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Spatial variability of soil physical-hydric attributes under bovine trampling in agreste of Pernambuco State, Brazil

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ABSTRACT. Soils under pastures suffer physical modifications, in greater or lesser intensity, via the action of animal trampling. Thus, the aim was to evaluate the spatial dependence of soil physical attributes under bovine trampling. The trial was performed at Roçadinho Farm, Agreste of Pernambuco, Brazil, in a 40 x 40 m paddock that was managed with continuous stocking by bovines and 12 AU ha^{-1} stocking rate. Soil samples were collected before and after grazing using a 6 x 6 m grid, totaling 36 sampling points. At each point, the bulk density, total porosity, moisture, soil penetration resistance at 0.00 - 0.10, 0.10 - 0.20, and 0.20 - 0.30 m depth were estimated, as was the hydraulic conductivity on the saturated soil surface. Descriptive statistics and geostatistics supported the data analysis. A normal distribution was verified for all variables, which were scored as either low or high variability in terms of the variation coefficient. The physical attributes (density, total porosity, moisture, soil penetration resistance and hydraulic conductivity) of the soil sampled presented a strong spatial dependence before and after grazing.

Keywords: compaction soil; geostatistic; girolando; grazing; ordinary kriging.

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Introduction

Dairy livestock are of great economic importance for Agreste of Pernambuco State, where pastures occur across most of the region. Thus, research on this topic is of fundamental importance in supporting decisions by farmholders.

Soil diversity and its physical, chemical, biological, mineralogical, and morphological attributes, as well as its relief, stony characteristic, and climate, cause soils to respond differently to management, machine traffic, and animal trampling (Magliano, Fernández, Florio, Murray, & Jobbágy, 2017).

Soil under grazing suffers physical modifications in greater or lesser intensity via the action of animal trampling (Rauber et al., 2018; Spera, Santos, Fontaneli, & Tomm, 2010). Different soil attributes have been used to characterize the physical changes caused by compaction due to animal trampling or even due to different pastureland management practices. The physical parameters that are commonly used to characterize soil under pasture include bulk density, porosity (Cardoso, Wanderley, & Souza, 2016; Carvalho, Ruiz, Costa, Passos, & Araújo, 2014), soil penetration resistance (Cubillos et al., 2016; Redin et al., 2017), and soil-water infiltration (Cullotta et al., 2016; Suárez, Navarro, Campos, Flores, & Mejía, 2018).

Compaction refers to the initial stage, type, and water content present in soil (Costa et al., 2012; Pilon et al., 2017; Stavi, Shuker, Barkai, Knoll, & Zaady 2018). Thus, the compaction caused by animal grazing changes physical attributes through the repetitive and cumulative effects of trampling on soil (Capurro, Secco, Reichert, & Reinert, 2014). For this reason, porosity and the amount of water infiltration tend to decrease as the soil density and penetration resistance increases (Frolla, Aparicio, Costa, & Krüger, 2018). Thus, compacted soil can restrict plant root development (Ortigara et al., 2014) and diminish water infiltration (Miguel, Vieira, & Grego 2009). Consequently, pasture productivity is reduced (Bonetti, Paulino, Souza, Carneiro, & Silva, 2015).

Soil-water infiltration is a physical quality indicator for integrating factors that directly affect plant development (Pulido, Schnabel, Contador, Lozano-Parra, & González, 2018). In fact, infiltration velocity can represent the soil hydraulic conductivity, which becomes constant after a determined time (Di Prima et al., 2018; Nascimento, Almeida, Batista, & Coutinho, 2017).

The quantitative and qualitative characteristics of soil physical attributes in pastures as well as their spatial variability can be precisely realized by geostatistical analysis, which is an important tool in decision making processes and can support adjustments in soil management and pasture conservation (Bernardi et al., 2016; Wang & Shao, 2013).

Continuous stocking by bovines can modify soil physical structure in the long-term. Thus, we aimed to evaluate the spatial dependence of penetration resistance, moisture, bulk density, porosity, and hydraulic conductivity of soil under pasture in Agreste of Pernambuco State.

Material and methods

The trial was performed over 21 days on a commerce property of dairy cows at Roçadinho Farm at Capoeiras, located at Vale do Ipojuca microregion, Agreste meso-region of Pernambuco State, Brazil, 8° 36'S latitude and 36° 37'W longitude. Soil was classified as Planossol according to Agroecological Mapping of Pernambuco – Zape Digital (2001). Soil characterization was performed at the Laboratory of Soil Mechanical and Residues recovering at Federal University Rural of Pernambuco (Table 1), according to the methods described by the Brazilian Agricultural Research Corporation [EMBRAPA] (2011).

Table 1. Soil characteristics.

[1]Dp (kg dm^{-3})	[2]OM (g kg^{-1})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Textural Class
2.64	39.57	817.22	178.78	4.00	Loam Sand

[1]Density of particle; [2]Organic Matter.

