

# Production and quality of *Urochloa decumbens* (stapf) r.d.webster forage co-related to the physical and chemical properties of the soil

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## ABSTRACT

Frequently degraded pastureland characterized by low soil fertility and compacted surface is the basic environment of Brazilian livestock. The physical and chemical characterization of soil and its co-relationship with forage production are determining factors for performance of animals raised on pasture. The objective was to analyze the forage production of *Urochloa decumbens* grass correlated, linearly and spatially, with physical and chemical attributes of a savannah soil in Selvíria - MS, Brazil. A geostatistical web was introduced for the collection of soil and plant data, with 120 sampling sites within an area of 56.09 ha. The descriptive analysis of the data was undertaken and linear co-relationships, both simple and multiple, were established between plant and soil properties. Semivariograms were modeled and their respective krigings and cross-validations obtained, coupled to co-krigings (plant and soil). Production of dry matter and crude protein rates of *U. decumbens* may be estimated by regressions and the mechanical resistance to penetration and gravimetric humidity of the soil evaluated. Since organic matter rate and the gravimetric humidity of the soil are co-related spatially with the rate of crude protein of *U. decumbens*, they are the best factors to calculate or increase the forage crude protein rate.

**Key words:** geostatistics; precision agriculture; soil management and conservation; spatial variability.

## RESUMO

### Produção e qualidade de forragem de *Urochloa decumbens* (stapf) r.d.webster correlacionada com atributos físico-químicos do solo

A pecuária brasileira está fundamentada em pastagens, muitas vezes degradadas, e que tem como indicativos desta degradação, a queda de fertilidade do solo e a compactação superficial do solo. Portanto, a caracterização físico-química do solo e a sua correlação com a produção de forragem são determinantes para o desempenho animal em pasto. No ano de 2009, no município de Selvíria - MS, Brasil, em condições de Cerrado, objetivou-se analisar os atributos produtivos de *Urochloa decumbens* correlacionado-os, linear e espacialmente, com atributos físico e químicos de um solo de Cerrado. Foi instalada uma malha geostatística para a coleta de dados do solo e da planta, com 120 pontos amostrais, numa área de 56,09 ha. Realizou-se a análise descritiva dos dados, estabelecendo-se correlações lineares, simples e múltiplas, entre os atributos da planta e os do solo. Foram modelados semivariogramas, obtendo-se as respectivas krigagens e validações cruzadas. Também foram estabelecidas as cokrigagens de interesse (planta x solo). Tanto a produção de matéria seca quanto os teores de proteína bruta de *U. decumbens* podem ser estimados por meio de regressões, avaliando a resistência mecânica à penetração e umidade gravimétrica do solo. Os teores de matéria orgânica e a umidade gravimétrica do solo correlacionam-se espacialmente com os teores de proteína bruta da *U. decumbens*, demonstrando serem os melhores atributos para estimar ou aumentar o teores de proteína bruta da forragem.

**Palavras-chave:** geostatística; agricultura de precisão; manejo e conservação do solo; variabilidade espacial.

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## INTRODUCTION

Brazil has the most numerous commercial cattle herd in the world and the state of Mato Grosso do Sul contributes largely for such ranking. Although the country is known to have large areas for extensive planting of forages (Ribeiro-Júnior *et al.*, 2017), low productivity and unsatisfactory scientific indexes are verified when compared with rates from other countries which also export beef worldwide (Cavallini *et al.*, 2010; Pariz *et al.*, 2011; Montanari *et al.*, 2013a). In spite of low productivity rates, the Brazilian commercial cattle herd amounts to 209,541,109 units. It has been estimated that 89% are raised exclusively on pasture in native or cultivated pasturelands covering some 172 million ha and approximately 85% of this area is pasture of the genus *Urochloa* (Leal *et al.*, 2016).

Factors such as species, climate (water, light, and temperature), fertility and physical texture of soil, forage cycle, harvest management, animal monitoring, and others may affect the chemical composition and thus the availability of food energy (Leonel *et al.*, 2009; Lisbôa *et al.*, 2016). The production of dry matter and satisfactory rates of crude protein and acceptability by the animals are important factors in the selection of a cultivar for pasture sowing (Maranhão *et al.*, 2009).

According to Cavallini *et al.* (2010) and Montanari *et al.* (2010), studies on the spatial variability of the soil physical and chemical properties are highly relevant in agriculture and livestock-raising since they determine specific regions for management. The use of semivariograms at this phase helps in planning soil sample collection to analyze the spatial variability of the most interesting properties by geostatistical techniques that would help the farmer in determining and improving the productive, physical, and chemical capacity of the soil.

In fact, Pariz *et al.* (2011) investigated the spatial variability of forage productivity and the physical properties of soil planted with *U. decumbens* pasture in the Brazilian savannah and discovered that the geostatistical use could be underscored as an important tool to understand the interactions in a pasture ecosystem, reduce possible causes of degradation, and demonstrate the best alternative management for the soil-plant-animal complex. In an analogous way, Montanari *et al.* (2013b) evaluated the production of dry matter of *U. decumbens* according to the chemical attributes of a Latosol in Selvíria, MS, Brazil and verified that the organic matter content was a good index of soil quality when co-related to the productivity of *Urochloa* grass. Further, the rate of crude protein was also a good quality index of the forage plant with regard to the production of dry matter.

Taking into account the Brazilian relevance in livestock, the current paper evaluated the forage production of *U.*

*decumbens* grass correlated, linearly and spatially, with physical-chemical attributes of a savannah soil.

