Effect of three biowastes on the productivity potential of a sodic soil

Efecto de tres biorresiduos en el potencial productivo de un suelo sódico

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ABSTRACT

Three biowastes were applied to a Typic Haplustepts sodic soil in order to generate a Soil Productivity Potential (SPP) indicator derived from the biological, physical and chemical properties. The biowastes included swine manure (SM), vinasse (VS) and composted biosolids (CB) incorporated on experimental plots and left undisturbed. The assessment of the soil properties was done prior to and twice during the experiment. The biowastes produced, in general, an increase in the SPP, being higher that of swine manure at the lowest dose in the short term, and composted biosolids at the highest dose in the long term; the vinasse did not significantly increase the SPP at any dose. In the control plots, in contrast, the SPP decreased steadily during the experiment period. The application of the three biowastes reduced the exchangeable sodium percentage, as well as the electric conductivity, particularly with the swine manure and composted biosolids at the low and high doses, respectively. The total porosity did not change significantly, whereas the CO_2 production increased between all of the treatments and control. The SPP indicated that the biowaste addition improved the quality status of a sodic soil, particularly at the chemical level; hence, this practice could prevent the loss of productivity in the short and long term.

Key words: soil amendments, soil chemicophysical properties, soil improvement.

RESUMEN

Se aplicaron tres biorresiduos a un suelo sódico Typic Haplustepts, con el fin de generar un indicador del Potencial Productivo del Suelo (PPS), derivado de sus propiedades biológicas, físicas y químicas. Se emplearon los biorresiduos porquinaza (P), vinaza (V), y biosólidos compostados (BC), aplicados superficialmente en lotes experimentales sin alterar. Las evaluaciones de las propiedades del suelo se realizaron antes y dos veces durante el experimento. Los biorresiduos produjeron un incremento en el PPS, siendo mayor el de porquinaza a menor dosis en el corto plazo, y el de biosólidos compostados a mayor dosis en el largo plazo; vinaza no incrementó el PPS significativamente a ninguna dosis. En contraste, en el testigo el PPS disminuyó sostenidamente durante el tiempo del ensayo. La aplicación de los tres biorresiduos redujo el porcentaje de sodio intercambiable, así como la conductividad eléctrica, especialmente con porquinaza y biosólidos compostados en bajas y altas dosis. La porosidad total no varió significativamente, mientras que la producción de CO_2 aumentó en todos los tratamientos y el testigo. El PPS indica que la aplicación de biorresiduos mejora las condiciones del suelo sódico, particularmente a nivel químico, así que esta práctica podría prevenir pérdidas de productividad en el corto y largo plazo.

Palabras clave: enmiendas del suelo, propiedades fisicoquímicas del suelo, mejora de suelos.

Introduction

Sodic soils are widely present in farmlands, where there could be losses in crop productivity without adequate management. In the Cauca Valley region of southwest Colombia, it is estimated that there are around 20,000 ha with some degree of risk of salinity or sodicity, and 40,000 ha affected by saturation levels of sodium above 15% (Calero-Aguado *et al.,* 2013). The reduction in soil productivity is due to deflocculation processes and unavailability of base cations, such as Mg^{2+} and Ca^{2+}, which limit the aggregate stability and, therefore, leads to a poor physical condition of the soil. Sodium also affects plant development because of specific toxicity of this element in some species (Bauder *et al.,* 2014). In the Valle del Cauca department, progressive sodicity in crop soils is related to inadequate irrigation practices, a lack of routine monitoring of water quality, as well as the bicarbonate content, which leads to its transfer to the soil (Ramírez-Alzate, 2011).

Moreover, there are concerns about the massive generation of by-products derived from industrial and livestock processes, such as vinasse, wastewater biosolids, and pig manure. However, the use of these biowastes as amendments in degraded soils, or also as fertilizers, is a promising issue, while palliating their possible impacts on the environment. In Colombia, Ordinance 1287 (July 10th 2014) states the rate of use of biosolids in crop soils in relation to the content of heavy metals and biological risk (MVCT, 2014). Sugar mills have been also evaluating different ways

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of applying vinasse on sugar cane crops in order to restore the nutrients depleted by each harvest. Pineda *et al.* (2015) found an increase in phosphorus and potassium in the soil, as well as in the growth parameters of sugar cane fertilized with a dose of 60 m^3 ha^{-1} of vinasse. The swine industry is also aware of the use of pig manure as a soil amendment for crop production, which is a practical method to solve the disposal problem and can be an agronomically and economically viable management practice for sustainable crop production in some areas (Choudhary *et al.*, 1996). Yongchao *et al.* (2005) reported that a mixture of pig manure and rice straw had a significant effect on the enzymatic and microbial activity of the soil, as well as the respiration rate, when it was added to pots simulating a salinized environment with NaCl.

