	70	47	20	19	69.8	88.8	79	20	22.7	1.1	0.20	0.85	51	38	1.3
9	-	-	-	6.5	10.8	14	69	42	23	20	68.3	88.3	77	16	34.3	1.7	0.20	0.75	62	33	1.2
12	-	-	-	6.7	8.5	21	81	57	30	19	90.7	109.7	83	17	38.0	1.5	0.28	0.9	63	44	1.5
24	-	-	-	6.8	12.5	37	89	57	30	18	91.4	109.4	84	15	47.9	1.9	0.24	0.93	57	54	1.7
F-test	-	-	-	0.43^{ns}	0.97^{ns}	3.37*	0.91^{ns}	0.77^{ns}	0.72^{ns}	0.70^{ns}	0.81^{ns}	0.74^{ns}	1.08^{ns}	1.19^{ns}	0.81^{ns}	0.36^{ns}	0.58^{ns}	0.35^{ns}	0.25^{ns}	0.78^{ns}	0.70^{ns}
CV (%)	-	-	-	5.8	40.3	24.7	23.9	35.7	29.9	8.5	38.5	31.4	6.7	18.6	30.3	30.5	35.1	28.4	33	44.6	44.1
Contrast																					
Rate $_{(mean)}$	-	-	-	6.6	9.7	22	76	49	24	19	76.7	95.7	80	17	34.7	1.6	0.23	0.81	58	41	1.4
Min. Fert.	-	-	-	6.6	10.8	9	85	64	31	20	98.2	117.7	82	18	24.8	0.8	0.29	0.95	42	35	1.0
F-test	-	-	-	0.02^{ns}	0.31^{ns}	3.91*	0.68^{ns}	2.58^{ns}	1.12^{ns}	0.49^{ns}	1.94^{ns}	2.00^{ns}	1.34^{ns}	0.96^{ns}	0.93^{ns}	2.22^{ns}	1.57^{ns}	0.38^{ns}	2.65^{ns}	0.42^{ns}	1.27^{ns}

^{ns}, *, and **: no significant, significant at 5 and 1 % probability, respectively. Min. Fert.: mineral fertilization. N inorg: NH_4^+-N + NO_3^--N.

(Bezerra et al., 2009). In contrast, one of the hypotheses for an increase in Zn is that this can be attributed to the concentration of Zn in the organic compost (Souza et al., 2012).

In the subsurface layer (0.20-0.40 m), significant differences were noted for P as a function of compost application. As found in contrast analysis of the surface layer (0.00-0.20 m), significantly higher P concentrations were observed for the treatments with applications of organic fertilizer (Table 4).

The addition of organic materials to the soil reduces its ability to adsorb P, increasing availability of the element to plants. The organic materials also block the sites for adsorption of Fe and Al oxides in the soil, diminishing the ability to fix $H_2PO_4^-$. That situation can facilitate mobility of P in the soil profile in soluble organic forms of the element, as happens in forest systems (Novais et al., 2007).

Results similar to those found in this study for the P variable were obtained by Galvão and Salcedo (2009) in a study with cattle manure applied regularly in a rural region of the state of Paraíba in areas cultivated with potato, common bean, corn, cassava, cowpea, and fava bean. In addition, the effect of adding organic byproducts and compost on P retention by the soil depends on the concentration of P in the organic fertilizer. The immobilization of P in the soil solution causes it to be greater than the mineralization of organic P when the byproduct has less than 2 g kg^{-1} of total P (Novais et al., 2007). The organic compost made with wastes from slaughter of goats and sheep has a concentration of 9 g kg^{-1} (Table 2).

Analysis of micronutrients, S, and Na in the subsurface layer (0.20-0.40 m) for the 2014 crop did not reveal significant results as a function of compost application, the same result observed for contrast analysis (Table 4). In a study evaluating the properties of soil fertilized with municipal solid waste compost, Mantovani et al. (2005) observed that nutrients leached from the surface layer (0.00-0.20 m). The compost studied by these authors also had a low C/N ratio (11:1) and the cultivated soil contained 16 % clay (*Argissolo Vermelho-Amarelo*), explaining the rapid mineralization of nutrients and low fixation capacity.

The soil properties that were influenced by compost application, in both crop years (2013 and 2014), fit a linear regression model, except for inorganic N (2013 crop), NO_3^--N, and Na (2014 crop), in which cases the best fits were by quadratic equations (Figures 2 and 3).