## MATERIAL AND METHODS

The experiment was performed In the Teaching, Research and Extension Farm (FEPE) in Selvíria, MS, Brazil, of the Engineering Faculty of the Universidade Estadual Paulista (UNESP), 51°24'46" W and 20°21'44" S (Figure 1); mean altitude 342 m. The soil in the area is a typical medium-texture Red-Yellow Latosol (Oxisol), a moderate, hypodystrophic, alic, caulinitic, hypoferric, very deep, moderately acid, with 410 g kg<sup>-1</sup> of sand, 70 g kg<sup>-1</sup> of silt, and 520 g kg<sup>-1</sup> of clay at 0-0.20 m depth. The initial chemical attributes of the soil, assessed respectively at the depths of 0.0-0.10 and 0.10-0.20 m, were: pH (CaCl<sub>2</sub>) = 4.9 and 4.7; H+Al = 26 and 22 mmol<sub>c</sub> dm<sup>-3</sup>; P (resin) = 10 and 5 mg dm<sup>-3</sup>; K<sup>+</sup> = 0.6 and 0.1; Ca<sup>2+</sup> = 9 and 7; Mg<sup>2+</sup> = 4 and 3 mmol<sub>c</sub> dm<sup>-3</sup>; and V = 34 and 31%. The *Urochloa decumbens* pasture was implemented in 1978 and has been managed under continuous stocking (mean stocking rate of 1.5 UA in that period) for Guzerá cattle raising, receiving liming and fertilization during implementation and rehabilitation in 1988. It is currently in a stage of moderate degradation, with losses in productivity and quality, broadleaf weeds, and soil compaction.

According to Köppen, climate is Aw, featuring megathermal humid climate, with dry winters and hot rainy summers. Mean annual rainfall is approximately 1232 mm; mean annual temperature is close to 24.5 °C and relative humidity between 70 and 80%.

*Urochloa decumbens* (cultivar Basilisk) was planted about 25 years ago and has been extensively employed, with liming when required, to upgrade base saturation at 60%. For data collection in March 2009, *U. decumbens* was in its tenth reformation year with surface scarification and liming.

Directions x and y of the cartesian coordinate system were defined in the allocation of the experimental design, with 120 sampling sites distributed in 56.09 ha (1060.23 × 529.00 m). Spacing of sites varied between 35.18 and 279.93 m. Soil and plant properties, individually collected around each sampling site of the experimental design were analyzed. Soil properties comprised mechanical resistance to penetration (RP) and gravimetric humidity (GH) at layers 0-0.10 m (RP1 and GH1); 0.10-0.20 m (RP2 and GH2); 0.20-0.30 m (RP3 and GH3); 0.30-0.40 m (RP4 and GH4); 0.40-0.50 m (RP5 and GH5); and 0.50-0.60 m (RP6 and GH6). Resistance to penetration was evaluated once by impact penetration meter at each site and calculated according to the following expression (Dalchiavon *et al.*, 2011):

$$RP = \left\{ 5.581 + 8.891 \times \left[ \frac{N}{(P - A) \times 10} \right] \right\} \times 0.0981 \quad (1)$$

in which RP is the soil mechanical resistance to penetration (MPa); N is the number of impacts by the penetration-meter hammer for reading; and A and P are, respectively, penetration readings in the soil before and after impacts (cm). Deformed samples of soil were collected by shovel drill, with 0.10 m diameter and 0.20 m height, to determine GH ( $\text{kg kg}^{-1}$ ). The hydrogenionic potential (pH  $\text{CaCl}_2$ ) of the soil and organic matter (OM) rates by organic carbon were determined from the same samples. The latter was obtained by the humid combustion method through calorimetry, by the following formula:

$$OM = C \times 1,724 \times 10 \quad (2)$$

in which OM is the rate of organic matter ( $\text{g dm}^{-3}$ ) and C is the rate of organic carbon. Soil samples were analyzed in the Physics and Soil Fertility Laboratories of the Universidade Estadual Paulista, Ilha Solteira, SP, Brazil.

Plant factors comprised production of forage green matter (GM); production of forage dry matter (DM); rate of crude protein (CP); neutral detergent fiber rate (NDF); total digestible nutrient rates (TDN); and ash rates (ASH), collected above pasture height (0.20 m). Samples for the evaluation of the production of green matter of the *Urochloa* grass were collected by a  $2 \times 2$  m metal square. The material within the square was harvested at approximately 0.20 m from the ground. A sample was then retrieved from the material, conditioned in a paper package, weighted and placed in a forced-air buffer at  $55^\circ\text{C}$  for 72 h. The production of the forage dry matter was determined. Neutral detergent fiber and TDN rates were determined according to methodology by Werner *et al.* (1997), whereas rates of crude protein and ashes were determined following Silva & Queiróz (2002).

Classical description analysis was performed for each factor under analysis by SAS (Statistical Analysis System, version 8.2.), in which mean, median, minimum and maximum rates, standard deviation, coefficient of variance, kurtosis, asymmetry, and distribution of frequency were calculated. Co-relation matrix was prepared to determine the simple linear co-relationships for combination, two by two, between the factors under analysis. The modeling of simple

linear regressions was henceforth performed on Excel sheets. On the other hand, multiple linear regression of the dependent variables (plant factors) was performed by computer package of SAS ("stepwise") at 10% probability for the inclusion and exclusion of the variables in the model and compared to the independent variables (plants or soil factors). Consequently, those that provided the best equation to estimate the respective dependent variable would be selected.

Geostatistical analysis was undertaken by Gamma Design Software 7.0, following procedures by Dalchiavon and Carvalho (2012). Spatial dependence was analyzed for each factor by calculating the semivariograms, in which adjustments were performed in the first place by the initial selection of the lowest sum of the squares of the deviants (SSD); the highest coefficient of determination ( $r^2$ ); and the highest evaluator of spatial dependence (ESD). Interpretation of ESD also followed method by Dalchiavon and Carvalho (2012):  $\text{ESD} < 20\%$  = spatial variable with very low dependence (VL);  $20\% \leq \text{ESD} < 40\%$  = low dependence (L);  $40\% \leq \text{ESD} < 60\%$  = fair dependence (F);  $60\% \leq \text{ESD} < 80\%$  = high dependence (H); and  $80\% \leq \text{ESD} < 100\%$  = very high dependence (VH).

Co-krigings between plant factors and between the later and soil factors were performed.