The experimental area was 40 x 40 m, wherein a 6 x 6 m grid was used, resulting in 36 sampling points, with a 5-m border and a 8 x 10 m rest area for animals attached to the pasture that contained water and 16 m^2 of shade (Figure 1). The soil was prepared with a harrow plow prior to planting, and fertilizer was not applied because the area had no declivity. The management system was continuous stocking in soil under pasture composed of *Brachiaria decumbens*, a drought-resistant crop plants. Grazing was performed by three girolando heifers, each with a 300 kg body weight. The grazing period started when the canopy had a 90-cm height and ended when it had a 20-cm height, as suggested by Fidalski and Alves (2015).

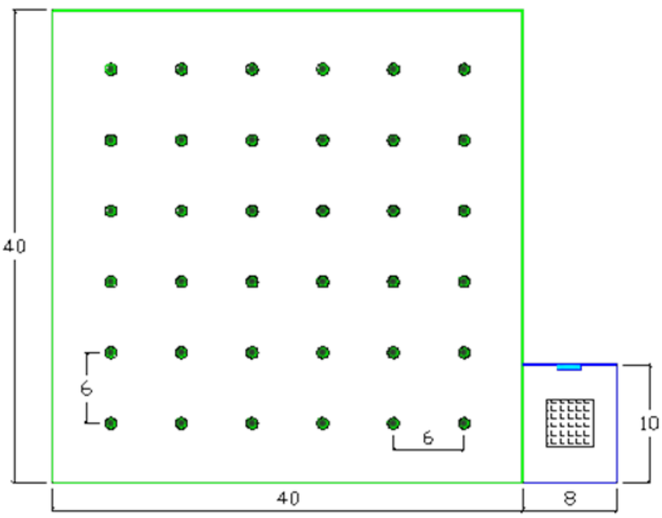

Figure 1. Sketch of trial pasture: sampling points ( ), rest and shade area for animal relief ( ).

For each sampling point, the penetration, moisture, bulk density, total porosity and particles density of soil at 0.0 - 0.10, 0.10 - 0.20, and 0.20 - 0.30 m depth, and hydraulic conductivity on saturated soil surface were measured. Sample collection was performed prior to and after grazing. For an undisturbed soil sample, an Uhland sampler was used.

The density of particle (Dp) was estimated by the volumetric flask method. Gravimetric moisture (GM) was estimated by oven drying, and soil bulk density (BD) was estimated by the volumetric ring method, with the soil dried mass kept at 105°C and using an extraction ring of known volume. Total porosity (TP) was calculated by the correlation between BD and Dp (EMBRAPA, 2011).

To measure soil penetration resistance (PR) a penetrometer of reduced impact was used (model IAA/Planalsucar/Stolf), with number of impacts dm^{-1} transformed to dynamic resistance (MPa) according to Equation 1 proposed by Stolf (1991).

$$PR = \frac{M + m + \left(\frac{M}{M + m} \times \frac{M \times h}{X}\right)}{A} \quad (1)$$

where:
PR – Soil penetration resistance, kgf cm^{-2} (kgf cm^{-2} × 0.098 = MPa);
M - Mass of piston, 1.6 kg;
m - Mass of machine without piston, 1.5 kg;
h - Height of piston fall, 54 cm;
X – Penetration of machine stick, cm by impact;
A - Area of cone, 1.35 cm^2.

The soil-water surface infiltration was characterized using the Beerkan method, which is based mainly on simplified infiltration assays and analyzing the soil particle size distribution (Di Prima, Lassabatere, Bagarello, Iovino & Angulo-Jaramillo, 2016). A PVC ring was used with a 150 mm diameter, 15 volumes of 150 mL water, and a chronometer. In the grazing area, the ring was inserted in the soil at a 1-cm depth to avoid lateral losses of water during the process. The water volumes were consecutively spilt in the cylinder, where another volume was spilt after every emptying. The time required for every volume to infiltrate into the soil was recorded, and the process was stopped when the infiltration velocity became constant or after 15° of volume emptying. Hydraulic conductivity was estimated as described by Bagarello, Di Prima, Iovino, and Provenzano (2014) in Equation 2. According to the authors, this methodology should be applied only for soil surfaces.

$$K_0 = \frac{b}{0.467\left(\frac{2.92}{r} + 1\right)} \quad (2)$$

where:
K_0 – Hydraulic conductivity in saturated soil, mm s^{-1};
b – Slope of an equation linearized in function of cumulative infiltration over time;
r – Ring radius, 75 mm;
α – adopted 0.012 as suggested by Reynolds, Bowman, Drury, Tan, and Lu (2002), for practices in permeameter and infiltrometer in soil that ranges from thick sand to compacted clay.