The long-term effects of biowastes on soils have proven to be beneficial. Avnimelech *et al.* (1994), in a two-year evaluation, found that the addition of municipal solid waste compost was even superior to gypsum in reclaiming alkaline soils. Further authors supported this finding, showing that gypsum alone is not able to restore saline-sodic soils, but when combined with municipal solid waste sequentially, the physical, chemical and biological properties were restored (Hanay *et al.,* 2004).

Diacono and Montemurro (2010) summarized the long-term effects of organic amendments on soil fertility, demonstrating that, among others, the regular addition of composted organic residues increased the soil physical fertility, mainly by improving the aggregate stability and decreasing the soil bulk density. In addition, the crop yield increased with long-term applications of municipal solid waste compost, and there was no tangible evidence demonstrating negative impacts of heavy metals applied to soils, particularly when high-quality compost was used for long periods.

Since biological, physical and chemical properties do not reflect by themselves the productivity and conservation status of a soil, it is necessary to establish quality soil indicators that link together all of the characteristics of a soil. The available methodologies only focus on analytical techniques, reducing the entire concept (soil quality) to the sum of their parts (soil properties). In contrast, an alternative methodology to measure soil status is the Soil Productivity Potential (SPP), a synthetic indicator that includes both analytical and synthetic properties (such as thermal conductivity, porosity and exchangeable sodium percentage) in order to generate an overall diagnosis of the soil, which conducts to differential management strategies and fertilization with the identification of areas with distinct productivity potential (Zúñiga *et al.,* 2008). This indicator has been evaluated on three livestock hillside farms in the Cauca valley, showing that slight changes in humidity and fertility influence the SPP and are related to the microbial activity (Rojas *et al.*, 2009).

The aim of this study was, thus, to measure the effect of three biowastes on the SPP indicator in a soil affected by sodicity through the evaluation of their biological, chemical and physical properties in undisturbed conditions of the Cauca Valley region, Colombia.

Materials and methods

Location and georeferencing

The experiments were carried out in the Moraima farm, located in the Cerrito municipality, Valle del Cauca Department. The experimental field was set at the coordinates 3°38’44” N and 76°13’18” W, at 973 m a.s.l. At the time of the experiments, the farm was being used for cattle production. Geographically, the Moraima farm is part of a basin between the Central and Western Ranges of the Andes, in the floodplain of the Cauca river. The average temperature is 24°C, with a maximum of 30°C and a minimum of 18°C, while precipitation reaches 1,200 mm $year^{-1}$.

Soil survey and taxonomy

The parental material of the soils are gross flood particles, deep and drained, high fertility and gross texture. The soils of the farm are part of the Marsella consociation. This consociation is classified as a Typic Haplustepts, gross-loam, mixed, superactive, isohypertermic, represented by the modal profile CC806 (IGAC, 2004). The slope is less than 1%, representative of flat topography. Three samplings of the plots were done, one before the start of the experiments, a second one a month after the application of the treatments, and a last one seventeen months later. For the chemical and biological properties, altered samples were taken with a shovel in the first 20 cm of the soil profile, and, for the physical properties, a bore soil sampler with a cylindrical core inside was used. At each plot, three samples were taken.

Physical and chemical analysis of the soil and biowastes

The samples were analyzed at the Agrilab Laboratories in Bogota for the chemical properties and in the laboratory of Environmental Physics of Universidad del Valle in Cali for the biological and physical properties. Table 1 sums up the analytical methodology.

TABLE 1. Methodologies used in the analysis of sodic soil treated with biowastes.

Parameter	Method
Texture	Bouyucos
Bulk density	Richards
Thermal conductivity	Electrothermal
pH	Potenciometer
Organic carbon	Walkley and Black
Electric conductivity	Saturation extract
K, Ca, Mg, Na	Ammonium acetate. Atomic absorption
P	Olsen/colorimetric
Microelements	Melhich I
Microbial activity	Titration

Vinasse was obtained from the Providencia sugar mill located in the Cerrito municipality. The swine manure was produced and composted on the Moraima farm, and the composted biosolids from the Cañaveralejo wastewater plant in Cali.

Field tillage and experiment design

The tillage of the experiment field was done by passing twice with a cross chisel in order to build up ridges and set adequate conditions to incorporate the three different biowastes. After this, ten 12 x 40 m plots were defined for the application of the biowaste treatments, each plot containing fifteen ridges.

Each biowaste (composted biosolid, swine manure and vinasse) had three levels of dose application, for ten treatments, including the control, distributed in a completely randomized design with three replicates. The doses were calculated according to the availability of each biowaste in the source and dividing them by three (Tab. 2). The time between each application of the biowastes was approximately 2 months, the first one in early March, 2012 and the second one mid-May, 2012.

The treatments were applied to the plots by using a knapsack in the case of the vinasse, whereas for the biosolids and swine manure, it was done by hand for the surface distribution, homogeneously. The plots were left undisturbed until the end of the experiments.