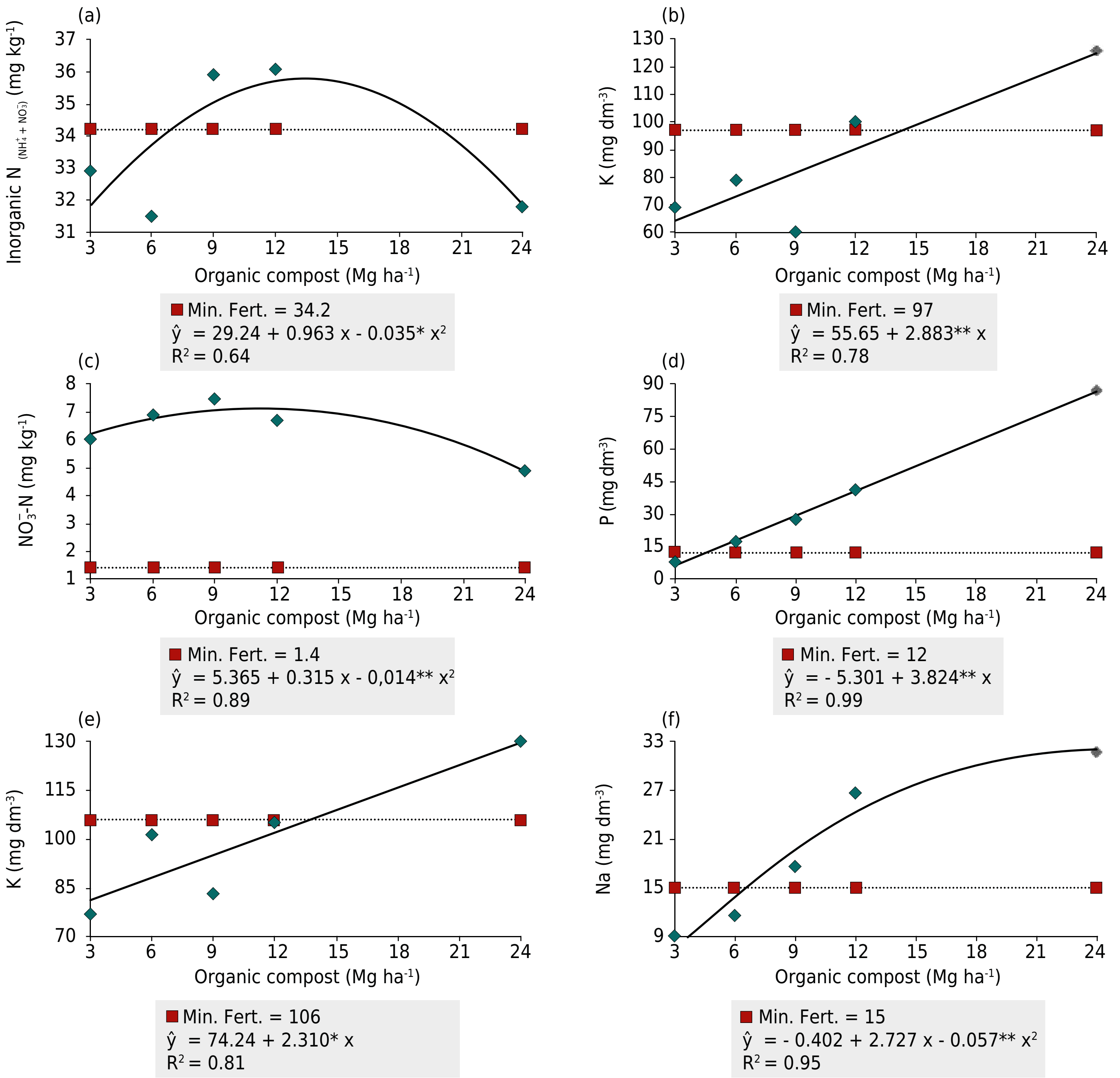

Figure 2. Concentration of inorganic nitrogen (a) and potassium (b) for the 2013 crop; concentration of nitrate (c), phosphorus (d), potassium (e), and sodium (f) for the 2014 crop, in the soil surface layer (0.00-0.20 m) as a function of application rates of organic compost. * and **: significant at 5 and 1 % probability, respectively. Min. Fert.: Mineral Fertilizer.

