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Influence of spatial soil variability on productivity and physiological quality of soybean seeds

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Abstract

Seed production fields present spatial and temporal variability in the physical and chemical characteristics of the soil, thus influencing the yield and quality of the produced seeds. The objective of this study was to characterize the spatial variability in soil attributes providing physiological quality and productivity in soybean seeds in two commercial production fields, aiming to define areas of agronomic management. The experiment was carried out in the 2014/15 and 2015/16 crop seasons in a 100×100 m grid. Soil sampling was performed at a depth of 0-200 mm with a 75×75 m grid. The soybean samples were collected at the end of the 2014/15 crop season. Therefore, soil analysis was determined only in the 2014/15 crop season. The plants' agronomic characteristics and the productivity and physiological quality of produced seeds were determined for both crop seasons. Thus, it was concluded that the study site presented spatial variability in soil characteristics, phosphorus content, organic matter, cation exchange capacity, sand, and clay content, and the agronomic characteristics of soybean plants cv. BMX Desafio RR, including plant height, number of nodes per plant, number of pods with three seeds, number of pods with seeds, number of seeds per plant, seed weight per plant, seed weight per linear meter, productivity, and germination. Seed productivity showed a strong spatial dependence, while germination showed a moderate spatial dependence. Three management zones were determined according to the spatial distribution of the results obtained.

Keywords: *Glycine max* L., precision agriculture, seed quality, yield components.

Introduction

The seed is fundamental to the soybean production cycle because it is through seeds that new cultivars become available in the marketplace (PESKE *et al*., 2012); therefore, the seeds' quality is of great importance to ensure the success of crops. It has already been demonstrated that high-quality seeds show high performance during germination and emergence processes, thus ensuring strong and vigorous seedlings with greater speed of emergence and development (FRANÇA-NETO *et al*., 2010).

New technologies are being developed to improve seed production conditions, aiming to increase productivity and seed quality while decreasing production costs and mitigating environmental impacts. These new technologies aim at precision agriculture, establishing a modern tool to help producers make timely decisions that influence the success of their agriculture; in this case, the production of seeds in fields (COLAÇO *et al*., 2018). Characterizing the spatial variability of crop performance is the first step in developing new site-specific management strategies. A proper understanding of the level of variability within cropping fields enables farmers and researchers to estimate the potential benefit and opportunities for precision agriculture practices (PRINGLE *et al*., 2003; ROBERTSON *et al.*, 2008; TISSEYRE; MCBRATNEY, 2008).

According to Corá *et al*. (2004), agronomic management areas of production focusing on ground area and crop volume are integral to precision agriculture. However, the definition of this practice and where it should be implemented depends on prior knowledge, including an understanding of the variability of soil conditions and climate and how plants respond to these factors. Similarly, Resende *et al.* (2014) reported that the establishment of specific areas of management results in information that makes possible the elaboration of performance maps of productive cultures inside areas of cultivation, and these maps of product yield reflect the interaction between all the production factors in agriculture: soil, plant, and climate.

The relationship between fields and the production of seeds in certain areas shows that the spatial variability attributes of the soil contribute to the physiological quality and productivity of seeds. This relationship identifies regions that produce seeds with higher physiological quality and regions that produce seeds with lower physiological quality. The same phenomenon has been observed in productivity (Mattioni *et al*., 2011; Mondo *et al*., 2012; Mattioni *et al*., 2013; Gazolla-Neto *et al*., 2016). However, defined management areas for the production of seeds and technology implementation have not yet been adequately elucidated.

This study aimed to characterize the variability in the spatial attributes of soil that determine the physiological quality and productivity of soybean seeds in one commercial production field, aiming to define precise areas of agronomic management.

Materials and methods

The experiment was conducted in Rondonópolis, MT, Brazil. Commercial field production of soybean seeds (*Glycine max* (L) Merrill), cultivar BMX Desafio RR, with an area of 32.8 ha (16° 35’ 24.0’ S latitude, 54° 52’ 08.3° W longitude) during the 2014/15 and 2015/16 crop seasons (Figure 1), with soil classified as typical dystrophic red latosol (EMBRAPA, 2006). The field cultivation history indicates soybean and second-crop corn under a no-tillage system for more than ten years, presenting a homogeneous appearance; the agronomic management in terms of time and space is the same across the whole area. There are two crop seasons in Brazil, so in this field, soybeans were cultivated in the 2014/15 crop season, followed by corn in 2015, then soybeans again in 2015/2016.

