ISSN 2175-6813

Revista Engenharia na Agricultura

Viçosa, MG, DEA/UFV - DOI: 10.13083/reveng.v29i1.12556 v.29, p.254-262, 2021

SPATIAL VARIABILITY OF CHLOROPHYLL CONTENT IN A TIFTON 85 BERMUDAGRASS PASTURE IN A TROPICAL REGION

João Luiz Jacintho[1], Gabriel Araújo e Silva Ferraz[2], Brenon Diennevan Souza Barbosa[3], Patrícia Ferreira Ponciano Ferraz[2] & Sthéfany Airane dos Santos*[2]

1 - Federal Institute of Northern Minas Gerais, Department of Education, Araçuaí, Minas Gerais, Brazil.

2 - Federal University of Lavras, School of Engineering, Department of Agricultural Engineering, Lavras, Minas Gerais, Brazil.

3 - Klabin S /A, Telêmanco Borba, Paraná, Brazil.

Keywords:
Precision agriculture
Geostatistics
Pasture
Semivariograms
Kriging

ABSTRACT

Precision Agriculture techniques, such as the management of spatial variability of crop attributes, have been studied for several crops. However, few studies have been performed on Tifton 85 bermudagrass. Thus, this work aimed to analyse the spatial variability of chlorophyll content in a Tifton 85 bermudagrass production area, located in Seropédica, Brazil. A georeferenced grid was created to measure the chlorophyll content in two periods using a portable chlorophyll metre. Different geostatistical methods and models were evaluated in order to identify which had the best fit to analyze the spatial dependence of the chlorophyll content.The atribute was mapped based on interpolation by the ordinary kriging method. Therefore, kriging interpolation was used to create isoline maps, which were used to observe the spatial variability of the chlorophyll content. The methodology and maps generated proved to be of great value to the Tifton 85 bermudagrass producers.

Palavras-chave:
Agricultura de precisão
Geoestatística
Pastagem
Semivariograma
Krigagem

VARIABILIDADE ESPACIAL DO TEOR DE CLOROFILA EM PASTAGEM DE CAPIM-TIFTON 85 EM REGIÃO TROPICAL

RESUMO

Técnicas de Agricultura de Precisão, como o gerenciamento da variabilidade espacial dos atributos das plantas, foram estudadas para várias culturas. Entretanto, poucos estudos foram realizados para o capim-tifton 85. Assim, este trabalho teve como objetivo analisar a variabilidade espacial do teor de clorofila em uma área de produção de capim-tifton 85, localizada em Seropédica-RJ, Brasil. Uma malha georreferenciada foi criada para amostrar o teor de clorofila em dois períodos, utilizando-se um medidor portátil de clorofila. Foram avaliados diferentes métodos e modelos geoestatísticos, com o intuito de identificar qual possuía o melhor ajuste para analisar a dependência espacial do teor de clorofila. O atributo foi mapeado com base na interpolação pelo método de krigagem ordinária. Portanto, a interpolação por krigagem foi usada para criar mapas de isolinhas, que foram utilizados para se observar a variabilidade espacial do teor de clorofila das plantas. A metodologia e os mapas gerados provaram ser de grande valia para os produtores de capim-tifton 85.

SECTION EDITOR IN CHARGE
Michael Silveira Thebaldi

Received 20 May, 2021 • Accepted 02 Jul, 2021 • Published 28 Sep, 2021

Email (corresponding author)*: thethsantos@hotmail.com

INTRODUCTION

The use of *Cynodon* grasses in agriculture has grown exponentially due to the advantages they provide, especially in tropical and subtropical regions (HANNA; ANDERSON, 2008; BASEGGIO *et al*., 2015). In Brazil, Tifton 85 bermuda grass (Cynodon spp.) is predominantly used among ranchers (PEDREIRA *et al*., 2018). The extensive use of this forage by Brazilian ranchers is due to the advantages offered by this species, such as high hay productivity and tolerance to saline and sodic soils (FONSECA *et al*., 2006).

The monitoring of nutritional status and the management of Tifton 85 can be carried out by estimating the chlorophyll content (SILVA *et al*., 2011). This variable is directly proportional to the levels of some nutrients, mainly nitrogen. According to Barbieri Júnior *et al*. (2010), chlorophyll directly influences the amount of solar radiation absorbed by plants, and chlorophyll concentrations in leaves are closely related to photosynthetic rates and primary productivity.

For the proper management of a pasture area, according to Silva *et al*. (2011), it is possible to use a "chlorophyll meter" to directly measure the chlorophyll content in a plant and use the data obtained to indirectly estimate the need for nitrogen fertilization in the area (BARBIERI JÚNIOR *et al*. al., 2012), reducing sampling time and cost when compared to laboratory analyses.

