Revista Verde 16:3 (2021) 238-244

Revista Verde
de Agroecologia e Desenvolvimento Sustentável
Green Journal of Agroecology and Sustainable Development

Spatial variability of the horizontal structure and production of biomass in Massai grass in an agropastoral system

Variabilidade espacial da estrutura horizontal e produção de biomassa do capim massai em sistema agropastoril

Carlos Henrique Batista[1]; *Otacílio Silveira Júnior*[2]; *Ítalo Cordeiro Silva Lima*[3];
José Alberto Ferreira Cardoso[3]; *Rossini Sôffa da Cruz*[5]; *Antônio Clementino dos Santos*[6]

[1]Bachelor in Agronomic Engineering, Instituto Federal de Educação, Ciência e Tecnologia, Dianópolis, Tocantins, carlosagronomiaifto@gmail.com. [2]PhD and Soil Laboratory Technician, Instituto Federal de Educação, Ciência e Tecnologia, Dianópolis, Tocantins, otacilio.junior@ifto.edu.br. [3]Teacher, Instituto Federal de Educação, Ciência e Tecnologia, Dianópolis, Tocantins, italo.lima@ifto.edu.br, jose.ferreira@ifto.edu.br. [4]Teacher, Instituto Federal de Educação, Ciência e Tecnologia, Colinas do Tocantins, Tocantins, rossini.cruz@ifto.edu.br. [5]Teacher, Universidade Federal do Tocantins, Araguaína, Tocantins, clementino@uft.edu.br.

ARTICLE
Received: 12 Feb. 2021
Accepted: 18 June 2021

Key words:
Geostatistics
Level of degradation
Pasture management

ABSTRACT

In Brazil, 60% to 80% of cultivated pastures show some degradation level. Thus, the objective was to evaluate the variability of the horizontal structure and biomass of Massai grass in an agropastoral system as a diagnosis of degraded pasture. We performed the georeferencing in a 12m × 13m mesh, totaling 48 sampling stations, and evaluated grass's biomass and structural characteristics at each station. We submitted the data to descriptive statistics and geostatistical analysis. We observed a process of degradation of pasture in the experimental area. Under these conditions, most of the characteristics of the pasture's horizontal structure and the production of biomass showed spatial dependence with high variability. Geostatistics efficiently represented and understood the variability of the studied attributes, enabling developing a specific pasture recovery management plan.

Palavras-chave:
Geoestatística
Manejo de pastagem
Nível de degradação

RESUMO

No Brasil, estima-se que 60% a 80% das pastagens cultivadas apresentam algum grau de degradação. Assim, objetivou-se avaliar a variabilidade da estrutura horizontal e da biomassa do capim massai em um sistema agropastoril, como diagnóstico de pastagem degradada. O georreferenciamento foi realizado em malha de 12 m × 13 m, totalizando 48 pontos. Em cada ponto, a biomassa e as características estruturais do capim massai foram avaliadas. Os dados foram submetidos à estatística descritiva e análise geoestatística. Na área experimental, observou-se um processo de degradação da pastagem e, nessas condições, a maioria das características da estrutura horizontal do pasto e da produção de biomassa apresentaram dependência espacial com alta variabilidade. A geoestatística mostrou-se eficiente na representação e compreensão da variabilidade dos atributos estudados, possibilitando o desenvolvimento de um plano específico de manejo de recuperação de pastagens.

INTRODUCTION

In Brazil, the Cerrado has stood out as a driver of agribusiness in beef production in recent decades. According to Araújo et al. (2017), about 95% of beef is produced on pastures, in a total area of about 167 million hectares. However, inadequate management of soils and pastures represents the main critical points that affect the sustainability of animal production based on pastures, leading to a condition of degradation of pastures (PENATI et al., 2014).

According to Dias-Filho (2011), the indicators of degraded pastures do not show a standardized methodology. Therefore, pasture areas are considered degraded in a given location or productive in another site. Thus, evaluating the conditions of pastures is essential to relate soil degradation with forage degradation, to establish pasture and soil recovery management (SCHIPPER et al., 2014).

Geostatistics is an essential tool for detecting the existing spatial variability in the environment, allowing us to analyze characteristics and their random and spatial aspects. Still, geostatistics can create variability of characters, identify the degree of spatial dependence, and provide information to allows the study of the phenomenon to be analyzed (RODRIGUES et al., 2014).

The pasture has morphological components that occupy the space in the vertical and horizontal directions. The abundance and distribution of these components also influence the degree of forage occupation. Studying

doi: 10.18378/rvads.v16i3.8684

occupation mechanisms and the factors that influence their understanding is fundamental to understanding the system (SANTOS, 2011).

The pasture horizontal structure variability under degradation is little explored, and intervention is usually carried out through recovery management over a heterogeneous area. This practice may underestimate or overestimate the current needs for cultivated areas (ALENCAR et al., 2016).

Grasses of the genus *Megathyrsus* are among the most used forage plants in different animal production systems in Brazil (GOMES et al., 2011). Among the types of *M. maximum*, the Massai grass is promising for intensive use due to its high leaf biomass production, low stalk production, high leaf blade/stem ratio, and high tillering capacity (LOPES et al., 2013).

Thus, this research aims to characterize the horizontal structure and forage biomass production in a *Megathyrsus maximus* cv. *massai* in agropastoral system using a geostatistical approach as a diagnostic strategy for degraded pasture.