## RESULTS AND DISCUSSION

The descriptive analysis of the plant data and the soil chemical properties showed low variability for NDF, TDN, pH1, and pH2; medium for ASH; high for CP, OM1, and OM2; and very high for GM and DM (Table 1). As a rule, data were highly similar to those reported by Dalchiavon *et al.* (2013a) and Montanari *et al.* (2013b,c) when they investigated the variability of the chemical factors of soils cultivated with rice, *Urochloa*, and beans, respectively. The soil physical factors were medium (RP4 to RP6, UG1 to UG6) and high (RP1 to RP3) data variability has been registered (Table 2). High variability for RP data up to 0.30 m is mainly due to management of reform and incorporation of corrective measures in the pasture and to the effect of



**Figure 1:** Place of study implementation in a Brazilian savannah (Selvíria, MS, Brazil, 2009).

**Table 1:** Descriptive analysis of the attributes of *U. decumbens*, pH, and organic matter rates of a dystrophic Red-Yellow Latosol of the Brazilian savannah (Selvíria, MS, Brazil, 2009)

Probability of Attribute	Descriptive statistical measures									
	Mean	Median	Rate		Standard deviation	Coefficient			Probability of test (b)	
			Minimum	Maximum		Variation (%)	Kurtosis	Asymmetry	Pr<w	FD
GM (t ha <sup>-1</sup> )	5.39	5.012	0.428	14.992	3.014	55.9	1.161	1.002	10 <sup>-4</sup>	ND
DM (t ha <sup>-1</sup> )	1.50	1.372	0.140	4.172	0.895	59.7	1.734	1.354	10 <sup>-4</sup>	ND
CP (%)	7.59	7.67	2.94	12.56	15.9	21.0	0.382	0.264	0.643	NO
NDF (%)	67.18	67.20	56.78	76.11	36.6	5.5	-0.226	-0.073	0.911	NO
TDN (%)	55.75	55.76	52.05	60.11	15.3	2.7	-0.244	0.114	0.857	NO
Ash (%)	7.96	7.92	5.30	11.80	11.7	14.7	0.395	0.454	0.220	NO
pH1	5.0	5.0	4.1	5.9	0.3	6.2	0.344	0.029	0.212	NO
pH2	4.8	4.8	4.2	5.8	0.4	7.4	0.514	0.467	8.10 <sup>-4</sup>	ND
OM1 (g dm <sup>-3</sup> )	12.6	12.0	7.0	22.0	3.8	29.9	“0.679	0.479	10 <sup>-4</sup>	ND
OM2 (g dm <sup>-3</sup> )	13.7	13.0	11.0	22.0	3.3	24.3	“0.280	0.564	10 <sup>-4</sup>	ND

<sup>1</sup>GM - green matter; DM - dry matter; CP - crude protein; NDF - neutral detergent fiber; TDN - total digestible nutrients; pH1 - hydrogenionic potential 1; pH2 - hydrogenionic potential 2; OM1 - organic matter 1; OM2 - organic matter 2; FD - frequency distribution; ND - non-determined; NO - normal.

**Table 2:** Descriptive analysis of the soil mechanical resistance to penetration and gravimetric humidity of a dystrophic Red-Yellow Latosol of the Brazilian savannah ( Selvíria, MS, Brazil, 2009)

Probability of Attribute	Descriptive statistical measures									
	Mean	Median	Rate		Standard deviation	Coefficient			Probability of test (b)	
			Minimum	Maximum		Variation (%)	Kurtosis	Asymmetry	Pr<w	FD
RP1 (MPa)	1.505	1.459	0.873	2.576	0.371	24.6	-0.562	0.045	0.174	LN
RP2 (MPa)	2.121	2.076	1.001	3.365	0.436	20.6	0.800	0.294	0.050	NO
RP3 (MPa)	2.018	1.971	1.014	3.284	0.408	20.2	0.779	0.486	0.051	NO
RP4 (MPa)	1.795	1.820	1.014	2.412	0.238	13.2	0.873	-0.453	0.102	NO
RP5 (MPa)	1.731	1.713	1.048	2.605	0.274	15.9	0.301	0.191	0.874	NO
RP6 (MPa)	1.753	1.755	1.048	2.605	0.291	16.6	-0.201	0.099	0.931	NO
GH1 (kg kg <sup>-1</sup> )	0.108	0.106	0.037	0.159	0.019	17.9	0.811	-0.025	0.105	NO
GH2 (kg kg <sup>-1</sup> )	0.101	0.101	0.061	0.150	0.016	16.2	0.054	0.301	0.686	NO
GH3 (kg kg <sup>-1</sup> )	0.099	0.101	0.054	0.142	0.015	15.2	0.607	0.155	0.942	NO
GH4 (kg kg <sup>-1</sup> )	0.100	0.100	0.057	0.137	0.015	15.1	0.336	0.058	0.292	NO
GH5 (kg kg <sup>-1</sup> )	0.103	0.104	0.080	0.132	0.012	12.0	-0.648	0.065	0.050	NO
GH6 (kg kg <sup>-1</sup> )	0.106	0.106	0.063	0.138	0.014	12.9	-0.198	“0.132	0.223	NO

RP1, RP2, RP3, RP4, RP5, and RP6 - soil resistance to penetration; GH1, GH2, GH3, GH4, GH5, and GH6 - soil gravimetric humidity, in depthFD - frequency distribution; ND - non-determined; NO - normal.

trampling by animals on these layers. The above indicates the soil heterogeneity evaluated by the high coefficients of variations and with the consequent interference in the forage production of the region. Souza *et al.* (2006), Dalchiavon *et al.* (2011), and Montanari *et al.* (2013a) also investigated the variability of the physical properties in managed soils with sugarcane, soybean, and *Urochloa* in their respective geostatistical studies and reported coefficients of variation similar to those of the current analysis.

With the exception of GM, DM, pH2, OM1, and OM2, which had a non-determined frequency distribution, and RP1 with log normal frequency distribution, all the other factors provided a normal frequency distribution (Tables 1 and 2). Probability varied between 0.050 (RP2) and 0.664 (UG3) and showed that centrally trend measures did not represent atypical rates in the distribution, which is typical of plant data, as underscored by Dalchiavon *et al.* (2013b).