The application of precision farming (PA) techniques, defined as agricultural practices based on information to manage the spatial variability of a crop (BERNARDI *et al*., 2016), combined with grass management, has the potential to increase productivity.

Within the PA, the use of GNSS (Global Navigation Satellite System) has a fundamental role in the application of remote sensing and geostatistics, which are fundamental techniques for the assessment of the spatial and temporal variability of attributes related to soils and plants of a crop .

For the processing of georeferenced data, geoprocessing is used, which include technologies for collecting, processing, analyzing and making available information with geographic reference (CÂMARA *et al*., 2004). Modeling via GIS makes it possible to merge these layers of information, expanding the ability to interpret data and assisting in decision making for the management of the production system (FILIPPINI ALBA, 2014).

Geostatistics is the study of a natural phenomenon, which can be characterized by the distribution in space of one or more variables, called "regionalized variables" (JOURNEL; HUIJBREGTS, 1978). The study of these variables aims to solve the estimation problems for those places where sampling was not performed (SANTOS *et al*., 2017).

As Brazil has large areas of pastures used for livestock or hay production and has had difficulties to expand the areas of planted pastures, the adoption of PA techniques is essential. PA tools were initially used in grain crops, but there are already several experimental and practical results indicating the potential for use in pastures (BERNARDI; PEREZ, 2014; BERNARDI *et al*., 2016).

The present study aims to evaluate the spatial and temporal variability of chlorophyll content in an area with Tifton 85 grass using geostatistics and kriging techniques to generate thematic maps representing the spatial variability of chlorophyll content in a grass pasture canopy -Tifton 85.

MATERIALS AND METHODS

Study area

The study area is located in the Seropédica municipality, Rio de Janeiro state, Brazil, at geographical coordinates 22°44'38''S and 43°42'27" W SIRGAS 2000 and belongs to the Federal Rural University of Rio de Janeiro. The study field has a total area of 3.25 ha cultivated with Tifton 85 bermudagrass. The climate of theregion is classified as Aw, according to Köppen's classification (KÖPPEN, 1936), with mean annual precipitation of 1,213 mm and mean annual temperature of 23.9 ºC. Figure 1 shows the variation of temperature and precipitation during the study period.

Sampling grid

The study area was delimited using an SP-60 GPS receiver (Garmin, Kansas, USA). In this area, two sampling grids (Figure 2) were delimited. Sampling grid 1 (A1-07/09/2014) was defined considering a 15 x 15 m spacing between samples, generating a total of 57 sampling points and a sampling density of 17.6 points ha^{-1} on the referenced date. Sampling grid 2 (A2-07/16/2014) was defined considering a spacing of 30 x 30 m, generating a total of 47 sample points (14.46 points ha^{-1}). The geographical coordinates of the sampling points were also collected with the help of the GPS receiver.