MATERIAL AND METHODS

We performed the study in an experimental area at the Federal Institute of Tocantins, Campus Dianópolis (11º38'05"S, 46º45'55"W, and 578m altitude). The region's climate, according to Koppen's classification, is Aw (hot and humid). The average annual temperature is 24.5 ºC, and the average annual relative humidity is 65%, with 1532 mm of annual precipitation (SOUZA et al., 2019). The soil used in the experiment was the Plinthossolo Pétrico Concretário (EMBRAPA, 2013).

We used a geostatistical model to assess the spatial dependence in the present study using different phenomena of spatial dependence, the exponential, Gaussian and spherical. The sampling was perfomed in an area of agropastoral system formed by the association of dwarf coconut (*Cocos nucifera* L.) with *Megathyrsus maximus* cv. *massai*, in a total area of 6,446m², divided into four parcels. Sheep facilities are located in the center of the area.

The experimental area was demarcated in a regular grid of 12 m × 13 m, totaling 48 georeferenced points, marked with GPS (Global Position System, GARMIN/GPSmap 76CS x, precision of 2 m). We evaluated the degradation process, forage biomass production, and structural characteristics of the massai grass at each point.

We based the diagnostic evaluation of pastures on Rodrigues et al. (2014) study with adaptation. The diagnosis evaluates the frequency of clumps, empty spaces, and spaces with invaders (%) in a 1.0 m × 1.0 m frame (subdivided into 0.1 m × 0.1 quadrants m) at each georeferenced point. The frequency of each variable was obtained by visual assessment in each quadrant, occupying the soil surface (bush, empty spaces, or weeds).

The height of the Masai grass canopy was measured using a graduated ruler. We measured each point six times, each point represented by the average of these measurements. Biomass samples were collected using a 0.5 m × 10 m frame. We evaluated at all georeferenced points, and the biomass cut was representative of the average canopy height. Then, samples within the frame to the ground level were taken to the soil laboratory, weighed, and separated into forage mass (green and senescent) and weed mass (green and senescent). Each material was weighed again and dried at 55 ºC for 72 h in a forced air circulation oven to estimate the dry mass of grass.

The determination of the population density of tillers was obtained by counting the tillers contained in a rectangle of 0.25 × 1.0 m in each georeferenced point. After counting, the values were converted to m^2 to determine the number of tillers per m^2. Forage volumetric density, kg cm^{-1} ha^{-1}, was calculated by dividing the forage mass by the canopy height.

We used descriptive statistics, consisting of measures of position (mean, median, and mode), dispersion (minimum, maximum, and standard deviation), and distribution (coefficients of variation, asymmetry, and kurtosis). The hypothesis of normality was verified by the Kolmogorov-Smirnov (KS) test at the level of 5% probability with the aid of the statistical program BioEstat 5.3. (AYRES, 2011)

The coefficient of variation (CV%) was used to measure the variability according to Warrick and Nielsen (1980) in weak CV <12%, moderate CV between 12% and 62%, and strong CV > 62%. The asymmetry coefficient (AC) was used as a precision characteristic. The normalized distribution function at AC = 0 is symmetric distribution, AC>0 is a right-skewed distribution, and AC<0 is a left-skewed distribution.

According to the intrinsic hypothesis, the spatial variability was determined through the construction of the semivariogram. The semivariograms were fitted to spherical, exponential, linear, and Gaussian theoretical mathematical models to define the values of the nugget effect (C0), extent and plateau (C + C0).

The patterns of spatial dependence were estimated by semivariance and autocorrelation as a function of the distance γ (h) (MATHERON, 1963) using the GS + software (ROBERTSON, 1998) and the equation (1).

$$\gamma(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)} Z(\mathrm{Xi})Z(\mathrm{Xi}+\mathrm{h})^2(1) \qquad (1)$$

Where, γ (h) = experimental semi-variance; h = distance between sampling points; N (h) = number of pairs of values obtained Z (xi); Z (xi + h), separated by a distance h; Z = studied parameter; Xi and Xi + h = sample point positions (VIEIRA et al., 1983).

The theoretical model for classification of the Degree of Spatial Dependence (DEG) was determined as a relationship between structural variance (C) and plateau (C + C0). Therefore, we can classify the DEG, according to Robertson (1998), in weak spatial dependence (GDE <0.25), moderate spatial dependence (0.25 ≤ GDE <0.75), and strong spatial dependence (GDE ≥ 0.75), Equation 2.

$$GDE=\frac{C}{C+C_0} \qquad (2)$$

GDE = degree of spatial dependence; C = structural variance; C + C0 = plateau.

The selection of the best fitted model of the semivariograms was performed assuming the smallest sum of the square of the residues (SQR), in the largest DGE and the highest coefficient of determination (R^2). Besides, the presence of anisotropy was calculated in four directions in the semivariograms with amplitude at 45º (0, 45, 90 and 135°). We chose to analyze 90º isotropic semivariograms. We did not find any anisotropy. The interpolation of values was performed by the kriging method, to make maps of isolines, using the Surfer software version 13.0 (GOLDEN SOFTWARE, 2015).

The levels of pasture degradation in an agropastoral system were defined from the methodology proposed by Spain and Gualdrón (1991), according to the restrictive parameters and deterioration status (Table 1).

Table 1. Pasture Degradation stages regarding restrictive parameters and degradation level of deterioration.

