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Full Length Research Paper

Characterization and classification of salt affected soils and irrigation water in Tendaho sugarcane production farm, North-Eastern Rift Valley of Ethiopia

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Considerable area of land is becoming unproductive every year because of salinity and sodicity in lowlands of Ethiopia. For sound land use and irrigation water management, it is a paramount important to know the chemical composition of soils and irrigation water. Therefore, the study was aimed to evaluate the physicochemical properties of soils and irrigation water of Tendaho sugarcane production farm, located in north-eastern rift valley of Ethiopia. Depth wise soil samples from 4 different locations and 1 irrigation water sample from 2 sub-samples (from delivery head and the influent river) were collected. The result of the particle size analysis indicates that majority of the soils were heavily textured. The pH of the soil in all parts of the study area ranged from 7.8 to 8.6. Electrical conductivity readings of most of the studied soil profiles were high. Exchangeable sodium percentage values showed actual sodium toxicity problem (ESP>15) in the first profile and potential sodium toxicity (ESP>1) in the remaining profiles. On the other hand, the irrigation water has a low sodicity hazard; however, pH (7.65) and EC (0.654 dS/m) values clearly indicated that it is moderately alkaline and saline. Hence, coupled with water and soil analysis results, there will be a potential danger of sodicity and actual salinity development in the intended irrigation scheme. Thus, selection of crop type and proper irrigation methods should be designed for sustainability of soil productivity in the study area.

Key words: Salt affected soil, irrigation water, characterization and classification, sugarcane production.

INTRODUCTION

Ethiopia has great agricultural potential because of its vast areas of fertile land, diverse climate and large available labor pool (MoFED, 2010). However, agricultural production is very low because of various natural hazards and poor agricultural practices that have greatly reduced the productivity of soils. Soil is the basis of agriculture and natural plant communities (Udoh et al., 2016). Soil is at the root of food shortage, food insecurity or

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undernourishment which has assumed global dimension in the last three decades (Ogunkunle, 2015). In Rift Valley of Ethiopia, about 200 ha of irrigable land are dumped every year due to sodicity and associated land drainage problems (Heluf, 1987).

Debela (2017) explained that, soil salinity and alkalinity problems are particularly severe in developing countries, especially arid and semiarid regions, resulting in damage to the livelihoods of people in the short term, and with long term effects on food security of the country. Besides to these, heavy fertilizer application, use of poor quality irrigation water and inadequate drainage has contributed to rising groundwater tables leading to salinity-induced land degradation (Qureshi et al., 2013; Sarwar et al., 2015).

The rate of the occurrence of problematic soil in the Rift Valley areas of Ethiopian becomes particularly higher where water tables are near the soil surface with having high dissolved salts and irrigating without giving due consideration (Mesfin, 1998). As part of Rift Valley areas, Tendaho sugar cane production in Ethiopia could face salinity/sodicity problems unless proper land management activities are carried out based on the scientific data gained from land suitability evaluation (Janzen, 1988).

Seid and Genanew (2013) noted that, the existence of potential sodicity is not only in the soil but also in the irrigation water and their study underlines the need for selection of salt tolerant crops and good water management by using appropriate irrigation methods to sustain productivity. This has significant contribution to deciding the type of crop to be produced and appropriate irrigation methods for sustainability of soil productivity. For appropriate land use and water management in irrigated area, knowledge of the chemical composition of the soil characteristics, water, drainage condition and irrigation methods should be evaluated before implementation of irrigation projects (Seid and Genanew, 2013).

This calls for special attention for their proper management to ensure sustainable agricultural productivity and environmental quality. The indiscriminate land use practices in Dupti Tendaho Sugarcane production factory, Northeastern Ethiopia, have given rise to serious ecological problems and loss of land resources. Efforts to address these problems are highly essential, particularly in generating the needed information necessary for proper land use planning to guarantee sustainable agricultural development and environmental quality. Owing to the aforementioned facts, this study was undertaken to characterize and classify the soils and irrigation water in Tendaho sugarcane production farm.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Tendaho irrigation project (Dupti plantation) which is found at Dubti Woreda, Afar regional state. It is situated at a longitude of about 40°57'486"E and a latitude of 11°40'786"N. The study area is located at about 590 km North East of Addis Ababa, capital city of Ethiopia. The farm occupies a total area of 6,500 ha, which is topographically gentle/flat surface. It is situated at Latitude and Longitude of 11° 41’ 20’’ N to 11° 48’ 40’’ N and 41° 6’ 0 ’’E to 41° 41’30’’E, respectively and at an altitude of 402 masl. (Figure 1). Mean monthly rainfall ranges from 3.9 to 57.7 mm per year, average annual minimum and maximum temperatures are 20.2 and 37.1°C, respectively. Sugar cane is being cultivated in Tendaho farm by using furrow irrigation system from Awash River.

Sampling site selection, and soil and water sampling

Sampling site selection

Prior to the opening of soil profiles, personal field observation of the area within the valley was carried out to determine which specific areas should be selected as representative sites of the study area on the basis of land use. The sampling site section was done on the bases of irrigation history of irrigated lands.

Accordingly, four representative soil profiles study sites were selected which are representing different cultivation histories. Profile 1 is located at the most low-lying portion of the farm. This area of farm has long been irrigated for cotton production; and is fundamentally a challenging farm site to manage it under the ordinary farm management practices and repetitive crop failure has been occurred. Profile 2 represents, non-irrigated shrub field (the area currently not being used for production).

Irrigated matured sugarcane production farm (Profile 3) represents the land area which has been used to grow sugarcane for more than 4 years. Finally, Profile 4 represents the fallow land with no production (no any plant). In addition, four composite surface soil samples (0 to 30 cm depth) were collected from the farm lands represented by the four different soil profiles. Each composite surface soil sample was collected from a plot size of 25 m by 25 m from the land area represented by the respective soil profile. Accordingly, each composite surface soil sample was made from 16 (4 x4) randomly collected sub-samples of 0 to 30 cm depth. The randomly collected sub-samples were bulked to form composite samples.

Soil profile sampling

After site selection, representative soil profiles were opened. Accordingly, one fresh profile (1.20 m wide, 2.00 m long and 1.06 to 2.00 m deep) was opened on each representative site and soil samples were collected from each depth of the profiles. The soil profiles opened on each site were described for their morphological properties in the field and soil samples were collected depth wise from each genetic horizon or soil layer for characterization of their physicochemical properties in laboratory. Profiles were all divided into soil layers according to the evidence of pedogenic horizon development when applicable and to sampling layers where genetic horizons were not evident. Sampling and description of the layers were made according to FAO (2006) guidelines for soil profile and site descriptions, and soil color was interpreted using the Munsell Color Chart.

Laboratory analysis of soil samples

The soil samples was air-dried, ground and sieved through a 2 mm (10 meshes) size sieve and through a 0.5 mm (40 meshes) size sieve for parameter requiring such fine soil particles. Particle size

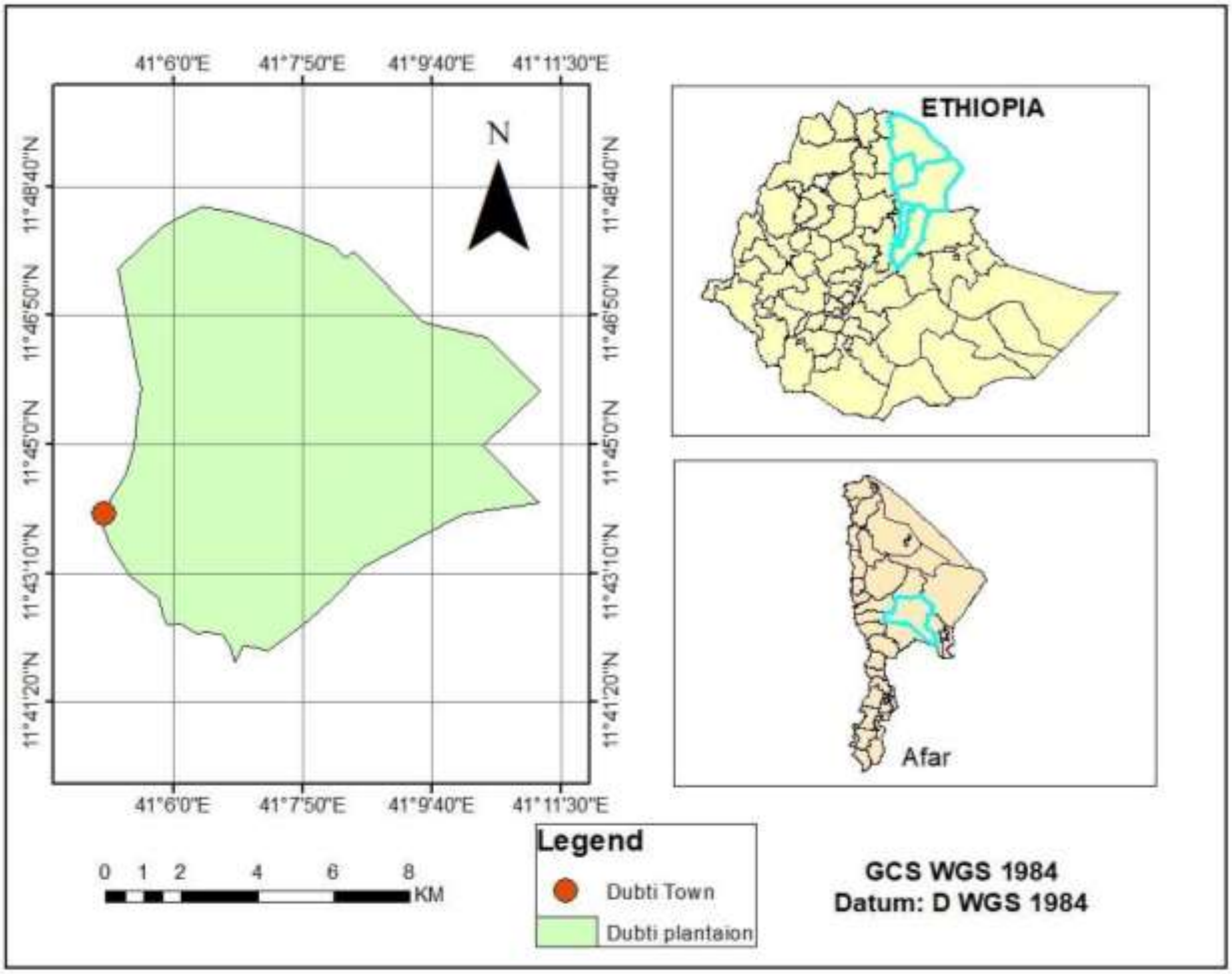

Figure 1. Location map of the study area

distribution was determined by Bouyoucos hydrometer method. Soil pH was read by pH meter in a soil: liquid ratio of 1:2.5. EC measurement was performed using saturated paste extracts. Total nitrogen of the soil was determined by wet-oxidation procedure of the Kjeldahl method (Bremner and Mulvaney, 1982). Organic carbon was determined by the wet combustion method of (Walkley and Black, 1934). Available phosphorus was determined by the Olsen method (Olsen et al., 1954) as outlined by FAO (2002). Exchangeable bases and cation exchange capacity (CEC) of the soils were determined by ammonium acetate of 1 M leaching at pH 7 while calcium carbonate (CaCO3) was determined by acid neutralization (titration) method using HCl (Van Reeuwijk, 1993).

Water quality analysis

A water sample was prepared from sub-samples collected at two sites, that is the irrigation delivery head site and the influent river (inlet to) the dam and at five different time intervals so that representative water samples could be obtained. The irrigation water samples from the dam were collected in one day. The collection and handling of the irrigation water samples was done in accordance with the procedures outlined by the US Soil Salinity Laboratory Staff (1954). Based on this principle one liter water sample was taken from Awash River for analysis of pH, EC, Ca, Mg, Na, Cl, K and SAR. Sodium adsorption ratios (SAR) of the soil solution and irrigation water samples were computed as:

$$SAR = Na^{+}/[(Ca^{2+} + Mg^{2+})/2]1/2$$

Where concentrations of all constituents are given in meq/l

Data analysis

The data generated from laboratory analyzed descriptive statistics. One way analysis of variance was used to compare the physical and chemical properties of soil between and within soil mapping units. All the data were edited, coded and analyzed using statistical package for social science (SPSS) software version 22.0.

RESULT AND DISCUSSION

For characterizing the physico-chemical properties of soils, the sampling site section was done on the bases of uniformity of land attributes. Accordingly, the catchment had four representative soil profiles study sites which are representing different cultivation histories of the area.

Table 1. Physical characteristics of the studied soils in four sites.

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Soil textural class
Profile 1				
0-30	52	30	18	Clay
30-80	28	58	14	Silt clay loam
80-167	18	54	28	Silt loam
Profile 2				
0-31	38	40	22	Clay Loam
31-87	28	58	14	Silt clay loam
87-122	18	50	32	Loam
Profile 3				
0-28	38	40	22	Clay Loam
28-83	32	54	14	Silt clay loam
83-160	28	46	26	Clay loam
Profile 4				
0-32	42	30	28	Clay
32-81	32	52	16	Silt clay loam
81-160	16	54	30	Silt loam

Soil physical properties

In the soil profile description, the horizon boundaries of the pedons were marked by clear to gradual and smooth boundary characteristics. The surface horizons of these pedons had clear and smooth boundaries and the subsurface horizons had diffused to gradual and smooth boundaries. It is an indicator of a more or less uniform development of the horizons of the profiles. Depth of all the representative pedons was ranged from 122 to 167 cm. All sampled pedon representing different land use were found to be deep in depth with layers indicating limited soil profile development and dominated by silt loam and silt clay loam. The results revealed that the surface soils of Profiles 1, 2, 3 and 4 have the color of were light gray, dark gray, brown and gray in colour (dry) and grayish brown, dark grayish brown, brown and dark gray (moist), respectively.

The mean clay content of the surface layers varied from 38 % for Pedon 2 soils to 52% for pedon 1 soils. Also, except for Pedon 2, the clay content of all Pedon decreased with depth. The mean silt content varied from 30% at the surface layer (0-30cm depth) of Pedon 1 and 4 soils to 58% at the subsurface layer (31-87cm depth) of Pedon 2 soil. In the subsurface layer (30-87 cm depth), it varied from 52% to 58%. The silt content of Pedon 4 increased with depth where as other Pedon was consistent.

In this study, the lowest sand content (14%) was recorded in the subsurface layers (28 to 87 cm depth) of pedon 1, 2 and 3 soil and highest (32%) mean sand contents was recorded subsurface of surface layer (0-31cm depth) of Pedon 2. This relatively lower content of sand at the subsurface layers may indicate eluviation of clay and silt from the overlying layers and subsequent accumulation in the subsurface layers. The significant variations in respective particle size distribution observed in the different soil layers indicate the presence of distinct lithological discontinuity within the soil profile. Generally, results of the particle size analysis indicate that the majority of the soils are heavily textured. These properties may have an impact on movement of air and water within the soil (Brady and Weil, 2002).

Such abrupt changes in the distributions of the sand and silt fractions with corresponding changes in the clay contents with soil profile depths indicate the occurrence of erosion and sedimentation processes, resulting in deposition of sediments differing in particles sizes and/or parent materials in the area. Similar findings were reported by Abayneh (2001) in connection to his study of the soils of Raya Valley, Ethiopia. Moreover, Heluf (1985) observed evidences for the presence of litho-logical discontinuities or variability in mineralogy indicating a difference from which the horizons have been formed in the soils of Melka Sedi-Amibara plains (Table 1).

Soil chemical properties

Soil reaction and electrical conductivity

The pH values of surface soil horizons of the studied pedons varied from 7.8 to 8.6, which can be described as moderately alkaline and strongly alkaline as suggested by Park et al. (2011). In pedon1, the pH values dicreased from 8.4 (in surface horizon) to 8.2 (in sub-surface horizon), and it comes back again to 8.6 in last sub-surface horizon Pedons 2 and 3 also showed similar pattern, it was 8.3 and 8.2 in the surface horizons; decreased to 8.0 and 7.9 and it come back again to 8.4 and 8.5 in the last sub-surface horizon, respectively. In contrast, in pedon 4, the pH was increased from 7.9 in the surface horizon to 8.3 and come back again to 7.8 in the last subsurface horizon (Table 2). The rise in pH was attributed to the highest concentration of HCO_3- and the subsequent results of Residual Sodium Carbonate (Seid and Genanew, 2013).

Electrical conductivity of the first site ranges from non saline (0.97 ds/m) for the surface layer and to moderately saline 7.5 ds/m for the next subsurface layer. Whereas EC of the second site was non-saline that ranges between 0.459 dS/m on the surface soil (0 to 31) to 0.83 dS/m in the sub soils of the lower layers (31 to 155 cm) soil depth (Table 2). In site three, all the layers were found to be moderately saline with the EC of 7.455 from the top layer and (6.9 and 5.085) in the consecutive sub surface horizons. On the other hand, the result of EC in pedon four showed that it is non saline 1.68 ds/m for the first layer of the profile but moderately saline (4.635 to 7.29) for the consecutive subsurface horizons.