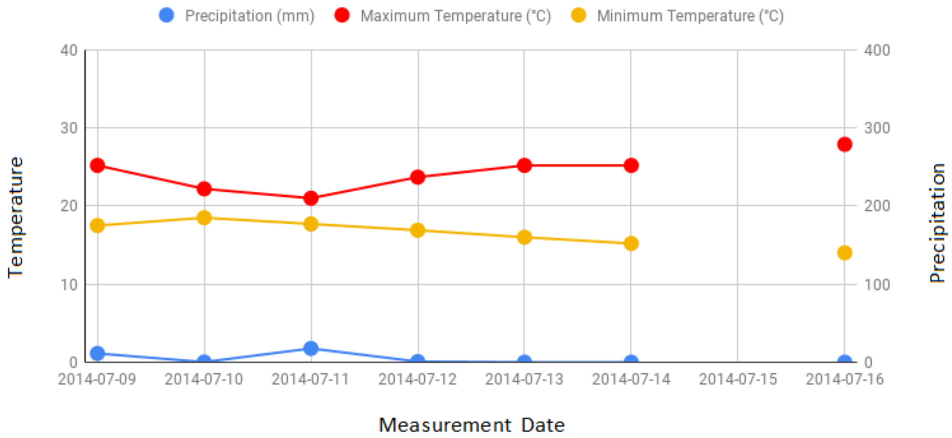

Figure 1. Climograph of study area

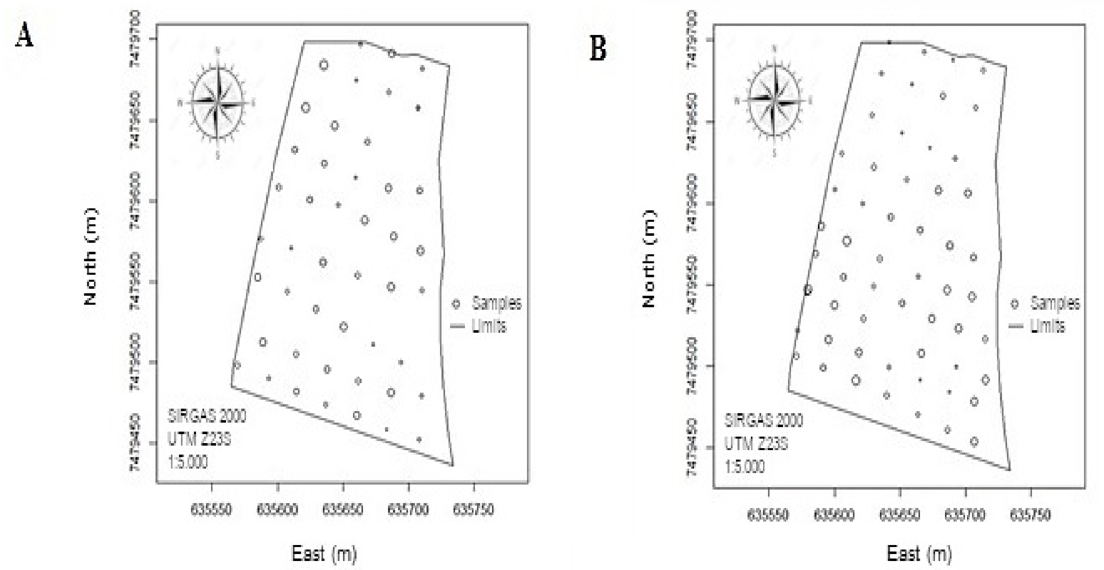

Figure 2. Sampling grids: (A)- 09/16/2014, (B)- 07/16/2014

The chlorophyll content was determined using a portable chlorophyll metre, model CFL 1030 (Falker Automação Agrícola, Porto Alegre, Brazil), operated according to the technical specifications provided by the equipment's manual. For the sampling, the first fully expanded leaf (in the direction from the end to the base of the tiller) was selected, which was fully exposed at the time of sampling, according to the methodology described by Barbieri Júnior *et al*. (2012).

Descriptive statistic analyses

A descriptive statistical analysis of the collected data was performed, evaluating the maximum, minimum, mean, coefficient of variation (CV), standard deviation (SD), and variance (Var) to observe variations in the collected dataset.

Geostatistical analyses

The spatial dependence of the chlorophyll content was analysed by fitting classical (MATHERON, 1965) (Equation 1) and robust (Equation 2) semivariograms.

$$\hat{\gamma}(h)=\frac{1}{2N(h)}\sum_{i=1}^{N(h)}\left[Z(x_i)-Z(x_i+h)\right]^2 \qquad (1)$$

Where N(h) represents the number of experimental pairs of observations, $Z(x_i)$ and $Z(x_i+h)$ at locations x_i and xi+h, respectively, separated by a distance h. The semivariogram is represented by the graph (h) versus h. By fitting the mathematical model to the (h), the coefficients of the theoretical semivariogram model are estimated: nugget effect (C_0), sill (C_0+C_1) and range (a) (CRESSIE, 1992). According to Ferraz *et al*. (2012), the robust estimator of the semivariogram is less susceptible to the influence of the dataset values than the classical estimator. Thus, the robust estimator is described in Equation 2:

$$\hat{\gamma}(h)=\frac{1}{2}\frac{\left[N(h)^{-1}\,\Sigma_{N(h)}\sqrt{\left|\left(Z(xi+h)-Z(xi)\right)\right|}\right]^4}{0.457+\frac{0.494}{N(h)}} \quad (2)$$

This estimator considers that the differences $Z(x_i+h)-Z(x_i)$ are distributed normally for all pairs $(x_i+h,\ x_i)$. The denominator of the equation is the trend correction, and the square root transformation of the differences is presented, similar to the moments of a normal distribution (FERRAZ *et al*., 2012).

The semivariogram models were fitted with error minimization methods, namely, the Ordinary Least Squares (OLS) and Weighted Least Squares (WLS) methods, estimated using the classical and robust estimation methods and the Maximum Likelihood (ML) and Restricted Maximum Likelihood (REML) methods. For all error minimization methods, the spherical, exponential, and gaussian models were fitted to the experimental semivariograms.

The best fit models were selected based on the cross-validation method (ISAAKS; SRIVASTAVA, 1989), using the mean error (ME), root mean square error (RMSE), average standard error (ASE), and root mean square standardized error (RMSSE). The criteria for choosing the best fit model were the ME and ASE values closest to zero, the lowest RMSE value, and the RMSSE value closest to one (FERRAZ *et al*., 2012).