1	Strengh and quality	<25	LIGHT
2	1+ small plant population	25-50	MODERATE
3	1+2+Invaders	50-75	STRONG
4	1+2+3+Ants and termits	>75	VERY STRONG
5	1+2+3+4+ poor ground cover	>75	VERY STRONG
6	1+2+3+4+5+erosion	>75	VERY STRONG

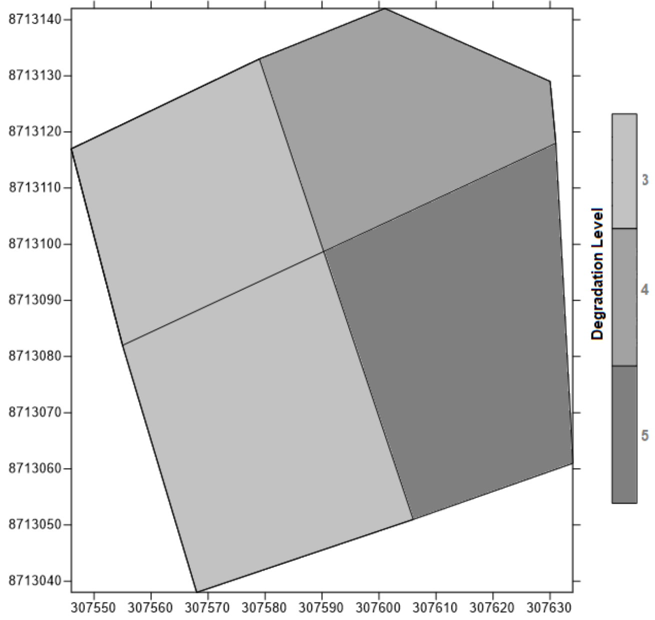
Source: Spain e Gualdrón (1991).

RESULTS AND DISCUSSION

According to the classification criteria of the restrictive parameters and deterioration status proposed by Spain and Gualdrón (1991), we observed a strong and very strong level of degradation in the experimental area, the agropastoral system formed by the association of coconut trees with a pasture of *Megathyrsus maximus* cv. *massai* (Figure 1).

The agropastoral system studied was used for three years without soil correction and fertilization, grazed by sheep, and managed in continuous grazing without stocking control. Therefore, the pasture degradation was probably due to the lack of adjustments in the pasture height before and after grazing, overgrazing, inadequate rest period, competition for nutrients and water between forages and coconut roots, and lack of fertilization management.

Figure 1. Degradation level map of maasai grass pastures in an agropastoral system, Dianópolis, Tocantins.



Thus, geostatistics emerges as an important tool to understand the interactions in the pasture ecosystem, reduce possible causes of degradation and indicate better soil-plant-animal management alternatives (PARIZ et al., 2011).

Table 2 shows the descriptive analysis of forage biomass production and structural characteristics of Massai grass. Most of the variables failed in the assumption of normality, that is, canopy height, number of clumps, empty spaces (%), forage spaces (%), spaces with weeds (%), number of weeds, and dry mass of weeds.

Tablel 2. Agronomic and structural characteristics of massai grass in an agropastoral system under pasture degradation.

Variable	Min	Max	Apl	Md	M	CV (%)	S	As	C	K-S
Height (cm)	4.00	45.00	41.00	15.00	17.63	78.88	8.88	1.17	1.73	NS
Nº of Clumps (unit/m²)	0.00	15.00	15.00	7.00	6.88	9.56	3.09	0.40	0.43	NS
Empty Area (%)	0.00	35.00	35.00	8.50	10.21	61.74	7.86	1.14	1.17	NS
Forage (%)	0.00	103.00	103.00	32.00	38.67	644.74	25.39	1.06	0.44	NS
Invasider (%)	0.00	90.00	90.00	57.50	53.21	484.30	22.01	-0.89	0.33	NS
Nº of invaders (unit/m²)	10.00	346.00	336.00	140.00	152.90	767.07	85.83	0.47	-0.57	NS
Tiller Density (unit/m²)	68.00	1588.00	1520.00	772.00	785.00	1187.53	344.64	0.43	0.24	0.01
GMg (kg/ha)	18.00	12011.00	11993.00	1105.00	1599.00	44200.00	2103.34	3.33	13.19	NS
DMg (kg/ha)	7.00	3015.00	3008.00	392.00	552.58	3956.42	628.66	2.43	6.04	NS
DMdead (kg/ha)	0.00	147.00	147.00	15.00	27.48	1278.55	35.76	2.03	3.85	0.01
GMinv (kg/ha)	0.00	8760.00	8760.00	1676.00	1926.63	26900.00	1613.99	1.97	5.85	0.01
DMinv (kg/ha))	3.00	1906.00	1903.00	490.50	558.27	1370.12	370.15	1.44	3.02	0.01
Mass per tiller (g)	0.00	1.00	1.00	0.00	0.21	0.02	0.14	6.93	48.00	0.01
Content DM grass (%)	21.00	60.00	39.00	32.00	34.98	101.81	10.09	0.99	0.13	0.01
Content DM invader (%)	15.00	62.00	47.00	30.00	31.10	115.12	10.73	1.13	1.01	0.01
Mass by invader	0.00	12.00	12.00	1.00	1.42	6.89	2.62	3.03	9.92	0.01

Mim= Minimum value, Max= Maximum value, M= Average, Md= Median, Apl= Amplitude, S= Standard Deviation, CV= Coeficient of variation, As= Coeficient of assimetry, C= Curtosis, K-S= Kolmogorov-Smirnov test, GMg= Green mass of grass, DMg= Dry Mass of grass, DMdead= Dry mass of dead grass, GMinv= Green mass of invader, DMinv= Invader dry mass.