Green matter (GM) and DM productivity were 5.39 and 1.50 t ha<sup>-1</sup>, respectively (Table 1). Dry matter rate was actually low when compared with productivity reported by Montanari *et al.* (2013b,a). Low DM productivity was high due to the fact that the area was a continuous pasture at that moment, with more than 10 years after reformation and without any fertilization, with only one animal unit per hectare. In fact, it simulated the normal conditions used by the farmers in the region. However, there was a great decrease in mean annual productivity of *U. decumbens* in low fertility soils and rates between 1 and 2 t ha<sup>-1</sup> of DM were normal (Serrão and Simão Neto, 1971). In fact, tropical forages provide dry matter according to clear-cut seasonality, or rather, between the rainy and dry seasons, and thus determine the lack of uniformity in the distribution of production throughout the year (Evangalista *et al.*, 2004; Crusciol *et al.*, 2012; Pariz *et al.*, 2017).

The 7.59 percentage of CP in the DM (Table 1) showed that it was 15% higher than the rate reported by Montanari *et al.* (2013b), when these authors studied the same forage species in a Latosol in Selvíria, MS, Brazil. According to Milford and Minson (1966), CP rate in DM is adequate since only rates lower than 7% of DP in the forage actually show any reduction in the intake of DM by the animals. In fact, it reduces the digestibility of DM caused by nitrogen deficiency to the ruminal bacteria.

Means of NDF, TDN, and ASH were 67.18%, 55.75%, and 7.96%, respectively. It should be emphasized that the higher the ADF, the less is the digestibility. On the other hand, NDF has a negative co-relationship with forage intake, with 40% of ADF and 60% of NDF as the respective limits of digestibility and intake. As a rule, TDN rates were over 55%, which was considered the best by Van Soest (1994) in tropical forages.

In the case of the soil chemical properties, pH provided high acidity (pH between 4.4 and 5.0) with low OM availability, following classification by Rajj *et al.* (1997). In fact, these rates were lower than 15 g dm<sup>-3</sup> (Table 1) and partially explained the low production of the forage DM.

It should be highlighted that RP provided the lowest rates, considered medium (1.0 ≤ RP < 2.0 MPa) by Arshad *et al.* (1996), up to 0.10-m depth and between 0.30 and 0.60 m (Table 2). However, RP rates were considered high (2.0 ≤ RP < 4.0 MPa) between 0.10 and 0.30 m, since rates above 2.0 MPa in most cultures start showing limitations to the normal development of the root system (Tormena *et al.*, 1998). The above rates clearly show the effects of natural thickening of the neighboring layers and the effects of animal trampling of the upper layers. The phenomenon mainly depends on soil class, humidity rate, animal density rates, mass of forage produced (deficient soil covering), and the forage species in the system (Marchão *et al.*, 2007).

It is not only important to underscore RP rates but also the soil humidity conditions (GH) from which the data were obtained, since these qualities are normally inversely proportional (Dalchiavon *et al.*, 2011). It must be emphasized that, at the instance soil data collection was done, GH was between 0.099 (UG3) and 0.108 kg kg<sup>-1</sup> (UG1) (Table 2). Montanari *et al.* (2013a) researched the co-relationship of forage production with the physical properties of an Argisol in Aquidauana, MS, Brazil and reported 4.761 MPa (RP) and 0.088 kg kg<sup>-1</sup> (GH) for the 0-0.20 m layer. Above data were highly critical than those in current research. On the other hand, Pariz *et al.* (2011) studied the spatial variability of forage productivity and the physical properties of soil with *U. decumbens* pasture in the Brazilian savannah and registered 3.177 MPa (RP) and 0.140 kg kg<sup>-1</sup> (GH), also at the 0-0.20 m layer.

Studies on Pearson's linear co-relationships of DM and CP with the soil properties revealed the following, featuring relevant agronomy interest: DM had positive and significant co-relationships (n = 120) with GH3 (r = 0.221\*), UG5 (r = 0.247\*\*), and UG6 (r = 0.371\*\*), agreeing with rates by Cavallini *et al.* (2010), who reported positive co-relationship between DM and GH. Analogically, CP co-related negatively with RP3 (r = -0.192\*), UG1 (r = -0.183\*), UG2 (r = -0.308\*\*), UG3 (r = -0.313\*\*), UG4 (r = -0.328\*\*), UG5 (r = -0.317\*\*), and UG6 (r = -0.330\*\*). The analyses of such co-relationships demonstrated that the higher the humidity rate in the soil, the greater the production of dry matter by forage. In fact, an increase in hydric availability would ensue and, therefore, a probable improvement in the absorption of the soil nutrients, with better vegetal growth. However, the forage CP would be lower since the co-relationship between DM and CP was significantly high (r = -0.331\*\*), probably due to the effect of high N leaching from the mineralization of the soil OM.

Potential (Equations 3 to 6) and linear (Equations 7 to 12) equations were modeled, which demonstrated a positive co-relationship between DM and GH, showing that increase in GH would have a positive effect on DM (Equations 3 to 5) due to a greater biomass production. Although tolerant to water deficits, *U. decumbens* still revealed seasonality in reproduction caused by drought or low temperatures.

On the other hand, inverse relationships occurred between CP and RP3 and between CP and GH (Equations 6 to 12), in which an increase in RP3 and in GH would have a negative effect on CP due to the physical restrictions imposed on root growth by direct compact (RP increase) or indirectly by soil drenching caused by compact, with an increase in GH. Therefore, the production of DM will be 1.27, 1.28, and 1.27 t ha<sup>-1</sup> when GH3, GH5, and GH6 are, respectively, 0.099, 0.103 and 0.106 kg kg<sup>-1</sup> (Equations 3 to 5; Table 2). According to the model, CP will be 9.91, 7.58, 7.58, 7.59, 7.57, 7.58, and 8.00% when RP3, GH1, GH2, GH3, GH4, GH5, and GH6 are, respectively, 2.018 MPA, 0.108, 0.101, 0.099, 0.100, 0.103, and 0.106 kg kg<sup>-1</sup> (Equations 6 to 12; Table 2).