Soil Productivity Potential (SPP) modeling

SPP is a synthetic variable that links together the soil analytical and synthetic properties. Analytical properties are those that directly give a characterization of the soil, such as exchangeable sodium percentage and macroporosity, whereas synthetic properties are those that give an idea of the status of the soil, specifically through the energy flow, as heat or electricity, and are indirectly determined by the thermal conductivity and resistivity. The model for the determination of this parameter was set up with fuzzy logic. The interface used to process the data was Fis-Pro 3.4. Figure 1 shows a scheme of the fuzzy logic processing. The input variables were total pore space, thermal conductivity and ESP, whereas the output was SPP.

TABLE 2. Applied biowaste doses and treatments in a sodic soil.

Biowaste	Treatment	Application 1	Application 2	Total
Vinasse (L ha^{-1})	VS1	1,000	1,000	2,000
	VS2	5,000	5,000	10,000
	VS3	10,000	10,000	20,000
	Total VS			32,000
Composted biosolid (kg ha^{-1})	CB1	1,000	2,000	3,000
	CB2	5,000	20,000	25,000
	CB3	10,000	50,000	60,000
	Total CB			88,000
Swine manure (kg ha^{-1})	SM1	1,000	2,600	3,600
	SM2	5,000	6,500	11,500
	SM3	10,000	10,000	20,000
	Total SM			35,100
Control	C	0	0	0

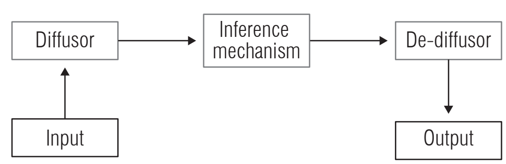


FIGURE 1. Interface used for fuzzy logic in Fis-Pro 3.4.

With this basis, labels were assigned to identify the subordination degree of each variable and the ranges at which they are consider low, medium or high. Through the application of fuzzy rules IF and AND to the prior ranges, the SPP estimation was inferred. The biological and physical properties, as well as the SPP data were statistically analyzed with a Tukey test and SPSS software (Statistical Procedures Companion, Upper Saddle River, NJ).

Results and discussion

Physical and chemical characterization of the soil and biowastes

The physical characteristics of the Marsella consociation showed moderately fine textures in the arable layer. The bulk density was high (1.50 to 1.56 g cm^{-3}), whereas the particle density ranged from medium to high (2.57 to 2.88

g cm^{-3}); regarding total porosity in the topsoil, a dominance of micropores versus macropores was noticed (44.3% and 12.7%, respectively).

The soils of the experiment field are typically sodic, clayey, showing an average exchangeable sodium percentage (ESP) of 72.88% and an electric conductivity (EC) of 3.7 dS m^{-1}, whereas the soil reaction was slightly to moderately alkaline (pH 7.7 to 9.3). The concentration of Ca^{2+} and Mg^{2+} ranged from 1 to 8 cmol$_c$ kg^{-1} and 0.7 to 7.6 cmol$_c$ kg^{-1}, respectively; these values are within the ranges reported for this type of soils (Verma *et al.,* 2013; Ahmad *et al.,* 2016). Limitations for plant growth and soil exploitation are related to the calcium/magnesium ratio, high sodium saturation ratio (>70%), low content of microelements and mildly to moderately alkaline soil reactions (Tab. 3).

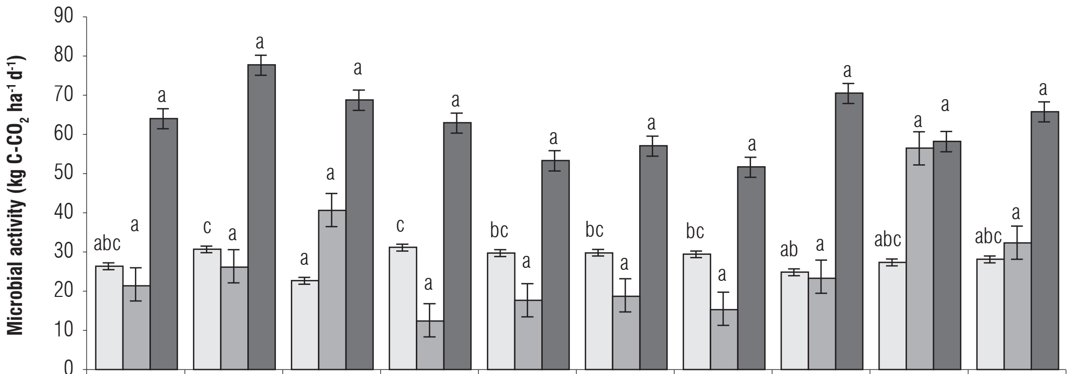
Physical, biological and chemical properties as affected by the biowastes