The lack of normality detected on data is probably due to the inadequate management of forage systems, greater concentration of animals in specific paddocks, shading on the canopy, and areas close to the sheep facilities, and other site-specific factors. High coefficient of variation values were observed for the studied attributes (Table 2), considered strong, above 62%, according to the classification proposed by Warrick and Nielsen (1980).

Therefore, a geostatistical approach is suitable when there is a high variation in data related to sample points. However, the evaluation of data normality in the case of non-normality is not a requirement for applying geostatistical techniques (ASSUMPÇÃO; HADLICH, 2017).

The results of kurtosis and asymmetry indicate positive asymmetry on most variables, with mean values higher than the median, implying that the probability of high frequency was below the mean, except for the percentage of weed, showing negative asymmetry. According to the classification criteria for the coefficient of variation (CV) proposed by Warrick and Nielsen (1980), all forage biomass production and structural characteristics showed high variability (CV> 60%), except for the number of clumps, tiller mass, and weeds, showing low variability.

According to the geostatistical analysis, most of the variables analyzed showed spatial dependence, with high variability (Table 3). However, our studies showed that tiller mass, tiller density, dry mass of senescent grass (kg ha^{-1}), dry weed mass (kg ha^{-1}), and weed mass in degraded pasture do not show spatial dependence. Therefore, we did not use geostatistical analyzes.

We fitted the variables to linear (tiller density, DMdead, GMinv, DMinv and mass per tiller), spherical (canopy height, number of clumps, empty spaces, GMg, forage, and weed percentage), and Gaussian models (forage spaces, spaces with invaders and DMg) (Table 3). The combination of the nugget effect (C0) with level (C0 + C) resulted in a predominance of strong and low spatial dependence (GDE). We found a moderate GDE only for the number of clumps and dry mass of grass (Table 3).

Table 3. Model and parameters estimated by semivariogram for agronomic and structural characteristics of massai grass in a degraded agropastoral system.

Variables	Model	Co	Co+C	Ao	[Co/Co+c)]x100	GDE
Height (cm)	Spheric	0.10	70.70	17.40	99.90	Strong
Nº of Clumps (unit/m²)	Spheric	3.57	9.50	14.56	62.40	Moderate
Empty Area (%)	Spheric	15.04	61.62	24.41	75.60	Strong
Forage (%)	Gausian	73.00	562.80	11.43	87.00	Strong
Invasider (%)	Gausian	4100	39300	283.71	89.60	Strong
Tiller Density (unit/m²)	Linear	84359	84359	152.74	0.00	Low
GMg (kg/ha)	Spheric	79000	2662000	16.90	97.00	Strong
DMg (kg/ha)	Gausian	20200	308800	15.41	93.50	Strong
DMdead (kg/ha)	Linear	862.51	862.51	152.74	0.00	Low
GMinv (kg/ha)	Linear	2197134	2197134	152.74	0.00	Low
DMinv (kg/ha))	Linear	104162	104162	152.74	0.00	Low
Mass per tiller (g)	Linear	0.03	0.03	152.74	0.00	Low
Content DM grass (%)	Spheric	54.78	108.70	28.81	49.60	Moderate
Content DM invader (%)	Spheric	79.00	466.30	14.37	83.10	Strong
Mass by invader	Linear	4.01	4.01	172.74	0.00	Low

The high spatial dependence promotes an adequate spatial structure and accurate information in areas where no sample information was collected (LIMA et al., 2010). However, if the nugget effect (C0) with plateau (C0 + C) of the semivariograms were more distinct, the variability would be smaller, resulting in a reliable estimate, in this case using the mean of the data as the response variable (SOUZA et al., 2014).

We found a greater range of variables in spaces with invaders (%), showing higher similarity between the samples at 283.71 m (Table 3), a result related to the low horizontal variation, considerably reducing the number of samples in larger perimeters. In comparison, we observed the smallest reach in forage spaces (%), 11.43 m, attributed to the significant variability of the forage mass within the area, in disagreement with the results found by Rodrigues et al. (2014). These authors observed higher values, 477 m, to diagnose the horizontal structure of Mombaça grass.

According to Corá and Beraldo (2006), the higher the range value, the greater the geostatistical reliability, ensuring accuracy in estimating data that are not estimated by the Kriging method. Therefore, representative maps can be adjusted to their reality. Thus, these results allow us to map and characterize the production of forage biomass and the structural characteristics of the massai grass in levels of degradation of pastures through the geostatistical approach.

The canopy height isoline maps showed greater leaf elongation in the central region of the study area (Figure 2A). We observed similar behavior in green grass mass (Figure 4A) and dry grass mass (Figure 4B). These responses may be related to proximity to sheep facilities and areas for use as animal feed, resulting from the contribution of animal manure and food waste, which can generate a rich source of organic fertilizer after recycling. In large pasture areas, the distribution of excreted nutrients usually occurs irregularly (SILVA et al., 2013). Still, animals tend to defecate at fixed and predetermined points, resulting in recycling nutrients in the pasture ecosystem. In the long term, they can cause empty spaces in low fertility soils and the appearance of invaders, initiating the pasture degradation process (VENDRAMINI et al., 2007).

Figure 2. Spatial distribution of canopy height (A) and clump numbers (B) of massai grass in a degraded agropastoral system, Dianópolis, Tocantins.