After fitting the semivariogram models, the Tifton 85 chlorophyll content was interpolated for non-sampled sites using the ordinary kriging interpolation method. Subsequently, the thematic maps were prepared for the two sampling dates.

Descriptive statistical analysis and geostatistical analysis were performed using the geoR library of the R (CORE DEVELOPMENT, 2014) statistical computer system (RIBEIRO JÚNIOR; DIGGLE, 2001).

RESULTS AND DISCUSSION

Descriptive statistics

The measured chlorophyll contents have a CV above 10%, indicating variability among the data (Table 1). According to Gomes e Garcia (2002), a CV below 10% indicates homogeneity.

The CV, according to the classification of Warrick and Nielsen (1980) was intermediate, where the highest CV was observed for the sampling on 07/16/14 (40.3%). This variation can be attributed to the size of the sampling grid used during these periods.

The mean values of the two periods were similar (26.33 and 25.93). The maximum, minimum, and median values were lower for the sampling on 07/16/14, which was due to the plants being at a later development stage. As a consequence, the SD and Var were larger for this period, indicating a greater variability of the data in the area.

As noted, the data referenced to the mean, minimum and maximum values found in Table 1 shows the variation in values for this variable. However, knowledge of these measures alone cannot be used as the only way to identify a variable expression in an area. Therefore, a geostatistical analysis is carried out with the objective of verifying the spatial variability of a variable and, if identified, thematic maps are made that help to understand its behavior in the field.

Spatial distribution

The cross-validation criteria allowed the selection of the best semivariogram models for each data collection date (Table 2 and 3). The chlorophyll content values for the sampling on 07/09/2014 were estimated using the WLS-C method with a spherical model (Table 2 and Figure 3A). For the sampling on 07/16/2014, the variability of chlorophyll content was estimated using the ML method fitted with the exponential model (Exp) (Table 3 and Figure 3B).

Table 1. Descriptive statistics of chlorophyll content for the two sampling periods

Date	Mín.	Máx.	Mean	Median	SD	Var	CV
07/09/2014	8.90	44.70	26.33	27.30	8.00	63.93	30.4%
07/16/2014	5.70	52.80	25.93	24.20	10.46	109.42	40.3%

Table 2. Methods, models and estimated parameters of the experimental semivariograms for the chlorophyll variable on the date 07/09/2014

Method	Model	C_0	C_1	$C_0 + C_1$	a	a'	EM	RMSE	ASE	RMSSE
OLS-C	Sph	0.0	63.7	63.7	34.0	34.0	0.2	8.3	0.0	1.2
OLS-C	Exp	0.0	64.7	64.7	12.4	37.0	0.2	8.4	0.0	1.6
OLS-C	Gau	52.4	14.1	66.5	47.5	82.2	0.0	8.2	0.0	1.0
WLS-C	Sph	0.0	64.0	64.0	32.8	32.8	0.2	8.3	0.0	1.9
WLS-C	Exp	54.8	111.3	166.1	763.7	2287.8	-2.6	8.3	-1.1	1.0
WLS-C	Gau	56.9	14.2	71.0	77.7	134.5	6.8	8.2	4.5	1.0
OLS-R	Sph	18.4	38.7	57.1	22.3	22.3	0.1	8.1	0.0	1.1
OLS-R	Exp	49.6	27509.8	27559.4	195450.8	585518.	3.5	8.3	3.1	1.1
OLS-R	Gau	32.2	24.9	57.1	5.6	9.6	0.1	8.1	0.0	1.1
WLS-R	Sph	17.3	40.9	58.2	23.4	23.4	0.1	8.1	0.0	1.1
WLS-R	Exp	53.5	11668.8	11722.3	138499.9	414908.	0.0	8.3	0.6	1.1
WLS-R	Gau	33.9	24.3	58.2	6.4	11.1	0.1	8.1	0.0	1.1
ML	Sph	41.8	20.4	62.2	19.4	19.4	0.0	8.1	0.0	1.0
ML	Exp	34.3	27.9	62.2	1.5	4.3	0.0	8.1	0.0	1.0
ML	Gau	27.4	34.8	62.2	0.7	1.2	0.0	8.1	0.0	1.0
REML	Sph	42.4	21.2	63.6	18.6	18.6	0.0	8.1	0.0	1.0
REML	Exp	26.4	37.2	63.6	0.8	2.5	0.0	8.1	0.0	1.0
REML	Gau	40.8	22.7	63.6	1.5	2.6	0.0	8.1	0.0	1.0