The biological properties of the soil, measured as the microbial activity, were not significantly affected by any biowaste, in comparison with the control plot. Although the degree of this activity tended to increase up to the seventeenth month, this could be attributed not only to the treatments but also to the growth of vegetal layer on the undisturbed plots. This explain the higher microbial activity in the control plots. Notably, CB decreased it at all three doses, unlike VS and SM, where this parameter went progressively increased with each dose. However, at the end of the experiment, the microbial activity reached a non-significant steady value throughout all of the treatments and control (Fig. 2). Barbarick *et al.* (2004), pointed out that the control and biosolids treatments in shrublands had statistically the same qCO_2 at 6 years after application, indicating that biosolids did not produce increased adverse stress on the microbial population. The increase in the CO_2 production over time observed in this study could be attributed to a lesser microbial C biomass or to a microbial stress induced by the amount of added biowastes. This differed from that indicated by Montenegro-Gómez *et al.* (2009), whose findings showed a decrease over time in CO_2 production in a mollisol treated with vinasse.

TABLE 3. Physical, chemical and biological characterization of biowastes applied to a sodic soil.

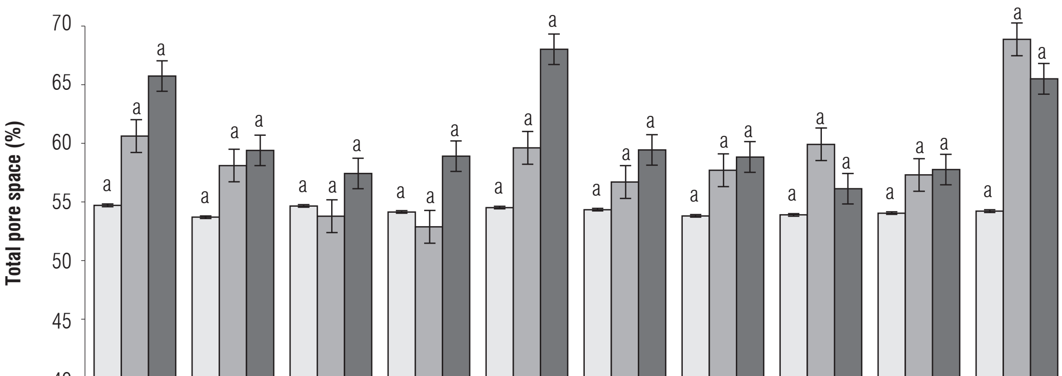
Parameters	Units	Sodic soil	Vinasse	Composted biosolids	Swine manure
Bulk density	g cm^{-3}	1.53	-	0.61	0.56
Total porosity	%	57	-	-	-
Microporosity	%	44.3	-	-	-
Macroporosity	%	12.7	-	-	-
Humidity	%	17.2	-	56.3	10.4
Clay	%	50	-	-	-
Silt	%	26.4	-	-	-
Sand	%	23.6	-	-	-
Texture	-	Ar	-	-	-
MA	kg CO_2/ha per day	21.8	-	-	-
OOC	%	-	10.5	9.8	30.4
pH	-	8.71	4.50	8.81	7.08
EC	dS m^{-1}	3.7	20.0	23.3	30.6
Ca	cmol$_c$ kg^{-1}	1.3	48.2	30.3	85.5
Mg	cmol$_c$ kg^{-1}	1.7	23.2	4.1	65
Na	cmol$_c$ kg^{-1}	37.8	69.5	1.8	20.4
SAR	%	31.1	-	-	-
ESP	%	72.8	-	-	-
Mn	mg kg^{-1}	0.2	32.4	-	425
B	mg kg^{-1}	0.4	13.4	-	52
Zn	mg kg^{-1}	0.0	20.0	1686	2700
Cu	mg kg^{-1}	0.1	38.3	185	58
Fe	mg kg^{-1}	0.3	-	57331	2400

MA, microbial activity; OOC, oxidizable organic carbon; EC, electric conductivity; SAR, sodium adsorption ratio; ESP, exchangeable sodium percentage.



	VS1	VS2	VS3	CB1	CB2	CB3	SM1	SM2	SM3	C
Month 0	26.39	30.69	22.70	31.16	29.75	29.86	29.44	24.87	27.36	28.16
Month 1	21.77	26.41	40.72	12.65	17.74	18.98	15.56	23.73	56.49	32.44
Month 17	64.0	77.7	68.8	62.9	53.3	57.0	51.7	70.5	58.2	65.8

FIGURE 2. Microbial activity of a sodic soil with applications of biowastes. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ± SD. See abbreviatons in Tab. 2.