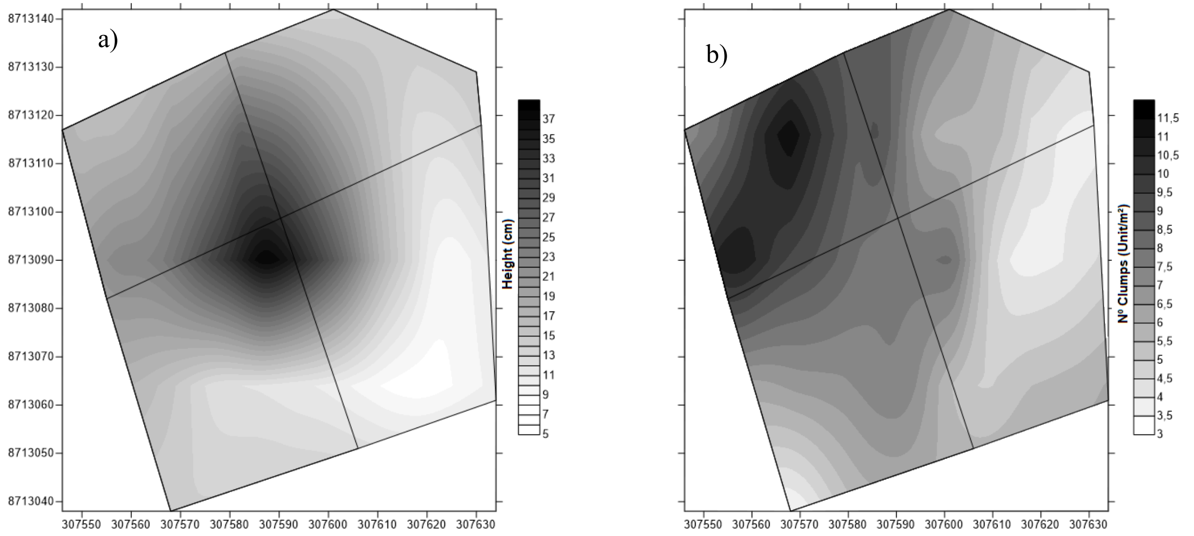
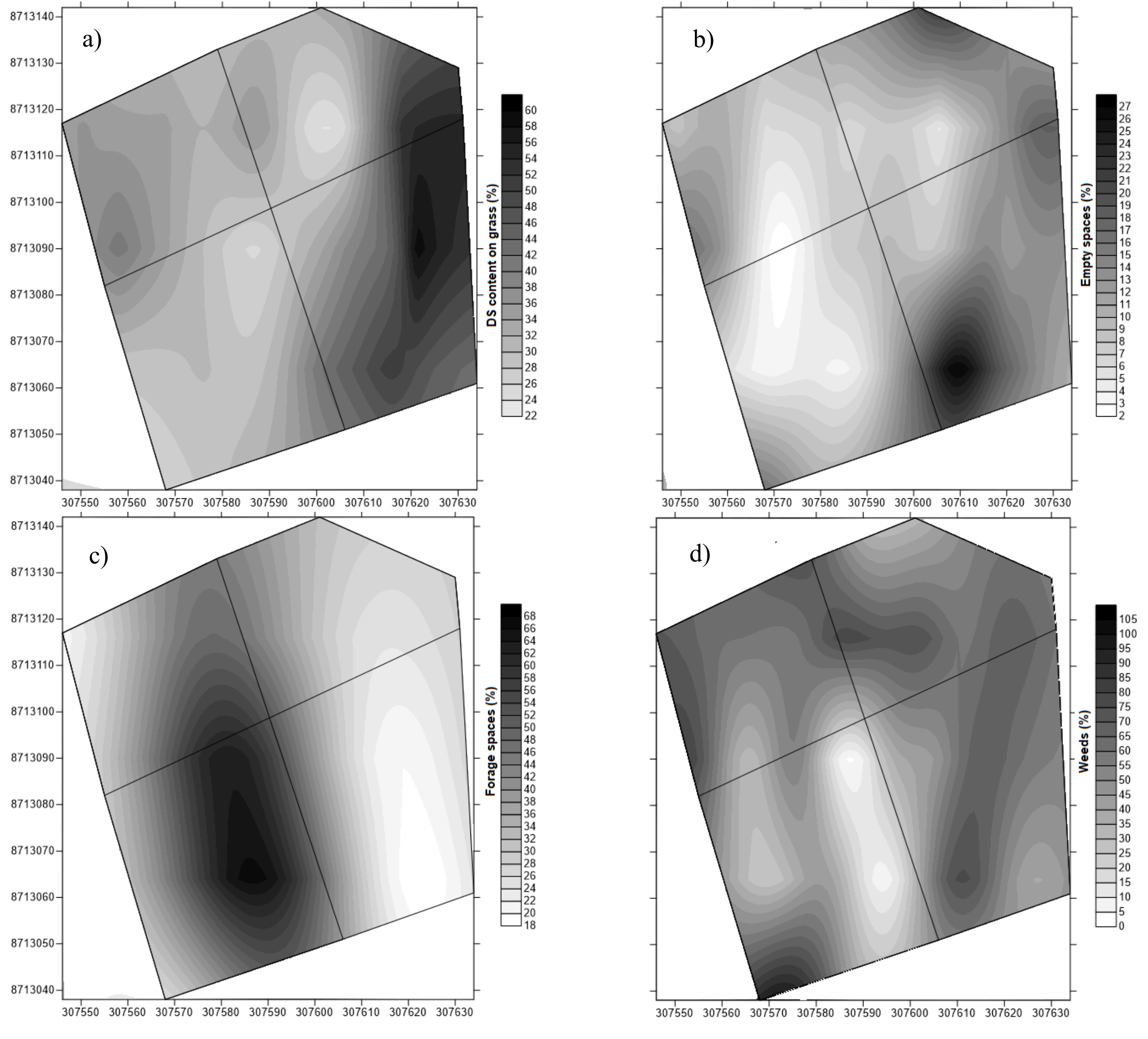