Model (Equation 13) for the analysis of multiple linear regression of CP due to the soil physical and chemical properties explains approximately 21.9% of CP variation rate of *U. decumbens* (R<sup>2</sup> = 0.219\*\*). The coefficients of the independent variables RP4 and RP5 were significant at 1%, whereas coefficients of GH3 and GH6 were significant at 5% probability. By means of the above regression and taking into account the mean rates of the independent factors (Table 2), CP rate of 7.60% may be estimated. Since this rate is close to the mean CP rate in current analysis (7.59%), the exactness of Equation 13 and its agronomic importance in estimating the parameter are confirmed.

$$DM = 10.75 \times GH3^{0.923**} \quad (r=0.237**) \quad (3)$$

$$DM = 50.63 \times GH5^{1.619**} \quad (r=0.317**) \quad (4)$$

$$DM = 85.46 \times GH6^{1.874**} \quad (r=0.400**) \quad (5)$$

$$CP = 8.554 \times RP3^{0.210*} \quad (r=-0.196*) \quad (6)$$

$$CP = 9.21 - 15.09* \times GH1 \quad (r=-0.183*) \quad (7)$$

$$CP = 10.62 - 30.05** \times GH2 \quad (r=-0.308**) \quad (8)$$

$$CP = 10.87 - 33.09** \times GH3 \quad (r=-0.313**) \quad (9)$$

$$CP = 11.06 - 34.90** \times GH4 \quad (r=-0.328**) \quad (10)$$

$$CP = 11.78 - 40.79** \times GH5 \quad (r=-0.317**) \quad (11)$$

$$CP = 11.68 - 38.52** \times GH6 \quad (r=-0.330**) \quad (12)$$

$$CP = 13.228 - 2.584** \times RP4 + 2.164** \times RP5 - 22.534* \times GH3 - 23.601* \times GH6 \quad (r^2=0.219**) \quad (13)$$

Except for pH1, pH2, RP2, RP3, RP4, RP5, RP6, #GH2, #GH5, and #GH6 with pure nugget effect, the other properties revealed spatial dependence and their distribution in space was not randomized (Tables 3 and 4).

**Table 3:** Simple semivariogram parameters adjusted for *U. decumbens* attributes pH and organic matter rates of a dystrophic Red-Yellow Latosol of the Brazilian savannah (Selvíria, MS, Brazil, 2009)

Attribute	Adjustment parameters					SDE			Cross-validation		
	Model	Co	Co+C	Ao (m)	r2	SSR	%	Class	a	b	R
GM	exp (295)	4.09	8.18	510.0	0.908	7.23.10 <sup>-1</sup>	50.0	M	1.06	0.804	0.374
DM	gau (320)	4.00.10 <sup>-1</sup>	7.23.10 <sup>-1</sup>	115.3	0.479	1.42.10 <sup>-2</sup>	44.7	M	2.40.10 <sup>-1</sup>	0.831	0.346
CP	exp (383)	3.58.10 <sup>-1</sup>	2.62	180.0	0.981	9.94.10 <sup>-3</sup>	86.3	VH	3.15	0.586	0.324
#NDF	gau (308)	3.36	8.42	108.5	0.732	7.94.10 <sup>-1</sup>	60.1	H	1.10.10 <sup>-1</sup>	0.531	0.288
#TDN	gau (311)	1.12	1.57	120.0	0.494	2.47.10 <sup>-2</sup>	28.6	L	1.00.10 <sup>-1</sup>	0.833	0.243
Ash	esf (304)	5.71.10 <sup>-1</sup>	1.14	666.0	0.908	2.71.10 <sup>-2</sup>	50.0	M	1.00.10 <sup>-2</sup>	1.000	0.443
pH1	pne	9.68.10 <sup>-2</sup>	9.68.10 <sup>-2</sup>	-	-	-	-	-	-	-	-
pH2	pne	1.25.10 <sup>-1</sup>	1.25.10 <sup>-1</sup>	-	-	-	-	-	-	-	-
OM1	sph (318)	1.47	1.39.10	287.0	0.952	3.43	89.4	VH	7.70.10 <sup>-1</sup>	0.938	0.722
OM2	sph (386)	5.00	1.24.10	454.0	0.994	2.21.10 <sup>-1</sup>	59.6	M	4.70.10 <sup>-1</sup>	0.967	0.578

GM - green matter, DM - dry matter, CP - crude protein, FDN - neutral detergent fiber, TDN - total digestive nutrients; ASH - ashes, pH - hydrogenionic potential; OM - organic matter, in depth; SSR - sum of the square of residues; SDE - spatial dependence evaluator, with M - mean, VH - very high, H - high; L - low.

# = attribute with data residue; parenthesis succeeding model = number of pairs in the first lag; exp = exponential, gau = gaussian, sph = spheric; pne = pure nugget effect.