C0 – Nugget effect; C1 – Contribution; C0 + C1 – sill; a – range; a' – practical range; EM – Mean Error; RMSE – Root Mean Square Error; ASE – Average Standard Error; RMSSE– Root Mean Square Error; OLS-C – ordinary least squares Classic estimator; WLS-C – weighted least squares Classic estimator; OLS-R - Ordinary Least Squares Robust estimator; WLS-R – Weighted Least Squares Robust estimator; ML – Maximum Likelihood; REML – Restricted Maximum Likelihood; Sph – spherical; Exp – Exponential; Gau – Gaussian

Table 3. Methods, models and estimated parameters of the experimental semivariograms for the chlorophyll variable on the date 07/16/2014

Method	Model	C_0	C_1	$C_0 + C_1$	a	a'	EM	RMSE	ASE	RMSSE
OLS-C	Sph	0.0	96.1	96.1	33.1	33.1	-0.2	9.8	-0.0	1.2
OLS-C	Exp	0.0	98.9	98.9	14.0	41.9	-0.1	9.6	-0.0	1.1
OLS-C	Gau	0.0	96.9	96.9	17.0	29.4	-0.2	11.6	-0.0	2.7
WLS-C	Sph	0.0	97.6	97.6	31.1	31.1	-0.2	9.9	-0.0	1.2
WLS-C	Exp	0.0	99.0	99.0	11.6	35.0	-0.1	9.8	-0.0	1.1
WLS-C	Gau	0.0	98.1	98.1	15.6	27.4	-0.2	10.8	-0.0	2.4
OLS-R	Sph	0.0	97.9	97.9	32.9	32.9	-0.2	9.8	-0.0	1.2
OLS-R	Exp	0.0	100.6	100.6	13.6	40.9	-0.1	9.6	-0.0	1.1
OLS-R	Gau	0.0	98.8	98.8	17.0	29.5	-0.2	11.6	-0.0	2.6
WLS-R	Sph	0.0	99.1	99.1	30.7	30.7	-0.2	10.0	-0.0	1.2
WLS-R	Exp	0.0	100.3	100.3	11.1	33.2	-0.1	9.9	-0.0	1.1
WLS-R	Gau	0.0	99.6	99.6	15.7	27.1	-0.2	10.7	-0.0	2.3
ML	Sph	71.8	46.0	117.8	149.5	149.4	0.0	9.5	0.0	1.0
ML	Exp	61.0	56.3	117.3	51.0	152.9	-0.0	9.5	0.0	1.0
ML	Gau	81.6	38.1	119.7	84.8	146.8	0.0	9.6	0.0	1.0
REML	Sph	71.0	135.3	206.3	420.4	420.4	0.0	9.4	0.0	1.0
REML	Exp	69.1	149.6	218.7	260.1	779.4	0.0	9.4	0.0	1.0
REML	Gau	82.3	62.4	144.7	110.0	190.4	0.0	9.6	0.0	1.0

C0 – Nugget effect; C1 – Contribution; C0 + C1 – sill; a – range; a' – practical range; EM – Mean Error; RMSE – Root Mean Square Error; ASE – Average Standard Error; RMSSE– Root Mean Square Error; OLS-C – ordinary least squares Classic estimator; WLS-C – weighted least squares Classic estimator; OLS-R - Ordinary Least Squares Robust estimator; WLS-R – Weighted Least Squares Robust estimator; ML – Maximum Likelihood; REML – Restricted Maximum Likelihood; Sph – spherical; Exp – Exponential; Gau – Gaussian

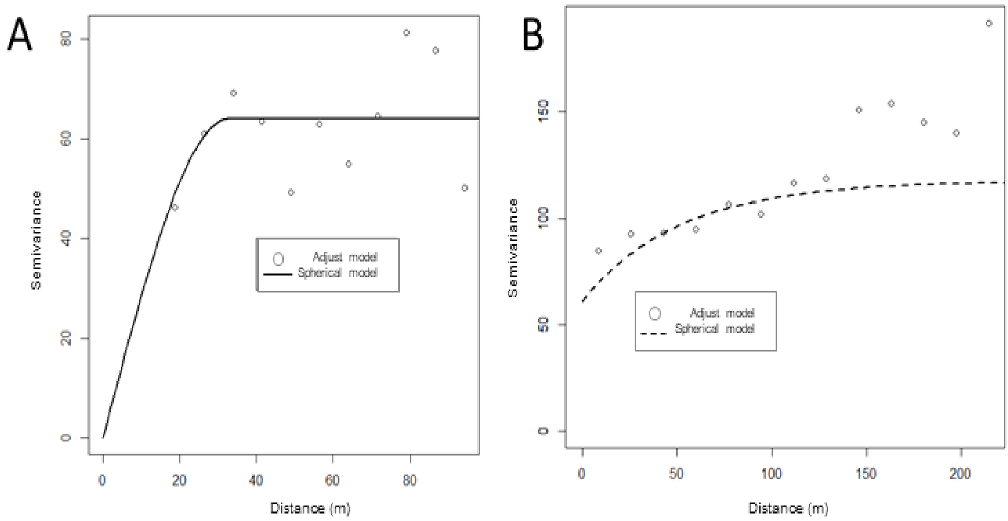

Figure 3. Semivariograms chosen according to the WLS-C method and spherical model for 07/09/2014 (A) and using the ML method and exponential model for 07/16/2014 (B)