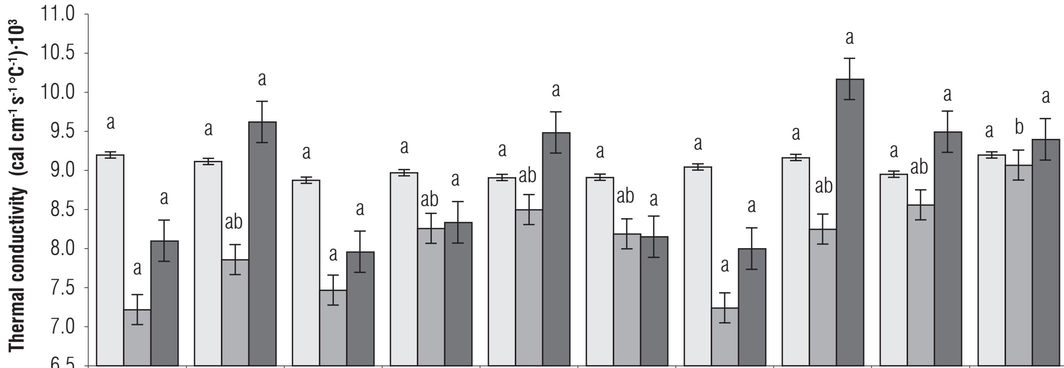


	VS1	VS2	VS3	CB1	CB2	CB3	SM1	SM2	SM3	C
Month 0	54.6	53.6	54.6	54.1	54.4	54.3	53.7	53.8	54.0	54.1
Month 1	60.5	58	53.7	52.8	59.5	56.6	57.6	59.8	57.2	68.7
Month 17	65.6	59.3	57.3	58.8	67.9	59.3	58.7	56.0	57.7	65.4

FIGURE 3. Total pore space of a sodic soil with applications of biowastes. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ± SD. See abbreviatons in Tab. 2.

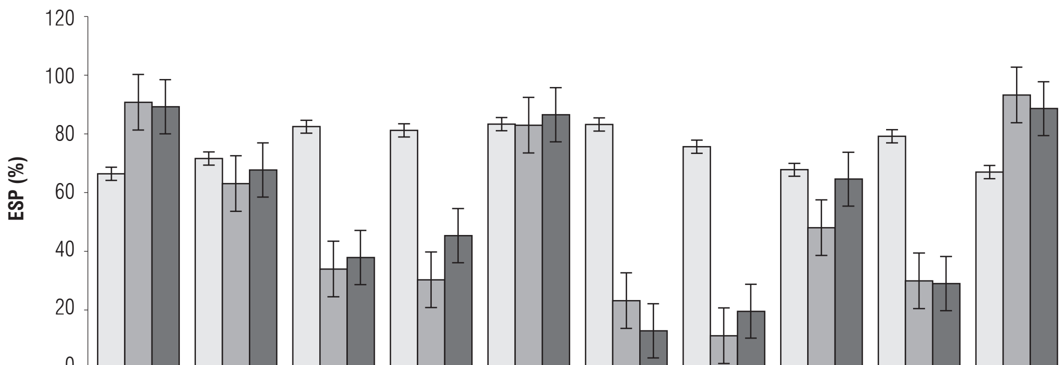
The total pore space exhibited an increase over time in all of the treatments, except SM2. In the control plots, this property underwent a slight decrease, which is a signal of a compaction process in the soil, in contrast with that observed in the treated plots (Fig. 3).

In this study, it was found that the total porosity was affected by the treatments at the beginning and the end of the experiment, but not significantly, by augmenting the air fraction of the soil. Other researchers have also observed that the bulk density and porosity suffered changes with biowaste amendments. Ramírez-Pisco *et al.* (2007) found a reduction in the bulk density of a degraded soil from a brick mine when treated with biosolids at high doses (4 and 8% w/w). This result is in agreement with Linlin *et al.* (2014), whose findings showed a steady and significant decrease in bulk density and an increasing total porosity in a two-year field experiment with four combinations of compost and furfural. Mondal *et al.* (2015) also reported a lessening in bulk density with sewage sludge applications in a Typic Haplustept sandy loam soil. However, the results of this study are more related with those of Peñarete *et al.* (2013), who registered a slight, but not significant reduction in bulk density, and an increase in macroporosity in a vertic endoaquept soil amended with three types of biosolids. A possible explanation given by the authors was that the high content of clay in the soil, plus the water regime of the period of evaluation, induced a compaction process despite the addition of biowastes.



	VS1	VS2	VS3	CB1	CB2	CB3	SM1	SM2	SM3	C
Month 0	9.20	9.12	8.88	8.97	8.91	8.91	9.05	9.17	8.95	9.20
Month 1	7.22	7.86	7.47	8.26	8.50	8.19	7.24	8.25	8.56	9.07
Month 17	8.1	9.6	8.0	8.3	9.5	8.2	8.0	10.2	9.5	9.4

FIGURE 4. Thermal conductivity of a sodic soil with applications of biowastes. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ± SD. See abbreviatons in Tab. 2.