Based on the field contours, a one-hectare grid was drawn for soil sampling, resulting in 36 sampling points in the field. A soil sample was collected one day before seeding using a hydraulic kit at a 0–200 mm depth and sent to a soil laboratory. In the soil laboratory, the sample

Figure 1 – Location of geographical area under study: coordinates 16° 35’ 24 .0” S, 54° 52’ 08.3” W, altitude 559 m.

Source: Google Earth Pro (2017).

was analyzed for pH (in water); phosphorus (P; mg dm^{-1}); potassium (K; mg dm^{-1}); calcium (Ca; cmolc dm^{-3}); magnesium (Mg; cmolc dm^{-3}); hydrogen (H; cmolc dm^{-3}); organic matter (MO; g dm^{-3}); sand (g kg^{-1}); silt (g kg^{-1}); clay (g kg^{-1}); cation exchange capacity (CEC; cmolc dm^{-3}); base saturation (V; %); Ca/Mg ratio; Ca/K ratio; Mg/K ratio. These analyses were carried out according to recommendations for soybean cultivation in Brazil by EMBRAPA (2011).

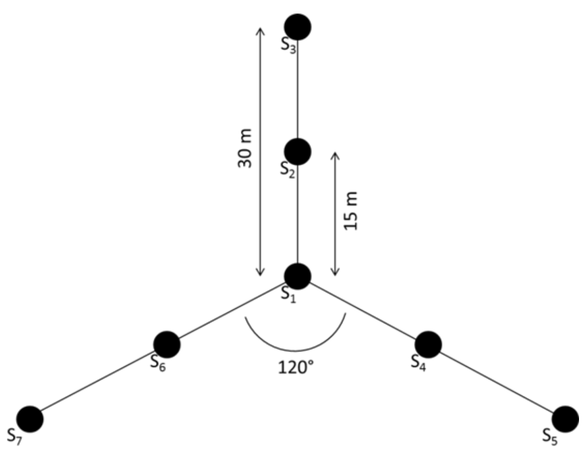
In 2014, the seeding took place on 23 October using a Case IH® seeder in 30 lines, calibrated to sow 24 seeds m^{-1} with 0.45 m between lines. The soybean field was planted in a no-tillage system from corn (2014), and fertilization was performed by adding 350 kg ha^{-1} of 5-20-20 (NPK). Six insecticide applications (three for Lepidoptera and three for Hemiptera) and three fungicide applications were performed during the crop season. Likewise, in 2015, the seeding took place on October 21 and 22 using the same seeder and calibration. Again, the soybean field (2015/16) was planted in a no-tillage system from corn (2015), and fertilizing was performed by adding 350 kg ha^{-1} in 5-20-20 (NPK). The same number of insecticides and fungicide applications were performed. Data on temperature and relative moisture were monitored throughout the crop season via a weather station on the farm.

The harvest took place on 24 February 2015, when the crop reached physiological maturity, which was determined when the average water content in the seed was 18%. In the 2015/16 crop season, the harvest occurred on 13, 14, and 15 February 2016.

Forty-nine plant samples were collected from a 0.56 ha area grid for more precision. There were 49 whole plants collected from a 7 m linear strip with seven subsamples one linear meter apart in each sample. One sample was central (georeferenced), and the others were distributed across 15 and 30 m rays, with the angle between each ray being 120° (Figure 2). In that same scheme, the number of plants was counted to check the seeding density (adapted from Gazolla-Neto *et al.* (2016)).

All plants collected from each sampling grid were threshed manually, except 14 plants per sample, which were used to determine the agronomic characteristics. All seeds obtained were packed in paper bags and dried in a dryer at 35°C with air in circulation until an average moisture content of 13% was obtained. Finally, the seeds were sent to the Seed Analysis Laboratory of the Federal University of Pelotas, where they were stored in a cold chamber until the germination analysis.

Figure 2 – Representation of the distribution of points at which subsamples of plants were obtained. Each position represents a sampling grid.



Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

The agronomic characteristics measured were as follows: height of the plant, determined by measuring with a measuring tape the distance from the cotyledon to the far end of the main stem; height of the first pod, measured distance from the cotyledon to the first pod on the plant; number of nodes at the main stem; diameter of the stalk, evaluated at the height of the cotyledon using a digital caliper ; the number of pods with one, two, three, four, and no seeds; number of pods per plant; number of pods with seeds per plant; number of seeds per plant; and weight per thousand seeds, accomplished through eight repetitions of 100 seeds each according to the rules for analyzing seeds (RAS) (BRASIL, 2009).

Based on the results obtained from the thousand seeds' weight and the number of seeds per plant, the weight of seeds per plant (g pl^{-1}) was calculated, which, together with the density in seeding, was used to determine the weight of seeds per linear meter (g m^{-1}) and the yield (kg ha^{-1}). Retention in sieves was also tested using 7.0, 6.5, 6.0, and 5.5 mm and without perforation (bottom blind) sieves. After three minutes of constant shaking, the number of seeds retained in each sieve was weighed separately on an analytical balance and calculated in percentages for each size sieve.

Finally, the germination test was conducted using 400 seeds distributed in eight repetitions of 50 seeds each, sown in rolls of paper moistened with distilled water using a quantity of three times the dry weight and conditioned in a germinator at 25°C. According to RAS, the counting of normally sprouted seedlings was conducted five and eight days after seeding (BRASIL, 2009).

The data obtained from soil, plants, and seeds were submitted for descriptive statistical analysis and geostatistical analysis using R software (R Core Team 2015) and the geoR package (RIBEIRO JUNIOR; DIGGLE, 2001). For geostatistics analysis, an initial exploratory analysis of the data was conducted, and its space dependence was tested through graphic diagnosis, where empiric semivariograms and their envelopes were simulated 1000 times. Finally, for those variables that presented dependency on the space, the parameters of two geostatistics models (average (μ), sill (σ^2)) and (nugget (τ^2) and range (Φ)) were estimated, and the choice of the best model was made using the maximum likelihood method.

The best-adjusted models were determined according to the kriging and the digital models of variables. Additionally, a map was created of the occurrence of seeds with a germination percentage greater than 80%, the minimum value established through Brazilian legislation for the commercialization of soybean seeds, with a probability greater than 0.8. Equally, dependency on space (ADE) was estimated according to Cambardella *et al*. (1994), where ADE = $[\tau^2/(\tau^2 + \sigma^2)]*100$. Dependency on space was considered weak when the ADE was greater than 75%, moderately dependent when the ADE was between 25% and 75%, and tightly dependent when the ADE was less than 25%, agreeing with the ranking of the same authors. Finally, the management zone was defined using R software based on Molin (2002).

Results and discussion

Table I presents the descriptive statistics of the soil attributes. The mean and median values for most variables in the soil are similar, suggesting symmetry in the distribution of data. However, magnesium, hydrogen, sand content, and base saturation did not present a normal distribution according to the Shapiro-Wilk (1965) test ($p < 0.05$).

The agronomic components in soybeans are influenced by edaphoclimatic conditions and fertilization, especially phosphorus and potassium. Phosphorus is essential for flowers, pods, and seed weight. Potassium is also important for seed weight and yield, the height of plants, viable seeds, and germination (BATISTELLA FILHO *et al*., 2013).

In general, it was observed that the field soil was homogeneous, and the soil attributes analyzed presented low variation in coefficients. For example, according to Montanari *et al*. (2008), the main characteristics of red latosol are that its attributes are homogeneous both vertically and horizontally. However, in this field, phosphorus and potassium presented coefficient variation (Table 1) classified as medium (between 12% and 24%) according to the ranking based on Warrick and Nielsen (1980). The results agree with those observed by Mattioni *et al.* (2013). They, working on a seed field with different soil, identified that phosphorus and potassium were the nutrients that presented more significant variation. Equally, Cavalcante *et al*. (2007), assessing the content of some soil attributes under different management techniques, observed variation in the coefficients for P and K more outstanding than 24% in all the management techniques studied.