Indeed, in most of the studied profiles, electrical conductivity (EC) of the soils was higher than 4 dS/m, indicating that there would be actual salinity hazard in the soils of the study area (US Salinity Laboratory Staff, 1954). On the other hand, in all profiles except profile 3, the electrical conductivity was increasing from horizon 1 to 2 while decreasing from horizon 2 to 3; this could be due to the fact that soil salt may be leached out from the surface to sub-surface horizons. (Lelago et al., 2016)

Cation exchange capacity (CEC)

The result revealed that, in all of the opened profiles excavated on different land uses, medium to higher values of CEC were observed both in the surface horizons and the underlying horizons (Table 2). In the surface horizons, values of CEC varied from 27.38 cmol (+)/kg soil in profile opened on irrigated land used to grow sugarcane (Profile 3) to 64.42 cmolc kg-1 soils on non-irrigated shrub field (Profile 2). In the subsurface horizons, the CEC values varied from 26.20 cmol (+)/kg soil on site which has long been irrigated for cotton production (Profile 1) to 49.38 cmol (+)/kg soil in profile opened fallow land (Profile 4). The CEC of the soils in both surface and sub-surface layers ranged was high to very high as per rating set by Lelago et al. (2016). This indicates that, the soils have well in buffering capacity to changes in chemical properties caused by land use system (Hazelton and Murphy, 2007). The high to very high CEC values in the soils of the study area indicates the presence of more weather able primary minerals as a plant nutrient reserve and thus such soils are considered to be soils capable of satisfactory production if other factors are favourable (Lelago et al., 2016).

Soil organic matter and total nitrogen

Organic carbon of all horizons varied from 0.164 - 0.753% (Table 2), which can be described as very low ($\leq$ 2%) according to Tahere et al. (2005) rating. This could be due to the fact that the arid areas have relatively lower amount of OM because of lower vegetation and is an indication of absence of healthy soil biological conditions in the study area (Seid and Genanew, 2013). In addition, Yihenew (2002) revealed that most cultivated soils of Ethiopia are poor in their organic matter content due to low amount of organic materials applied to the soil and complete removal of the biomass from the field.

According to the ratings given in Tahere et al. (2005), total nitrogen content of all profiles (ranging 0.019 to 0.061%) of the study area is very low (≤ 0.1). Similar to contents of organic carbon, amount of total nitrogen in subsurface horizon of all pedon generally showed relatively higher than other upper and bottom horizons. Thus, variation in total nitrogen content is related to variation in content of organic carbon. The lowest level of total nitrogen content indicates the presence of nitrogen deficiency in most of the soils of the study area. The low levels of nitrogen in the soils could be attributed to the poor farming system prevailing in the area, which is characterized by nutrient mining in the absence of replacing crop nutrients through addition of legume crop residues and manures and crop rotation (Brady and Weil, 2002).

Available phosphorus and calcium carbonate

Based on the observed values of available phosphorus, the soils represented by profile 1 had medium (13.53) available P values at the surface horizon and low (5.73 and 5.57) at the consecutive bottom layers of the profile with a decreasing trend of P down the profile. On the other hand, in site two and three the profiles have lower contents of available phosphorus (6.87 and 7.26) for surface soils and 12.40 and 11.09 (medium) for the next subsurface layer and decreased to 6.25 and 5.07 for the last subsurface soil horizon, respectively (Table 2). In the last site (profile 4), there was decreasing trend of available P down the profile; from medium (10.178) for surface to low (8.13 to 4.96) for the consecutive subsurface layers.

For all of the pedon, contents of calcium carbonate showed an increasing pattern with depth (Table 2). Contents of $CaCO_3$ ranged from 3.20% in the last subsurface horizon of pedon 2 to 11.49% in the last subsurface horizon of pedon 3. On the other hand, in all pedons except the first pedon the last subsurface horizon showed relatively higher levels of calcium carbonate than surface layers. Thus, this situation could be attributed to the movement of calcium carbonate solutes laterally downward to the lowest slope position. Generally, the

Table 2. Chemical composition of soils at four sites across soil depth.

Depth (cm)	pH (H_2O)	EC ds/m	TN %	OC %	OM %	Available P (mg kg^{-1})	CEC (cmol (+)/kg)	K (cmol (+)/kg)	Na (cmol (+)/kg)	ESP (%)	$CaCO_3$ (%)	Ca (cmol (+)/kg)	Mg (cmol (+)/kg)	Base Sat. (%)
Profile 1														
0-30	8.4	0.97	0.058	0.276	0.47	13.53	48.66	0.91	2.4	4.93	5.37	22.34	7.46	90
30-80	8.2	7.5	0.025	0.164	0.28	5.73	32.10	1.02	9.3	28.96	6.62	41.23	2.59	97
80-167	8.6	2.57	0.020	0.252	0.43	5.57	26.20	0.96	3.175	12.06	5.61	29.24	1.23	81
Profile 2														
0-31	8.3	0.459	0.061	0.734	1.26	6.87	64.42	0.87	1.89	2.93	3.20	34.58	1.48	88
31-87	8.0	0.83	0.032	0.464	0.79	12.40	43.60	1.11	4.5	10.32	4.63	31.35	1.77	84
87-155	8.4	0.489	0.019	0.351	0.60	6.25	32.10	0.91	3.625	11.27	8.49	27.92	1.32	83
Profile 3														
0-28	8.2	7.455	0.056	0.753	1.29	7.26	27.38	1.08	1.56	5.69	7.23	35.94	1.40	82
28-83	7.9	6.9	0.037	0.429	0.74	11.09	47.50	0.91	5.3	11.15	4.67	27.25	1.19	67
83-160	8.5	5.085	0.031	0.480	0.82	5.07	37.12	0.99	2.125	5.71	11.49	29.15	1.36	83
Profile 4														
0-32	7.9	1.68	0.059	0.206	0.35	10.17	61.48	1.04	0.78	1.27	3.25	42.94	2.80	95
32-81	8.3	7.29	0.036	0.229	0.39	8.13	49.38	1.04	2.5	5.06	7.54	30.48	1.77	73
81-160	7.8	4.635	0.022	0.238	0.41	4.96	37.24	0.84	1.92	5.15	11.27	26.66	1.40	84

result revealed that all layers of the profiles are found to be more that 2%; which resulted in the presence of a calcaric soil material (Hazelton and Murphy, 2007) (Table 2).

Exchangeable cations and percentage base saturation (PBS)

The predominant soluble cation was Ca^{2+} throughout the profile, followed by Mg^{2+} at the surface layer of profile 1 (0-30 cm) and 4 (0-32 cm) and Na^{+} at all the rest layers of the profile. The order of abundance of the basic exchangeable cations was Ca > Mg > Na > K in pedon 1 and 4 of surface and Ca > Na > Mg > K in the rest all horizons of pedons (Table 2). In line with the explanation given by Heluf (1985), the lower of amount of $CO3^{2-}$ throughout the profile seemed to have favored the adsorption of the divalent cations by the soil exchange site to a significant extent. In addition, the CEC of the study area varies between 27.38 and 64.42 cmol (+) kg^{-1} soil on the surface layers, while it ranges from 26.20 to 49.38 cmol (+) kg^{-1} on the sub surface soils. This indicates the high availability of cation saturation in the study site. Similar findings were also reported by Eylachew (2004) on soils of the Rift Valley System of Ethiopia showing andic properties.

Furthermore, the explanation given by Abejehu (1993) also reported the dominance of exchangeable Ca throughout the depths in soils of the Metehara State Farm of the Middle Awash Valley of the Ethiopian Rift System. Similar findings were also explained by Fasika (2006) on soils of the Alage ATVET College Campus of the Ethiopian Rift Valley.

Percent base saturation (PBS) values are used as indicator of soil fertility status. In general, the soils of the study area had high base status values, containing over 70% (Table 2) and thus indicating the presence of hypereutric base status. The high PBS values in all the horizons also indicate the existence of low leaching processes in the horizons which might be due to the influences of poor drainage conditions of the profiles as well as the presence of appreciable

Table 3. Physico-chemical properties of soils at three four (mapping units) (Mean + SE).

Soil parameter	Mapping unit\Level of significance						
	Site One	**Site Two**	**Site Three**	**Site Four**	**F-value**	**p-value**	**Rating**
pH	8.400±0.2	8.23±0.21	8.2±0.3	8.0±0.26	1.329	0.331	High
EC (dS/m)	3.68±3.40	0.593±0.21	6.48±1.22	4.535±2.81	3.426	0.073	Low to medium
TN (%)	0.03±0.02	0.04±0.02	0.04±0.013	0.039±0.018	0.074	0.972	Low
OC (%)	0.22±0.059^{b}	0.5±0.19^{a}	0.55±0.17^{a}	0.22±0.02^{b}	5.308	0.026	Low
OM (%)	0.39±0.10^{b}	0.88±0.33^{a}	0.94±0.30^{a}	0.38±0.030^{b}	5.205	0.028	Low
Avail. P (ppm)	8.27±4.55	8.50±3.38	7.80±3.04	7.75±2.62	0.033	0.991	Low to medium
CEC(cmol (+)/kg)	35.65±11.64	46.70±16.38	37.33±10.06	49.36±12.12	0.84	0.50	High
K	0.96±0.055	0.96±0.12	0.99±0.08	0.97±0.11	0.060	0.980	High
Na	4.95±3.77	3.33±1.32	2.99±2.02	1.73±0.87	1.014	0.436	Medium to high
ESP	15.31±12.34	8.17±4.56	7.51±3.14	3.82±2.21	1.473	.293	Low to medium
CaCO$_3$	5.86±0.66	5.44±2.73	7.79±3.44	7.35±4.01	0.433	0.736	**-**
BS	89.33±8.02	85.00±2.64	77.33±8.96	84.00±11.0	1.084	0.410	**-**

Similar letters or no letters with rows indicate that there is no significant difference among parameters, α = 0.05.

amounts of base nutrients in the soils (Sunitha et al., 2010) (Table 3).

The level of exchangeable sodium percentage of the profile opened at the most low-lying portion of the farm varied from 4.93 at the surface (0 to 30) to 28.96 at the depth of 30 to 80 cm. According to Horneck et al. (2007), soils with >15 ESP have a high sodicity risk due to the effects of Na on soil structure and toxicity to crops. Accordingly, the soils represented by this profile were characterized by sodicity hazards. On the other hand, the other profiles of the study area aranges from 1.27% at the surface soil (0 to 32 cm) of profile 4 to 11.27% at the last subsurface (87 to 155 cm) of profile 2. These ESP values show that there is sodium toxicity problem in the first study sites to reduce the sugarcane crop yield and other study sites are no actually sodic. In general, soils with exchangeable Na >1 cmol (+)/kg should be regarded as potentially sodic (Brady and Weil, 2002). This indicates that the soils of other profiles are also potentially sodic.

Soil chemical characters among mapping units

The ANOVA results indicated that there were significant variations for OC and OM among the four mapping units (profiles). Accordingly, significantly higher ($P<0.05$) OC (0.5±0.19 and 0.55±0.17) and OM (0.88±0.33 and 0.94±0.30) were recorded on profile two and three.
However, soil pH, EC, TN, available phosphorus, CEC, K, Na, ESP, CaCO$_3$ and base saturation were not significant different among the four sites with different land use. On the other hand, except some soil properties (pH, CEC, K, Na), most of them are available in low amount according to FAO guideline (Table 3).

Irrigation water quality

Irrigation water quality was analyzed for SAR, pH, EC and other parameters of the water. The amount of sodium in irrigation water is of special concern due to sodium effects on the soil and poses a sodium hazard usually expressed in terms of SAR. SAR is calculated from the ratio of sodium to calcium and magnesium as they tend to counter effects of sodium. The SAR value of Awash River was found to be 1.17 (Table 4). Thus, the irrigation water in use had a low sodicity hazard. Similar findings were also reported for the Awash River water at the Matahara Sugar State Farm (Abejehu, 1993; Alamirew, 2002) in the Middle Awash Valley Ethiopia.

The average pH value of the irrigation water for Awash River at the delivery head site and the influent river is 7.65 (Table 4). On the other hand, the EC of the irrigation water was 0.654 dS m^{-1}. These pH and EC values clearly indicated that the irrigation water was moderately alkaline with the salt content classified as moderately saline (0.654 EC (dS/m) (Table 4) as outlined by different researchers (Biswas, 1998; Ayers and Westcott, 1985). The dominant ions in the irrigation water samples were dissolved HCO$_{3-}$ and Ca^{2+}, followed by Na+. This indicated that bicarbonates of calcium and sodium ions were the dominant salts in the irrigation water which was in agreement with the findings of Alamirew (2002) on the Awash River.

Indeed, the water sample revealed that the irrigation water was medium in soluble salt concentration (salinity hazard), low in sodicity hazard and safe in residual sodium carbonate hazard (US Salinity Laboratory Staff, 1954) (Table 4).

Conclusion

Effective control of soil salinity requires better understanding on the extent and distribution of salts. This work focused on the recognition of the problem, by characterizing the physicochemical properties of the soils

Table 4. Chemical composition of water used for irrigation of the two sites.

Water parameters	Units	Degree of Restriction (Biswas, 1998; FAO, 1985b soil Bulletin 55; Ayers and Wesstcott,1985)			Values for Awash river	Severity status
		None	Slight to moderate	Severe		
Electrical Conductivity(EC)	ds/m	<0.70	0.70-3.00	>3.00	0.654	Slight to moderate
Sodium (Na^+)	meq/l				1.05	Normal
SAR	$meql^{-1/2}$	<3.00	3.00-9.00	>9.00	1.17	Low
Calcium (Ca^{2+})	meq/l	0 – 800: normal range		-	1.25	Normal
Magnesium (Mg^{2+})	meq/L	0 – 120: normal range		-	0.4	Normal
Potassium (K^+)	-	-	-	-	0.091	Normal
HCO_{3-}	-	-		-	2.25	Normal
pH	pH scale	6.5 - 8.4: normal range		-	7.65	Moderately alkaline

and irrigation water for intended irrigation scheme with reference to standard suitability class. The results revealed that most of the soil physical properties showed variability in their total distribution within the depths of the soil profiles.

Regarding the soil's chemical properties, the soil pH ranged from 7.8 to 8.6 qualifying for moderately to strongly alkaline in reaction. Maximum ECe (7.5 dS/m) and ESP (28.96) values were recorded from the subsurface horizon of profile 1, which is classified as saline-sodic while Profile 2 is classified as non saline non sodic. On the other hand, profiles 3 and 4 were found to be saline and potentially sodic soils. The predominant soluble cations were Ca^{2+}, Mg^{2+} and Na^+ throughout the profile.

In addition, the CEC of the study area indicates the high availability of cation saturation in the study site. On the other hand, the high Percent Base Saturation (PBS) values in all the horizons are used as indicator of soil fertility status and the existence of low leaching processes in the horizons. Moreover, the water sample revealed the water is low in sodicity hazard while EC indicated that the water is medium in soluble salt concentration (salinity hazard) and pH clearly showed that the irrigation water was moderately alkaline.

Hence, the study underscores the need for the scientific reclamation program of salt affected soils and waters for increasing the biological productivity of these habitats. In line with this, a due emphasis be given for frequent monitoring of irrigation waters, selection of suitable verities and crops, removing of excess salts by leaching, adopting judicious means of irrigation and fertilizer application together with the addition of organic manures and fallowing lands with the raclamative grasses; for such sustainable and productive utilization of the land resources, are critical.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of poultry litter biochar on Ultisol physical properties

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A study was carried out to investigate the effect of biochar produced from the pyrolysis of poultry litter feedstock in some of the physical properties of a Yellow Red Argisol eutrophic typical (Ultisol), located in the municipality Lagoa Seca, State of Paraiba, Brazil, that is, granulometric analysis, bulk density, porosity and available water capacity. Six doses of biochar (0; 10; 15; 20; 25 and 30 ton ha^{-1}) were incubated into an Ultisol samples during 60 days. All assays were carried out in duplicate. After the incubation period, the soil samples were analyzed in relation to physical properties. The results of this study confirmed that the biochar prepared from the poultry litter improved these properties, that is, modified the granulometric analysis, led to a decrease in bulk density, an increase in total pore volume as well as an increase in water content mainly in matric potential 0.5065 MPa. The biochar dose, 30 ton ha^{-1} was better in soil density and porosity; in the water retention the best biochar dose was 15 ton ha^{-1}; however, as the biochar effects on the physical properties were very small, it suggests to investigate larger amounts of this material in the application of the soils.

Key words: Poultry litter, soil amendment, soil physical, porosity, bulk density.