According to geostatistical analysis, the semivariogram modelling using the spherical model did not detect spatial variability in Figure 3, for the sampling on 07/09/2014, showing a pure nugget effect. Thus, the spatial variability of chlorophyll content in this area and for this sampling grid (30 x 30 m) is considered to be random, and according to Cambardella *et al*. (1994). The distances between samples must be reduced to detect the spatial variability in chlorophyll content. However, this result can also be attributed to field measurement errors. In Figure 3B, spatial dependence was detected, with a C_0 value of 61.02 for 07/16/2014.

The values differed in the two sampling periods, with 32.764 m on 09/07/2014 and 152.909 m on 07/16/2014. According to Ferraz *et al*. (2012), a sampling plan that considers the existing spatial variability would also have to consider the differences in the range found, always using values lower than the smaller range value to construct a more adequate sampling grid.

After fitting the semivariogram, chlorophyll values were estimated by ordinary kriging for the entire area. The thematic maps of the spatial distribution of chlorophyll content for the two periods are represented in Figure 3.

An analysis of the maps (Figure 4) reveals the temporal variation of the chlorophyll content during the study period. In the northern region of the area Figure 4B (07/16/2014), there was a reduction in the estimated chlorophyll content relative to Figure 4A (07/09/2014). Oliveira *et al*. (2010) found similar results for the chlorophyll content in June and July, when there is a reduction of the photoperiod, lower water availability, and lower net radiation (decreasing mean air temperatures), with a consequent reduction of the growth rates of the plants.

Another plausible explanation for the chlorophyll content variation can be attributed to the climatic factors and relief of the study site. The automatic weather station at Seropédica km 47 of the Brazilian National Institute of Meteorology (INMET) recorded that in the days before the 07/09/2014 sampling, there was a seven-day dry period, interrupted by 11.2 mm of rainfall on the eve of the first measurement (INMET, 2014) and that in the interval between measurements, there was another dry period. This accumulation of dry periods may have triggered senescence of the plants, thus affecting their development. This reduction in chlorophyll content in grasses caused by water scarcity was reported by Silva *et al*. (2006), where the reduction of chlorophyll was observed in grasses under increased water deficit.

The most significant decrease in chlorophyll content occurred in the northern part of the area, which is the highest region. This high slope reduces the water infiltration (OLIVEIRA *et al*., 2012) and storage rates in the soil. The centre-south part of the area presents a less irregular relief, which facilitates water storage by the soil and helps with crop maintenance.

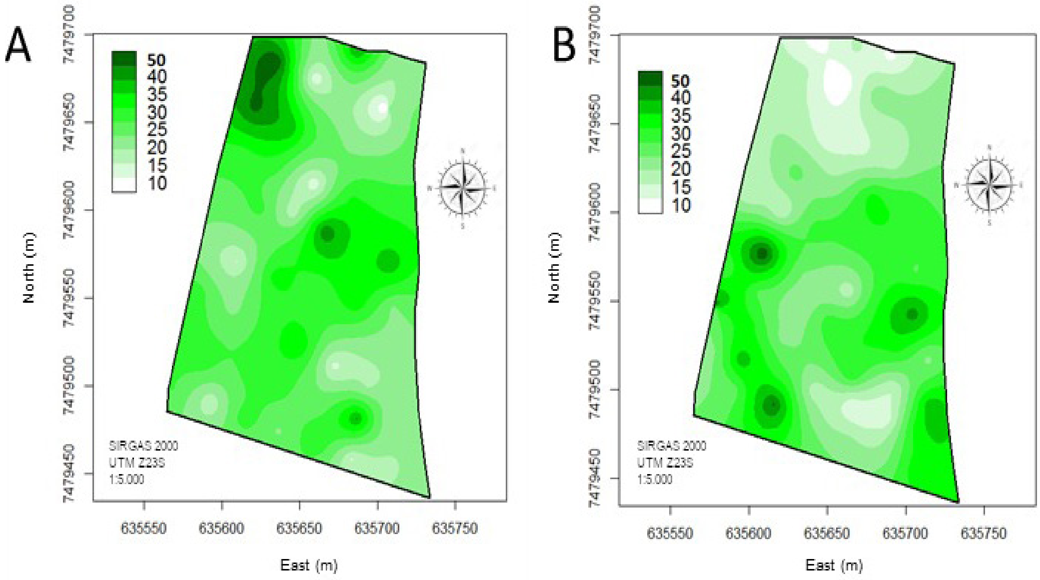

Figure 4. Spatial distribution maps of chlorophyll content for days 07/09/2014 (A) and 07/16/2014 (B)

The thematic maps of chlorophyll content (Figure 4) in conjunction with chemical soil attributes maps are important tools for the management of Tifton 85 bermudagrass, reducing the yield variability in the area during the production cycle.