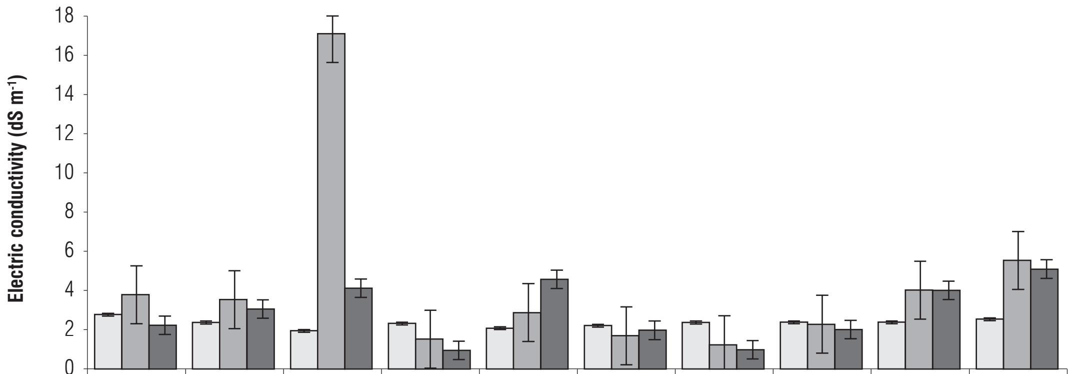
	VS1	VS2	VS3	CB1	CB2	CB3	SM1	SM2	SM3	C
Month 0	65.79	70.98	81.70	80.49	82.58	82.48	74.93	67.17	78.47	66.41
Month 1	89.9	62.5	33.7	30.1	82.2	23.0	11.2	47.6	29.7	92.4
Month 17	88.4	67.1	37.6	44.9	85.7	12.8	19.4	64.0	28.8	87.8

FIGURE 5. Exchangeable sodium percentage (ESP) of a sodic soil with applications of biowastes. Error bars indicate standard deviation. See abbreviatons in Tab. 2.

Porosity is the most important macroscale parameter for the thermal conductivity of dry soils: the thermal conductivity of a dry soil linearly increases as the porosity decreases (Yun and Santamarina, 2008). As seen in Fig. 4, the thermal conductivity at the first month of evaluation with VS1, VS3 and SM1 significantly differed from control. This means that in these plots, the soil underwent an increase in air volume.

Concerning the chemical properties, it was observed that the addition of biowastes affected several parameters, which could change the characterization of the soil as sodic. The ESP in the control plots remained stable at the two samplings dates, at values of 87.8-92.4%. VS1 and CB2 did not change significantly the ESP, but at their highest doses this property went consistently lower. This effect was also observed when using SM1 (Fig. 5).

The chemical properties of the soil, such as ESP, EC and SAR were significantly affected by the three added biowastes. High doses of VS and CB, and low doses of SM, demonstrated a reduction in the ESP more than 50%, reaching values near 15% in the case of CB3 and SM1. In the case of VS, the trend was negatively correlated with the dose, whereas with CB and SM, the medium dose presented a gap with the other doses. This could be related to the sampling variations. García-Orenes *et al.* (2005) previously reported a decreased ESP, from 33.7% to 21.8% in a salinized Xeric Torrifluvent amended with three levels of sewage sludge. The results of Linlin *et al.* (2014) indicated that organic



	VS1	VS2	VS3	CB1	CB2	CB3	SM1	SM2	SM3	C
Month 0	2.77	2.37	1.94	2.31	2.07	2.20	2.37	2.38	2.38	2.53
Month 1	3.8	3.5	17.1	1.5	2.9	1.7	1.2	2.3	4.0	5.5
Month 17	2.23	3.05	4.11	0.94	4.57	1.97	0.98	2.01	4.01	5.09

FIGURE 6. Electric conductivity of soil of a sodic soil with applications of biowastes. Error bars indicate standard deviation. See abbreviatons in Tab. 2.

amendments could help reduce the ESP and thus, improve saline soils. Our results showed that the CB and SM were more effective in controlling the Na content in a sodic soil.

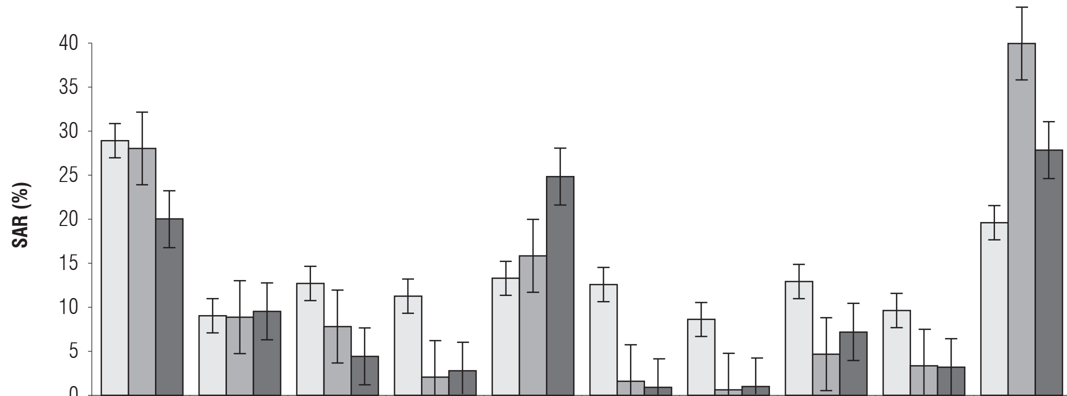
The EC of the soil showed no significant changes in the control plots, but it went progressively lower in the plots with decreasing doses of SM. The inverse effect was observed with VS, particularly at the seventeenth month of the evaluation. The CB exhibited an irregular trend, but it decreased the EC below the control in two of the applied doses. Fig. 6.