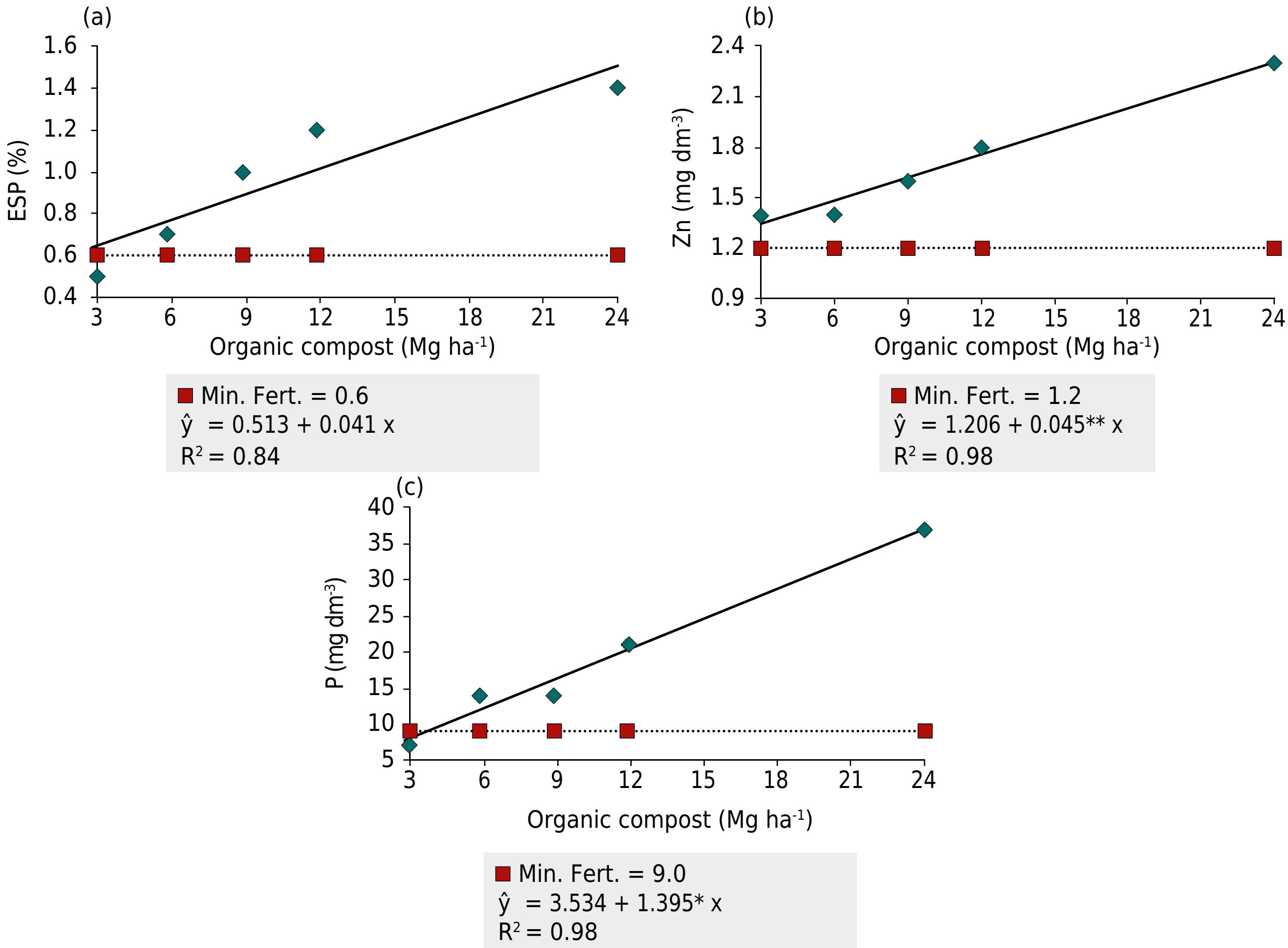

Figure 3. Percentage of exchangeable sodium - ESP (a) and zinc concentration (b) in the surface layer (0.00-0.20 m); concentration of phosphorus (c) in the subsurface layer (0.20-0.40 m) for the 2014 crop, as a function of application rates organic compost. * and **: significant at 5 and 1 % probability, respectively. Min. Fert.: Mineral Fertilizer.

The results obtained for K (Figures 2b and 2e) can be explained by the fact, as reported by Ernani et al. (2007), that in animal wastes, a large portion of K is found in available form. In other words, there was same response as in mineral fertilizers. Similar results were reported by Zeviani et al. (2012). When compared to the initial concentration of this nutrient (Table 1), a possible explanation for reduction in the values found (Figures 2b and 2e) is the uptake of the nutrients by the plants and possible losses from leaching, even though the corn was grown without irrigation. Mantovani et al. (2005) also observed similar results using municipal waste compost.

With respect to inorganic N and NO_3^--N, the maximum points of the two variables were significant, i.e., 11.3 and 13.6 Mg ha^{-1} for inorganic N (2013 crop, Figure 2a) and NO_3^--N (2014 crop, Figure 2c), respectively. A possible explanation for the quadratic behavior is the rapid mineralization of the organic compost, which has a low C/N ratio, indicating that application of higher quantities of this material can facilitate losses by leaching (Oliveira et al., 2011). Some authors have reported that the application of large quantities of organic materials with low C/N ratio can result in denitrification, which would explain the quadratic behavior observed in this study. Vieira and Cardoso (2003) pointed out that the quantities of N required by crops, and thus the amounts that should be supplied by mineral fertilizers to avoid losses to the environment, depend on the stages of the crop in question. However, those same authors did not take this factor into account when discussing the use of sewage sludge (C/N = 10); the need to consider the stage of the crop in question could be extended to application of other organic wastes. Inadequate application can cause large losses of N in the initial stage of crops, a matter of particular concern for crops sown during rainy periods (rainfed crops), because of high moisture levels. In addition, rainfall can increase the leaching of NO_3^--N, creating anaerobic microsites, which, associated with the presence of C in the organic waste, increases the losses of N by denitrification.

The results presented in tables 3 and 4, from routine analysis of the 2013 and 2014 crops, respectively, for the surface layer (0.00-0.20 m), indicate that the average values for mineral fertilization and organic compost treatments are classified as medium or high for P, K, Ca, and Mg, whereas they are low for organic matter and acidity (pH) in the two years, according to the classification levels reported by Fernandes (1993) for the state of Ceará.

With respect to assessment of the nutritional state, the results were not significant for macro- and micronutrients as a function of organic compost application rates in the 2013 crop, except for relative chlorophyll content, where the value increased with rising compost application rates. The contrast analysis for the variables N, P, and RCC revealed higher values when using mineral fertilization than organic compost (Table 5). This superiority of the mineral fertilizer mixture can be attributed to its better solubility in relation to the organic compost, despite the latter's low C/N ratio.