CONCLUSIONS

- The chlorophyll content present in Tifton 85 grass evaluated in the two study areas showed heterogeneity by calculating the coefficient of variation obtained in the basic statistics. Through interpolation by ordinary kriging, it was possible to select the best method and best model to adjust the data and thus make the spatial variability maps of the chlorophyll content.
- The use of geoestistics associated with PA was an important tool to identify the spatial and temporal distribution of chlorophyll content in Tifton 85 grass in non-sampled locations, which will reflect in a better management for this crop.

AUTHORSHIP CONTRIBUTION STATEMENT

JACINTHO, J.L.: Data curation, Funding acquisition, Investigation, Methodology, Writing – review & editing; **FERRAZ, G.A.S.**: Conceptualization, Project administration, Supervision, Visualization, Writing – review & editing; **BARBOSA, B.D.S.**: Formal Analysis, Software, Validation, Visualization, Writing – review & editing; **SANTOS, S. A.**: Project administration, Resources, Supervision, Visualization, Writing – original draft; **FERRAZ, P.F.P.**: Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENTS

The authors would like to thanks, the National Council for Scientific and Technological Development (CNPq) and the Coordination for the Improvement of Higher Education Personnel (CAPES) for the scollarship to the authors, the Federal University of Lavras (UFLA) and the Rural Federal University of Rio de Janeiro (UFRRJ) for the support.

REFERENCES

BARBIERI JUNIOR, É.; ROSSIELLO, R. O. P.; SILVA, R. V. M. M.; RIBEIRO, R. C.; MORENZ, M. J. F. A new chlorophyll meter for estimating chlorophyll content in leaves of Tifton 85 grass. **Ciência Rural,** Santa Maria, v.42, n.12, p.2242-2245, 2012.

BARBIERI JUNIOR, É.; ROSSIELLO, R. O. P.; MORENZ, M. J. F.; RIBEIRO, R. C. Comparison of direct methods of extraction and quantification of chlorophyll content in leaves of Tifton grass 85. **Ciência Rural**, Santa Maria, v.40, n.3, p.633-636, 2010.

BASEGGIO,M.NEWMAN,Y.;SOLLENBERGER, L. E.; FRAISSE, C.; OBREZA, T. Planting rate and depth effects on Tifton 85 bermudagrass establishment using rhizomes. **Crop Science**, v.55, n.3, p.1338-1345, 2015.

BERNARDI, A. C. C.; NAIME, J. M.; RESENDE, A. V.; BASSOI, L. H.; INAMASU, R. Y. Precision Agriculture: Results of a New Look. Brasília: Embrapa**,** 2014.

BERNARDI, A. C. de C.; PEREZ, N. B. Agricultura de precisão em pastagens. In: BERNARDI, A. C. de C.; NAIME, J. de M.; RESENDE, A. V. de; BASSOI, L. H.; INAMASU, R. Y. (Ed.). Agricultura de precisão: resultados de um novo olhar. Brasília, DF: Embrapa, 2014.

BERNARDI, A. C. de C.; BETTIOL, G M.; FERREIRA, R. de P.; SANTOS, K. E. L.; RABELLO, L. M.; INAMASU, R. Y. Spatial variability of soil properties and yield of a grazed alfalfa pasture in Brazil. Precision Agriculture, v. 17, n.6, p. 737-752, 2016.

CÂMARA, G.; MONTEIRO, A. M.; DRUK, S.; CARVALHO, M. S. Análise espacial e geoprocessamento. In: DRUCK, S.; CARVALHO, M. S.; CÂMARA, G.; MONTEIRO, A. M. Análise espacial de dados geográficos. Planaltina, DF: Embrapa Cerrados, 2004.

CAMBARDELLA, C. A.; MOORMAN, T. B.; PARKIN, T. B.; KARLEN, D. L.; NOVAK, J. M.; TURCO, R. F.; KONOPKA, A. E. Field-scale variability of soil proprieties in central Iowa soils. **Soil Science Society America Journal**, Medison, v.58, p.1240-1248, 1994.

CRESSIE, N. Statistics for spatial data. **Terra Nova**, v.4, n.5, p.613-617, 1992.