The EC with VS exhibited a growing pattern at the seventeenth month of the evaluation; one explanation is that its inherent content of sulfates, sodium and phosphates contributed to the increase in the EC in the plots treated with this biowaste. Gemtos *et al.* (1999) did not found a significant variation in this parameter by adding two levels of vinasse to a clayey and a silty clay loam soil from Greece. However, Alfaro and Ocampo-Cinchilla (2008), who worked with two levels of vinasse in a vertisol, noticed an important increase in the EC, from 0.29 to 16.49 $mS.cm^{-1}$. The low EC values achieved with CB3 and SM1 reflected in their effect on the ESP and SAR, indicating that these two biowastes have an important capacity to alleviate the effects of sodicity in soils. The latter improves the soil structure by increasing the aggregate stability and decreasing the bulk density (Mondal *et al.,* 2015). For the salinized soil, this improvement was primarily due to a reduction in the ESP (García-Orenes *et al.,* 2005).

The latter results indicate that the applications of CB and SM were more effective at amending the sodic and saline properties of soils rather than VS, which actually could enhance these characteristics by increasing the EC. Concomitantly with the ESP and EC, the SAR was also affected in the plots treated with the biowastes (Fig. 7). The reduction in the Na^+ content had a direct effect on the SAR, which in turn went down to less than 2% (CB3 and SM1). This means that the effects of the biowastes on the physical properties of saline soils could be indirect, through the modification of chemical attributes, such as sodium content or SAR. This parameter was significantly decreased in the treated plots, particularly with SM. The VS showed a trend similar to that of the ESP, which is consistent with the decrease of sodium in the soil. Low SAR levels indicate better physical conditions in clayey soils (Rengasamy, 2010).

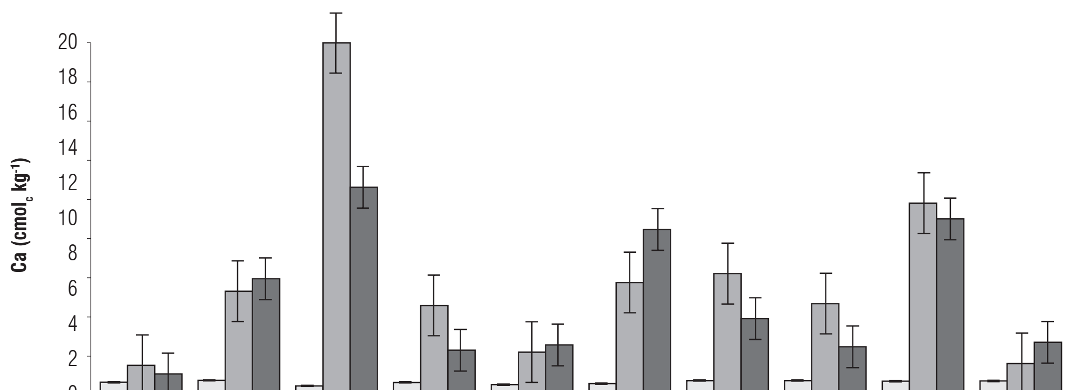
On the other hand, the higher Ca^{2+} levels caused by the biowaste application, particularly with VS3, also affected the SAR. SM3 also raised the content of this cation in the soil, as compared to the control, but the losses in time were not as marked as with VS3 (Fig. 8).

Previous studies have reported that Ca^{2+} could improve the soil structure by forming cationic bridges between clay particles and soil organic matter. In addition, Ca^{2+} can inhibit clay dispersion and the associated disruption of aggregates by replacing Na^+ and Mg^{2+} in clay and aggregates, thereby promoting aggregate stability (Linlin *et al.,* 2014). Other researchers have stated that municipal solid wastes increased Ca^{2+} and Mg^{2+} in soils in a three-year experiment. The positive changes in soil fertility were connected mainly with an increase in available nutrients, such as Mg, as well as an improvement of soil sorption properties (Weber *et al.,* 2007).