INTRODUCTION

The organic matter has implications directly or indirectly on some chemical and physical phenomena in the soil. The direct effects are related to the high specific surface area and the large amount of surface charges in organic matter.

Indirectly, organic matter interferes in soil physical behavior by its effects on soil aggregation and consistency, acting on the formation of aggregates and, therefore, on the distribution of pore size, as well as retention and availability of water in the soil. To improve physical soil properties and fertility there is a need to increase soil organic carbon content.

For this purpose, integrated use of organic and inorganic fertilizer is becoming an emerging trend.

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Organic fertilizers such as chicken litter, compost and manure, are used nowadays as a source of organic carbon but their rate of decomposition is very high (Palm et al., 2001). Because of this, there is need to use such organic fertilizer, which is recalcitrant to decomposition for a long period, and maintain the soil organic carbon status.

There is currently a lot of study soil compaction by effecting limiting root growth of plants. Plants are the source of life in the living world. They perform many ecological functions in their environment, and they shape the life of living things in the environment where they live. The life of living things in the world is directly or indirectly dependent on plants (Sevik and Cetin, 2015; Cetin, 2016; Guney et al., 2016). The ability of plants to fulfil their functions primarily depends on the availability of appropriate climatic and edaphic conditions (Guney et al., 2016; Cetin and Sevik, 2016). Therefore, soil is one of the absolutely necessary conditions for plant existence, which is essential for the life of living things.

The soil is defined as “the part of the solid earth that has been altered by the loosening of the earth, humus formation and chemical decomposition, by the transport of humidification and chemical decomposition products”. However, when it is examined in detail, the soil is a very complex structure and the biological and biochemical process in the soil is the basis of the terrestrial ecosystem (Cetin and Sevik, 2016; Sevik et al., 2016; Turkyilmaz et al., 2017). In this respect, it is very important to examine the structural change of the soil and to determine its relation with the plant.

Some studies shows that it examined the change of the soil structure in the forests according to the tree species. An attempt to determine some soil characteristics based on tree species and depth of soil was made within the scope of the study. Soil is important for forest and landscape. Enzymes in the soil structure ensure that they are alive in forest areas (Sevik and Cetin, 2015; Cetin and Sevik, 2016).

The poultry sector in Brazil has been expanded as can be seen from 1.7 to 12.3 million tons per year of chicken meat from 1987 to 2013. However, due to prohibition on the use of poultry litter in animal feed, an excess of this residue has been generated (União Brasileira de Avicultura 2007, 2014). Among the alternatives for the final destination of the chicken litter is its direct use in the agricultural soil as a source of organic matter and nutrients, or the production of energy and biofertilizer in biodigesters (Andrade et al., 2015). Biochar obtained by pyrolysis of chicken manure represent an additional option for recycling this waste in agriculture and then it might be applied to soils as an amendment. This waste is of special interest for the production of biochar in Brazil due to the high production generated by year, as Corrêa and Miele (2011) is around 6.8 million m^3.

Biochar is defined simply as charcoal that is used for agricultural purposes. It is a product of thermal decomposition of biomass produced by the slow thermo-chemical pyrolysis of biomass under oxygen-limited conditions. Their properties depend upon the type of biomass used for feed stock and pyrolysis conditions that is, charring time, rate and temperature (Mukherjee and Lal, 2013).

The poultry litter biochar has many agricultural benefits; it is a useful resource to improve the chemical properties of soil, such as, for example, increasing soil pH, cation exchange capacity (Chaves and Mendes, 2016), fertilizer-use efficiency and increase crop production, particularly for long-term cultivated soils (Van Zwieten et al., 2010). However, the growth parameters of crambe, (Vasconcelos et al., 2017), sesame and sunflower plants (Furtado et al. 2016 a,b) decreased with the doses of poultry litter biochar applied in the soil, that is, the doses used in this research harmed the development of plants, probably due to increased salinity in the soil.

According to Jien and Wang (2013), many studies have reported the use of biochar in soil improving the chemical properties in highly weathered tropical soils (Iswaran et al., 1980; Liang et al., 2006). However, few studies have investigated the effects of biochar on soil physical properties (Atkinson et al., 2010). According to Kimetu and Lehmann (2010), the biochar improve the soil aggregation stability because biochar is characterized by recalcitrant C from microbial degradation and by a charged surface with organic functional groups; and, it retains soil moisture, helping plants through periods of drought more easily (Lehmann et al., 2006).

Several researchers studying the effects of organic matter on soil physical properties (clay content, soil density, flocculation power, porosity, and compaction) have found positive results. However, these effects of organic matter and still others on the physical properties of the soils must be different, or not, of the effects of the biochar in them. Therefore, it is necessary to study the effects of the biochar in the physical properties of the soils.

The objective of this study was to evaluate the effects of biochar produced from poultry litter on the physical properties of a predominant soil of the humid region located on the eastern slopes of the Borborema Plateau, with mild climate and rainfall exceeding 1200 mm per year. It is acidic soil with low activity clay intensely cultivated with fruit crops, pastures, sugarcane and various food crops.

MATERIALS AND METHODS

The experiment was carried in Irrigation and Salinity Laboratory of the Department of Agricultural Engineering, UFCG, at May, 2017. The sample soil was collected from the top layer (0 to 0.20 m) of a Yellow Red Argisol eutrophic typical (Ultisol) located in the municipality Lagoa Seca, State of Paraiba, Brazil. The physical-chemical characterization was performed in air-dried soil sample passed through a 10 mesh (2mm) sieve (air-dry fine earth, ADFE) according to the methodology of EMBRAPA (1997) (Table 1).

Table 1. Chemical and physic characterization of Ultisol and biochar samples.

Attributes	Ultisol	Attributes	Biochar
Calcium (cmol$_c$ kg^{-1})	1.56	Calcium (g kg^{-1})	48.3
Magnesium (cmol$_c$ kg^{-1})	1.18	Magnesium (g kg^{-1})	14.6
Sodium (cmol$_c$ kg^{-1})	0.06	Sodium (g kg^{-1})	7.3
Potassium (cmol$_c$ kg^{-1})	0.26	Potassium (g kg^{-1})	47.16
Hydrogen+Aluminum (cmol$_c$ kg^{-1})	1.27	Hydrogen+Aluminum	-
Electrical conductivity (mS cm^{-1})	0.16	Electrical conductivity (mS cm^{-1})	12,69
Organic carbon (g kg^{-1})	8.60	Organic carbon (g kg^{-1})	-
Phosphorus (mg kg^{-1})	4.9	Phosphorus (g kg^{-1})	29.4
pH H_2O (1:2.5)	5.7	pH H_2O (1:2.5)	10.2
Sand (g kg^{-1})	736.0	Sand (g kg^{-1})	836.8
Silt (g kg^{-1})	100.3	Silt (g kg^{-1})	100.0
Clay (g kg^{-1})	163.7	Clay (g kg^{-1})	63.2
Bulk density (g cm^{-3})	1.29	Bulk density (g cm^{-3})	-
Porosity (%)	51.32	Porosity (%)	-

The biochar used in this study were produced from poultry litter (PL), a solid waste resulting from chicken rearing, under slow pyrolysis, by SPPT Technological Research Ltda. The attributes present in Table 1 were found according to the methodology of Andrade and Abreu (2006). The biochar sample was submitted to dispersive energy spectroscopy (DES) (that is, a semi-quantitative quantification of the sample), which identified the presence of the chemical elements (Table 1).

In order to get an impression of the biochar pores, it was visualized the morphology of the chars by electron - microscopic and optical microscopy images using SEM Hitachi TM-1000 and OM Hirox KH-1300, respectively. To evaluate the effect of biochar in soil physical properties, initially, soil and biochar samples were passed through a 10 mesh (2 mm) sieve, then, samples soil (0.4 kg) were placed in plastic pots (experimental units), mixed with biochar according to the treatments (0; 1.6; 2.3; 3.1; 3.9 and 4.6 g, corresponding to 0; 10; 15; 20; 25 and 30 ton ha^{-1}, respectively) and incubated during 60 days using deionized water at about 60% of field capacity.

All assays were carried out in duplicate. After this period, physical properties of samples soil were performed according to the methodology described by EMBRAPA (1997). Particle size was analyzed by densimeter method, also known as hydrometer method, proposed by Bouyoucos. Bulk density (a) was determined by the graduated test tube method, and particle density (b) by the volumetric flask method. The total porosity was calculated as [(b-a) / b] x 100; and moisture contents of the samples were measured at different matric potentials (1.52; 1.01; 0.51; 0.10; 0.033 and 0.01 MPa). The moisture of the samples was determined by the Richard extractor (EMBRAPA, 1997).

RESULTS AND DISCUSSION

The amount of the mineral particles that compose the soil, clay, silt and sand, varied according to the increasing doses of biochar applied to the soil, and the amount of sand increased by around 8.18%, while the amounts of silt and clay decreased by around 40.08 and 12.22%, respectively (Figure 1). Probably this variation is in agreement with the behavior of the biochar; although this material is organic, when analyzed regarding textural behavior presented 836.8; 100.0 and 63.2 g kg^{-1} of sand, silt and clay.

In fact, biochar is not formed by these mineral particles, but according to the size of the particles of biochar, during the particle size analysis, using sodium hydroxide, as a dispersant, behaves as if it were the mineral particles in relation to the size of the particles. Therefore, the increasing application of biochar to the soil increased the amount of particles with the size corresponding to sand in the granulometric analysis of the soil mix with biochar.

The physical properties of the soil evaluated in this study were influenced by the mixture of soil with biochar. Bulk density and the pore space of soil have a significant effect on soil properties as well as on plant growth (Aslam et al. 2014). The results indicated a decrease in bulk density (Figure 2A) and increase in porosity (Figure 2B) in the biochar-amended soil corroborating Jien and Wang (2013) and Abel et al. (2013).

Soil porosity is related to aeration and soil water movement. Aeration refers to the ability of soils to meet the respiratory demand of the biological life of the soil. For this, there is a need for continuous exchange of oxygen and CO_2 between the atmosphere and the soil, which is influenced by the proper porosity of the soil. Besides, the water retention influencing the development of the plants, the movement of the water acts to control the temperature and aeration of the soils.

According to Mukherjee et al. (2013), the soil bulk density varies inversely with the porosity as a function of the application of biochar, this is because porosity of biochar is very high and when it used in soil it significantly decrease bulk density by increasing the pore volume. The higher the number of pores (macro pores) the soil presents, the lower its density.

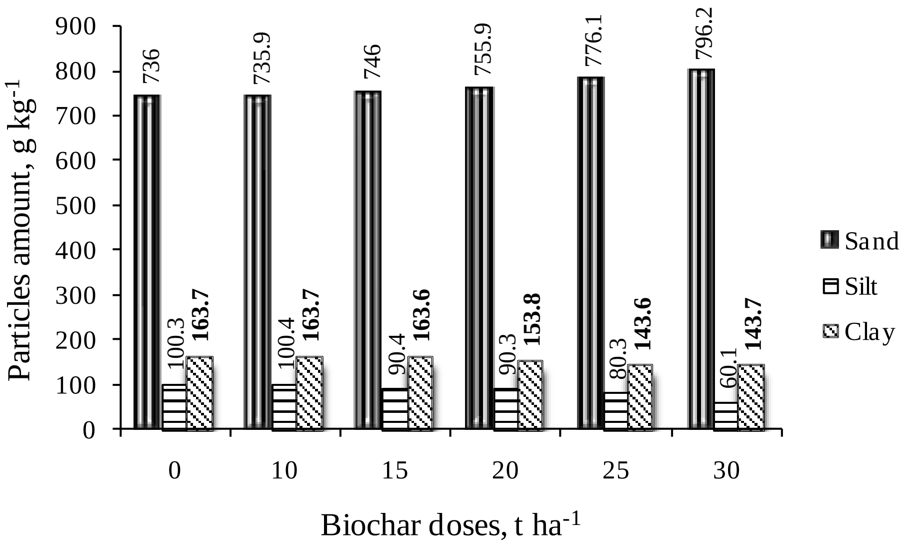

Figure 1. Particle size distribution of mixed soil with biochar

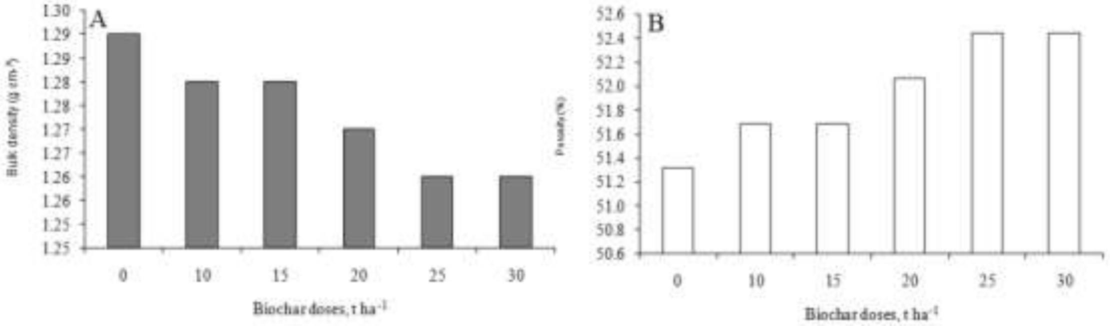

Figure 2. Changes of bulk density (A) and porosity percentage (B) from the biochar-amended soil with 0; 10; 15; 20; 25 and 30 t ha^{-1} application rates.

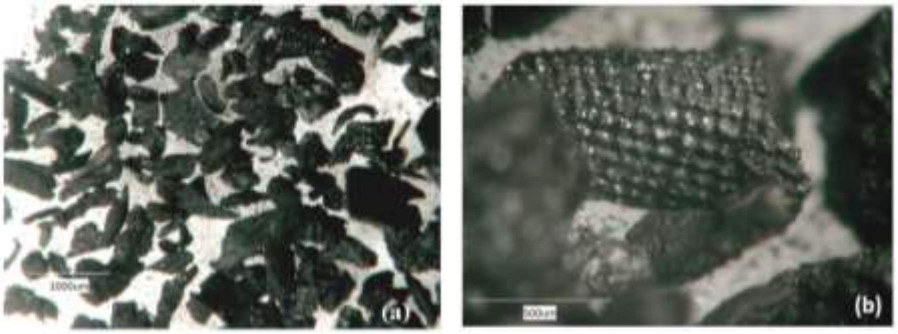

Figure 3. Photomicrographs of the biochar samples obtained by optical microscopy (a) with 1000X magnification; (b) with increase of 2000X.

According to Abel et al. (2013), this variation, probably, occurs due to different sheric shape and structural rigidity of the used chars. Through optical and electron microscopy can observe the different shapes of the biochar used in this work (Figures 3 and 4). In the images, it can observed the shapes and the distribution

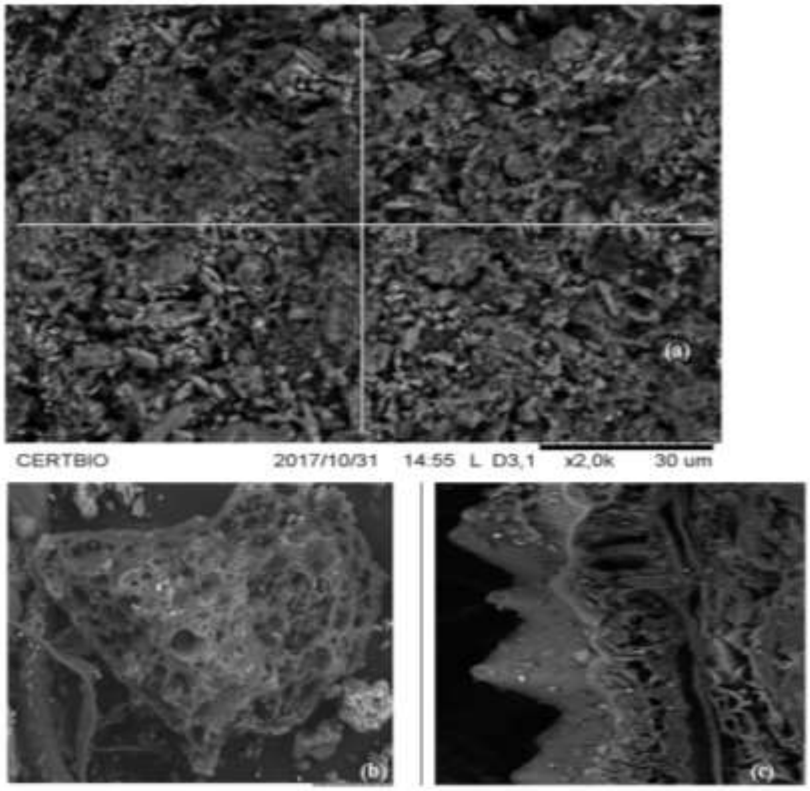

Figure 4. Photomicrographs of the biochar samples obtained by SEM. (a) with increase of 1000X; (b) and (c) with increase of 2000X.

of the particles (Figure 3a), as well as a topographic structure with high roughness (Figure 3b).