Table 5. Nutrients concetrations in corn leaves for the 2013 and 2014 crops, and summary of analysis of variance

Rate	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	RCC
Mg ha^{-1}	g kg^{-1}						mg kg^{-1}					
2013 Crop												
3	28.7	2.83	20.9	4.6	1.08	1.38	28	12	335	41	23	51.6
6	27.3	2.93	22.7	4.1	1.14	1.22	21	10	435	34	22	53.3
9	26.3	2.76	20.5	4.2	1.26	1.35	23	10	340	31	21	53.0
12	30.3	2.69	18.8	4.2	1.00	1.13	26	10	357	32	23	57.6
24	32.8	3.01	20.4	4.1	1.24	1.35	26	11	418	36	24	58.4
F-test	2.12^{ns}	0.70^{ns}	2.28^{ns}	0.51^{ns}	1.57^{ns}	2.91^{ns}	0.78^{ns}	1.03^{ns}	1.05^{ns}	1.14^{ns}	1.06^{ns}	3.76*
CV (%)	12.1	10.6	8.9	12.5	14.6	9.8	24.1	18.2	23.8	20.4	9.24	5.6
Contrast												
Rate (mean)	29.1	2.84	20.7	4.2	1.14	1.29	25	11	377	35	23	54.8
Min. Fert.	32.9	3.26	21.4	4.3	1.29	1.40	11	353	22	38	21	60.7
F-test	4.59*	5.82**	0.55^{ns}	0.03^{ns}	2.01^{ns}	1.71^{ns}	1.34^{ns}	0.01^{ns}	0.31^{ns}	0.70^{ns}	0.05^{ns}	6.68*
2014 Crop												
3	18.9	2.78	17.2	2.8	0.95	2.18	11	9	103	19	24	46.9
6	18.7	3.16	17.4	3.0	0.96	1.78	10	9	76	19	23	45.4
9	20.8	3.40	17.5	2.9	0.98	2.10	10	7	82	18	20	45.6
12	21.5	3.64	16.4	3.2	1.11	2.38	8	9	92	22	26	51.8
24	22.9	3.73	16.4	3.2	1.23	2.70	6	10	84	21	22	53.8
F-test	3.85*	5.88**	1.91^{ns}	2.63^{ns}	6.74**	4.57*	0.73^{ns}	2.56^{ns}	2.61^{ns}	1.09^{ns}	0.82^{ns}	3.17*
CV (%)	8.9	9.5	4.7	7.3	9.1	14.4	56.1	13.8	14.8	17.2	22.6	8.9
Contrast												
Rate (mean)	20.6	3.34	17.0	3.0	1.05	2.23	9	9	87	20	23	48.7
Min. Fert.	25.7	3.23	18.0	3.4	1.10	2.83	10	10	105	29	7	58.2
F-test	20.32**	0.42^{ns}	5.14*	4.67*	0.52^{ns}	13.02**	0.62^{ns}	6.30**	5.63*	19.30**	0.01^{ns}	18.42**

^{ns}, *, and **: no significant, significant at 5 and 1 % probability, respectively. Min. Fert.: mineral fertilization. RCC: relative chlorophyll concentration (SPAD index).

In the 2014 crop, the compost application rates had a positive influence on leaf concentrations of N, P, Mg, S, and the RCC, i.e., as the application rates increased, the foliar levels of these elements rose, as did the indirect measurement of chlorophyll. Contrast analysis revealed a significant influence for N, K, Ca, S, Cu, Fe, Mn, and RCC. For all these measurements, mineral fertilization led to higher values than organic compost (Table 5).

In comparison of the results obtained for the 2013 crop regarding compost application (average) and leaf diagnosis values with those reported by Cantarella et al. (1997), Mg and S levels were low, while Fe was above the range considered adequate for corn. The concentrations of the other elements were within the ranges suggested by those authors. With regard to the effect of mineral fertilization, the concentrations of Mg, S, and Fe were below the range considered adequate, while Cu was above that range. For the 2014 crop, the elements with concentrations below the adequate levels were N, Mg, and B in the organic compost treatments, whereas for mineral fertilization, the elements N, P, and Zn were below the reference ranges.

A strong relation exists between leaf N level and relative chlorophyll content (SPAD index) in corn plants (Argenta et al., 2001; 2004). They proposed a SPAD index of 55.3 as the critical level for the crop. Therefore, the data obtained in this study for N concentration (which increases along with increasing compost application rates) are consistent with other results in the literature because reach the critical levels proposed by Cantarella et al. (1997) for N, and consequently by Argenta et al. (2004) for the indirect measurement of chlorophyll.

The regression equations and coefficients of determination of the leaf diagnosis variables that were significant as a function of the organic compost application rates are shown in figure 4. For P, the maximum point was obtained with a compost application rate of 18.9 Mg ha^{-1}. The results for macronutrients (N, P, and S), with increased values in accordance with increasing application rates, are also consistent, since, according to Malavolta (2006), organic matter is a source of N, P, S, and B.

With respect to corn yield, there was a significant difference in the 2014 crop and also in accumulated yield (2013 + 2014 crops) due to application of organic compost (Table 6), with increasing yields as a function of increasing application rates (Figure 5). In the 2014 crop and the accumulated yield, mineral fertilization produced better results than the organic compost in the contrast analysis (Table 6). Despite the superiority of mineral fertilization, there was a residual effect of application of compost from one crop to the next. Adami et al. (2012), in a study on fertilization with poultry litter, also found a residual effect on yield of black oat in succession with corn.

The application of mineral fertilizer (without topdressing) has an effect equal to that of high application of cattle manure (50 Mg ha^{-1}) in boosting corn yield (Cancellier et al., 2011). Moreover, in a study on the possible residual effect of swine biofertilizer, Santos et al. (2011) reported there is a need for complementation of essential nutrients, especially N and K. Therefore, it is reasonable to assume that the combination of mineral and organic sources of nutrients has a positive effect on various crop yields.