Initially, descriptive statistical analyses (minimum, maximum, average, median, standard error, coefficient of variation, asymmetry, and kurtosis) were performed on the soil physical attribute data collected in the field trial. The data normality hypothesis was estimated by Kolmogorov-Smirnov test.

To verify the spatial variability of variables over time, the results were analyzed by geostatistical methods of semivariogram analysis (Vieira, 2000). Spatial autocorrelation among neighbors was estimated by semivariance γ (h), through Equation 3:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - z(x_i + h)]^2 \quad (3)$$

where: N(h) is the number of value pairs $Z(x_i)$ and $Z(x_i + h)$, separated by the h vector. The $\gamma(h)$ equation in function h correspondent values, namely, semivariogram, is a function of only the h vector.

The GS+ 7.0 (Gamma Design Software, 2012) adjusted the semivariogram models. The choice of the best model adjusted to semivariogram was based on coefficient of determination (R^2). Surfer 9 (Golden Software, 2010) was used to manipulate and observe the spatial distribution through isolines map building for variables with ordinary kriging. Maps scales of RP were constituted according to the levels adapted by Soil Survey Staff (2017), where low: RP < 0.1 MPa; moderate: 0.1 - 2.0 MPa; high: 2.0 - 4.0 MPa; very high: 4.0 - 8.0 MPa; and extremely high: RP > 8.0 MPa.

To analyze the spatial dependence degree (SDD) of soil attributes the classification of Cambardella et al. (1994) was applied. Strong spatial dependence was considered for semivariograms with a nugget effect < 25% of threshold, moderate for those between 25 and 75%, and weak for those > 75%.

Variability of parameters was estimated using the coefficient of variation as reported by Warrick and Nielsen (1980), where: CV < 12%, 12 ⩽ CV < 60%, and CV ⩾ 60% represented low, moderate, and high variability attributes, respectively.

Results and discussion

The results for descriptive statistics before and after grazing showed similarity for the average and median, which indicated a symmetric distribution; the measures of central tendency were dominated by typical values in the distribution (Tables 2 and 3). According to the Kolmogorov-Smirnov test, all variables had normal distribution, with coefficients of asymmetry and kurtosis similar or equal to zero (Cunha et al., 2017).

The coefficient of variation (Table 2) revealed low variability for soil bulk density (BD) at all depths and total porosity (TP) at a 0.0 - 0.1 m depth, similar to the results of Ribeiro et al. (2016), who observed the spatial variability of cohesive soil physical attributes submitted to conventional management and direct seeding methods. Penetration resistance (PR) for 0.1 - 0.2 m and 0.2 - 0.3 m depth, gravimetric moisture (GM) for all depths, TP for 0.1 - 0.2 m and 0.2 - 0.3 m depth, and hydraulic conductivity (K_0) all had moderate variability. The PR for 0.0 - 0.1 m showed high variability, as also reported by Mion et al. (2012), who analyzed the spatial variability of the physical attributes in a yellow argisol under alternate sheep grazing; those authors attributed their results to high variability of the average, showing a distribution with high heterogeneity of data.

Table 2. Descriptive statistic parameters of soil physical-hydric attributes at 0 - 0.1, 0.1 - 0.2 and 0.2 - 0.3 m depth, before grazing.

Variables	[1]MIN	[2]MAX	Average	Median	[3]SE	[4]CV	[5]A	[6]K	[7]D
				0.00 – 0.10 (m)					
PR (MPa)	0.55	3.46	1.31	0.87	0.89	68.30	1.24	0.09	0.22*
GM (%)	6.79	17.53	13.43	14.06	2.90	21.70	-0.29	-0.95	0.10*
BD (kg dm^{-3})	1.49	1.85	1.65	1.64	0.08	4.80	0.21	-0.40	0.09*
TP (%)	32.85	42.71	37.476	37.95	2.67	7.10	-0.07	-0.84	0.10*
				0.10 – 0.20 (m)					
PR (MPa)	0.87	7.67	3.81	3.46	2.03	53.40	0.30	-0.97	0.12*
GM (%)	4.93	15.94	10.39	11.03	3.33	32.00	0.02	-1.15	0.06*
BD (kg dm^{-3})	1.41	1.87	1.67	1.70	0.13	8.10	-0.38	0.89	0.08*
TP (%)	29.22	46.90	37.00	37.04	5.31	14.40	0.26	-1.03	0.06*
				0.20 – 0.30 (m)					
PR (MPa)	3.46	10.58	6.40	6.39	2.61	40.80	0.14	-0.10	0.19*
GM (%)	5.59	14.09	9.55	9.54	1.90	19.90	0.43	0.18	0.13*
BD (kg dm^{-3})	1.31	1.94	1.61	1.65	0.16	10.50	-0.07	-1.06	0.18*
TP (%)	29.79	52.48	39.51	38.62	6.10	15.40	0.34	-0.88	0.17*
				Hydraulic conductivity in saturated soil surface					
K_0 (mm s^{-1})	0.007	0.04	0.02	0.02	0.01	44.70	0.77	0.15	0.20*

PR: Penetration Resistance; GM: Gravimetric Moisture; BD: Bulk Density; TP: Total Porosity; K_0: Hydraulic Conductivity of soil. [1]MIN: Minimum; [2]MAX: Maximum; [3]SE: Standard Error; [4]CV: Coefficient of Variation; [5]A: Asymmetry; [6]K: Kurtosis; [7]D: Normality by K-S *Significant at 5%.