**Table 4:** Parameters of simple semivariograms adjusted for the mechanical resistance of the soil to penetration and gravimetric humidity of a dystrophic Red-Yellow Latosol of the Brazilian savannah (Selvíria, MS, Brazil, 2009)

Attribute	Adjustment parameters										
	Model1	Co	Co+C	Ao (m)	r2	SSR	SDE		Cross-validation		
							%	Class	a	b	R
RP1	sph (306)	3.90.10 <sup>-3</sup>	9.28.10 <sup>-2</sup>	107.0	0.626	1.60.10 <sup>-4</sup>	95.8	VH	1.00	0.328	0.210
RP2	pne	1.90.10 <sup>-1</sup>	1.90.10 <sup>-1</sup>	-	-	-	-	-	-	-	-
RP3	pne	1.68.10 <sup>-1</sup>	1.68.10 <sup>-1</sup>	-	-	-	-	-	-	-	-
RP4	pne	5.81.10 <sup>-2</sup>	5.81.10 <sup>-2</sup>	-	-	-	-	-	-	-	-
RP5	pne	7.37.10 <sup>-2</sup>	7.37.10 <sup>-2</sup>	-	-	-	-	-	-	-	-
RP6	pne	8.48.10 <sup>-2</sup>	8.48.10 <sup>-2</sup>	-	-	-	-	-	-	-	-
#GH1	exp (379)	5.40.10 <sup>-5</sup>	5.40.10 <sup>-5</sup>	183.0	0.361	1.37.10 <sup>-8</sup>	83.7	VH	0	0.928	0.390
#GH2	pne	2.20.10 <sup>-4</sup>	2.20.10 <sup>-4</sup>	-	-	-	-	-	-	-	-
GH3	sph (310)	4.70.10 <sup>-5</sup>	2.58.10 <sup>-4</sup>	763.0	0.946	2.37.10 <sup>-9</sup>	82.0	VH	0	0.990	0.688
#GH4	sph (292)	5.50.10 <sup>-5</sup>	1.11.10 <sup>-4</sup>	479.0	0.880	2.99.10 <sup>-10</sup>	50.4	MH	0	1.104	0.499
#GH5	pne	9.20.10 <sup>-5</sup>	9.20.10 <sup>-5</sup>	-	-	-	-	-	-	-	-
#GH6	pne	1.53.10 <sup>-4</sup>	1.53.10 <sup>-4</sup>	-	-	-	-	-	-	-	-

RP - mechanical resistance to penetration; GH - gravimetric humidity, in depth; SSR - sum of the square of residues; SDE - spatial dependence evaluator, with VH - very high and MH - medium height.

<sup>1</sup> #: attribute with data residue; parenthesis succeeding model: number of pairs in the first lag; <sup>(b)</sup> sph: spheric, epp: pure nugget effect; exp: exponential.

GM - green matter, DM - dry matter, CP - crude protein, FDN - neutral detergent fiber, TDN - total digestive nutrients; ASH - ashes, pH - hydrogenionic potential; OM - organic matter, in depth; SSR - sum of the square of residues; SDE - spatial dependence evaluator, with M - mean, VH - very high, H - high; L - low.

<sup>1</sup> # = attribute with data residue; parenthesis succeeding model = number of pairs in the first lag; exp = exponential, gau = gaussian, sph = spheric; pne = pure nugget effect.

The coefficient of spatial determination ( $r^2$ ) of simple semivariograms lay between 0.361 (#GH1) and 0.994 (OM2). It was the best semivariogram adjustment when analyzed by  $r^2$ . Since the geostatistical extremes ( $A_0$ ) lay between 107.0 (RP1) and 763.0 m (GH3), extreme rates for specific and localized managements that will be employed as reference in future research should not be lower than 107 m, since they are the distance within which the rates of a specific quality are equal. For spatial dependence evaluation (SDE), classification varied between low (#TDN; SDE = 28.6%) and very high spatial dependence (RP1; SDE = 95.8%).

In the case of CP, OM1 and GH3, or rather, the factors that provided co-krigings higher than  $r^2$  (Table 5), CP showed exponential model,  $r^2 = 0.981$ ,  $A_0 = 180$  m, and very high SDE (86.3%). In the case of OM1, spherical model, the parameters  $r^2$ ,  $A_0$ , and SDE were respectively 0.92, 287.0 m, and 89.4%, whereas, in the case of GH3, with spherical adjustment, they were 0.946, 763.0 m, and 82.0%. Cavallini *et al.* (2010) modeled sphere-type semivariograms for CP whose parameters  $r^2$ ,  $A_0$ , and SDE were respectively 0.96, 41.1 m, and 50.0%. Pariz *et al.* (2011) also registered a sphere-type semivariogram model for GH, and respective parameters  $r^2$ ,  $A_0$ , and SDE with 0.61, 26.5 m, and 50.3%. However, Montanari *et al.* (2013b) reported that OM (0-0.10 m) provided an exponential-type experimental semivariogram with parameters 0.81 ( $r^2$ ), 17.7 m ( $A_0$ ), and 96.7% (SDE). Similarly, CP provided a Gaussian-type semivariogram with respective rates 0.95 ( $r^2$ ), 25.6 m ( $A_0$ ), and 66.5% (SDE) for the above-mentioned geostatistical parameters. The above revealed that the analysis of the variables provided distinct behaviors in current research.