On the other hand, these two elements' minimum and maximum values present a wide range (Table 1). Corá *et al*. (2004) reported that a wide range in the value of one nutrient in the soil could present problems for management decisions, as fertilizer is applied based on average values. Because of this, quantities can be overestimated or underestimated, resulting in economic losses or environmental impacts and poor physiological seed quality.

Table 2 presents the results for variables in the geostatistical analysis that represent dependency on space. Phosphorus, organic matter, and CEC

Table 1 – Descriptive statistics analyzing 36 samples of soil collected in a field producing soybean seeds, cv. BMX Desafio.

Attribute	Mean	Median	Value		Standard deviation	Coefficients			Normality
			Min.	Max.		Var	K	A	
pH	6.0	6.0	5.7	6.3	0.1	2.4	-0.221	-0.114	0.133
P	31.4	32.3	20.8	41.9	5.1	16.3	-0.332	-0.354	0.458
K	64.4	64.0	46.0	89	12.9	20.1	-0.928	0.390	0.063
Ca	3.2	3.2	2.4	4.1	0.4	11.8	-0.288	0.127	0.736
Mg	1.2	1.2	1.0	1.5	0.1	10	0.432	0.450	0.008
H	4.3	4.4	3.3	4.8	0.4	9.3	0.871	-1.125	0.001
MO	37.6	36.8	30.4	44.5	3.2	8.5	-0.271	0.098	0.772
Sand	270.7	273.0	207.0	323.0	27.7	10.2	0.376	0.009	0.012
Silt	152.9	152.0	139.0	166.0	6.7	4.4	-0.501	-0.277	0.195
Clay	576.4	578.0	534.0	635.0	22.6	3.9	0.549	0.130	0.158
CEC	8.9	8.9	7.4	10.1	0.6	6.6	0.303	-0.114	0.484
V	51.5	51.3	43.1	61.5	3.8	7.4	1.376	0.759	0.023
Ca/Mg ratio	2.7	2.7	2.4	2.9	0.1	3.7	3.130	-1.375	0.000
Ca/K ratio	20.0	19.2	12.0	29.7	4.9	25.0	-0.892	0.218	0.315
Mg/K ratio	7.3	7.5	4.5	10.8	1.8	24.1	-0.956	0.165	0.358

Notes: pH (water); phosphorus (P; mg dm $^{-1}$); potassium (K; mg dm^{-1}); calcium (Ca; cmolc dm^{-3}); magnesium (Mg; cmolc dm^{-3}); hydrogen (H; cmolc dm^{-3}); organic matter (MO; g dm^{-3}); sand (g kg^{-1}); silt (g kg $^{-1}$); clay (g kg^{-1}); cation exchange capacity (CEC; cmolc dm^{-3}); base saturation (V; %); Ca/Mg ratio; Ca/K ratio; Mg/K ratio. K= Kurtosis; A= Asymmetry; Var.= Variation.

Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

content showed less than 25% dependency on space, indicating high dependency (Table 2). In contrast, the soil content of sand and clay presented a spatial dependency greater than 75% (Table 2), indicating a weak dependency according to the ranking in Cambardella *et al.* (1994). The results agree with those observed by Montanari *et al.* (2008), who identified spatial dependency evaluators classified as strong for phosphorus, organic matter, and CEC in red latosol soil.

Equally, the adjusted range in all the geostatistical models of soil variables was more than 100 m (Table 2), the minimum distance between sampling points, indicating that using a one-hectare grid was appropriate for collecting data mapping these variables. On the other hand, the results of the nugget effect of the phosphorous, organic matter, and CEC variables were low (Table 2) at slightly above zero, indicating that the sampling error was minimal, according to the levels established Oda-Souza *et al.* (2008). This result indicates a strong dependency on space among said variables. Molin and Faulin (2013) stated that the magnitude of the nugget effect is important for kriging because the higher the difference in the semivariogram sill, the higher the phenomenon continuity, the lower the estimation variance, and the higher the estimation confidence.

