THE INTERNATIONAL SOCIETY OF PRECISION AGRICULTURE PRESENTS THE
13th INTERNATIONAL CONFERENCE ON
PRECISION AGRICULTURE
July 31-August 4, 2016 • St. Louis, Missouri USA

# SPATIAL VARIABILITY AND CORRELATIONS BETWEEN SOIL ATTRIBUTES AND PRODUCTIVITY OF GREEN CORN CROP

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**A paper from the Proceedings of the**
**13th International Conference on Precision Agriculture**
**July 31 – August 4, 2016**
**St. Louis, Missouri, USA**

***Abstract.*** *In Brazil, the progressive development in the cultivation of the corn for consumption in the green stadium stands by the relevant socio-economic role that this related to multiple applications, the attractive market price and continuous demand for the product in nature. Therefore, this study was to analyze the correlations and spatial variability of the productivity of the culture of the green corn in winter, in alluvial soil of the type Cambisols eutrophic in the amount areas and Hydromorphic eutrophic in plain grounds. The experiment went carried in the agricultural year of 2013/2014 in the commercial area belonging to Kassuga Farm, located in the city of Register, in the Ribeira Valley region, SP, Brazil. The delimited experimental area was of 4,97 ha constituted of a sampling grid distributed 68 collection points of georeferenced data, with an average spacing of 25 m between the demarcations. The sowing of the green corn went carried through in the winter, in succession to the rice crop, in the no-tillage system. The agronomic characteristics evaluated were; plant height, length, diameter, productivity of tangs with straw and without straw and productivity of corn grain in the green stage. The data relating to agronomic characteristics of green corn underwent exploratory analysis, classical descriptive and adherence to the distribution Normal. The data do not present a normal distribution were submitted to geostatistical analysis. The information analyzed demonstrated results with average values for height of plant, length and diameter of corncob with straw of 273,4 and 579 mm and without straw 213,8 and 481 mm. the average productivity of the tang with straw and without straw were 20.56 t ha$^{-1}$ and 13 t ha$^{-1}$ , respectively, while the grain reached 7.17 t ha$^{-1}$. The coefficient of variation shows higher values for corncob without straw productivity and grain* *yield. There were positive and significant correlations between the variables. Thus, the cultivation of green corn in the study region went considered viable, due to the satisfactory results of crop productivity. The division of the area on management units went considered adequate to the development of localized agricultural practices.*

***Keywords.*** *Precision Agriculture, management zones, variable rate*

## Introduction

Corn is one of the most important crops for humanity due to its high yield potential and the various forms of use in food and feed, fresh and in industry (Rocha et al., 2011). Corn on the cob in the green stage is marketed throughout Brazil for consumption of cooked corn, roasted or processing as mush, ice cream, cakes, and other products (Santos et al., 2011). The latest information on corn production in Brazil are related to national statistics 2006, showing that the yield was 268,265 tons, thus the state of São Paulo was considered the largest producer of corn with 39,591 t, followed by Pernambuco and Paraíba that produced 35,639 and 26 769 t, respectively (IBGE, 2016). In the year 2013 accounts for the largest volume distributed through CEAGESP, São Paulo, sold 59,627 tons of corn (AGRIANUAL, 2015).

Knowledge of the spatial and temporal variability of soil attributes related to production capacity of culture, provides relevant information for the diagnosis of conditioning factors that enable the rationalization and optimization of the application of lime and fertilizers in the soil of cultivated areas, by using precision agriculture, contributing to the economic, social and environmental sustainability of agricultural production systems.

The use of precision agriculture techniques, such as its use in the specific management of soil fertility, has been widely used. The input measurements are applied differently in order to meet the specific needs of each location, optimizing the production process and reducing the environmental impacts of agricultural practices (Bottega et al., 2013). According to Amado et al., (2007), the maize crop is one that presents the greatest potential for the definition of management zones.

Brazil has the potential to expand the production of corn, but more studies are needed to support and enable high productivity coupled with product quality (Luz et al., 2014). However, information on the cultivation of corn for fresh consumption are scarce, especially in relation to obtaining varieties and better crop management (Albuquerque et al., 2008). The fertility and the availability of nutrients in the soil are essential to the development of culture, especially the P, which is almost all translocated to the seed (80-90%) (Rabbit & France, 2014) and nitrogen, the second major exported nutrient in corn grain (Coelho et al., 2012).