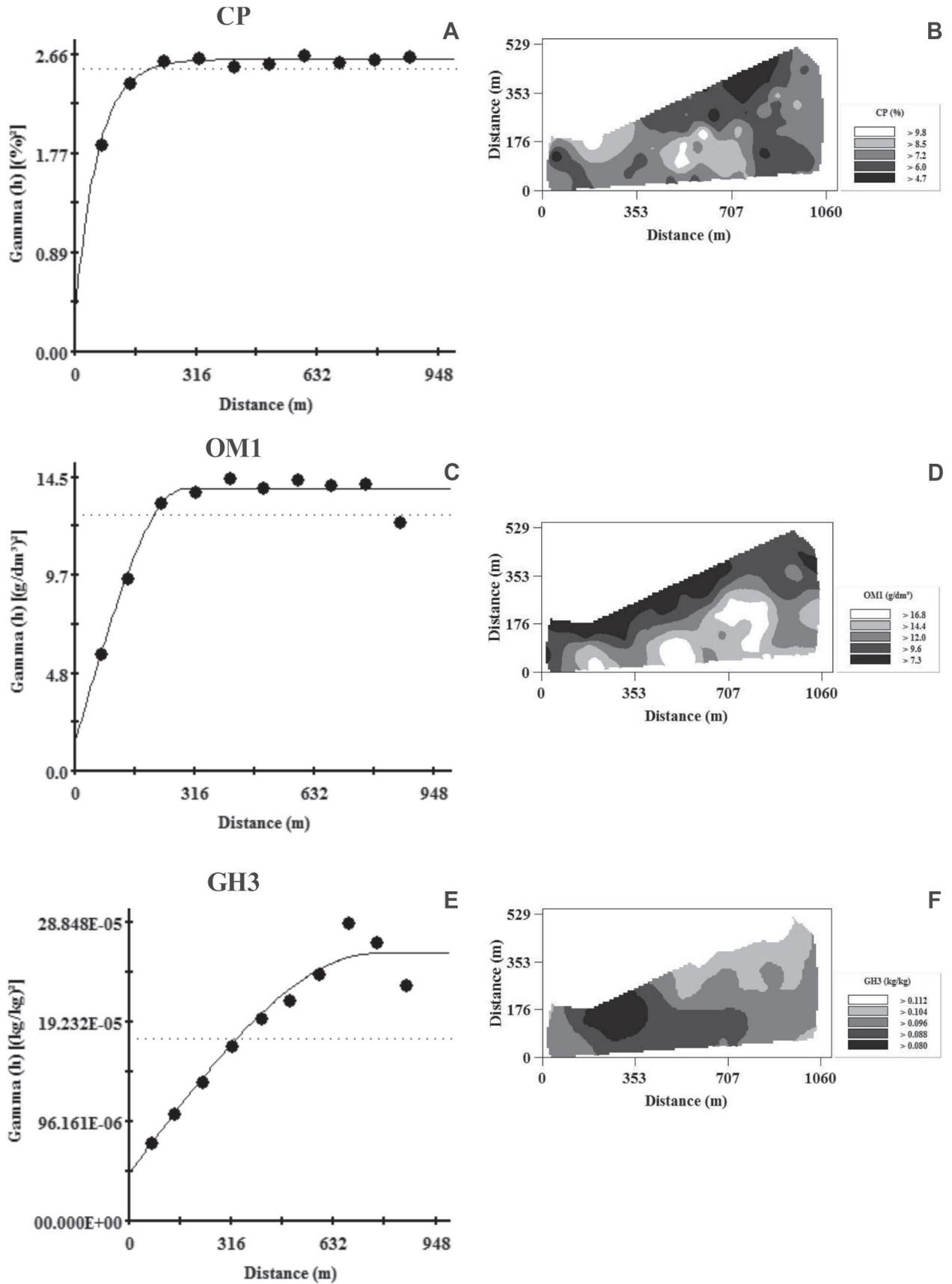
The crude protein kriging map showed a high direct spatial co-relationship with OM1 and an inverse relationship with GH3 (Figure 2), especially within the central region where the highest CP rates occurred (7.2 to > 9.8%) (Figure 2b). The above coincided spatially with the highest OM1 rates (12.0 to > 16.8 g dm<sup>-3</sup>; Figure 2d) and with the lowest GH3 rates (0.080 to 0.096 kg<sup>-1</sup>; Figure 2e). On the other hand, lowest CP rates (4.7 to 7.2%) may be observed on the extremities of the maps, whereas OM1 rates were between 7.3 and 12.0 g dm<sup>-3</sup>. Similarly, GH3 rates were included between 0.096 and > 0.112 kg<sup>-1</sup>, with a slight compact in the zones. This fact is common on the margins of the area where trampling of animals and traffic of agricultural machines are highest. It should be emphasized that OM mineralization is the main N source since the relationship with CP is direct and, due to excess of humidity (highest GH), N leaching could occur and, therefore, an inverse response with forage CP rates.

Since co-kriging between CP and OM1 by the Gaussian model provided a limit of 318.7 m and high SDE (99.9%), it became clear that 72.2% of CP spatial variability may be

**Table 5:** Parameters of cross-semivariograms adjusted for attributes of *U. decumbens* and the physical and chemical characteristics of a dystrophic Red-Yellow Latosol of the Brazilian savannah (Selvíria, MS, Brazil, 2009)

Attribute	Adjustment parameters						Cross-validation				
	Model	Co	Co+C	Ao (m)	r <sup>2</sup>	SSR	%	Class	a	b	R
CP=f(OM1)	gau (106)	1,00.10 <sup>-3</sup>	1,23	318,7	0,722	8,21.10 <sup>-1</sup>	99,9	VH	4,26	0,437	0,330
CP=f(#GH1)	sph (238)	-1,00.10 <sup>-5</sup>	-4,30 <sup>-3</sup>	207,0	0,650	3,70.10 <sup>-6</sup>	99,8	VH	4,47	0,411	0,305
CP=f(GH3)	sph (273)	-1,00.10 <sup>-5</sup>	-1,10.10 <sup>-2</sup>	537,0	0,848	1,98.10 <sup>-5</sup>	99,9	VH	3,73	0,508	0,385
CP=f(#GH4)	sph (283)	-1,58.10 <sup>-3</sup>	-4,50.10 <sup>-3</sup>	555,0	0,458	8,73.10 <sup>-6</sup>	64,8	H	5,10	0,331	0,241

CP - crude protein; GH - gravimetric humidity; SQR - sum of squares of residues; SDE - spatial dependence evaluator, with VH - very high and H - high.  
 # = attribute with data residue; parenthesis succeeding model = number of pairs in the first lag; gau = gauss and sph = spheric.



CP - crude protein; OM - organic matter; GH - gravimetric humidity.