Based on Figure 4, it is observed that the morphology of the biochar sample presented a heterogeneous surface, divided into smooth and other rough parts, showing grooves resulting from surface pores for most of its extension. According to the analysis dispersive energy spectroscopy (DES), this sample showed potassium, 3.5%; calcium, 2.3%; nitrogen, 6.0%, chloride, 0.6%, aluminum, 0.8%, phosphorus, 0.6%, magnesium, 0.6%, sodium, 0.6%, silicon 0.2%, and sulfur, 0.1%, with a predominance of 69.9% of carbon and 14.9% of oxygen. Similar results were observed by Abel et al. (2013), Herath et al. (2013) and Jien and Wang (2013), investigating the chemical and physical effects in soils using biochar from feedstock maize, corn stover (*Zea mays*), the wood of white lead tress (*Leucaena leucocephala* (Lam) de Wit), respectively (Figure 4).

With respect to density variation, there was a decrease of 2.32% from the lowest (0 t biochar ha^{-1}) to the highest treatment (30 t biochar ha^{-1}) reaching 1.26 g cm^{-3}, similar to that observed by Laird et al. (2010) using 2 wt % biochar to the soil. The decrease in bulk density as a function of increasing doses of biochar was small, according to Herath et al. (2013) working with biochar produced from the pyrolysis of corn stover feedstock. The higher dose biochar amended soil exhibited higher porosity (52.45%) than the unamended control (51.32%), however this increase corresponded only to 2.2%. According to Herath et al. (2013), this increase in porosity was depend on type of biochar used and soil type where biochar was applied. In general, the increase in soil porosity is due to high porous nature of biochar, as can be seen in the Figures 3 and 4 (Mukherjee and Lal, 2013).

According to Rouquerol et al. (1999), the mesopores with a diameter of 20 to 50 nm in the biochar are associated with the adsorption of liquid and solid compounds, for example water, and once initial hydrophobicity (Bornemann et al., 2007) of biochar is overcome it has the potential to oxidise and absorb and retain water (Cheng et al. 2006). The content of water retained in the soil in a given tension is a specific characteristic of each soil and is the result of the joint and complex action of several factors. It depends on the content and mineralogy of the clay fraction, the organic matter content, the microstructure differences related to them and soil compaction.

The soil water retention curve, essential for the study of soil-water relationships, represents the relationship between the water content and the energy with which it is retained (Figure 5). Moisture contents of the samples soil

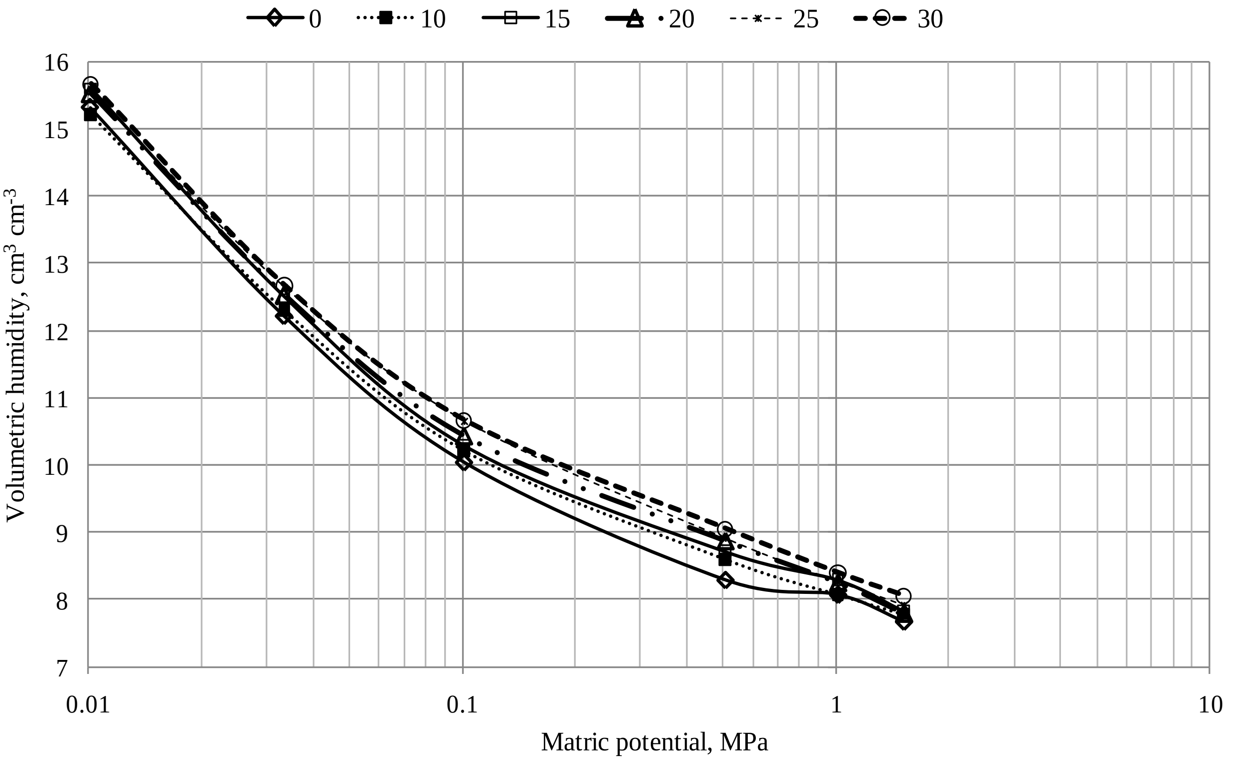

Figure 5. Water retention curve in the soil with different biochar dose.

mixed with biochar measured in the different matric potentials evaluated are observed in the retention curve (Figure 5). The samples amended with higher biochar dose show clearly an increase in moisture content in relation to the control sample in all matric potentials, although the greatest increase was observed in 0.5065 MPa.

The available water capacity is defined as the amount of water held between field capacity (0.01 MPa in sandy soil) and permanent wilting point (1.52 MPa). The highest variation of water available, according to the biochar doses related to the control, corresponded to 1.2% in the dose 15 t ha^{-1} of biochar. Several researchers observed an increase in the available water content as a function of the application of biochar in soil (Laird et al., 2010; Aslan et al., 2014), although most experiments carried out to date on this effect have used high rates of this amendment – as for example, 100 and 200 t ha^{-1} (Kammann et al., 2011) and 50 and 100 t ha^{-1} (Chan et al., 2007), which, according to Herath et al. (2013), are not practically feasible at the farmer level. However, Tryon (1948) and Herath et al. (2013) commented that the increase in the soil water retention capacity is dependent on soil texture and porosity, that is, it is significantly increased in soil water retention capacity in case of sandy soil by biochar application a because it increase soil porosity and also due to adsorptive nature of biochar.

In the present research, the biochar effects on the physical properties were very small, probably, due to the low application of this material in soil. The rate was only about 1% of the soil weight. This suggests for the next researches to increase the application rate to enhance the biochar benefits. In the case of the small increase of available water in the soil, this may also have been influenced by the small increase of the soil porosity with the application of biochar and/or short incubation time of the biochar in the soil. Even so, this small increase in available water can result in the growth and development of plants grown on this soil due to improved physical properties.

Conclusions

The properties of the biochar, in the same way as the effect of the same on the soil characteristics, vary according to the feedstock type in the production of the biochar, pyrolysis conditions and duration of charring. Biochar prepared from poultry litter through slow thermo-chemical pyrolysis, incubated in soil, improved the physical properties of the same, that is, modified the granulometric analysis, led to a decrease in bulk density, an increase in total pore volume as well as an increase in water content mainly in matric potential 0.5065 MPa. The biochar dose, 30 ton ha^{-1} was better in soil density and porosity; in the water retention the best biochar dose was 15 ton ha^{-1}; however, as the biochar effects on the physical properties were very small, it suggests to investigate larger amounts of this material in the application of the soils.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Phosphorus adsorption and its relationship to the physical and chemical characteristics with different soil classes

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In order to determine the characteristics of phosphorus adsorption using the Langmuir and Freundlich isotherms and its relationship with some of the chemical and physical properties of soils, a study was developed at the Embrapa Soil Laboratory with soil samples (0 - 30 cm) from four classes of topsoil: Orthic Chromic Luvisols, Eutrophic Cambisols, Fluvic Neossol and Eutrophic Cambisols Typical. The hyperbolic model of the Langmuir isotherm was fitted by the non-linear regression technique. We performed a correlation analysis between the isotherm parameter values and soil characteristics that reflected the Phosphate Maximum Capacity. The values of remaining phosphorus ranged from 16.28 to 43.73 mg L^{-1} for the soils. For the Langmuir isotherm, the maximum phosphorus adsorption capacity (MPAC) values ranged from 0.2793 to 0.3954 mg g^{-1} of soil. The RY soil had the largest amount of adsorbed phosphorus (0.3954 mg g^{-1}), giving this soil a high MPAC.

Key words: Tropical soils, phosphorus, buffering capacity.

INTRODUCTION

In Brazil, most soil has a high degree of weathering, with large amounts of iron and aluminum oxides and clays of the kaolinite group of minerals that have surface charges that vary according to the reaction of the soil solution (Schaefer et al., 2008). Thus, the soil can behave as either a source or a drain of P, acquiring most of the P added to the soil by linkage to colloids and making it unavailable to plants. As the degree of weathering of these soils is increased, they become more electropositive, adsorbing anions such as phosphates (Novais and Smyth, 1999; Carvalho Filho et al., 2015).

Many of these weathered soils, and even some less weathered, despite having levels of P that are not significant, only have a small amount of P available due

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Table 1. Physical and chemical characteristics of the soils in accordance with the methodology of Embrapa (1997).

Characteristics	Sois			
	TCo	**CXbe**	**RY**	**CXve**
pH H_2O (1:2,5)	6.8	6.6	6.8	6.5
Ca^{+2} (mmol$_c$ dm^{-3})	76.9	182.1	145.3	31.0
Mg^{+2} (mmol$_c$ dm^{-3})	29.5	39.3	63.5	20.5
Na^+ (mmol$_c$ dm^{-3})	1.1	0.7	1.1	0.5
K^+ (mmol$_c$ dm^{-3})	5.1	13.5	4.8	6.2
SB (mmol$_c$ dm^{-3})	112.6	235.6	214.7	58.2
H+Al (mmol$_c$ dm^{-3})	12.4	38.0	28.1	12.4
T (mmol$_c$ dm^{-3})	125.0	273.6	242.8	70.6
V (%)	90	86	88	82
Al^{+3} mmol$_c$ dm^{-3})	0.5	0.5	0.5	0.5
P mg dm^{-3} (Melich^{-1})	296.2	286.8	8.90	22.5
P mg dm^{-3} (RTA)	75.0	130.5	10.5	18.0
M.O (g kg^{-1})	11.2	28.8	20.9	10.2
Prem (mg L^{-1})	43.73	16.28	27.34	41.34
MPAC (mg g^{-1})	0.279	0.297	0.395	0.293
Sand (g kg^{-1})	726.4	716.8	450.1	726.6
Silt (g kg^{-1})	138.0	28.3	234.8	148.0
Clay (g kg^{-1})	135.6	254.9	330.0	125.4

TCo: Chromic Orthic Luvisol; CXbe: Eutrophic Haplic Cambisol; RY: Fluvic; CXve: Typical Eutrophic Cambisol.

to the low solubility of their forms of P and, by the strong interaction of phosphate with the soil, forming compounds of low solubility in soils linked to different combinations of iron, aluminum, calcium and organic matter (Rolim Neto et al., 2004; Bortoluzzi et al., 2015; Fink et al., 2016; Brito Neto et al., 2017). Despite its importance for the growth and development of plants, P is a macronutrient that is required in only small quantities, yet it is one of the elements that limit productivity in most cultures (Gatiboni et al., 2007) due to the adsorption phenomenon that is common to all soils. In northeastern Brazil, different classes of soil occur, from the least to the most weathered, with different energies of adsorption of P.

The reactions of adsorption and the precipitation of P in the soil begin as soon as P is added, so that in acidic and highly weathered soils, a portion of the P is adsorbed on the surface of clay minerals, such as iron and aluminum oxides, and another part precipitates with Fe and Al present in soil solution. However, in a few weathered soils with pH ranging from neutral to alkaline, part of the P added is adsorbed onto the surface of clay minerals and another portion precipitates with Ca in the soil solution. According to Gérard (2016), the P adsorption capacity of clay minerals may be similar to or higher than that of iron and aluminium oxides depending on the specific surface area of the particular soil components.

From a practical standpoint, it is not easy to separate the reactions of adsorption or precipitation of P in soil; to do this, isotherms of Langmuir and Freundlich adsorption are used to describe the P (Novais and Smyth, 1999). In this regard, our aim with this work is to determine the adsorption capacity of P in four soil samples from Brazil's Northeastern region.

MATERIALS AND METHODS

The experiment was conducted at the Laboratory of Soils and Plant Nutrition at the National Center Cotton of Embrapa Algodão. Four soil samples with different chemical, physical and mineralogical characteristics, collected at a depth of 0 - 30 cm corresponding to the topsoil, were used. The soils were classified according to the Brazilian System of Soil Classification (Embrapa, 2006) as Orthic Chromic Luvisols (TCO), Eutrophic Cambisols (CXbe) Fluvic Neossol (RY) and Eutrophic Cambisols Typical (CXve). Soil samples were loosened, air dried and passed through 2 mm mesh sieves for chemical and physical characterization (Table 1) according to Embrapa (1997).

Subsoil samples were taken to determine the Prem, being determined in the equilibrium solution obtained after shaking a soil sample with 5 cm^{-3} of 50 mL of $CaCl_2$ 10 mmol L^{-1} containing 60 mg L^{-1} P for five minutes, and allowing it to settle for decantation for 16 h (Alvarez et al., 2000). The P equilibrium concentration solutions used for adjusting the Langmuir and Freundlich isotherms were based on the values of P-rem in the soil (Alvarez et al., 2000) and corresponded to 0.0, 10, 20, 40 and 80 mg L^{-1} P for soils with P-rem between 30 and 44 mg L^{-1}, 0.0, 18.75, 37.50, 75.0 and 150 mg L^{-1} P for soils with P-rem between 10 and 19 mg L^{-1} and 0.0, 13.75, 27.5, 55.0 and 110 mg L^{-1} P for soils with P-rem between 19 and 30 mg L^{-1}.

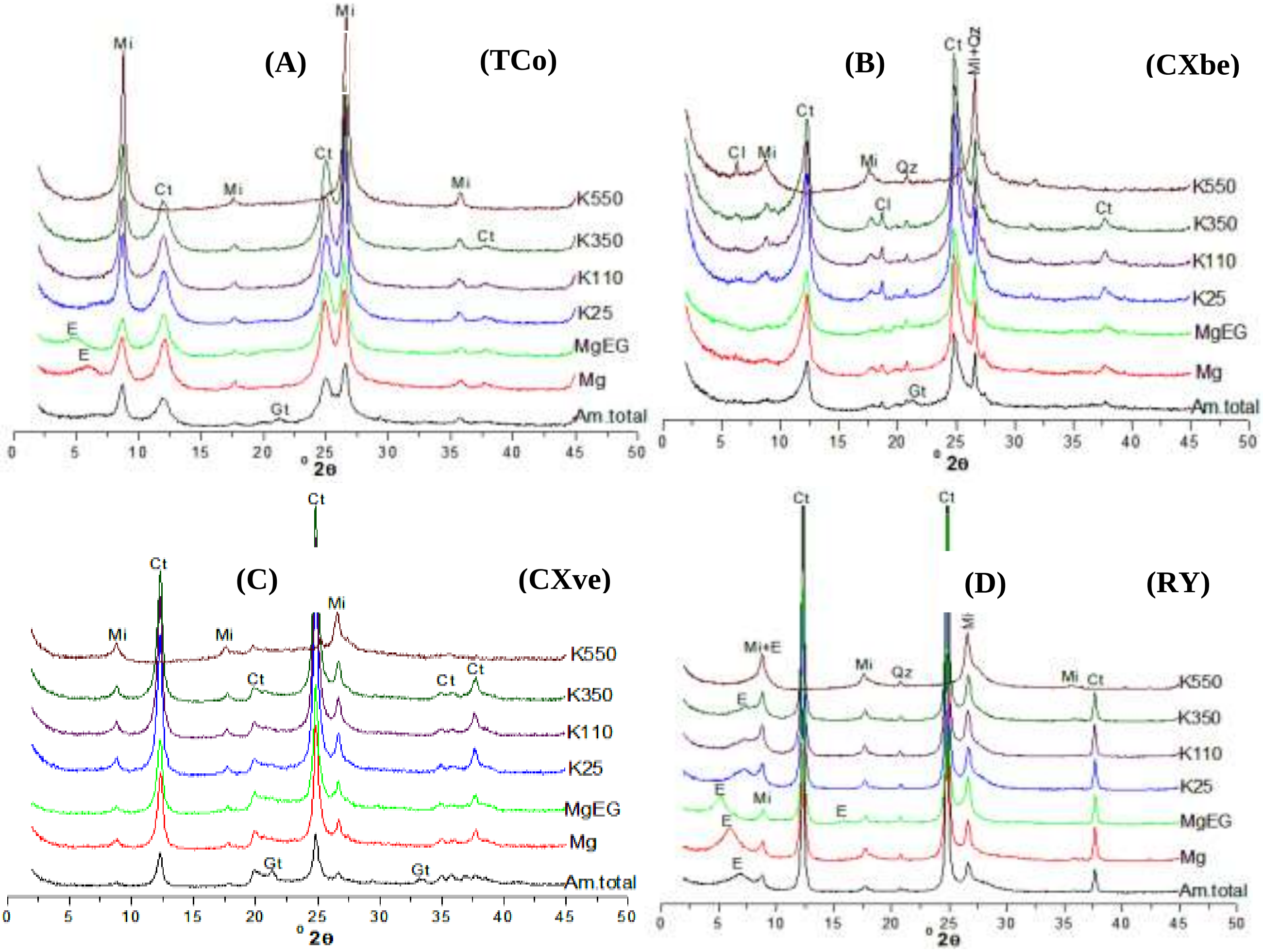

Figure 1. X-ray diffractogram of clay samples from (A) TCO, (B) CXbe, (C) CXve and (D) RY assembly-oriented CuKα radiation.