In field studies without irrigation, climate conditions (especially rainfall) have a strong influence on crop development, as observed in the present study (Table 6) in regard to the difference in yield obtained in the two years. Cassol et al. (2012) observed a similar effect studying the application of swine biofertilizer on corn grown without irrigation (rainfed cropping).

Because of the type of response (linear), higher application rates of the compost could be used to further improve corn yield since N is the nutrient most exported by this crop (Von Pinho et al., 2009). As mentioned by Souza et al. (2014a) in a study on the use of a byproduct of guava processing, the positive effects of applying organic material were found first in the soil, followed by the leaves, and then appeared in crop yield.

Another aspect to consider is that since the N level and SPAD index did not reach critical values, as mentioned, higher compost rates could have been applied (Figure 5). Furthermore, as shown in the tables on nutrient concentrations in the soil and plants and on yield results, the use of this organic compost based on wastes from slaughter of goats and sheep increased corn yields to a level above the average for the state of Ceará, which is especially important considering the crop yields of smallholders, who typically cannot afford commercial inputs to replace nutrients (Souza et al., 2014b). Hence, the use of this organic compost is an attractive alternative for reducing the need for waste treatment and for improving crop yields at the same time.

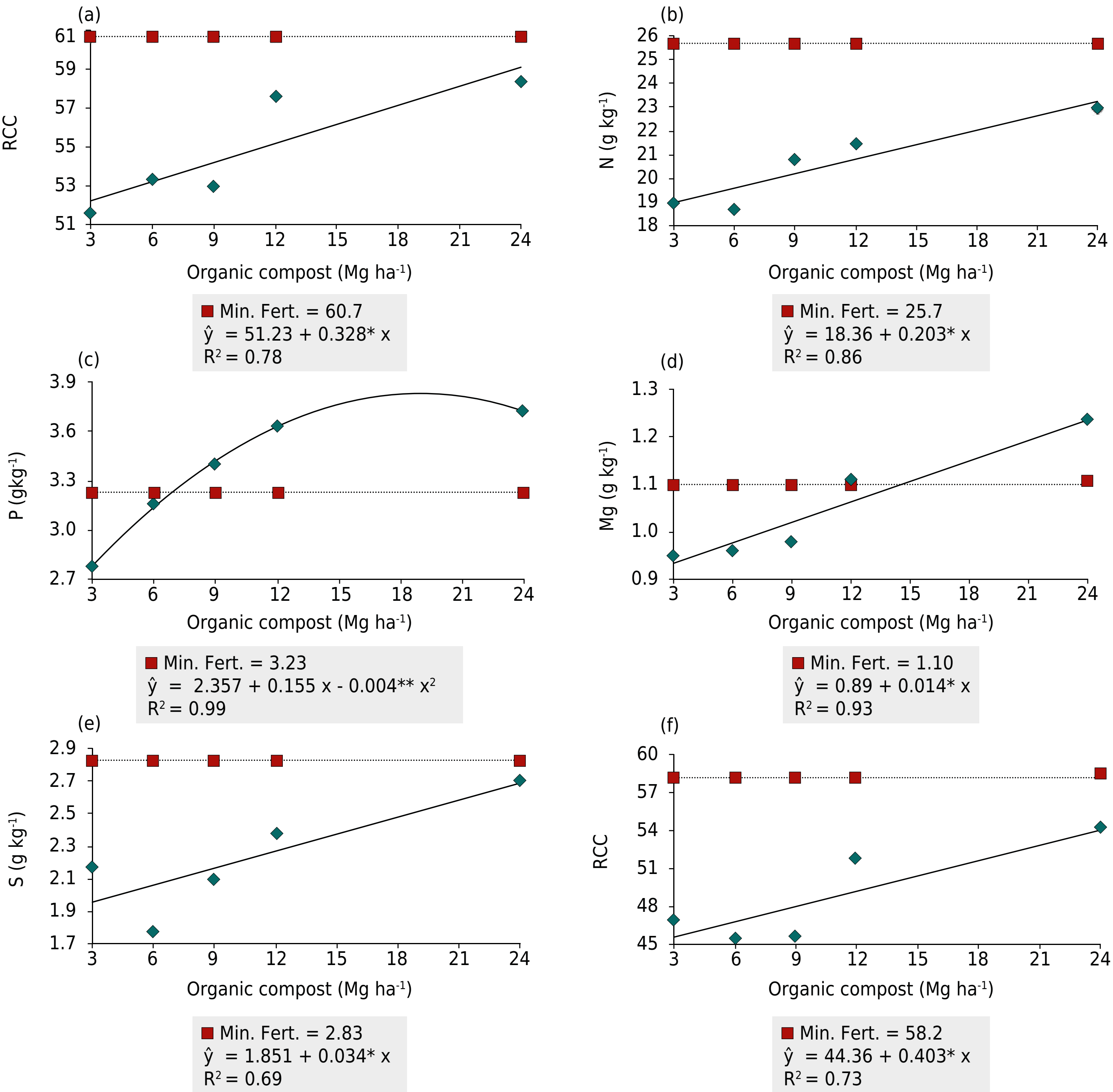

Figure 4. Relative chlorophyll concentration (a) in the 2013 crop; concentration of nitrogen (b), phosphorus (c), magnesium (d), sulfur (e) and relative chlorophyll concentration (f) in the 2014 crop in function of organic compost doses. * and **: significant at 5 and 1 % probability, respectively. Min. Fert.: Mineral Fertilizer.