Figure 3. Spatial distribution of massai grass dry matter content (a), empty spaces (b) and spaces with forage (c) and weeds (d) (%) in a degraded agropastoral system, Dianópolis, Tocantins.



The number of clumps (Figure 2B) showed an inverse relationship with dry grass mass production (Figure 4B). Our results support the hypothesis of the experimental condition, identifying the pasture degradation process (Figure 1). According to Pereira et al. (2015), the distribution and frequency of clumps are dependent on the management imposed on the forage grass. The authors demonstrated that growth strategies based on increasing the number of Integrated Physiological Units (IFUs) and increasing the number of individuals per IFUs, in addition to clump size and soil surface occupation, lead to modification of canopy light interception efficiency with potential impacts on pasture regrowth and forage accumulation. Therefore, we associate this inadequate clump development to the difficulty in producing photoassimilates, resulting in less vigorous clumps.

Concerning the spatial variation of empty spaces (Figure 3B), we observed an inverse relationship with the spatial variation of areas occupied by forages (Figure 3C) and dry grass mass (Figure 4B). At the same time, the distribution of invaders (Figure 3D and Figure 4C) follows a direct relationship with the empty space in isoline maps (Figure 3B), which leads us to believe that invaders occupy these spaces.

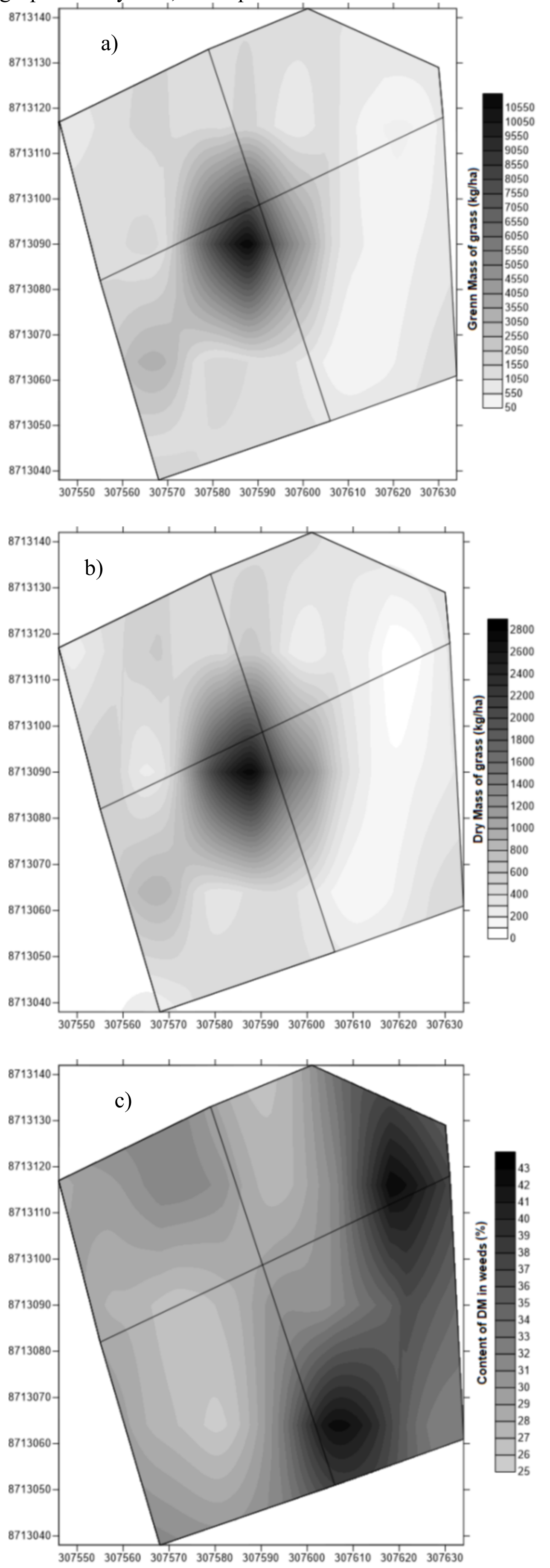
Müller et al. (2001), using *Panicum maximum Jacq* observed that pasture degradation decreased soil cover, representing an increase in the density of the soil surface layer due to greater exposure to rain and trampling under grazing. The degradation also reduced clay flocculation degree and soil porosity, the number of roots profile, and increased the root system close to the root surface. Therefore, the role of invasive plants as an indicator of pasture and soil degradation is clear (DIAS FILHO, 2011).

The observed response of dry mass production of grass with an estimated 552.58 kg ha-1 in 30 days (Figure 3A) was 60% lower than expected for this crop. Lopes et al. (2019), evaluating the biomass of massai grass under intensive management, verified maximum green forage biomass production yields of 5,172.9 kg ha^{-1} . ciclo^{-1} at a dose of 896 kg ha^{-1}.ano^{-1} of nitrogen. Loss of progress in forage vigor is associated with loss of production and the inability to recover spontaneously, related to forage degradation (TOWNSEND et al., 2012).