To determine the MPAC, 2.5 cm^{-3} of soil was used. Then, 25 mL of $CaCl_2$ 10 mmol L^{-1} was added to a 250-mL Erlenmeyer flask containing P according to the concentrations mentioned above. After horizontal shaking for 24 h, the suspensions were centrifuged at 3000 rpm for five minutes and then filtered. The content of P in the equilibrium solution was determined by colorimetry (Braga and Defelipo, 1974), which was performed in triplicate. From the data obtained in triplicate, Langmuir and Freundlich adsorption isotherms were constructed by plotting the amount of P adsorbed in the soil (Q) on the ordinate and the concentration of P in equilibrium solution (C) on the abscissa. The hyperbolic form of the Langmuir equation is given by the following expression:

$$X=\frac{(a+b+c)}{m\ (1+a.c)}$$

Where x/m is the amount of P adsorbed to the soil in mg P (x)/g soil (m), (b) is the MPAC (mg g^{-1}) of P in the soil, (c) is the concentration of P in the equilibrium solution (mg L^{-1}), and a is the constant related to the adsorption energy of the element in soil (mg L^{-1}) (Olsen and Watanabe, 1957). The constants and (b) were estimated by the linear Langmuir equation, obtained by transformation of the hyperbolic equation, which corresponds to: C/x/m= C+1/ab/b. The linear form of the Freundlich equation is given by the following expression: log (x/m)= log k+(1/n). log (c) Where: x/m is the mass of the solute associated with the solid phase (mg kg^{-1}), (c) is the solute concentration in equilibrium solution (mg L^{-1}), KF: is the coefficient of Freundlich adsorption (cm^3 kg^{-1}) and (n) is an estimate of the tuning parameter (dimensionless).

The clay fraction (Ø <0.002 mm) was separated in the Physics Laboratory of Embrapa Solos, according to Embrapa (1997). Simple linear regression equations were adjusted for the parameters of Langmuir and Freundlich isotherms, which were correlated with the soils' physical and chemical characteristics.

RESULTS AND DISCUSSION

X-ray diffraction indicated that the mineralogy of the clay fraction presented different characteristics among the soils analyzed. Minerals were identified from the following groups: kaolinite (Ka), Mica (Mi), smectite (E), chlorite (Cl), Goethite (Gt) and quartz (Qz). The TCO sample Figure 1A) revealed the presence of mica, kaolinite, smectite and goethite, where the order Mi>Ct>E>Gt

Table 2. Parameters of Langmuir and Freundlich isotherms estimated by linear regression fits to the soils.

Soils	Langmuir equation	R^2	P-rem (mg L^{-1})	MPAC (mg g^{-1})	a (L mg^{-1})	FCPm (mL g^{-1})
TCo	C/q= 3.580C-12.59	0.98	43.73	0.2793	0.2843	0.0795
CXBe	C/q= 3.361C-13.32	0.99	16.28	0.2975	0.2523	0.0750
RY	C/q= 2.529C-12.17	0.98	27.34	0.3954	0.2078	0.0822
CXVe	C/q= 3.408C-10.18	0.98	41.34	0.2934	0.3348	0.0982

Soils	Freundlich equation	R^2	K	N
TCo	C/q= 0.866C-1.749	0.85	0.018	1.155
CXBe	C/q= 0.885C-1.731	0.85	0.014	1.064
RY	C/q= 0.880C-1.710	0.83	0.019	1.130
CXVe	C/q= 1.880C-0.940	0.92	0.020	1.137

Prem: Remaining Phosphorus; MPAC: Maximum capacity of adsorption of phosphorus; a: binding energy; FCPm: Factor maximum capacity of phosphorus; k and n: Freundlich isotherm parameters.

indicates an estimate of the relative prevalence of each mineral held based on the XRD patterns. A sample of CXbe (Figure 1B) revealed the existence of kaolinite, mica, chlorite, quartz and goethite, and the estimate of the prevalence of these minerals was in accordance with the order Ct>E>Cl>Qz>Gt according to the XRD patterns.

Analysis of a sample of CXve revealed the presence of minerals such as kaolinite, mica, and goethite in the order Ct>E>Gt, demonstrating the predominance of these minerals in this soil (Figure 1C). The x-ray diffractogram for RY demonstrated the presence of kaolinite, smectite, mica and quartz in this order: Ct>E>E>Qz, representing the predominance of these minerals in the soil (Figure 1D), since the absence of goethite demonstrates the preservation of soil minerals, which may contribute to P availability to plants.

The high coefficients of determination obtained from the linearized equations of the Langmuir and Freundlich isotherms (Table 2) indicate that the mathematical models were adequately effective in quantifying the adsorbed P in these soils. The values for P-rem varied from 16.28 to 43.73 mg L^{-1}; these may be considered soils with an intermediate capacity of adsorption, according to the criteria presented by Alvarez et al. (2000) and Saadi et al. (2000).

The determination of P-rem assists in the interpretation of P and its critical level in the soil, allowing inferences about the buffering capacity of the soil (Grilli et al., 2007). TCO had a higher Prem (43.73 mg L^{-1}), characterizing it as a soil that has low Phosphate Maximum Capacity (PMC). CXbe presented the lowest Prem value (16.28 mg L^{-1}), indicating that the different soils have different P adsorption capacities, these being directly related to the chemical, physical and mineralogical properties of the soils (Table 2). Godinho et al. (1997), working with soils of the Rio Grande do Norte semi-arid region, obtained values of P-rem that ranged from 32.11 to 44.63 mg L^{-1}, which had a lower amplitude than those observed in this study. Rogeri et al. (2016) working with soils from Rio Grande do Sul region, obtained values of P-rem from 17.6 to 47.5 mg L^{-1}.

The values for MPAC (Table 2) according to the Langmuir model ranged from 0.2793 to 0.3954 mg g^{-1} soil. For the RY soil, which adsorbed the greatest amount of P (0.3954 mg g^{-1} soil), giving it a greater degree of soil weathering, possibly due to the higher content of clay, Ca and MO, this adsorption can be classified as very high according to the criteria established by Alvarez et al. (2000). The clay fraction is the most active portion of this phenomenon due to its high specific surface area (Ranno et al., 2007). This occurs because of the greater density of Lewis acid sites (Novais and Smyth, 1999) in the colloids on the soil's surface.

Based on the determination coefficients, it was observed that the Langmuir model was more efficient than the Freundlich in determining the MPAC in the soils, although there was variation in the k values (0.014 to 0.020) and the n values were higher than one in all of the soils, characterized with large amounts of active sites (Sposito, 1989) (Table 2). This amount of adsorbed P is consistent with the value obtained for the P-rem in RY (27.34 mg L^{-1}), characterized as a soil with a great capacity to adsorb P. This result is largely due to the granulometric and mineralogical constituents of the soil, which had the highest clay content among the soils, although the main constituent mineral, kaolinite, was one of the main factors that contribute to the adsorption of P, due to the 1:1 mineralogical structure, compared with the oxidized components, so was the predominant clay content.

Some authors consider that the clay content is mainly responsible for variations in soil PMC (Moughli et al., 1993; Vilar et al., 2010; Oliveira, 2015) it is common to find a significant positive correlation between soil clay contents and MPAC in the literature. There was a wide variation in values for energy of adsorption (a) for the four soils. Although RY had a high adsorption of P, this soil had a lower binding energy (0.2078 mg L^{-1}) between phosphate ions and soil colloids; thus, it may be inferred that despite the high value of MPAC, P is adsorbed by a relatively low binding energy and may become available to plants more easily (Table 2). A similar behavior was observed for the value of the maximum adsorption capacity of phosphorus (FCPm) in this same soil, with the second highest value, which is characterized as a soil that is highly resistant factor in its intensity, since the greater the value of FCPm in the soil, the greater the resistance to change in factor intensity (I), either by the addition or removal of P.

For the two cambisoils (CXbe and CXve), the MPAC values were very close to one another, 0.2975 mg g^{-1} soil for CXbe and 0.2934 mg g^{-1} soil for CXve in the Langmuir model, despite having a wide divergence in Prem values. However, the Freundlich model was more efficient for quantifying the P adsorbed to CXve and CXbe, with k values of 0.020 and 0.014, respectively, and n values greater than one, showing a high number of active sites of adsorption. Although these soils present almost the same value for MPAC, they have significantly different levels of clay; CXbe presented the highest P content (254.9 g kg^{-1}), with CXve lagging behind with 125.4 g kg^{-1} (Table 2). According to Novais and Smyth (1999), the clay fraction is the most active contributor to this phenomenon because of its high specific surface area, due to the higher density of Lewis acid sites on the surfaces of colloids.

Different values were also observed for adsorption energies of P in the two FCPm cambisoils. The higher energy of adsorption was observed for CXve (0.3348 mg L^{-1}) and the lower in CXbe (0.2523 mg L^{-1}), demonstrating a behavior contrary to the values of MPAC for these soils. This behavior is directly related to the fact that the amount of goethite in CXve is greater than in CXbe, even with this greater amount of adsorbed P (Table 2). These results approach those found by Moreira et al. (2006) in four soils (Typic, Acrisol, and Regolíticos Typic Oxisol) from different regions of Ceará State in Brasil, with MPAC values ranging from 0.1099 to 0.3448 mg g^{-1} soil.

The value of MPAC has been used on the recommendation of P. However, according to Novais and Kamprath (1979), using just MPAC to predict the amount of soil P for plant growth is insufficient, since other factors, intensity and capacity, are required in the process of predicting the responses of plants to fertilization. According to Novais and Smyth (1999), the need for more extensive measurements (amount adsorbed) and other intensive factors (quality of adsorption), called FCPm (MPAC × adsorption energy), may become clearer, with MPAC tending to a constant and adsorption energy varying with the status of P in the soil.

Among the soils, TCO had the smallest amount of adsorbed P (0.2793 mg g^{-1} soil) by the Langmuir model; however, it had the second highest value for the binding energy of P (0.2843 L mg^{-1}) (Table 2). This smaller amount of adsorbed P can be directly related to the amount of clay present in the soil (135.6 g kg^{-1}) among the more sandy soils, and the low content of organic matter in the soil (Table 2). According to Fink et al. (2016), the role of organic matter is ambivalent, since it can adsorb P as well as block the adsorption sites that occur on the surfaces of clays and oxides of iron and aluminum. However, this high value for the binding energy can be related to the presence of goethite in the mineralogical composition of the soil, causing the phosphate ions to become more strongly adsorbed to soil colloids.

The Freundlich isotherm parameters were less efficient in quantifying P than the Langmuir, with 0.018 for the k value and 1.155 for the n value (Table 2). The Fe and Al oxides are taken as constituents of the clay fraction, and as more effective for P adsorption (Fink et al., 2016), with goethite being considered the main component of the clay fraction responsible for this phenomenon in the soils of Central Brazil (Fink et al., 2016). The higher P adsorption capacity of soils in relation to their hematite Goethite content was also found by Curi and Franzmeier (1984) and can be credited, according to Frossard et al. (1994), to the differences in accessibility of the surface phosphate OH^- groups. By affecting the extent of the mineral's reactive surface, the morphology of the iron oxide crystals also influences P adsorption (Camargo et al., 2015).

Conclusions

The values of maximum adsorption capacity for phosphorus (MPAC) in the soils ranged from 0.2793 to 0.3954 mg g^{-1}, with a positive correlation between MPAC and the clay content.

The Langmuir isotherm was more efficient in determining the MPAC of the soil compared to the Freundlich isotherm. Also, P adsorption parameters (MPAC, Prem, and the constant k of the Freundlich equation) are reliable variables to characterize phosphorus adsorption.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Wet bulb dimensions associated with different flow and terrain declivity

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Geometry information of wet bulb is important for the design of projects and management of drip irrigation, mainly to estimate the volume of wet soil, emitter flows and irrigation time. This study aims to determine the dimensions of wet bulb formed by drippers with different flow and terrain declivities. For this, soil moisture levels were determined throughout the soil profile after drip irrigation with three flow emitters associated with four terrain declivities. It was verified that when the terrain was in level, there was greater radial migration of water on the soil surface with increase in the flow dripper, resulting in more open wet bulbs. On the other hand, increases in flow and declivity provide lower vertical percolation of water, obtaining smaller depth of moisture in the soil profile. Therefore, different terrain declivities and flow drippers influence wet bulb geometry and moisture distribution, indicating the importance of relief in the positioning of emitters in drip irrigation.

Key words: Trickle irrigation, drippers, soil moisture.

INTRODUCTION

Different population increase and natural resources, including water are finite. And, due to increasing demand for these resources, words such as rationality, management and productivity are heard more frequently (Salvador, 2014). Thus, drip irrigation offers opportunities for optimizing these concepts, providing improvements in yield and efficiency of water use, influencing positively the quality of food production (Valipour, 2012a).

According to Tolentino Júnior et al. (2014), drip irrigation is a technology that has been expanding quickly in modern irrigated agriculture. This irrigation technique is characterized by applying small volumes of water in high frequency and directly in the root zone of crops, preserving the soil at field capacity and preventing water loss by evaporation and percolation (Frizzone et al., 2012; Valipour, 2012a). This application results in a

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Table 1. Soil physical properties studied in different soil depths.

Depth of soil (cm)	ρs (g cm^{-3})	N (cm^3 cm^{-3})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Textural class
0-5	1.40	0.45	613	189	198	Sandy loam
5-15	1.33	0.49	577	187	236	Loam
15-30	1.30	0.49	563	162	275	Loam
30-45	1.25	0.51	536	113	351	Clay loam
45-60	1.24	0.55	518	120	362	Clay loam
60-75	1.34	0.50	535	133	332	Clay loam

ρs is specific mass of soil and, N is total porosity.

volume of wet soil, known as wet bulb.

The knowledge of the distribution of water in the soil is of great importance both for the dimension of irrigation systems as well as in its management, because the determination of emitters spacing, number of emitters and evapotranspiration rates depend on the previous information about the soil's water movement (Souza and Matsuura, 2004; Valipour, 2014). Moreover, the high investments required in the implementation of this irrigation system cannot provide financial returns to the farmer, if he does not use proper techniques of irrigation management aimed at rationalization of water use and increased productivity.

Thus, several studies have been developed for determining the dimensions and characteristics of the wet bulb associating different flows, operation times and soil types (Coelho et al., 1995; Nogueira et al., 2000; Souza and Matsuura, 2004; Rivera, 2004; Baker et al., 2008; Maia et al., 2010; Levien et al., 2012; Valipour, 2012b; Tolentino Júnior et al., 2014). And, although it is clear that the radius (horizontal dimension) is favored by the capillary of soil, flow emitter, application time, water retention capacity of the soil and the wet depth (vertical dimension) controlled by the gravitational force, that is, the drainage capacity of the soil, these relationships have not been clearly studied in association with different terrain declivities. This may result in wet bulbs with different geometric characteristics, compared to the terrain without declivity.

It is worth pointing out that, in Brazil the followings are considered: Permanent Preservation Areas (APP) or non-cultivated areas, hillsides, with declivity above 45°, and equivalent to 100% in the line of maximum gradient, hill top, mound, mountains and sierras, with a minimum height of 100 m and average slope larger than 25° (47%), and areas delimited from contour corresponding to two-thirds of the minimum height of elevation, which is defined by horizontal plains or adjacent water surface or undulating reliefs (Brasil, 2012). It is observed the law of situating farmlands in regions with not very restricted declivity values.