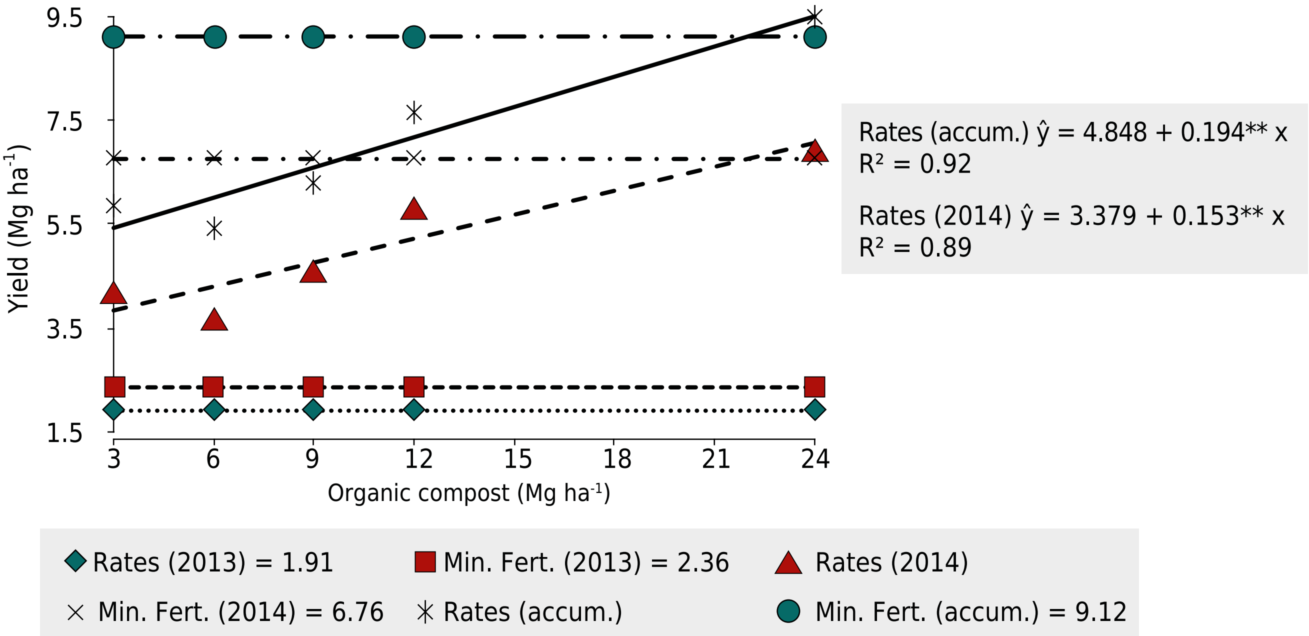

Figure 5. Corn yield as a function of application rates of organic compost. **: significant at 1 % probability. Min. Fert.: Mineral Fertilizer; accum.: accumulated.

Table 6. Corn grain yield and accumulative yield, for the 2013 and 2014 crops, and analysis of variance

Rate	Grain yield		Accumulated yield
$Mg\ ha^{-1}$	$Mg\ ha^{-1}$		
	2013	2014	2013 + 2014
3	1.70	4.14	5.84
6	1.75	3.69	5.44
9	1.71	4.61	6.32
12	1.86	5.81	7.67
24	2.51	6.95	9.46
F-test	1.39^{ns}	10.04^{**}	7.19^{**}
CV (%)	30.7	16.6	16.6
Contrast			
Rate (mean)	1.91	5.04	6.94
Min. Fert.	2.36	6.76	9.12
F-test	2.51^{ns}	15.85^{**}	14.95^{**}

^{ns} and **: no significant, significant at 5 and 1 % probability, respectively. Min. Fert.: mineral fertilization.

CONCLUSIONS

Organic compost derived from waste from the breeding and slaughter of small ruminants in rate of 24 $Mg\ ha^{-1}$ increased the levels of phosphorus, potassium, sodium, and zinc in the surface layer (0.00-0.20 m) of a Haplic Luvisol in relation of mineral fertilization in 616, 21, 114 and 90 % in second crop.

Application of the organic compost in higher rate (24 $Mg\ ha^{-1}$) increased the leaf concentrations of N, Mg, and S, as well as the relative chlorophyll content, and boosted the yield of corn plants grown in the semiarid region in 27, 32, 36, 20 e 85 %, respectively, in relation of lower rate (3 $Mg\ ha^{-1}$). Corn yield was higher with application of organic compost in rate of 24 $Mg\ ha^{-1}$ than mineral fertilizer combination in second crop.

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REFERENCES

Abreu MF, Andrade JC, Falcão AA. Protocolos de análises químicas. In: Andrade JC, Abreu MF, editores. Análise química de resíduos sólidos para monitoramento e estudos agroambientais. Campinas: Instituto Agronômico; 2006. p.121-58.