Figure 3 presents the digital models of the soil attributes that represent dependency on space. Phosphorus (Figure 3A) variation between 20.8 and 41.9 mg dm^{-3} (Table 1) was observed in the soil, with the grids located in the northeast and the north center of the field presenting the lowest values. The organic matter and cation exchange capacity (Figures 3B and 3C, respectively) showed similar behavior, with the lowest values in the regions to the east and center of the field and higher values in the south-center and southeast. Finally, the clay and sand content (Figures 3D and 3E, respectively) presented a contradictory behavior: the eastern region of the field showed the highest clay content and the lowest sand. At the same time, the reverse was confirmed in the western region of the field. However, two variables were evaluated as weak in terms of spatial dependence, with ADE values of 91.63% for clay and 92.38% for sand (Table 2). Equally, as observed in Table 1, the variation of clay content ranged between 534 and 635 g kg$^{-1,}$ and the variation of sand content ranged between 207 and 323 g kg^{-1}. Variation coefficients of 3.9% for clay and 10.2% for sand (Table 1) show that the variability of these two attributes is low, according to the ranking proposed by Warrick and Nielsen (1980).

Regarding agronomic characteristics, it was initially observed that seeding was achieved with a high degree of precision, with an average of 21.1 ± 1 pl m^{-1} and a variation coefficient of 4.6% (Table 3). The seeding density of approximately 466.000 pl ha^{-1} is appropriate

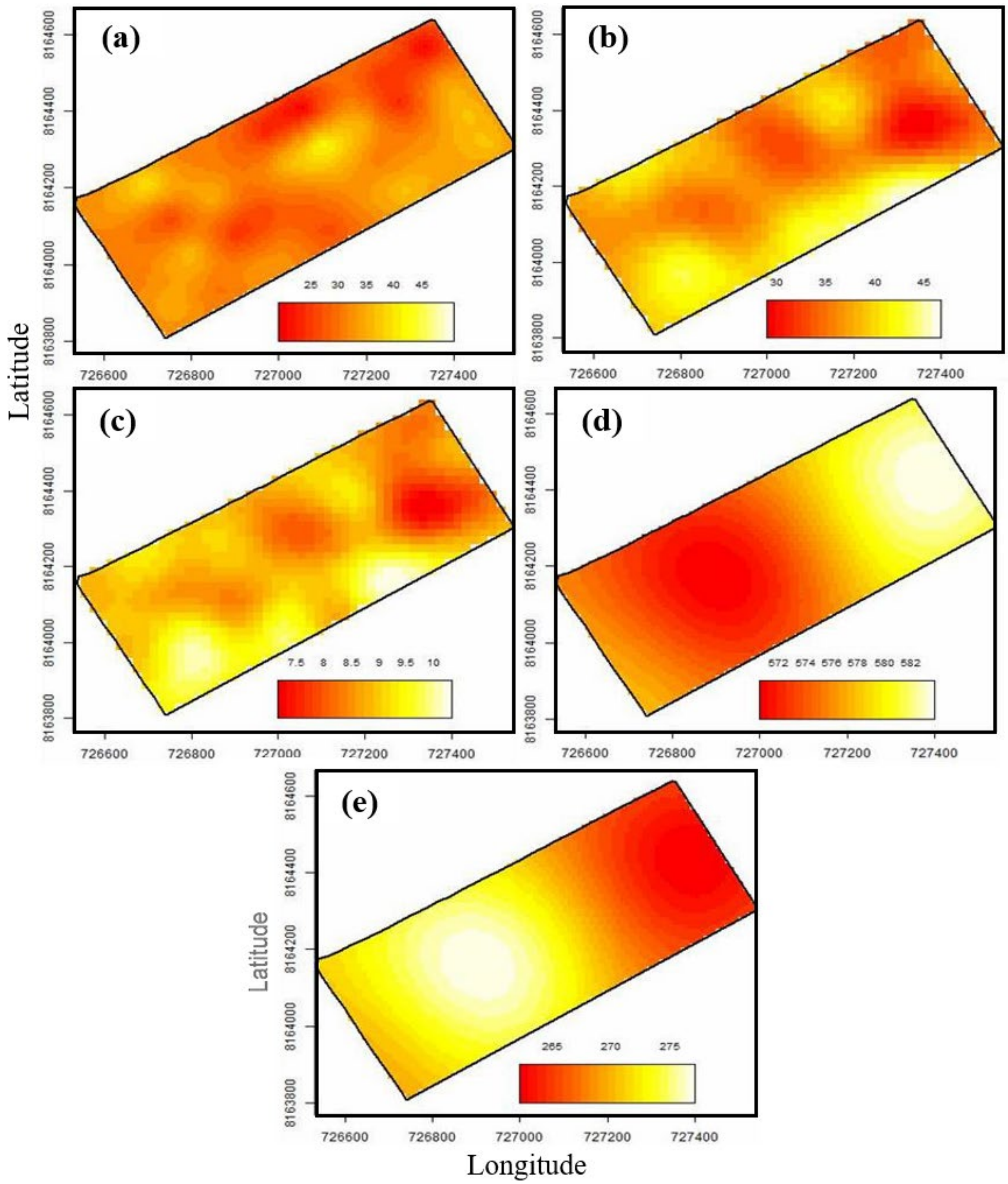
Table 2 – Geostatistical models and dependency on space (ADE) of variables in soil.