	VS1	VS2	VS3	CB1	CB2	CB3	SM1	SM2	SM3	C
Month 0	28.9	9.0	12.7	11.2	13.3	12.6	8.6	12.9	9.6	19.6
Month 1	28	8.86	7.78	2.04	15.8	1.57	0.61	4.66	3.35	39.9
Month 17	20	9.5	4.39	2.76	24.8	0.88	0.99	7.17	3.18	27.8

FIGURE 7. Sodium absorption ratio of a sodic soil with applications of biowastes. Error bars indicate standard deviation. See abbreviatons in Tab. 2.



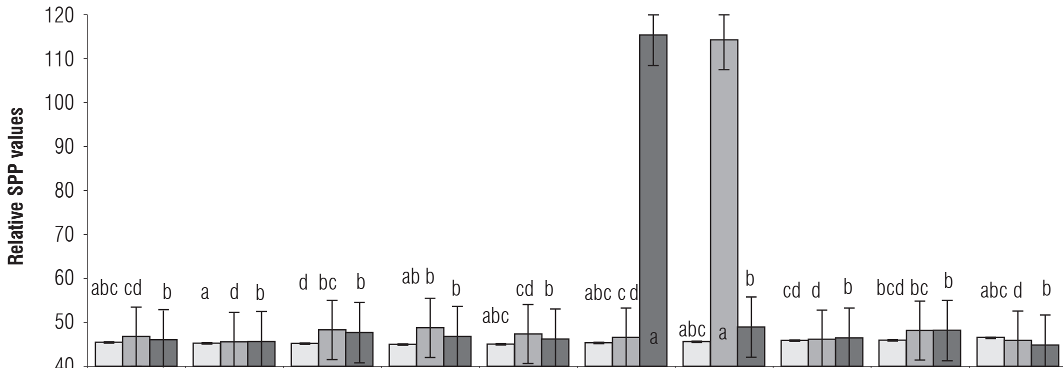
	VS1	VS2	VS3	CB1	CB2	CB3	SM1	SM2	SM3	C
Month 0	0.74	0.85	0.53	0.73	0.60	0.66	0.84	0.84	0.80	0.81
Month 1	1.7	5.9	20	5.1	2.45	6.4	6.9	5.2	10.9	1.8
Month 17	1.2	6.6	11.8	2.55	2.85	9.4	4.35	2.75	10	3

FIGURE 8. Calcium content in soil of a sodic soil with applications of biowastes. Error bars indicate standard deviation. See abbreviatons in Tab. 2.

SPP as affected by biowaste applications

The evaluation of the SPP throughout the whole experiment showed that, in the control plots, the trend was to progressively decline over time, unlike with the biowastes, where, in all cases, this parameter increased, but only significantly with CB3 and SM1 at the seventeenth and first month, respectively (Fig. 9). This suggests that CB3 has a long-term effect on the soil productivity, rather than SM1, in which the SPP experienced a decline from the first to seventeenth month.

The changes produced by the biowastes, mainly in the chemical properties of the soil, concomitantly influenced the SPP parameter. It was expected that CB3 and SM1 would exhibit the highest values of SPP, principally because of the decrease in sodicity and salinity characteristics (SAR, ESP, EC). According to Zúñiga *et al.* (2007), values below 90 are considered low, values between 90 and 102 are medium, and values above 102 are high. The diminishing trend in the SPP observed in the control plots is an indication of the loss of productivity in sodic soils without adequate management. This is in agreement with Rojas *et al.* (2009), who concluded that SPP is lower in soils with compaction processes. Cuero (2012) also reported that SPP is lower in soils with inadequate control practices for erosion. Although the physical properties, such as total porosity and thermal conductivity, were not affected significantly by the biowaste treatments, the reduction in ESP and SAR, and the increase in the divalent cations, improved the SPP parameter.



	VS1	VS2	VS3	CB1	CB2	CB3	SM1	SM2	SM3	C
Month 0	45.94	45.71	45.67	45.43	45.48	45.82	46.11	46.40	46.50	47.16
Month 1	47.38	46.08	49.04	49.57	48.05	47.16	120.71	46.68	48.90	46.44
Month 17	46.60	46.16	48.39	47.41	46.79	121.92	49.76	47.04	48.92	45.30

FIGURE 9. Changes in SPP for each treatment during the time for a sodic soil with applications of biowastes. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$) ± SD. See abbreviatons in Tab. 2.

Conclusions

The surface application of vinasse, composted biosolids and swine manure to a Typic Haplustepts sodic soil mainly affected the chemical properties, but marginally affected the physical and biological ones; however, the soil productivity potential indicator reflected these changes. The above was corroborated by the fact that the SPP improved in the short and long term with the addition of SM and CB, respectively, whereas it decreased over time in the untreated plots, which means a deterioration of the quality status of the soil. In conclusion, the CB and SM were better amendments of sodic soils than VS, and the SPP synthetic indicator supported this. The findings of this study will help to avoid losses in crop productivity from poor condition in sodic soils in Cauca Valley through the proper application and management of the different biowastes generated by the industrial and livestock processes in this region and the application and interpretation of the SPP indicator.

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