The pasture degradation process is a complex phenomenon that involves causes and consequences and promotes a gradual decrease in the pasture support capacity (DIAS-FILHO, 2011). Globally, it is believed that anthropogenic influence and inadequate grazing management, mainly due to the lack of adjustments in stocking rate, are the leading causes of pasture degradation.

According to Townsend et al. (2012), we can recover pasture directly or indirectly. Direct manipulation is carried out through mechanical, chemical, and agronomic practices, with or without total or partial destruction of the vegetation. In indirect manipulation, there is the intermediate use of annual pasture or agriculture. Furthermore, we demonstrate that we can detect variability in a pasture through the geostatistical approach and suggest better management alternatives based on the actual level of degradation per area or paddock. The management practices for the recovery of the degraded regions must take into account the management strategies that consider the grazing habit of the animals and the physiology of plant growth to ensure the permanence of the pasture adopted in the areas (FONSECA et al., 2013; SOUZA et al., 2018). Thus, geostatistics emerges as an essential tool to understand pasture ecosystem interactions, reduce possible causes of degradation and indicate better soil-plant-animal management alternatives (PARIZ et. al., 2011).

Figure 4. Spatial distribution of green (a) and dry (b) mass of massai grass and weeds (c), dry matter content in a degraded agropastoral system, Dianópolis. Tocantins.



CONCLUSIONS

We found distinct levels of pasture degradation of massai grass: strong and very strong level. The lack of management caused the pasture degradation. The number of clumps and the high population density of existing tillers allows its recovery, as long as the invaders and soil fertility are properly managed.

The agronomic and structural characteristics of massai grass in the studied system under pasture degradation showed spatial dependence with high variability.

REFERENCES

ALENCAR, N. M.; MELO, J. C.; SANTOS, A. C.; CUNHA, O. F. R.; PAULA NETO, J. J. Distribuição espacial das propriedades do solo, produção do capim-marandu com a intensidade de pastejo. Revista Engenharia na Agrícultura, 24(4):338-349, 2016. 10.13083/reveng.v24i4.602.

ARAÚJO, F. R.; ROSINHA, G. M. S.; BIER, D.; CHIARI, L.; FEIJÓ, G. L. D.; GOMES, R. C. Segurança do Alimento Carne. Campo Grande: EMBRAPA-CNPGC, 2017, p.4.

ASSUMPÇÃO, H. C. P.; HADLICH, G. M. Estatística descritiva e estacionaridade em variáveis geoquímicas ambientais. Engenharia Sanitária Ambiental, 22(4):671-677, 2017. 10.1590/S1413-41522017142739.

AYRES, M. BioEstat 5.3: statistical applications in areas of biological and medical sciences. 5ed. Belém: Publicações Avulsas do Mamiraua, 2011, 361p.

CORÁ, J. E.; BERALDO, J. M. G. Variabilidade espacial e atributos do solo antes e após calagem e fosfatagem em doses variadas na cultura de cana-de-açucar. Engenharia Agrícola, 26(2):374-387, 2006. 10.1590/S0100-69162006000200005.

DIAS-FILHO, M. B. Degradação de pastagens: processos, causas e estratégias de recuperação. 4. ed. reimp. Belém: Embrapa Amazônia Oriental, 2011, 215p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, EMBRAPA. Sistema Brasileiro de Classificação de Solos. 3ed. Brasília: Embrapa, 2013, 353p.

FONSECA, A. A.; SANTOS, V. A. C. ALONSO, M. P.; SILVA, M. R. Intensificação na produção animal em pastejo: revisão bibliográfica. PUBVET, 7(11):1-22, 2013.

GOLDEN SOFTWARE. Surfer version 13. Colorado: Golden. 2015.

GOMES, R. A.; LEMPP, B.; JANK, L.; CARPEJANI, G. C.; MORAIS, M. G. Características anatômicas e morfofisiológicas de lâminas foliares de genótipos de *Panicum maximum*. Pesquisa Agropecuária Brasileira, 46(2): 205-211, 2011. 10.1590/S0100-204X2011000200013.

LIMA, J. S. S.; SOUZA, G. S.; SILVA, S. A. Amostragem e variabilidade espacial de atributos químicos do solo em área de vegetação natural em regeneração. Revista Árvore, 34(1):127-136, 2010. 10.1590/S0100-67622010000100014.

LOPES, M. N.; CÂNDIDO, M. J. D.; POMPEU, R. C. F. F.; SILVA, R. G.; CARVALHO, T. C. F.; SOMBRA, W. A.; MORAIS NETO, L. B.; PEIXOTO, M. J. A. Biomass flow in massai grass fertilized with nitrogen under intermittent stocking grazing with sheep. Revista Brasileira de Zootecnia, 42(1): 13-21, 2013. 10.1590/S1516-35982013000100003.

LOPES, M. N.; CÂNDIDO, M. J. D.; POMPEU, R. C. F. F.; SILVA, R. G.; CARNEIRO, M. S. S.; MORAIS NETO, L. B.; PEIXOTO, M. J. A.; CARVALHO, T. C. F. Biomass components and structure of massai grass fertilized with nitrogen and grazed by sheep. Arquivo Brasileiro Medicina Veterinária e Zootecnia, 71(4): 1411-1420, 2019. 10.1590/1678-4162-10051.