After grazing, BD and TP had low variability for all depths sampled, which was also found by Guimarães, Junior, Marques, Santos, and Fernandes (2016), who evaluated the spatial variability of soil physical attributes in latosol, argisol, and cambisol pastures and reported that their results were due to bovines having preferred spots in a pasture, which can promote greater soil heterogeneity. The PR, GM, and K_0 showed moderate variability (Table 3). In a study performed in Agreste of Pernambuco State by Tavares et al. (2014), the coefficient of variation was low for GM and moderate for PR. According to Santos et al. (2012), low variability shows lower attribute heterogeneity for the experimental area sampled, whereas moderate variability occurs due to soil use and management associated with machines and their implements as well as geomorphological processes, which provide greater homogenization of sand and clay. High variability indicates large soil heterogeneity in the field trial sampled.

The PR showed averages that were classified (Table 2) as moderate, high, and very high prior to grazing and as high, very high, and extremely high after grazing at 0.0–0.1, 0.1–0.2, and 0.2–0.3 m, respectively. Similar results were observed by Torres, Rodrigues Junior, Sene, Jaime, and Vieira (2012), who considered PR to be very high at six soil depths (0.0 through 0.6 m) in a pasture. According to Silveira, Melo Filho, Sacramento, and Pinto Silveira (2010), values between 2 and 2.5 MPa have been indicated as thresholds for soil penetration resistance of most plant species.

A small increment in soil moisture was observed after grazing due to precipitation that occurred prior to sample collection.

The BD had an average of 1.6 kg dm^{-3}. According to Reichert, Reinert, and Braida (2003), a density values of 1.65 kg dm^{-3} in sandy soils indicates a high probability of root growth restriction. In conventional grazing over 10 years, Guimarães et al. (2016) reported 1.27 kg dm^{-3} BD. The BD increase, which occurred mainly at the shallowest depths, can be related to high-intensity bovine trampling and, consequently, pasture degradation. As reported by Cecagno et al. (2016), BD is normally modified by bovine trampling and soil degradation, mostly at 0.0 - 0.1 m depth.

Table 3. Descriptive statistic parameters of soil physical-hydric attributes at 0 - 0.1, 0.1 - 0.2 and 0.2 - 0.3 m depth, after grazing.

VARIABLES	[1]MIN	[2]MAX	Average	Median	[3]SE	[4]CV	[5]A	[6]K	[7]D
				0.00 – 0.10 (m)					
PR (MPa)	0.87	6.05	2.35	2.16	1.23	52.40	0.97	0.03	0.10*
GM (%)	7.60	22.03	15.48	16.28	3.31	21.40	-0.46	-0.17	0.14*
BD (kg dm^{-3})	1.55	1.78	1.66	1.67	0.06	3.90	-0.12	-0.97	0.08*
TP (%)	32.51	39.86	36.37	36.34	2.15	5.90	-0.07	-0.77	0.08*
				0.10 – 0.20 (m)					
PR (MPa)	2.16	9.93	5.92	5.24	2.58	43.60	0.95	-0.16	0.14*
GM (%)	5.22	17.82	10.89	10.64	3.00	27.60	0.32	0.41	0.07*
BD (kg dm^{-3})	1.51	1.89	1.72	1.74	0.09	5.30	-0.63	-0.12	0.05*
TP (%)	28.23	43.57	34.91	34.30	3.57	10.20	0.66	0.08	0.16*
				0.20 – 0.30 (m)					
PR (MPa)	5.08	11.55	8.29	8.31	1.82	22.00	0.21	-0.76	0.22*
GM (%)	9.00	17.03	13.02	13.12	1.90	14.70	-0.31	0.24	0.07*
BD (kg dm^{-3})	1.36	1.90	1.63	1.63	0.12	7.80	0.09	-0.51	0.09*
TP (%)	28.21	45.29	37.87	37.04	4.69	11.90	-0.27	-0.95	0.10*
				Hydraulic conductivity in saturated soil surface					
K_0 (MM S^{-1})	0.004	0.02	0.01	0.01	0.003	33.50	0.27	-0.25	0.05*

PR: Penetration Resistance; GM: Gravimetric Moisture; BD: Bulk Density; TP: Total Porosity; K_0: Hydraulic Conductivity of soil. [1]MIN: Minimum; [2]MAX: Maximum; [3]SE: Standard Error; [4]CV: Coefficient of Variation; [5]A: Asymmetry; [6]K: Kurtosis; [7]D: Normality by K-S *Significant at 5%.