Thus, the aim of this study is to determine the dimensions of the wet bulb formed in the surface drip irrigation associated with different flows and declivities terrain.

METHODOLOGY

The study was conducted at the Instituto Federal Goiano - Campus Urutaí, in Urutaí - GO, located at 17° 29'06 "S, 48°12'27" W and 712 m of altitude, from February to July 2014. According to Köppen classification, the climate is Cwa, characterized as humid tropical; it has dry winter and rainy summer; it has average annual temperatures of 2000 mm and 28°C, respectively.

The experiment was set up in a 5×3 factorial design, with three replications; the treatments are constituted by irrigation in four terrain declivities (0, 10, 20 and 30%, corresponding to 0, 5.70, 11.30 and 16.70°, respectively) by auto-compensating drippers in three different flows (4, 5 and 8 L h^{-1}).

A drip irrigation system was set up to enable the operation of only one lateral line applying three auto-compensating emitters simultaneously in the same flow along the declivity.

In each application, tomato crop was used, considering the final stage of the culture, crop coefficient of 1.10 (Santana et al., 2011), evapotranspiration of 5.40 $mmdia^{-1}$ (Bernardo et al., 2006), two days irrigation frequency, percentage of wetted area (40%) (Bliesner and Keller, 1990), culture space of 1 × 0.4 m (Macedo et al., 2005) and 90% application efficiency. Thus, the system operating times for the flows 4, 5 and 8 Lh^{-1} were 32, 26 and 16 min.

For the determination of profile of the wet bulb, 1 h after completion of the application of irrigation depth, disturbed soil samples were collected by a screw-type auger, and taken to the laboratory for determination of moisture content. This sampling was performed in order to cover the entire profile wetted, both at horizontal (surface) and vertical plane (depth), forming a gridded mesh. For this, in the horizontal plane, it was used a spacing of 10 cm and, in the vertical plane, it was used a spacing of 15 cm, taking as a reference the drip emission point.

Table 1 shows the physical characteristics of the soil studied, and obtained as described in the methods of Embrapa (2011).

RESULTS AND DISCUSSION

Figures 1, 2 and 3 show the isoline of gravimetric moisture in percentage, showing the distribution of water inside the wet bulb, xy (ground surface), xz (along the emission line) and yz (perpendicular to the emission line) planes for flows 4, 5 and 8 L h^{-1}, respectively.

As the water infiltrates the soil, the upper layers of the soil will moisten from top-down gradually altering the moisture profile. As long as there is water supply, the

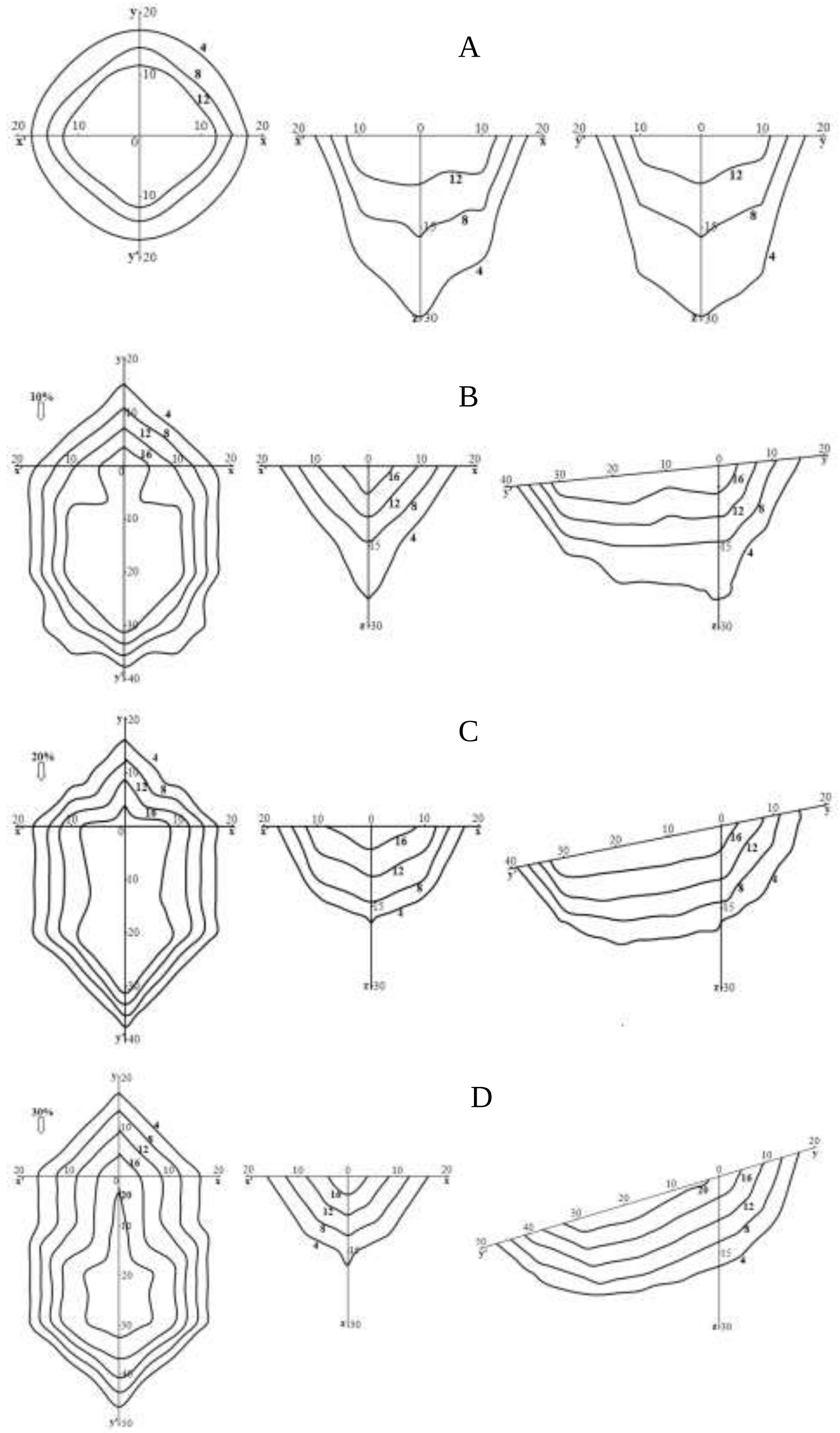

Figure 1. Isoline of gravimetric moisture, in percentage, for the flow of 4 L h^{-1}, on the declivity of: (A) 0%, (B) 10%, (C) 20%, and (D) 30%. The axes are listed in centimeters and z is the depth.

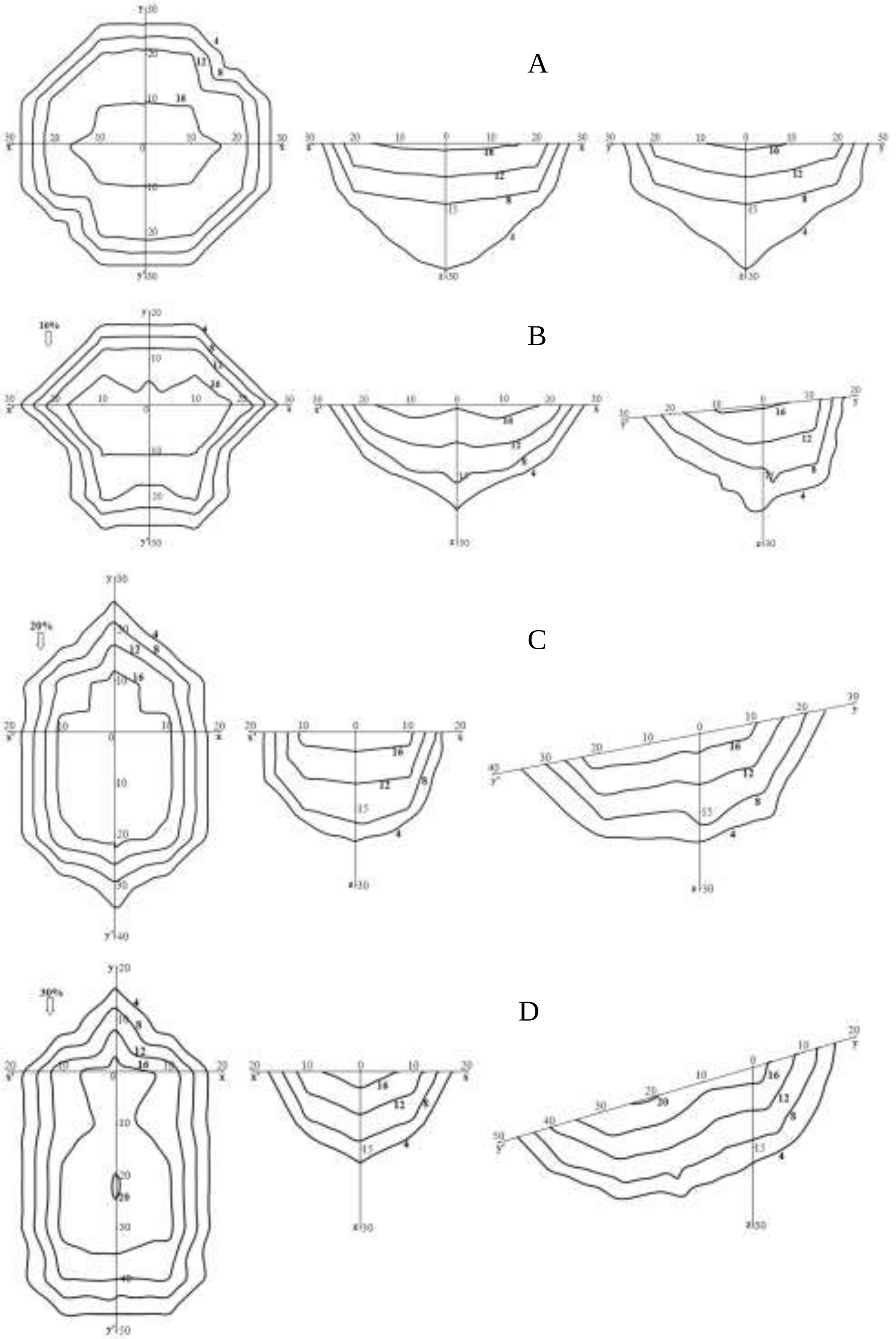

Figure 2. Isoline of gravimetric moisture, in percentage, for the flow of 5 L h^{-1}, on the declivity of: A) 0% B) 10% C) and 20% D) 30%. The axes are listed in centimeters, and z is the depth.

moisture profile tends to saturate in all the depth, and the surface will be, of course, the first level to saturate (Brandão et al., 2006).

Thus, for all wetted bulb profiles, samples were collected for the determination of moisture content 1 h after application of the irrigation depth. The water redistribution movement in the soil profile resulted in increased moisture content near the surface and it decreased with soil depth.

Analyzing Figures 1, 2 and 3, it is observed that the

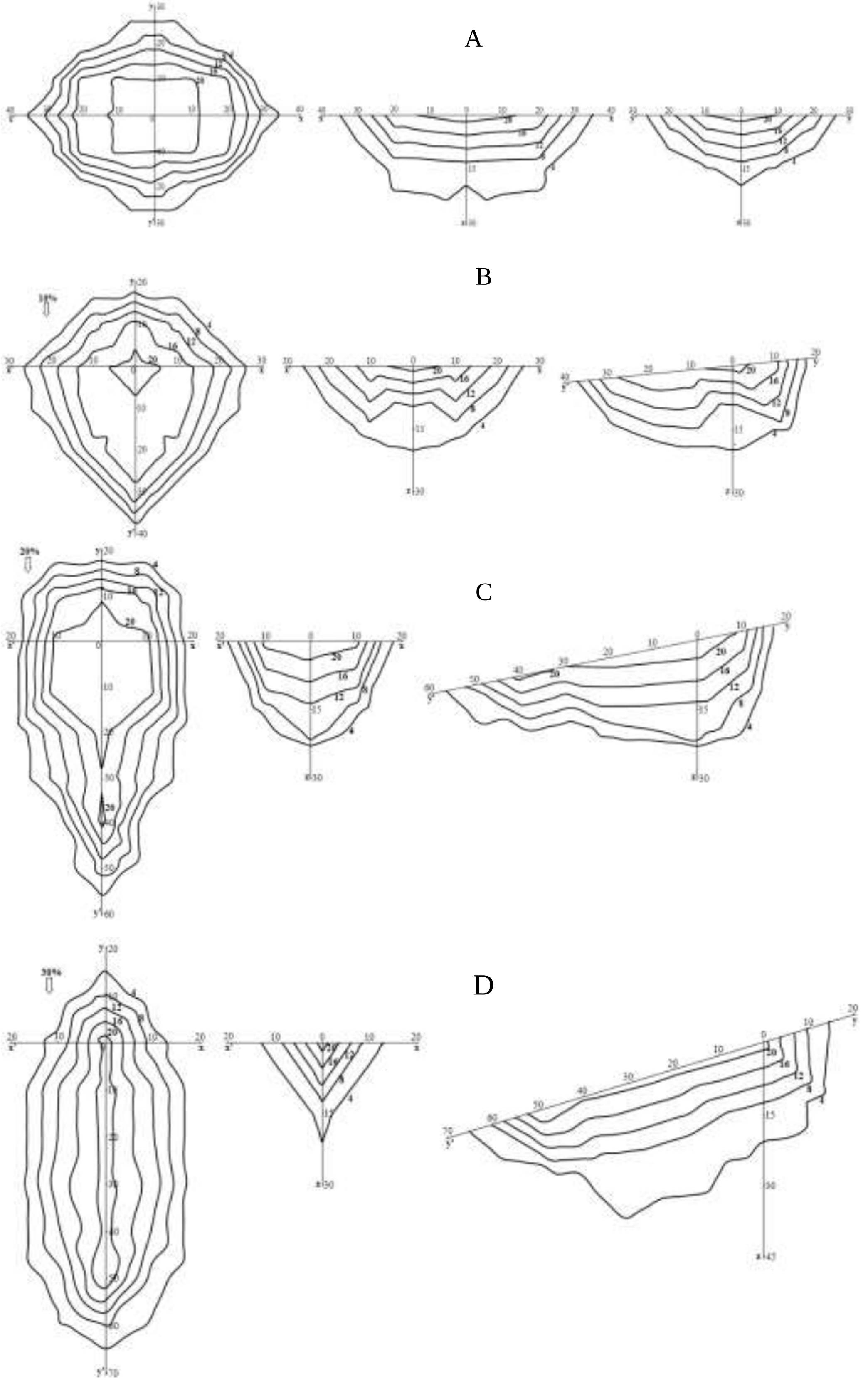

Figure 3. Isoline of gravimetric moisture, in percentage, for the flow of 8 L h^{-1}, on the declivity of: (A) 0%, (B) 10%, (C) 20%, (D) 30%. The axes are listed in centimeters, and z is the depth.

terrain declivity affect the behavior of the water distribution in the soil, wherein increments in the declivity resulted in a higher tendency to displace front of the wet bulb in the declivity direction. Barreto et al. (2008), evaluating wet bulbs through multiple cuts at trench, also noted the humid region development trend following the terrain declivity.

Moreover, it is verified that when the terrain was in level area (Figures 1A, 2A and 3A), there was greater radial migration of water on the soil surface with increase in the flow dripper, resulting in more open wet bulbs. On the other hand, increases in flow and declivity provided lower vertical percolation of water, obtaining smaller depth of moisture in the soil profile. This can be explained by the fact that water tends to move to the soil surface before the infiltration-percolation process begins.

Analyzing Figures 1A and 2A, it is observed that the bulb radius was smaller than its depth; similar situation was observed by Souza et al. (2007). In Figure 1A, it is verified that the radial distance achieved by the wetted surface was 18 cm, wherein Rivera (2004) and Nogueira et al. (2000), applying water by surface drip, obtained radial values of 35 and 25 cm, respectively. This difference may be due to the application volume (6 and 4.33 L) and standby time (24 h) for collecting samples, which were 2.17 L and 1 h, respectively.

Also, in the same Figure 1A, the maximum depth reached was 30 cm, while Barros et al. (2009) applying the volume of 3 L of water by subsurface drip irrigation with a flow emitter of 4 L h^{-1}, in a red nitosol; the value obtained was 18 cm of depth. Differences were caused, probably, by a higher content of clay in this soil type.

Figure 3A verified a predominance of radial dispersion on the vertical, similar to that observed by Maia et al. (2010) and Souza and Matsura (2004). According to Maia et al. (2010), the application rate of some emitters may be larger than the water infiltration capacity on the soil, which, therefore, will tend to form bulbs with larger surface width and less depth. Another important factor was that during the field test, the formation of a thin crust under the drip was observed, possibly by dispersing particles during application of water, which can be related to larger flow of the emitter and decreased porosity. This leads to soil hydraulic conductivity, which is in accordance with the results obtained by Rivera (2004).