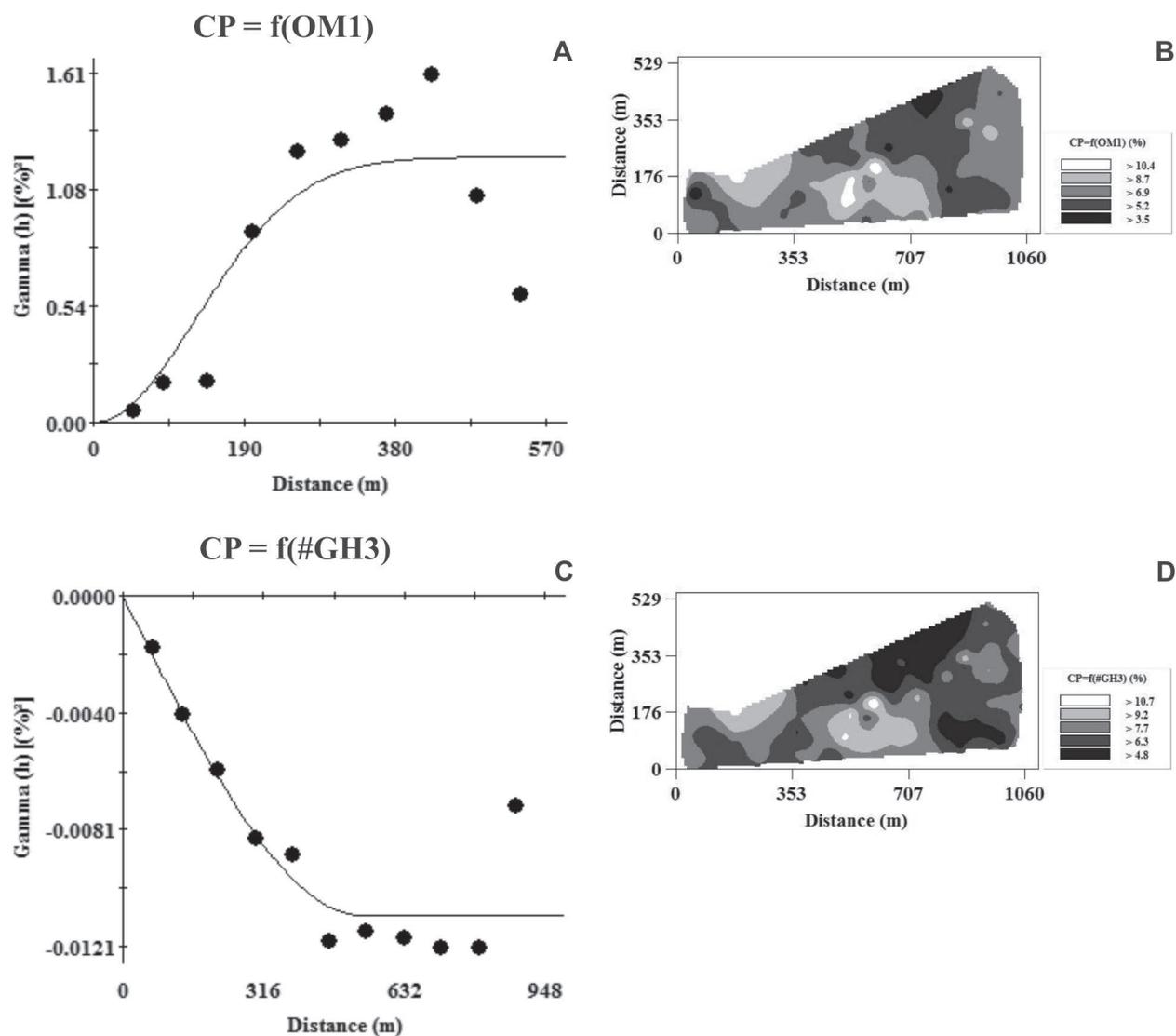
**Figure 2:** Semivariograms and maps of kriging of CP of *U. decumbens* and of OM1 and GH3 of a dystrophic Red-Yellow Latosol of the Brazilian savannah (Selvíria, MS, Brazil, 2009).

explained by the spatial variability of OM1 (Table 5, Figure 3a,b). In fact, the highest OM1 rates (Figure 3d) provided the highest CP rates (Figures 2b and 3b). The inverse is true. Consequently, from the spatial point of view of the researched area, expected CP rates in the sites where OM1 varied between 12.0 and 16.8 g dm<sup>-3</sup>, lies between 6.9 and 10.4%. On the other hand, in the sites where OM1 lies between 7.3 and 12.0 g dm<sup>-3</sup>, CP will be between 3.5 and 6.9%. This reveals the relevance of agricultural practices that aim at raising OM rates in the soil, since its benefits for the raising of CP rates for *U. decumbens* becomes evident through improvements in the physical (aggregation) or chemical (fertility) characteristics of the soil (Souza *et al.*, 2004; Boeni *et al.*, 2014; Rocha Junior *et al.*, 2014).

Cross semivariogram (spherical model) and the co-kriging map of CP due to GH3 proved that spatial variability

of GH3 accounted for 84.8% of the spatial variability of CB (Table 5; Figure 3c,d). The sites where the highest GH3 occurred (0.096-0.112 kg kg<sup>-1</sup>) were precisely and inversely those in which CP provided the lowest rates (4.8 -7.7%), whereas the sites where the lowest GH3 rates (0.080-0.096 kg kg<sup>-1</sup>) occurred were the sites in which CP had the highest rates (7.7-10.7%). This shows the negative influence of the excessive humidity of the soil on the development of *U. decumbens* in sandy soil and confirms that the species analyzed is not tolerant to environments with high humidity rates, even though it showed low requirements with regard to soil fertility.

Nevertheless, from the point of view of space and soil management, it may be seen that the organic matter and humidity rates of the soil may be perfectly used as indexes of CP rates in the dry matter of *U. decumbens*.



CP - crude protein; OM - organic matter; GH - gravimetric humidity.

**Figure 3:** Cross-semivariograms and co-kriging maps of CP of *U. decumbens* as a function of OM1 and GH3 of a dystrophic Red-Yellow latosol of the Brazilian savannah. Selvíria-MS/Brazil, 2009.

## CONCLUSIONS

The production of dry matter and the rate of crude protein of *Urochloa decumbens* may be estimated by regressions through the evaluation of the soil physical attributes such as the mechanical resistance to penetration (crude protein) and gravimetric humidity (dry matter and crude protein).

Organic matter and gravimetric humidity rates of the soil are co-related spatially with the crude protein rates of *Urochloa decumbens* and reveal the best attributes to estimate and increase the forage crude protein rate as a function of soil management.

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