Table 4. Parameters of semivariograms models and spatial dependence degree (SDD) prior to grazing time.

Attribute	Model	C_0	C_0+C	A	SDD %	R^2
			0.0 – 0.10 (m)			
PR	Spherical	0.039	0.822	11.280	4.750	0.821
BD	Spherical	0.00034	0.00443	8.740	7.675	0.599
TP	Spherical	0.230	6.909	8.790	3.329	0.839
			0.10 – 0.20 (m)			
PR	Spherical	0.290	3.071	11.770	9.443	0.893
BD	Spherical	0.00057	0.005	11.120	11.400	0.818
TP	Spherical	0.700	26.590	8.200	2.635	0.681
			0.20 – 0.30 (m)			
PR	Spherical	0.190	7.020	8.570	2.700	0.580
BD	Spherical	0.00310	0.059	12.440	5.29	0.996
TP	Spherical	0.718	38.633	16.990	1.858	0.969
			Hydraulic conductivity in saturated soil			
K_0	Spherical	0.000001	0.00022	11.69	0.454	0.987

C_0: Nugget Effect; C_0+C: Threshold; A: Reach; SDD: Spatial Dependence Degree (%); R^2: Semivariogram Adjustment.

The TP and K_0 average declined 2.93 and 5.65, 4.16 and 50.00%, respectively, after grazing; the decline in these factors can be explained by increases in PR and GM. The TP results observed in our study were similar to those of Lanzanova et al. (2007), who estimated the total porosity in soil under grazing (4 UA ha^{-1}) and reported that TP was reduced 18% at 0.0 - 0.05 m and 7% at 0.05 - 0.10 m after 14 days of grazing. The authors attributed this reduction to the pressure of animals on the soil. Likewise, Oliveira Júnior et al. (2014) observed the hydrodynamic attributes in Regolithic neosol under pasture and "caatinga" and reported average K_0 values of 0.063 mm s^{-1} for pasture and 0.125 mm s^{-1} for caatinga; however, soil management under pasture significantly changed the saturated hydraulic conductivity that was affected by animal trampling.

All semivariograms of the variables in this study were adjusted to the spherical model (Tables 4 and 5). This model has mostly been applied to describe the variability of soil attributes (Cambardella et al., 1994; Ribeiro et al., 2016).

By geostatistical analysis through semivariograms, TP had no spatial dependence at depths of 0.1–0.2 and 0.2–0.3 m after grazing (Table 5). Thus, the variability of this variable can be considered aleatory, and lower spacing will be necessary for sample collection to detect spatial dependence, as suggested by Cambardella et al. (1994). Likewise, Guimarães et al. (2016) reported a pure nugget effect for TP at 0.10 and 0.15 m after applying 10 x 10 m spacing to estimate the spatial dependence of the physical attributes of soil under pasture. The spatial dependence degree (SDD) was classified as strong for other variables analyzed. The SDD results were similar to those of Soares et al. (2015), who observed the spatial dependence of soil physical attributes under pasture.

Table 5. Parameters of semivariogram models and spatial dependence degree (SDD) after grazing.

Attribute	model	C_0	C_0+C	A	SDD %	R^2
			0.0 – 0.10 (m)			
PR	Spherical	0.276	1.805	9.560	15.300	0.904
BD	Spherical	0.00004	0.002	8.950	2.000	0.998
TP	Spherical	0.112	2.371	11.180	4.728	0.890
			0.10 – 0.20 (m)			
PR	Spherical	0.010	7.625	13.920	0.131	0.984
BD	Spherical	0.00009	0.003	8.720	3.000	0.523
TP	PNE	-	-	-	-	-
			0.20 – 0.30 (m)			
PR	Spherical	0.163	3.079	12.140	5.300	0.967
BD	Spherical	0.00001	0.016	8.270	0.062	0.937
TP	PNE	-	-	-	-	-
			HYDRAULIC CONDUCTIVITY IN SATURATED SOIL			
K_0	Spherical	0.000001	0.00001	9.560	10.000	0.934

C_0: Nugget Effect; C_0+C: Threshold; A: Reach; SDD: Spatial Dependence Degree (%); R^2: Semivariogram Adjustment; PNE: Pure Nugget Effect.

Kriging maps (Figure 2) allowed verification of the result that PR increased by 79.40, 55.40, and 29.50% at 0.0 - 0.1, 0.1 - 0.2, 0.2 - 0.3 m depth, respectively, after grazing. These results are similar to observed by Lanzanova et al. (2007), who evaluated the physical attributes of soil under grazing (4 AU ha^{-1}) and noticed an increase of 57% PR at 0.05 - 0.08 m after 14 days of grazing. Costa et al. (2012) reported a higher PR under different stocking rates (1.26, 5.57, 7.45, and 8.23 AU ha^{-1}) and at 0.2 - 0.3 and 0.3 - 0.4 m depth, with greater grazing intensity, in sandy-loam soil.