The main factors responsible for the low productivity of this culture, there are the irregular rainfall, low levels of nitrogen and phosphorus soil and lack of fertilizer research in field conditions that define the best doses of these elements for proper nutrition plants and higher crop productivity (Paiva et al., 2012). Considering the importance of contributing to the balance of the agricultural production system this work was to study the spatial variability and correlations between the chemical and physical properties of soil and the corn crop productivity, to identify and delineate management zones for individualized treatment.

## Material and Methods

The experimente was carried out on Kassuga Farm, located on Registro County, São Paulo State, Brazil, on geographic coordinates (UTM) 224376,007E e 7286702,736N, with average altitude of 8,3m and declivity of 0 to 5%. The climate on Registro County is Cfa according Koeppen classification, humid subtropical with hot summer, with temperatures averaging 22 ° C and annual rainfall of 1400 mm. The soil is part of the Environmental Systems Units, defined by Ross (2002) as a system of plains and river terraces of the Iguape River, described as flat land in the Lower Ribeira and / or the Ribeira Tectonic Depression region of sediment modern, in alluvial soil like Cambisols eutrophic in upstream areas and Hydromorphic eutrophic in lowland soils.

The production area defined for this study is 4,97ha, having been grown in the previous summer period the experimental installation (2013/14), with rice var. Moti (*Oryza sativa* L., var. glutinosa). After delineating the perimeter, the area was dried out and after a week, mowed is employing trailing weeder, distributing plant mass on the surface of the soil. About the area, we have established a regular grid with 68 georeferenced points spaced 25 m apart, constituting the sampling points. The frame and the points were processed using MapSource Software Garmin and TrackMaker Pro®, adopting system Geographic coordinates UTM (Universal Transverse Mercator), the WGS 1984 and 23J Zone, and the points identified and demarcated on field with the aid of a GPS navigation.

Sowing of autumn / winter crop was held on 26.06.2014, using conventional corn hybrid Pioneer 3646 with spacing of 0.90 m between rows and population of approximately 55,000 plants $ha^{-1}$. Sowing fertilization consisted in the application of 300 kg $ha^{-1}$ of NPK 04-14-08 formulation; the weed control was performed with atrazine at the rate of 3.0L $ha^{-1}$ with the weeds in the 2 to 4 leaves stage.

The samples of soli for chemical and physical analysis were collected at the end of the corn harvest, in December 2014. In each georeferenced point of the sampling grid, collected up four simple samples, representative of the layer of 0-0.20 m deep soil to form a composite sample. Then the 68 samples were sent to the Soil Chemical Analysis Laboratory for fertility purposes and size fractions. The agronomic traits in maize were tang productivity with and without straw and grain yield.

The data relating to soil properties and yield of corn underwent exploratory analysis for the presence of outliers and their influence on the measures of position and dispersion. Then we performed the descriptive statistics for the evaluation of measures of central tendency (mean, median and mode) and dispersion (standard deviation, variance, coefficient of variation), and adherence to the normal distribution, according to the Kolmogorov-Smirnov test (Goncalves et al., 2001) at levels 1 and 5% significance by means of ASSISTAT program (SILVA, 2011).

The data did not show normal distribution were submitted to geostatistical analysis (SOARES, 2006). Spatial analysis was performed with the help of GS +, version 9.0 (ROBERTSON, 2008). The structure and spatial dependence of the sampling points were evaluated by experimental semivariogram, where spatial dependence is defined by the range (Ao), the error made due to the minimum sampling spacing is defined by the nugget effect (Co) and the point wherein all semi variance of the sample is random influence is defined by level (C + Co) (Vieira, 2000). The coefficient of variation values (CV) that indicates the degree of variability of properties was characterized according to Warrick & Nielsen (1980). The degree of spatial dependence was classified according to the methodology proposed by Cambardella et al. (1994). For making contour map was used $GS^+$ version 9.0 software (ROBERTSON, 2008).

## Results and Discussion

The results in the data analysis by descriptive statistics showed high chemical soil fertility in the evaluated sample density. In the depth of 0-0,20m, the average levels of soil chemical properties were classified according to Raij et al., (1997), for the State of São Paulo, as high for calcium, magnesium, base saturation and capacity of total cation exchange, while those obtained for potassium, available phosphorus, organic matter and pHCaCl2 were considered average.