FERRAZ, G. A. S.; SILVA, F. M. D.; CARVALHO, L. C.; ALVES, M. D. C.; FRANCO, B. C. Spatial and temporal variability of phosphorus, potassium and of the yield of a coffee field. **Engenharia Agrícola**, v.32, n.1, p.140-150, 2012.

FILIPPINI-ALBA, J. M. Modelagem SIG em agricultura de precisão: conceitos, revisão e aplicações. In: BERNARDI, A. C. C.; NAIME, J. M.; RESENDE, A. V.; BASSOI, L. H.; INAMASU, R. Y. (Ed.). Agricultura de precisão: resultados de um novo olhar. São Carlos: Embrapa Instrumentação, 2014.

FONSECA, A. F.; MELFI, A. J.; MONTEIRO, F. A.; MONTES, C. R.; de ALMEIDA, V. V.; HERPIN, U. Treated sewage effluent as a source of water and nitrogen for Tifton 85 bermudagrass. **Agricultural Water Management**, v.87, n.3, p.328-336, 2006.

GOMES, F. P.; GARCIA, C. H. Statistics applied to agronomic and forest experiments. FEALQ: Piracicaba, 2002.

HANNA, W. W.; ANDERSON, W. F. Development and impact of vegetative propagation in forage and turf bermudagrasses. **Agronomy journal**, 100 (Supplement_3), S-103, 2008.

INMET - National Institute of Meteorology. Automatic Station Seropédica km 47. Available in: <www.inmet.gov.br/sonabra/pg_dspDadosCodigo.php?QTYwMQ >. 27 Set. 2014.

ISAAKS, E.H.; SRIVASTAVA, R. M. An introduction to applied geostatistics. New York: Oxford University, 1989.

JOURNEL, A. G. & HUIJBREGTS, J.C.H. Mining geostatistics. London: Academic Press, 1978.

KÖPPEN, W. Das geographische System der Klimate. In: KÖPPEN, W.; GEIGER, R. (Eds): Handbuch der Klimatologie. Berlin: Gebrüder Bornträger, 1936.

MATHERON, G. Les variables régionalisées et leur estimation. Paris: Masson, 1965.

OLIVEIRA, A. H.; da SILVA, M. A.; SILVA, M. L. N.; AVANZI, J. C.; CURI, N.; LIMA, G. C.; PEREIRA, P. H. Environmental characterization and prediction of soil organic matter contents in the Salto Sub-Basin, Extrema, MG. Semina: **Ciências Agrárias,** v.33, n.1, 2012.

OLIVEIRA, A. H.; da SILVA, M. A.; SILVA, M. L. N.; AVANZI, J. C.; CURI, N.; LIMA, G. C.; PEREIRA, P. H. Responses of Tifton 85 grass to nitrogen application & 58; soil cover, leaf área index and solar radiation interception. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia, v.**62, n.2, p.429-438, 2010.

PEDREIRA, C. G. S.; SILVA, V. J. D.; GUIMARÃES, M. S.; PEQUENO, D. N. L.; TONATO, F. Fixed versus variable rest period effects on herbage accumulation and canopy structure of grazed'Tifton 85'and'Jiggs' Bermuda grass. **Pesquisa Agropecuária Brasileira**, v.53, n.1, p.113-120, 2018.

R DEVELOPMENT Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2014. Available in: <http://www.R-project.org/>. Accessed Jun. 29, 2014.

RIBEIRO JÚNIOR, P. J.; DIGGLE, P. J. 2001. GeoR: a package for geostatisticalanalysis. **R-News**, v.1, p.14-18, 2001.

SANTOS,K.E.L.;BERNARDI,A.C.C.;BETTIOL, G. M.; CRESTANA, S. GEOSTATISTICS AND GIS IN THE DECISION MAKING OF THE USE OF INPUTS IN A PASTURE. **Brazilian Journal of Biosystems Engineering** v.11, n.3, p.294-307, 2017.

SILVA, M. M. P. D.; VASQUEZ, H. M.; BRESSAN-SMITH, R.; SILVA, J. F. C. D.; ERBESDOBLER, E. D. A.; ANDRADE JUNIOR, P. S. C. D. Photochemical efficiency of tropical forage grasses submitted to water deficiency. **Revista Brasileira de Zootecnia,** v.35, n.1, p.67-74, 2006.

SILVA, R. V. M. M.; ROSSIELLO, R. O. P.; MORENZ, M. J. F.; JUNIOR, É. B.; GOMES, R. L. T.; CAMARGO FILHO, S. T. Use of chlorophyll meter in the evaluation of nitrogen and potassium fertilization in Tifton 85 grass. **Revista Brasileira de Saúde e Produção Animal,** v.12, n.3, 2011.

WARRICK, A. W. Spatial variability of soil physical properties in the field. **Application of soil physics,** p.319-344, 1980.