Modification of spatial variability of PR before and after grazing can be explained by the fact that animals that are managed under continuous grazing stay in the same paddock without rest time. Additionally, clumped grass growth can promote bare soil with greater impact of animal hoof pressure. Consequently, there is a greater tendency for compaction, which was confirmed after grazing due to greater penetration resistance (Fernández, Alvarez, & Taboada, 2015).

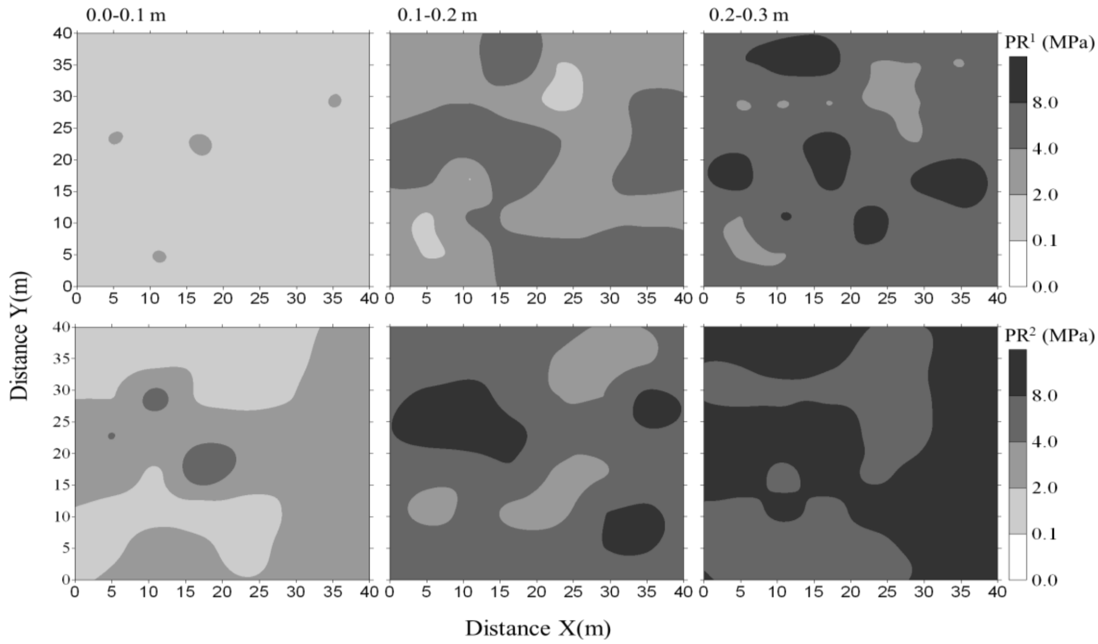

Figure 2. Kriging maps of PR¹ (MPa) before grazing and PR² (MPa) after grazing.

The threshold for BD suggested by Reichert et al. (2003) is 1.65 kg dm^{-3}. This value was surpassed across a large portion of the sampling area, mainly at 0.0 - 0.1 and 0.1 - 0.2 m depth after grazing. Likewise, Lima, Silvino, Melo, Lira, and Ribeiro (2015) studied a pasture with continuous grazing at Brejo of Paraíba and reported an average BD of 1.6 and 1.5 kg dm^{-3} at 0.0 – 0.10 and 0.10 – 0.20 m, respectively. According to Costa et al. (2012), the BD can be affected by animal trampling, especially at depths of 0.0 – 0.10 and 0.10 – 0.20 m.

In pastures with bovine rotational stocking and a 12 AU ha^{-1} stocking rate, Ortigara et al. (2014) reported that animal trampling changed the soil structure by increasing the BD and PR and decreasing the porous space. Thus, these findings are similar to those of our study.

In contrast to the literature, Bonetti et al. (2015) studied the soil physical attributes and soy bean productivity of a pasture managed with different stocking rates (1.5, 2.5, and 3.5 AU ha^{-1}) and canopy heights (0.25, 0.35, and 0.45 m) in a dystroferric Red latosol. The authors reported that after 120 grazing days, the soil physical attributes had small changes that were maintained near the threshold considered normal. Furthermore, the authors reported that a low stocking rate and soil moisture could have contributed to fewer impacts of animal trampling.

The TP and K_0 decreased as PR and BD increased (Figures 2, 3, 4, and 5), the results similar to findings of Guimarães et al. (2016). According to Mion et al. (2012), TP shows a strong correlation with PR, which tends to increase as TP is reduced. The increase of PR and BD and the decrease in TP are responsible for the decrease in K_0 and, therefore, for increased water runoff from rain or irrigation, which exacerbates the erosion process (Stefanoski, Santos, Marchão, Petter, & Pacheco, 2013).