The data variability, measured by the coefficient of variation (CV%) and according to the criteria proposed by Warrick & Nielsen (1980) was low (CV <12%) to pH values, the sum of bases (SB) and saturation ( V%) indicating less heterogeneity of these variables for the study area, which is consistent with studies by Santos et al. (2012) and Mattioni et. al., (2013). The organic matter (OM), extractable phosphorus (Pres.), Potassium (K), total cation exchange capacity (CEC), calcium (Ca) and magnesium (Mg), had a mean variability, corroborating the findings of Molin et al., (2010). The coefficient of variation for the phosphorus content (Pres.) Showed a moderate variability of the element in the study area, agreeing with Cherubin et al., (2015). The variability of soil fertility levels in the area may lead to inefficient fertilizer applications when it adopts the average value for fertilization and liming recommendation. According Rabbit (2003), the high amplitude demonstrates the possible problems that may be generated when using only the average of the results as a parameter for implementation of corrective and fertilizers.

The descriptive analysis of the results of the granulometric composition of the soil, silty clay demonstrate textural class, as suggested by Ferreira et al., (2010). Regarding the coefficient of variation (CV) clay and silt exhibited moderate values, while the sand showed a high CV, which is consistent findings by Oliveira et al., (2013).

The parameters analyzed regarding the chemical and physical soil properties showed no normal distribution of data by the Kolmogorov-Smirnov (KS) test. Other authors also found similar results for the soil chemical properties (Carvalho et al., 2002; Cambardella et al, 1994) with respect to the normality of the data.

The productivity of corn with and without straw showed no significant correlation with soil properties, according to Cerri et al., (2012), which also found similar results. The organic matter (OM) provided significant and positive correlation with most soil properties studied, with the exception of sand whose correlation was reversed and the pH showed no significant correlation. According to Hawk et al., (2013), organic matter acts as a supplier of P for plants, contributing significantly to the nutrition of the plant. The positive correlation with potassium (K), calcium (Ca), magnesium (Mg), sum of bases (SB) total cation exchange capacity (CEC), base saturation (V%) show that of the variation of these attributes They depend on the distribution of the content of organic matter in the soil. The ratio of soil organic matter with the texture is related to porosity and aeration, which by reducing tend to minimize the decomposition of organic matter, which may explain the positive correlation with clay and silt. The CTC in tropical soils, which is high by raising the levels of organic matter in the soil, was positively correlated with clay, corroborating Portugal et al., (2010). The P element in turn correlated positively with potassium (K), sum of bases (SB) and total cation exchange capacity (CEC), disagreeing with the results obtained by Montezano et al., (2006).

The study of the spatial distribution of data, elaboration of mathematical models which are suited better the behavior of each parameter (semi-veriogramas) show different settings, which parameters are presented in Table 1.

Table 1. Semivariograms parameters adjusted to the clay data, silt, sand, organic matter (OM), phosphorus (P) and potassium (K) in the autumn-winter 2014, Registro, Ribeira Valley, SP, Brazil.

| VARIABLE | MODEL | $C_0$ | $C_0$+C | $A_0$ | $R^2$ | RSS | GDE |
|---|---|---|---|---|---|---|---|
| Clay | Gaussian | 3450 | 7033,0 | 114,80 | 0,971 | 240027 | 49,05 |
| Silt | Spheric | 1226 | 3976,00 | 136,30 | 0,866 | 46308 | 30,83 |
| Sand | Spheric | 6120 | 15890 | 129,00 | 0,858 | 5932743 | 38,51 |
| MO | Spheric | 0,010 | 16,530 | 41,80 | 0,197 | 6,24 | 0,060 |
| $P_{res}$ | Exponential | 156,90 | 313,90 | 314,50 | 0,480 | 2468 | 49,98 |
| K | Spheric | 0,6860 | 1,9020 | 410,90 | 0,925 | 0,0242 | 36,06 |

$C_0$ = nugget effect; $C_0$ + C = level; $A_0$ = range; $R^2$= coefficient of determination; RSS= sum of the squared residuals; GDE = degree special dependency.