MATHERON, G. Principles of geostatistics. Economic Geology, 58(8):246-1266, 1963.

MÜLLER, M. M. L.; CECCON, G.; ROSOLEM, C. A. Influência da compactação do solo em subsuperfície sobre o crescimento aéreo e radicular de plantas de adubação verde de inverno. Revista Brasileira de Ciência do Solo, 25(3):531-538, 2001. 10.1590/S0100-06832001000300002.

PARIZ, C. M.; CARVALHO, M. P.; CHIODEROLI, C. A.; NAKAYAMA, F. T.; ANDREOTTI, M.; MONTANARI, R. Spatial variability of forage yield and soil physical attributes of a *Brachiaria decumbens* pasture in the Brazilian Cerrado. Revista Brasileira de Zootecnia. 40(10):2111-2120, 2011. 10.1590/S1516-35982011001000007.

PENATI, M. A.; CORSI, M.; CONGIO, G. F. S.; ALMEIDA, P. C.; GOULART, R. C. D.; SHIOTA, M. M. Effects of post-grazing forage mass on a beef cattle grazing system on Tanzânia grass pastures. Revista Brasileira de Zootecnia*,* 43(6):296-300, 2014. 10.1590/S1516-35982014000600003.

PEREIRA, L. E. T.; PAIVA, A. J.; GEREMIA, E. V.; SILVA, S. C. Grazing management and tussock distribution in elephant grass. Grass and Forage Science, 70(3): 406-417, 2015. https://doi.org/10.1111/gfs.12137.

ROBERTSON, G. P. Geostatistics for the environmental sciences: GS+ user's guide users guide. Plainwell: Gamma Desing Software. 1998. 152p.

RODRIGUES, M. O. D.; SANTOS, A. C.; RODRIGUES, M. O. D.; SILVEIRA JÚNIOR, O.; ARAÚJO, A. S.; OLIVEIRA FILHO, J. H. Diagnóstico da estrutura horizontal de capim mombaça em sistema silvipastoril pastejado por ovinos. AmazonSoil –I Encontro de Ciência do Solo da Amazônia Oriental, 91-101, 2014.

SANTOS, M. E. R. Variabilidade espacial da vegetação e produção animal monoespecífica: proposta de um modelo conceitual. Revista Brasileira de Agropecuária Sustentável, 1(1):129-136, 2011. 10.21206/rbas.v1i1.22.

SCHIPPER, L. A.; PARFITT, R. L.; FRASER, S.; LITTLER, R. A.; BAISDEND, W. T.; ROSS, C. Soil order and grazing management effects on changes in soil C and N in New

Zealand pastures. Agriculture, Ecosystems & Environment, 184(1), 67-75, 2014. 10.1016/j.agee.2013.11.012.

SILVA, R. G.; NEIVA, J. N. M.; SANTOS, A. C.; CÂNDIDO, M. J. D.; SOUSA, A. L. D.; LOPES, M. N.; SILVA, R. O.; CARNEIRO, L. C. Spatial distribution of feces and estimates of nitrogen return by dairy cows on mombasa grass pastures. Revista Brasileira de Zootecnia, 42(5): 369-380, 2013. 10.1590/S1516-35982013000500010.

SOUZA, Z. M.; SAOUZA, G. S.; MARQUES JÚNIOR, J.; PEREIRA, G. T. Número de amostras na análise geoestatística e na krigagem de mapas de atributos do solo. Ciência Rural, 44(2), 261-268, 2014. 10.1590/S0103-84782014000200011.

SOUZA, E. L.; CRUZ, P. J. R.; BONFÁ, C. S.; MAGALHÃES, M. A. Plantas forrageiras para pastos de alta produtividade. Nutri Time, 15(04), 8272-8284, 2018.

SOUZA, F. H. M.; VIOLA, M. R.; AVANZI, J. C.; GIONGO, M.;, VIEIRA FILHO, M. Thornthwaite's climate regionalization for the state of tocantins, Brazil. Floresta, 49(4), 783 – 792, 2019. 10.5380/rf.v49 i4.59188.

SPAIN, J. M.; GUALDRÓN, R. Degradación e rehabilitación de pasturas. In: LASCANO, C.; SPAIN, J. M. (eds.). Establecimiento y renovación de pasturas. Cali: CIAT, 1991, p.269-271.

TOWNSEND, C. R.; COSTA, N. L.; PEREIRA, R. G. A. Recuperação e práticas sustentáveis de manejo de pastagens na Amazônia. 1ed. Porto Velho: Embrapa Rondônia, 2012, 28p.

VENDRAMINI, J. M. B.; SILVEIRA, M. L.; DUBEUX JUNIOR, J. C. B.; SOLLENBERGER, L. E. Environmental impacts and nutrient recycling on pastures grazed by cattle. Revista Brasileira de Zootecnia, 369(1):139-149, 2007. 10.1590/S1516-35982007001000015.

VIEIRA, S. R.; HATFIELD, J. L.; NIELSEN, D. R.; BIGGAR, J. W. Geostatistical theory and application to variability of some agronomical properties. Hilgardia, 51(3):1-75, 1983.10.3733/hilg.v51n03p075.

WARRICK, A. W.; NIELSEN, D. R. Sapatial variability of soil physical properties in the field. In: HILLEL, D. (eds.). Application of soil physics. New York: Academic Press, 1980, p.319-344.