Adami PF, Pelissari A, Moraes A, Modolo AJ, Assmann TS, Franchin MF, Cassol LS. Grazing intensities and poultry litter fertilization levels on corn and black oat yield. Pesq Agropec Bras. 2012;47:360-8. doi:10.1590/S0100-204X2012000300007

Alves VMC, Vasconcellos CA, Freire FM, Pitta GVE, França GE, Rodrigues Filho A, Araújo JM, Vieira JR, Loureiro JE. Milho. In: Ribeiro AC, Guimarães PTG, Alvarez VHV, editores. Recomendações de fertilidade do solo do estado de Minas Gerais – 5ª Aproximação. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais; 1999. p.314-6.

Argenta G, Silva PRF, Bortolini CG, Forsthofer EL, Strieder ML. Relação da leitura do clorofilômetro com os teores de clorofila extraível e de nitrogênio na folha de milho. Braz J Plant Physiol. 2001;13:158-67. doi:10.1590/S0103-31312001000200005

Argenta G, Silva PRF, Sangoi L. Leaf relative chlorophyll content as an indicator parameter to predict nitrogen fertilization in maize. Cienc Rural. 2004;34:1379-87. doi:10.1590/S0103-84782004000500009

Barioni G, Fonteque JH, Paes PRO, Takahira RK, Kohayagawa A, Lopes RS, Lopes STA, Crocci AJ. Valores séricos de cálcio, fósforo, potássio e proteínas totais em caprinos fêmeas da raça parda alpina. Cienc Rural. 2001;31:431-5. doi:10.1590/S0103-84782001000300011

Bataglia OC, Furlani JPF, Teixeira PR, Furlani PR, Galo JR. Métodos de análise química de plantas. Campinas: Instituto Agronômico de Campinas; 1983. (Boletim técnico, 78).

Bezerra PSS, Takiyama LR, Bezerra CWB. Complexação de íons de metais por matéria orgânica dissolvida: modelagem e aplicação em sistemas reais. Acta Amaz. 2009;39:639-48. doi:10.1590/S0044-59672009000300019

Cancellier LL, Afférri FS, Adorian GC, Rodrigues VM, Melo AV, Pires LPM, Cancellier EL. Adubação orgânica na linha de semeadura no desenvolvimento e produtividade do milho. Semina: Cienc Agrár. 2011;32:527-40. doi:10.5433/1679-0359.2011v32n2p527

Cantarella H, Raij Bvan, Camargo CEO. Cereais. In: Raij Bvan, Cantarella H, Quaggio JA, Furlani AMC, editores. Recomendações de adubação e calagem para o estado de São Paulo. Campinas: Instituto Agronômico/Fundação IAC; 1997. p.43-7.

Cantarella H, Trivelin PCO. Determinação de nitrogênio inorgânico em solo pelo método da destilação a vapor. In: Raij Bvan, Aandrade JC, Cantarella H, Quaggio JA, editores. Análise química para avaliação da fertilidade de solos tropicais. Campinas: Instituto Agronômico de Campinas; 2001. p.270-6.

Carneiro WJO, Silva CA, Muniz JA, Savian TV. Mineralização de nitrogênio em Latossolos adubados com resíduos orgânicos. Rev Bras Cienc Solo. 2013;37:715-25. doi:10.1590/S0100-06832013000300018

Cassol PC, Costa AC, Ciprandi O, Pandolfo CM, Ernani PR. Disponibilidade de macronutrientes e rendimento de milho em Latossolo fertilizado com dejeto suíno. Rev Bras Cienc Solo. 2012;36:1911-23. doi:10.1590/S0100-06832012000600025

Chacón EAV, Mendonça ES, Silva RR, Lima PC, Silva IR, Cantarutti RB. Decomposição de fontes orgânicas e mineralização de formas de nitrogênio e fósforo. Rev Ceres. 2011;58:373-83. doi:10.1590/S0034-737X2011000300019

Ernani PR, Almeida JA, Santos FC. Potássio. In: Novais RF, Alvarez V VH, Barros NF, Fontes RL, Cantarutti RB, Neves JCL, editores. Fertilidade do solo. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2007. p.551-94.

Fernandes VLB. Recomendações de adubação de calagem e adubação para o Estado do Ceará. Fortaleza: Imprensa Universitária; 1993.

Ferreira DF. SISVAR: a computer statistical analysis system. Cienc Agrotec. 2011;35:1039-42. doi:10.1590/S1413-70542011000600001

Galvão SRS, Salcedo IH. Soil phosphorus fractions in sandy soils amended with cattle manure for long periods. Rev Bras Cienc Solo. 2009;33:613-22. doi:10.1590/S0100-06832009000300014

International Plant Nutrient Institute - IPNI. Fertilizantes; consumo de fertilizantes por região, nutrientes e natureza física. [Acesso: 19 Set. 2014]. Disponível em: http:// brasil.ipni.net/article/BRS-3132.

Lima GAS. Produção agrícola cearense e os programas sociais/Conab: Estado do Ceará. Fortaleza: Conab, 2014. [Acesso: 24 Ago 2015]. Disponível em: http://www.conab.gov.br/OlalaCMS/uploads/arquios/14_11_03_16_18_30_producao_agricola_cearense_e_os_programas_sociais_-_conab-2014.pdf.

Malavolta E. Manual de nutrição mineral de plantas. São Paulo: Agronômica Ceres; 2006.