Iglesias, Galantini, Krüger, and Venanzi (2014) also observed similar results when they evaluated TP distribution in areas with bovine trampling and different plant systems. The authors reported that trampling by animals reduced TP, mainly at a depth of 0.0 - 0.1 m.

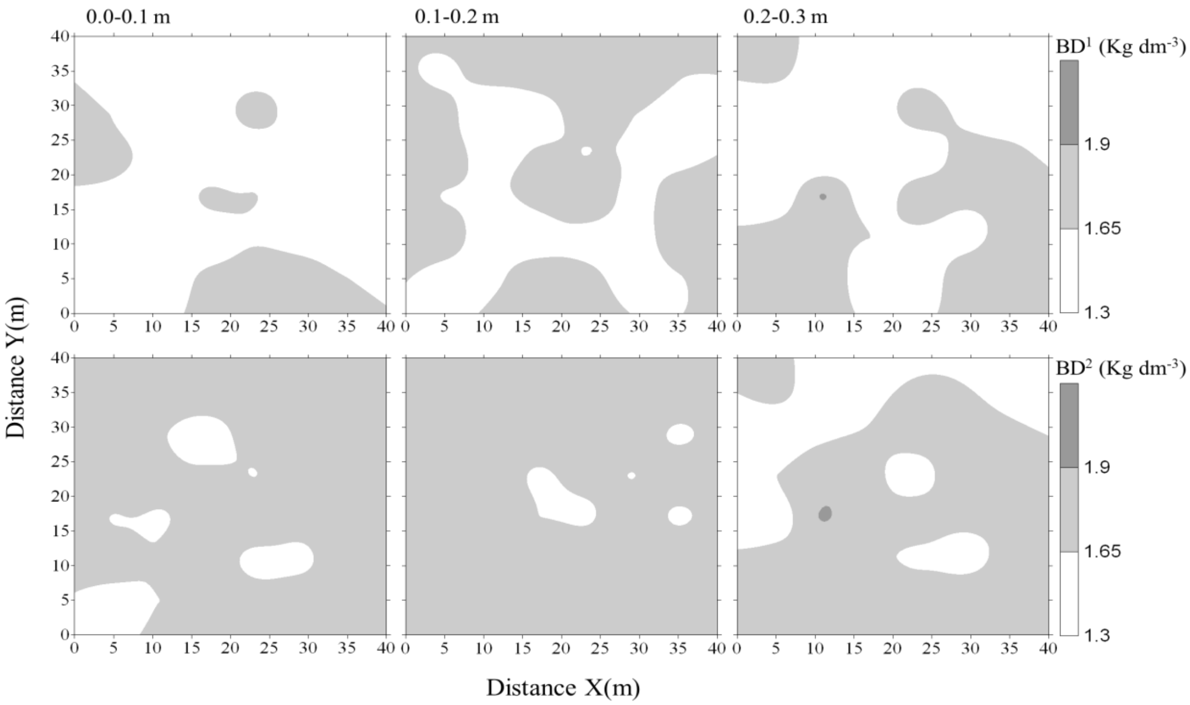

Figure 3. Kriging maps of BD^1 (kg dm^{-3}) before grazing time and BD^2 (kg dm^{-3}) after grazing time.

The K_0 was markedly reduced after grazing time, mainly due to the increased BD and PR, with a reduction in porosity. Likewise, Miguel et al. (2009) evaluated soil water infiltration as a function of trampling intensity at an alternate stocking rate (6 AU ha^{-1}) and reported a reduction of 70% for K_0 after the fifteenth grazing period through paddocks (Figure 5).

An evaluation of the compaction of the soil surface caused by 120 bovines grazing in a 100 x 70 m pastureland during three weeks by Tuffour, Bonsu, and Khalid (2014) found that grazing at any intensity affected the soil water infiltration because the animal hoof pressure greatly reduced the porous space of soil, which supported our results.

According to our results, after 21 days of grazing, animals degraded the soil with physical modifications, which is related to overgrazing, and management can modify soil physical attributes. However, grazing does not affect the soil physical quality in continuous or alternate stocking systems, as long as the stocking rate and forage mass are controlled (Fidalski et al., 2008). Adopting good management and maintaining the pasture can be a solution for those problems.