Maia et al. (2010) study the dimensions of the wet bulb by surface drip irrigation in four different application times (1, 2, 4 and 7 h) and four flow emitters (1, 2, 4 and 8 h L^{-1}) on a quartzarenic neosol; they verified that the maximum bulb diameter on the surface was lower than 60 cm in the time 1 h of application. Results are contrary to those obtained in this research; therefore, all the application time was lower than 1 h (16, 26 and 32 min), and in the declivity of 30%; for example, a maximum surface diameter larger than 60 cm was observed. This difference can be explained by the local topography of the experiment while that the terrain was leveled. This shows the importance of declivity in the dimensions of wet bulb.

The largest depth of water used for the applications occurred in the flow of 4 L h^{-1} and declivity of 0% (Figure 1A), whose value was 30 cm. Wherein, according to Bernardo et al. (2006), the effective depth of the root system of tomato cultivation is generally 40 cm. It was concluded that, even in the application that reached larger depth than 30 cm, there would be water loss by deep percolation if the tomato crop is established.

Conclusion

According to the experimental conditions, it can be concluded that the different terrain declivities and flow drippers influenced the wet bulb geometry and moisture distribution in your area, evidencing the importance of relief in the placement of emitters in surface drip irrigation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Nitrogen fertilization applied through drip fertigation and broadcasted in blueberry crop

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The aim of this experiment was to evaluate the effects of nitrogen fertilization on the blueberry crop throughout three consecutive years with different rates and ways of fertilizer application. The experiment was carried out in a commercial orchard located at the county of Vacaria-RS, in Southern Brazil utilizing the blueberry cultivar 'Bluecrop'. The treatments consisted of the broadcasted nitrogen rates: 0, 50, 100 and 150 kg.ha^{-1} to verify the crop's responsiveness to nitrogen fertilization. Looking for the best way of evaluating nitrogen deliverance, a second experiment was conducted in which a fixed rate of 150 kg.ha^{-1} of nitrogen was broadcasted and applied through fertigation. The nitrogen sources used in both fertilization systems were a mixture of half urea and half ammonium sulphate. Crop yield, number of fruits per plant and mean fruit weight were evaluated during three consecutive years, along with the levels of nutrients in the soil and leaf tissue after three years of broadcasted fertilization. The broadcasted nitrogen fertilization after three consecutive years reduced the soil pH and enhanced the aluminium saturation, but it increased the nitrogen and sulphur uptake by the leaves and reduced the leaves calcium content. These aspects led to a yield reduction of the blueberry crop. Weather conditions affected the efficiency of the N application method (broadcasted or fertigated).

Key words: Nitrogen fertilization, soil pH, *Vaccinium corymbosum*.

INTRODUCTION

Berry crops cultivation, which are fruits traditionally cultivated in temperate climate regions such as the EU and United States, is quickly gaining interest in Brazil. The main berries cultivated in Brazil are strawberries, raspberries, blackberries and blueberries (Fachinello et al., 2011), with strawberry most cultivated crop of the group (3500 ha), in Brazil, followed by blackberry (400 ha) and blueberry (200 ha) (Antunes and Hoffmann, 2012).

Blueberry crop is still recent in Brazil, but it has a great potential for expansion. The customers are increasingly demanding fruits with recognized beneficial health

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properties such as antioxidants and blueberry fruits meet this requirement. Another appeal for producers is the possibility to export the fruit during the EU's and USA's off season; these are motivating factors for the expansion of the crop, which has high revenues (Fachinello, 2008). However, more technical expertise on cropping systems and especially the suitability of nutritional aspects of the temperate climate regions of Southern Brazil is needed to facilitate further expansion of the crop in Brazil.

Blueberry crop has a distinct nutritional demand, wherein many cultural practices used in other fruit crops, are not suitable for blueberry production (Freire, 2006). This is related with the origin of blueberry plants, which is referred to low soil pH as well as the majority of the nutrients. Thus, blueberry crop requires low fertility, making its nutritional management quite specific and differentiated (Parra, 2007).

Nitrogen (N) is the most demanded nutrient by plants. On blueberry crop, it is fundamental in the vigour maintenance and it is responsible for the development of flower primordium and sprouting (Alarcon, 2003), but it has to be applied in ideal rates and at the correct moment, for an efficient absorption to avoid losses that may occur in several ways.

According to the Comissão de Química e Fertilidade do Solo RS/SC (2004), urea and ammonium sulphate along with ammonium nitrate are considered the main sources of nitrogen fertilizers. The same commission recommends that nitrogen fertilization for blueberry growth and production should be based on the plant's age; being recommended as reduced levels in the first year (10 g of N per plant); on the fifth year 30 g of N per plant and from the ninth year 60 g of N per plant.

The way blueberry orchards are fertilized varies in function of the amount of technologies available. Besides fertilizer broadcasting, blueberry fertigation is widely used through drip irrigation (Pagot, 2006), which delivers water directly to the root system, providing greater efficiency and easing the deliverance of soluble fertilizers to the system. Besides, fertigation makes easier the splitting of nitrogen levels, making possible nutrient supply accordingly to the crop's growth stage, and still reducing salinity stress (Spectrum Analytic, 2016).

Nitrogen fertilization management used nowadays in the blueberry crop aroused from other blueberry producing countries, with is completely different from edafoclimatic conditions. Thus, the present trial had the objectives of: (1) to evaluate the blueberry crop responsiveness to nitrogen fertilization; (2) to evaluate the best way of delivering the nitrogen fertilizer, if through broadcasting or fertigation.

MATERIALS AND METHODS

The experiment was conducted in a commercial orchard belonging to the company Blueberry Mudas e Sementes Ltda, localized in the municipality of Vacaria/RS, with geographical coordinates: latitude S 28°26'30'' longitude W 50°56'35'' altitude of 907 m above sea level. The cultivar chosen for the experiment was 'Bluecrop', which has shown good adaptation to the local weather conditions. The experiment site's soil presented the following chemical characteristics: pH 4.8; SMP index 4.4; organic matter 11.6%; Ca 5.7 comol$_c$.dm^{-3}; Mg 2.0 comol$_c$.dm^{-3}; Al 1.7 comol$_c$.dm^{-3}; H+Al 27.4 comol$_c$.dm^{-3}; Effective Cation Exchange Capacity (CTC$_{effective}$) 10 comol$_c$.dm^{-3}; CTC$_{pH7}$ 35.7 comol$_c$.dm^{-3}; Al saturation 17%; bases saturation 23.1%; P 22.9 mg.dm^{-3}; S 28.7 mg.dm^{-3}; and K 220 mg.dm^{-3}.

It was conducted in two trials at the same site throughout three consecutive years, beginning from 2013 and replicated in 2014 and 2015.

Experiment with rates of N was conducted in a randomized complete block design (RCBD) with four replications. Each plot consisted of three plants, where an untreated control and the N rates of 50, 100 and 150 kg.ha^{-1} were applied. For evaluating the effects of nitrogen (N) rates, the fertilizer was delivered through broadcasting, at the rates: 0, 50, 100 and 150 kg.ha^{-1}. The choice of the nitrogen rates was based on the maximum and minimum thresholds found in the literature, according to the plant's age (five years since the planting day).

The experiment compares the ways of delivering N fertilization; the experiment was conducted as RCBD with four replications of three plants per plot. It was used as a fixed rate of 150 kg.ha^{-1} delivered though broadcasting and fertigation.

In both ways of fertilizer deliverance, the sources of nitrogen were urea and ammonium sulphate in equal proportions.

The momentum in which the fertilizers were applied was followed in two steps, with half of the levels in each moment. The first application was done at the floral gems opening and the second 30 days later (CQFS – RS/SC, 2004).

The variables evaluated in both experiments were: number of fruits per plant, yield per hectare (kg/ha^{-1}), and mean fruit weight (g). In the third year of experiment, soil and leaf samples for the experiment with N rates were collected.

Leaf samples were obtained by collecting 20 mature and fully expanded (including petiole) leaves localized in the fifth and sixth stem nodes, counting from the extremity of young fruitful branches of the three plants in each plot, in the month of January. For soil sampling, samples were collected in a depth of 0 to 20 cm with three sub-samples per replication in the same date of the leaf sampling. Both chemical analysis was executed by the Laboratório de Química e Fertilidade de Solos at the University of Caxias do Sul.

Looking for the attendance of the ANOVA assumptions, the test of normality of the data was performed using Shapiro-Wilk test. In the first experiment, the results were subjected to analysis of variance ($p \leq 0.05$) through a mixed model to test the interaction of years and rates of nitrogen, and in case of significance the effects of rates were compared using regression analysis ($p \leq 0.05$), and the effects of years through Tukey test ($p \leq 0.05$).

In the second experiment, the data were subjected to analysis of variance ($p \leq 0.05$) through a mixed model to test the interaction of years and treatments for the variables yield, fruit number per plant and mean fruit weight, and in case of significance the effects of the ways of fertilizer deliverance were compared through the t test ($p \leq 0.05$). In all the cases, software Sisvar v.5.6 was used for the statistical analysis.

RESULTS AND DISCUSSION

Effect of broadcasted nitrogen rates on the production parameters

Broadcasted nitrogen fertilization presented significant effect to the variables yield and fruit quality beginning at

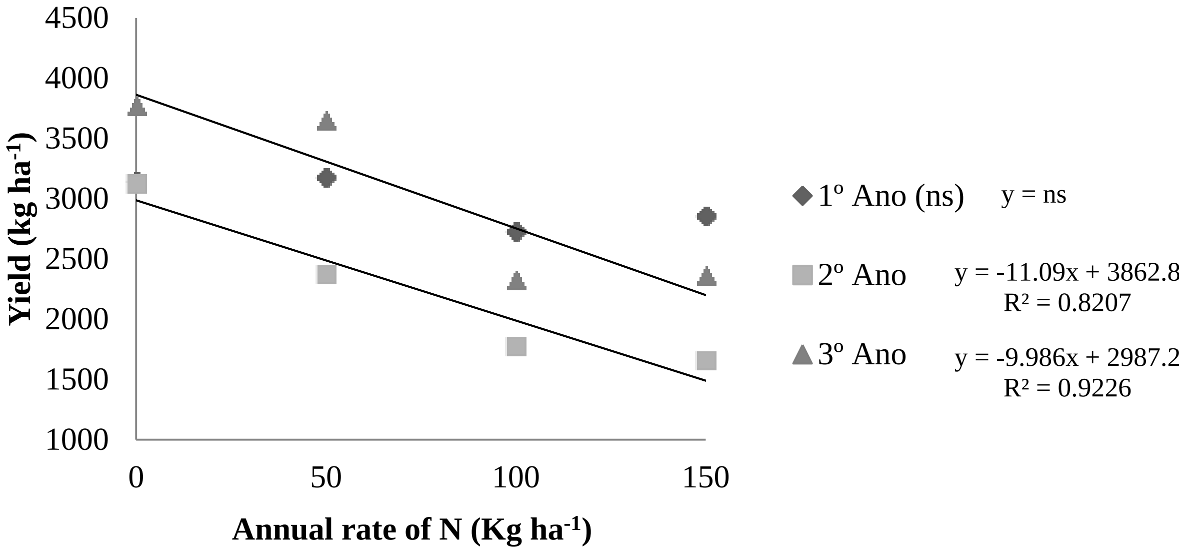

Figure 1. Blueberry fruit yield in function of broadcasted nitrogen rates over three consecutive years. Vacaria – RS, 2016. ns: Non significant by the F test (p≤0.05).

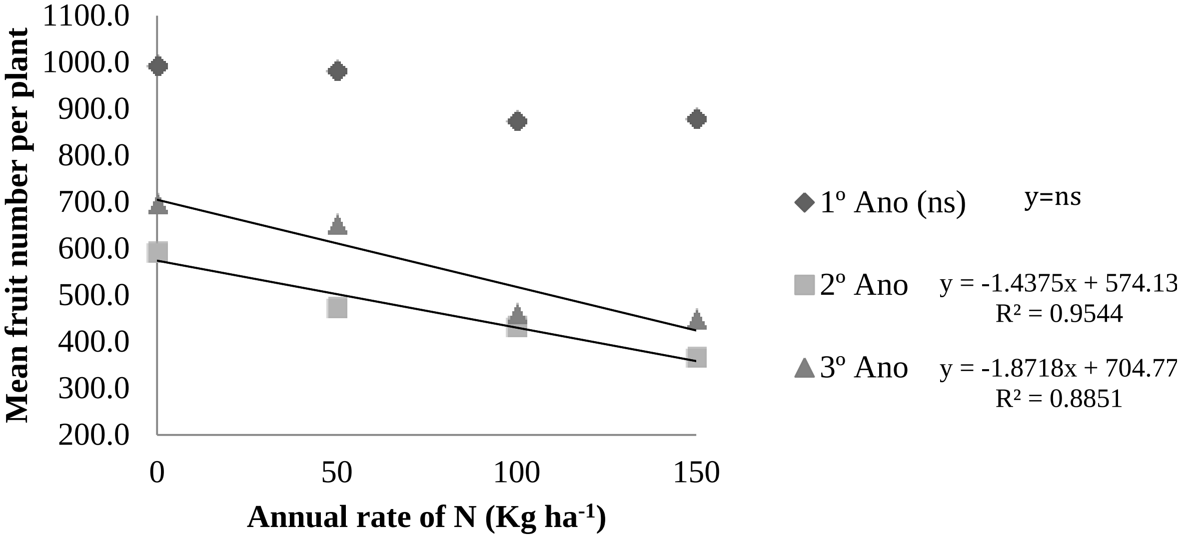

Figure 2. Mean blueberry fruit number per plant in function of broadcasted nitrogen rates applied over three consecutive years. Vacaria – RS, 2016. ns: Non significant by the F test (p≤0.05).

the second year of the experiment. Fruit yield decreased inversely proportional to the increment in nitrogen rate, as shown in Figure 1. The yield reduction was explained by the reduction in the number of fruits per plant (Figure 2), as well as the mean fruit weight (Figure 3). It is noteworthy that even with the mean fruit weight reduction, the results obtained in all the treatments for the second and third year are considered satisfactory for commercial standards, considering that the mean weight of an individual blueberry is 1.5 g (Carreira, 2012).

Previous studies with the cultivar 'Bluecrop', 'Mercik' and 'Smolark' (1995) recorded that nitrogen rates above 150 kg/ha^{-1} reduced the yield, which confirms our results. In the present experiment, however, the yield reduction started from the lowest nitrogen rate tested, demonstrating a higher sensitivity of the crop to the environmental conditions. Hanson and Hancock (1996) stated that the nitrogen level itself does not interact with blueberry yield. However, many factors interact with nitrogen availability required by the plants such as soil type, plant age, genotype, weather, etc. According to Bañados (2006), recommendations of rates and timing of

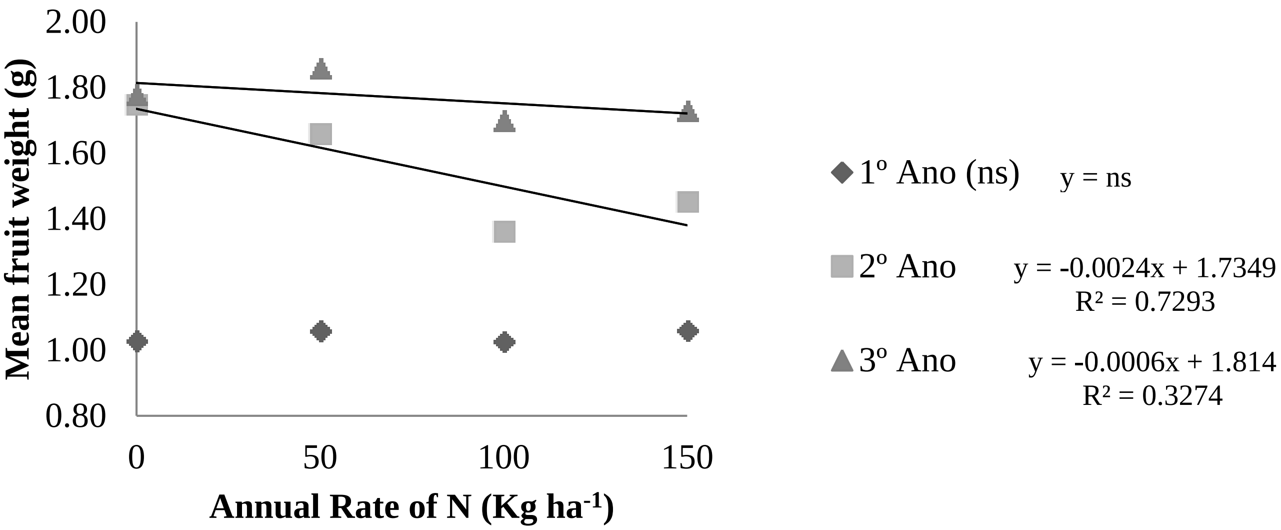

Figure 3. Mean blueberry fruit weight (g) in function of broadcasted nitrogen rates applied over three consecutive years. Vacaria – RS, 2016. ns: Non significant by the F test ($p \leq 0.05$).