The increased range was found for the variable K (410,90 m) and the lowest for the soil organic matter (41.80 m) (Table 1). According Cambardella et al. (1994), high values of nugget (C0) corresponds to the variation detected during the sampling process. It has been found that the spatial dependence of the analyzed attributes ranged from moderate to high (Table 1).

The semivariogram related to the clay content in the experimental area showed that the model that best fit the data was Gaussian, with 114,80m range value (Table 1), and the adjusted model is able to explain more than 97 % of the observed variation (R2 = 0.971), with moderate spatial dependence. The interpolation of the data showed that most of the area (62.96%), has clay content greater than 400.0 g kg-1 and the values below this, delimit another zone, highlighting two well-defined regions on this fraction Particle size. The Silt values show that the spatial dependence between the points presented data adjustment to the spherical model with range (A0) of 136,30m. Note that more than 86% (R2 = 0.866) of the observed variation is explained by the model, which describes a spatial dependence moderate degree (0.308), confirming Vieira et al., (2009). Indicate that the random variance (nugget effect) represents 30.8% of the level, and remaining 69.2%, corresponding to the spatial variance (C) of the data. Geographically, the data presented silt were distributed similarly in two well-defined areas. The values of sand content indicated a range of 129m, with the spherical model which best fit to the data, showing that there is a moderate degree of spatial dependence (GDE = 0.385), as shown in Table 1. The interpolation of data sand showed the greater part of the area with values between 130 and 310 g $kg^{-1}$, identifying a well-defined zone, the same occurring with values less than 130 g $kg^{-1}$.

Among all soil fertility parameters studied, we selected the content of soil organic matter, phosphorus and potassium by the importance that present in plant production and ear weight, and present correlations with sand values, silt and clay soil. The semivariogram values related to soil organic matter showed the spherical model as the best fit to the data with the reach of 41,8m and high degree of spatial dependence (Table 1), whose results agree with Vieira et al. (2009). The MO area values show two well-defined areas, with lower values, 25.9 g dm-3 (38.4 area%) and the other richer in OM, with values greater than 25.9 g dm-3 ( 61.6%). Analyzing the geographical position of the identified areas, it appears that higher MO values coincide with the zone of higher clay content, whereas the area with sand predominance is coincident with the lower values of soil organic matter. These data are in agreement with that indicated by Raij et al. (1996), which indicate values up to 15 g dm-3 as a soil indicator values with sandy texture to the State of São Paulo. The spatial behavior related to phosphorus, measured by semivariogram, adjusted to the exponential model, with a range of 314,5m, indicating moderate degree of spatial dependence (Table 1).

The model of spherical semivariogram was the best fit to K, with a range of 410.90 m and moderate spatial dependence. The phosphor exhibited spatial variability in the area under cultivation. It was found that most of the area (71.73%) had a P content lower than 32 mg dm-3 constituting the lower zone P concentrations in the soil, which coincide with the areas of low levels of organic matter and high percentage of sand. The heterogeneous behavior of P content in the soil, allows categorization in fertility classes in the study area, delimiting areas with potential for the recommendation of the differentiated management of fertilizer application at variable rate. Potassium was the chemical attribute with greater variability in the area, allowing the identification of three distinct regions as the nutrient levels. K levels in the soil, this study demonstrated considerable variability when they were categorized in fertility classes, delimiting different areas of management, with potential for recommending the application of this nutrient in variable rate.

## Conclusions

The model of spherical semivariogram was the best fit to K, with a range of 410.90 m and moderate spatial dependence. The phosphor exhibited spatial variability in the area under cultivation. It was found that most of the area (71.73%) had a P content lower than 32 mg dm-3 constituting the lower zone P concentrations in the soil, which coincide with the areas of low levels of organic matter and high percentage of sand. The heterogeneous behavior of P content in the soil, allows categorization in fertility classes in the study area, delimiting areas with potential for the recommendation of the differentiated management of fertilizer application at variable rate. Potassium was the chemical attribute with greater variability in the area, allowing the identification of three distinct regions as the nutrient levels. K levels in the soil, this study demonstrated considerable variability when they were categorized in fertility classes, delimiting different areas of management, with potential for recommending the application of this nutrient in variable rate.

### Acknowledgements

Our acknowledgments to Kassuga Farm to permit the conduction this experiment in your area.

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