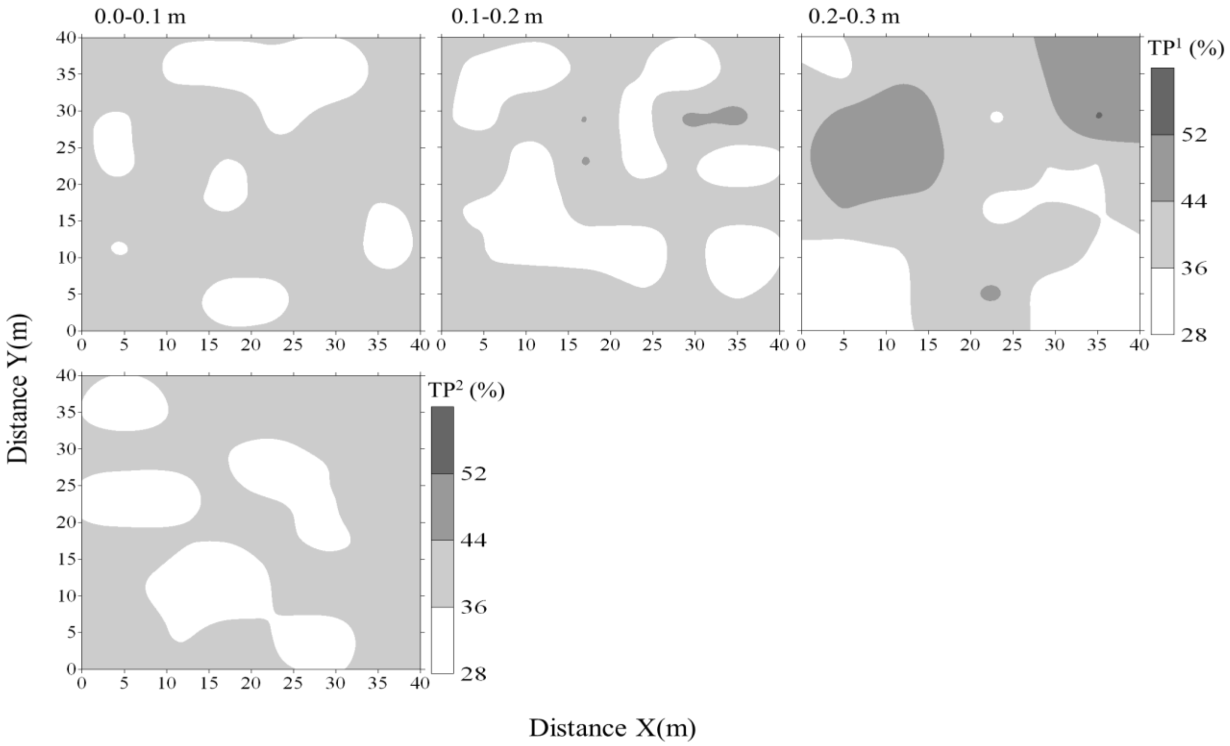

Figure 4. Kriging maps of TP¹ (%) before grazing and TP² (%) after grazing.

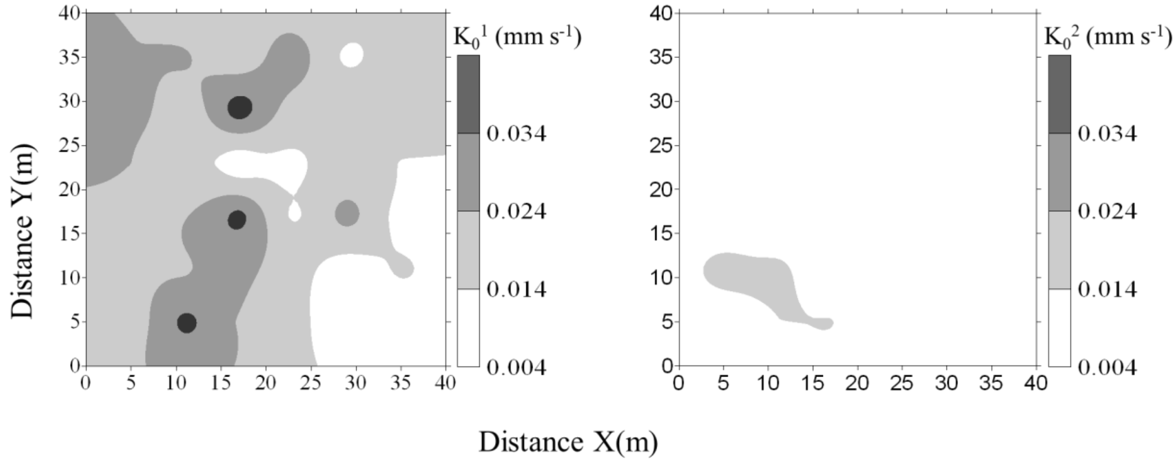

Figure 5. Kriging maps of K_0^1 (mm s^{-1}) before grazing and K_0^2 (mm s^{-1}) after grazing.

Conclusion

Penetration resistance, moisture, bulk density, and hydraulic conductivity of the soil had a strong spatial dependence before and after grazing.

Soil physical attributes were modified after grazing, which increased the penetration resistance and bulk density and reduced the hydraulic conductivity and total porosity.

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