Mantovani JR, Ferreira ME, Cruz MCP, Barbosa JC. Alterações nos atributos de fertilidade em solo adubado com composto de lixo urbano. Rev Bras Cienc Solo. 2005;29:817-24. doi:10.1590/S0100-06832005000500017

Menezes RSC, Sampaio EVSB, Giongo V, Pérez-Marin AM. Biogeochemical cycling in terrestrial ecossystems of the Caatinga Biome. Braz J Biol. 2012;72:643-53. doi:10.1590/S1519-69842012000400004

Nascimento MMA, Tabosa JN, Tavares Filho JJ. Avaliação de cultivares de milho no agreste semi-árido de Pernambuco. Rev Bras Eng Agric Amb. 2003;7:53-6. doi:10.1590/S1415-43662003000100009

Novais RF, Smyth TJ, Nunes FN. Fósforo. In: Novais RF, Alvarez VVH, Barros NF, Fontes RLF, Cantarutti RB, Neves JCL, editores. Fertilidade do solo. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2007. p.471-550.

Oliveira FF, Salcedo IH, Galvão SRS. Adubação orgânica e inorgânica de batatinha em solos arenosos: produtividade, nutrientes na planta e lixiviação. Rev Bras Eng Agric Amb. 2011;15:1228-34. doi:10.1590/S1415-43662011001200003

Oliveira RPM, Mauro AHP, Lima ES, Oliveira FF. Perfil metabólico de ovelhas Santa Inês em diferentes fases de gestação criadas em sistema semi-intensivo no estado Amazonas. Cienc Anim Bras. 2014;15:81-6. doi:10.5216/cab.v15i1.15720

Oliveira EL, Rodrigues GS, Santiago LB, Souza, HA. Compostagem de resíduos da produção e abate de pequenos ruminantes. Sobral: Embrapa Caprinos e Ovinos; 2015.

Resende KT, Teixeira IAMA, Biagioli B, Lima LD, Boaventura Neto O, Pereira Júnior JD. Progresso científico em pequenos ruminantes na primeira década do século XXI. Rev Bras Zootec. 2010;39:369-75. doi:10.1590/S1516-35982010001300040

Santos HG, Almeida JA, Oliveira JB, Lumbreras JF, Anjos LHC, Coelho MR, Jacomine PKT, Cunha TJF, Oliveira VA. Sistema brasileiro de classificação de solos. Brasília, DF Embrapa; 2013.

Santos MR, Sediyama MAN, Santos IC, Salgado LT, Vidigal SM. Produção de milho-verde em resposta ao efeito residual da adubação orgânica do quiabeiro em cultivo subsequente. Rev Ceres. 2011;58:77-83. doi:10.1590/S0034-737X2011000100012

Schimidt ER, Cruz CD, Zanúncio JC, Pereira PRG, Ferrão RG. Avaliação de métodos de correção do estande para estimar a produtividade em milho. Pesq Agropec Bras. 2001;36:1011-8. doi:10.1590/S0100-204X2001000800002

Silva FC, Abreu MF, Pérez DV, Eira PA, Abreu CA, Raij Bvan, Gianello C, Coelho AM, Quaggio JA, Tedesco MJ, Silva CA, Cantarella H, Barreto WO. Métodos de análises químicas para avaliação da fertilidade do solo. In: Silva FC, editor. Manual de análises químicas de solos, plantas e fertilizantes. Brasília, DF Embrapa Informação Tecnológica; 2009. p.107-90.

Siqueira GR. Avaliação do composto orgânico proveniente de resíduos da produção e abate de caprinos e ovinos [monografia]. Sobral: Instituto Federal de Educação, Ciência e Tecnologia do Ceará; 2013.

Souza HA, Cavalcante ACR, Tonucci RG, Pompeu RCFF, Souza MCR, Maia CE. Níveis críticos para atributos do solo pela distribuição normal reduzida em culturas anuais de subsistência. Rev Bras Eng Agric Amb. 2014b;18:425-30. doi:10.1590/S1415-43662014000400010

Souza HA, Oliveira EL, Modesto VC, Montes RM, Natale W. Atributos químicos do solo tratado com composto orgânico de carcaça e despojo de abate de caprinos e ovinos. Sobral: Embrapa Caprinos e Ovinos; 2012. (Comunicado técnico, 127)

Souza HA, Rozane DE, Amorim DA, Modesto VC, Natale W. Uso fertilizante do subproduto da agroindústria processadora de goiabas. II – Estado nutricional e produção de goiabas. Rev Bras Frutic. 2014a;36:725-30. doi: 10.1590/0100-2945-356/13

Viana FLE, Lima LD. Produção agropecuária. Fortaleza: Banco do Nordeste do Brasil; 2013.

Vieira RF, Cardoso AA. Variações nos teores de nitrogênio mineral em solo suplementado com lodo de esgoto. Pesq Agropec Bras. 2003;38:867-74. doi:10.1590/S0100-204X2003000700011

Von Pinho RG, Borges ID, Pereira JLA, Reis MC. Marcha de absorção de macronutrientes e acúmulo de matéria seca em milho. Rev Bras Milho Sorgo. 2009;8:157-73. doi:10.18512/1980-6477/rbms.v8n2p157-173

Zeviani WM, Silva CA, Carneiro WJO, Muniz JA. Modelos não lineares para a liberação de potássio de estercos animais em Latossolos. Cienc Rural. 2012;42:1789-96. doi:10.1590/S0103-84782012001000012