Table 1. Interaction of treatment (nitrogen rates) in function of the years according to the F test.

Treatment	Yield (kg ha^{-1})	Mean fruit number	Mean fruit weight (g)
Nitrogen rates	ns	**	ns
Years	***	***	***
N. rates×Years	*	**	ns
CV N. rates (%)	22.19	8.10	25.10
CV Years (%)	6.31	7.49	17.61
CV N. rates×Years (%)	6.96	6.04	13.91

ns: Non significant; *Significant at ($p \leq 0.05$); **Significant at ($p \leq 0.01$); ***Significant at ($p \leq 0.001$). CV: Coefficient of variation.

application of nitrogen varies with location, that is, there is influence of edafoclimatic factors and so studies have to investigate the best fertilization method for each producing region.

On the interaction of years and the treatments, significant differences were observed for the cropping yield throughout the years (Table 1). There was fruit yield variation along the years, as the fruit bearing in the first and third years were similar and lower fruit bearing in the second year (Figure 1).

The plant fruit number was greater in the first year even though no significant difference among N rates were found, and on the following two years there was a sharp reduction on the number of fruits per plant (Figure 2). In this case, there was significant difference when the interaction of N rates was analysed as shown in Table 1.

The mean fruit weight had significant variation among the three years, and there was an increase for this variable from the first to the third year. According to Rufato (2015), some temperate climate fruit crops may produce smaller fruits in years with elevated fruit bearing, being recommended as the fruit thinning in extreme cases, aiming to balance yield and quality. It was observed in this experiment at the year with greater fruit number (first year) that the fruits had reduced mean weight.

The variation on the variables tested in this experiment, observed along the years, stands out the influence of the weather on the crop's response to N fertilization. According to Cantarella (2007), the N cycle in the soil-plant system is quite complex, and it is controlled by physical, chemical and biological factors, greatly controlled by the weather conditions.

Effect of broadcasted nitrogen rates on the soil chemical parameters

In analysing the soil chemical condition, a reduction was observed on the pH levels with the rise of nitrogen rates, as shown in Figure 4A. In regards to the Al level, there was an enhancement in the soil levels, as shown in Figure 4B.

The reduction of the soil pH and the increment of the aluminium (Al) availability were reflected on the enhancement of the potential acidity (Figure 4G) and aluminium saturation (Figure 4H). According to Malavolta (2006), when the percentage of aluminium saturation surpasses 20%, it can be harmful for the crop and values above 45% are highly toxic for plants. The results obtained in this experiment demonstrated that only at the untreated control the Al saturation remained below 20%, while it reached 40% at the highest N rate tested (150 kg ha^{-1}). The increase in Al concentrations may account for the yield reduction noted at higher N rates.

Silveira et al. (2016) stated that in Southern Brazil a part of the blueberry orchards are presenting reduced growth rates or even plant death due to low soil pH and elevated levels of toxic Al, manganese (Mn) and iron (Fe), associated with poor or nonexistent mycorrhization for complexation of these metals, suggesting that a pH increase to 5.5 could soften these negative effects.

The levels of basic cations in the soil like calcium (Ca), magnesium (Mg) and potassium (K) presented effect in its concentrations being more elevated inversely proportional to the rates of N applied, as shown in Figure 4C, D, and E. The reduction in the levels of these nutrients resulted in a decrease of the soil bases saturation (Figure 4F).

This effect occurred through the reduction of the pH levels and elevation of the Al levels accordingly with the increment of the nitrogen rates negatively affecting the availability of other nutrients as explained by Malavolta and Cantarella (2007), where a usual nutrient interaction occurs with N and K as the uptake of one nutrient leading to the increment for the demand of the other nutrient, and the stimulus promoted to the plant by the supplementation of N may lead to the deficiency of K.

For the soil micronutrients, only boron (B) and Mn presented significant difference, with increasing levels as nitrogen rates were elevated. It is unlikely that B availability was affected by the treatments, as the majority of the available micronutrient is brought through the decomposition of the organic matter and conditions that favour its decomposition (Abreu et al., 2007). But the increment in the Mn levels is strictly related to the decrease of soil pH, observed on the treatments with elevated N rates. According to Lindsay (1972), the activity and consequently the availability of Mn in the soil solution enhances approximately 100 times per unit of pH decreased.

The levels of organic matter (OM), phosphorus (P), as well as the micronutrients zinc (Zn), cooper (Cu) and sodium (Na) did not show significant effect in function of the N rates tested.

Effect of broadcasted nitrogen rates on the plant nutrient uptake and leaf tissue contents

The application of different rates of nitrogen significantly influenced the absorption of macro- and micronutrients, as evidenced by the leaf tissue analysis. There was an increment on the levels of nitrogen and sulfur that was attributed to the fertilization with ammonium sulfate, which contains sulfur (S) in its composition, and a reduction in the levels of Ca and the micronutrients B, Zn and Cu with the application of growing rates of nitrogen, as shown in Figure 5.

These calcium level responses in the leaf tissue may be accredited to the preeminent concentration of the other ions (Malavolta, 2006). The author states that high concentration of NH^{4+} decrease the amount of uptaken calcium which might have occurred as a matter of the nitrogen rates elevation.

According to CQFS-RS/SC (2004), the concentration of N in the leaf tissue that are considered as normal for the blueberry crop are between the threshold of 18.0 to 21.0 mg/kg with the exception of the untreated control, which was below normal.

The macronutrients P, K and Mg did not present significant effect of leaf tissue levels when subjected to different rates of nitrogen ($p<0.05$).

Effect of the ways of delivering nitrogen on the production parameters

In regards to the ways of delivering nitrogen (broadcasted or through fertigation), using the rate of 150 $kg.ha^{-1}$, no significant differences were found between the two ways, for the production variables: cropping yield, mean fruit number per plant and mean fruit weight in all years, as shown in Table 2.

In an experiment testing rates of nitrogen of 0, 50, 100, and 150 kg ha^{-1}, using urea through fertigation and broadcasted ammonium sulfate, Bryla and Machado (2011) found that the fertigation method is more effective than broadcasted application only for the more elevated rates of nitrogen, differently from this trial where no effect of N fertigation was found for the tested rate.

Differences were observed along the years for the same application method, which stands out the importance of weather conditions on the N fertilization. It is known that the dynamics of nutrients in the soil of crops grown in the field is dependant of the season’s rainfall regime.

According to Yamada and Abdalla (2000), the nitrogen is a quite dynamic element in the soil and is susceptible to great losses, especially in the gas form, which may reach up 40% when applied without incorporation and associated to low rainfall.

Throughout the three years of the experiment, the rainfall regime that came about at the N fertilization application (September) until the end of the yield evaluations (December) yearly were elevated. The rainfall recorded in this period was 795, 718, and 999 mm, in 2013, 2014, and 2015, respectively (INMET,

Table 2. Blueberry production data as a function of the application of 150 Kg ha^{-1} of N in broadcasting and fertigation. Vacaria – RS, 2016.

Year	Yield/ha (kg)^{1}		No. of fruits/plant		Mean fruit weight (g)^{1}	
	Broadcasting	**Fertigation**	**Broadcasting**	**Fertigation**	**Broadcasting**	**Fertigation**
1º	2860^{ans}	2746^{a}	882^{ans}	735^{a}	1.06^{bns}	1.22^{b}
2º	1663^{bns}	1856^{a}	368^{bns}	428^{b}	1.44^{ans}	1.42^{ab}
3º	2141^{abns}	2251^{a}	428^{bns}	455^{b}	1.64^{ans}	1.62^{a}
CV (%)	3.10		18.0		22.05	

[1] Means submitted to logarithmic transformation (log (x)). Different lower case letters in the same column indicates the means are statistically different according to the Tukey test ($p \le 0.05$). ^{ns}Means in the same line did not differ according to the F test ($p \le 0.05$).

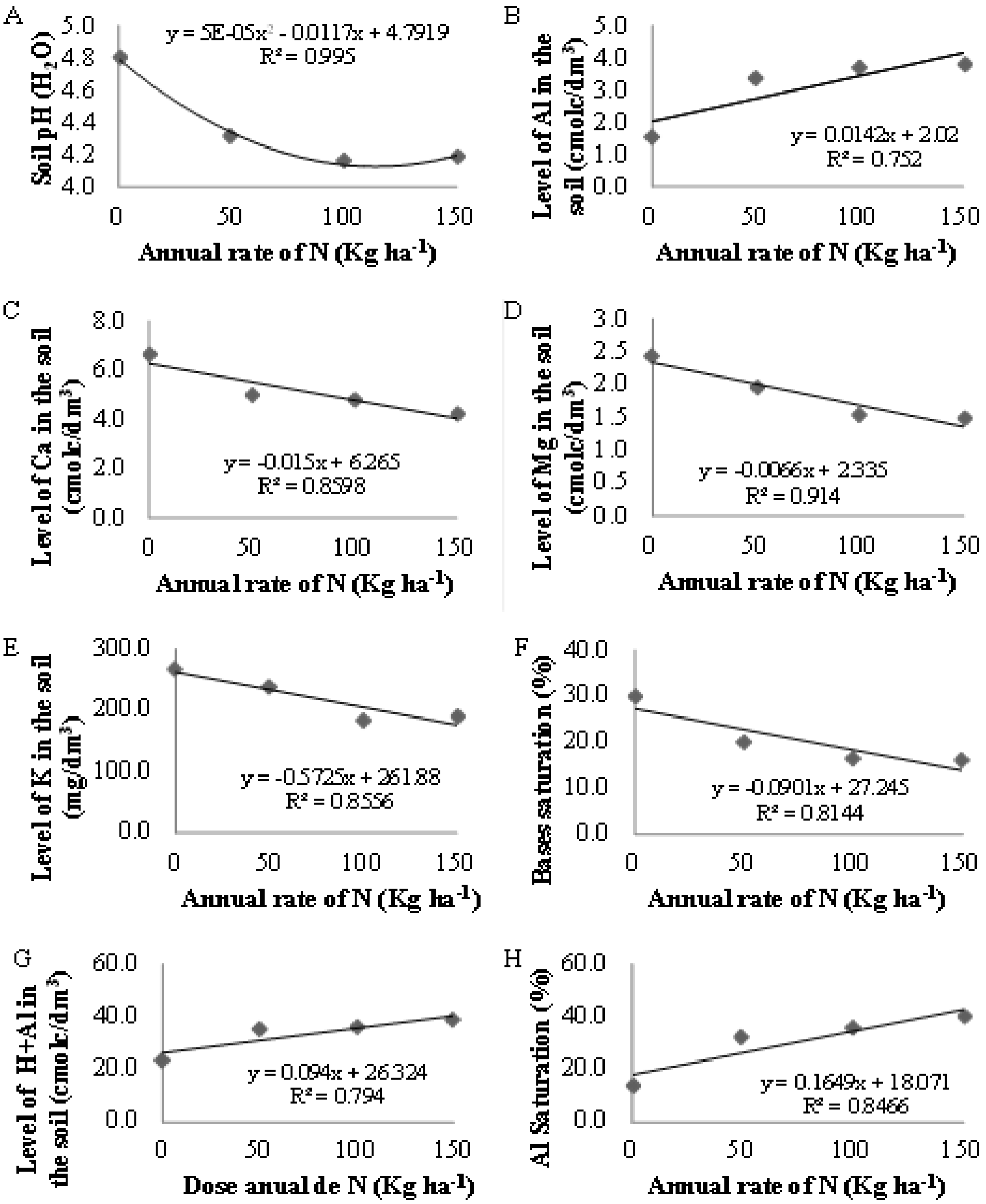

Figure 4. pH (A), level of Al (B), level of Ca (C), level of Mg (D), level of K (E), bases saturation (F), level of H+Al (G) and Al saturation (H) in the soil in function of broadcasted nitrogen rates applied on the blueberry crop. Vacaria – RS, 2016.

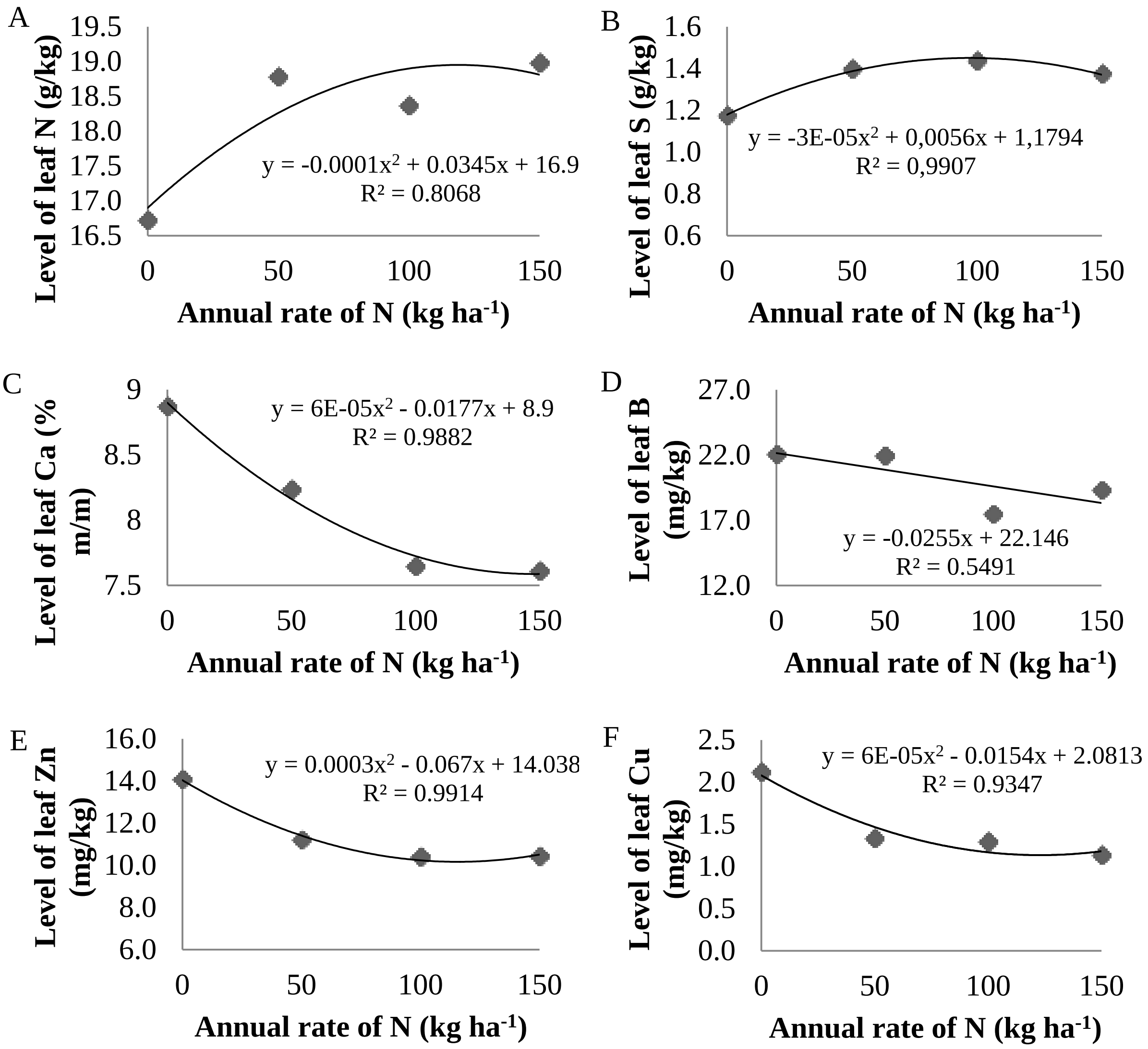

Figure 5. Level of leaf N (A), level of leaf S (B), level of leaf Ca (C), level of leaf B (D), level of leaf Zn (E) and level of leaf Cu (F), in function of broadcasted nitrogen rates in the blueberry crop. Vacaria – RS, 2016.

2017); moreover, the N applications took place in rainy days, and so it might have dwindled nitrogen losses and minimized possible effects of N fertigation.

Conclusions

(1) Broadcasted nitrogen fertilization decreases blueberry cropping yield. The optimal fertilization, in broadcasting, for Southern Brazil would be between 0 and 50 kg N ha^{-1}.
(2) The application of broadcasted nitrogen in increasing rates over three consecutive years reduced soil pH and increased Al saturation in the soil.
(3) Nitrogen fertilization increased the blueberry plant absorption of nitrogen and sulphur and drastically reduced the absorption of calcium.
(4) Weather conditions affected the efficiency of the N application method (broadcasted or fertigated).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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