Attribute	Model	Mean (μ)	Nugget Effect (τ^2)	Sill (σ^2)	Range (Φ)	ADE (%)
P	Spherical	31.43	0.010	25.6700	139.07	0.04
MO	Gaussian	38.14	0.053	12.4400	133.70	0.42
CEC	Gaussian	8.92	0.010	0.3462	106.41	2.81
Sand	Gaussian	269.42	690.410	56.9800	286.59	92.38
Clay	Gaussian	577.41	457.730	41.8300	283.44	91.63

Notes: phosphorus (P; mg dm^{-3}); organic matter (MO; g dm^{-3}); cation exchange capacity (CEC; cmolc dm^{-3}); sand (g kg^{-1}); clay (g kg^{-1}).

Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

Figure 3 – Digital models obtained by kriging analysis showing attributes in soil that represent dependency on space.



Notes: A) phosphorus (P; mg dm^{-3}); B) organic matter (MO; g dm^{-3}); C) cation exchange capacity (CEC; cmol c dm^{-3}); D) clay content (g kg^{-1}); E) sand content (g kg^{-1}).

Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

for BMX Desafio RR crop growth because of its low branching capacity. The next crop season, 2015/16, had an average of 20.4±2 pl m^{-1} with a standard variation of 10.0%, corresponding to a seeding density of 450.540 pl ha^{-1} (Table 3).

The variables of plant height, pods without seeds, percentage of seeds retained in 6.0, 5.5, and 5.0 mm sieves, and germination percentage presented no normality in the distribution of data, with high coefficients in standard deviation for crop season 2014/15 (Table 3). However, many of the variables analyzed presented similar mean and median values and low standard deviations and variation coefficients during the 2015/2016 crop season, except for the number of empty pods without seeds per plant. These characteristics of data normality are similar to the Shapiro-Wilk test for normality (Table 3).

The data for germination in both crop seasons show a difference of 10%, with 83% in 2014/15 and 73% in 2015/16. However, in the latter crop season, the seeds showed a lower germination rate than required by Brazilian legislation, which is 80% (BRASIL, 2013).

The difference in germination between the years of production can be a consequence of rain before the harvest during the crop season (Figure 4), which delays the harvest and exposes the seeds to the environment, resulting in loss of quality. In the period of physiological maturity and harvest, loss of moisture content in the seeds can occur, resulting in exposure to alternative cycles of humid and dry environments after maturity. These losses can be more intense in tropical areas because of the hot and humid climate, which can accelerate the deterioration process of the seeds (CASTRO *et al.,* 2016). Forti *et al.* (2013) found that the physiological potential of seeds is diminished when affected by moisture content loss, which can be prejudicial to the quality of soybean seeds.

The yield and seed germination variables (Table 3) identified a variation, with a yield from 4.3 to 7.6 t ha^{-1} and germination from 61% to 96%. These results agree with those obtained by Mattioni *et al*. (2012), who observed variations in soybean seed productivity approaching 1500 kg ha^{-1} and in germination approaching 30%. Equally, Mondo *et al*. (2012) observed the germination percentage of soybean seeds in one field to be between 73% and 98%.

The height of the plant and germination percentage of seeds did not show normal distribution (Table 4). Therefore, they were transformed using lambda (λ) at 6.5 and 3.5, respectively. According to the method of transformation in Box and Cox (1964), to accomplish parametric tests such as those performed in this experiment, it must be ensured that the data comply with the statistical assumptions of normality, homogeneity of variances, and independence observations.

According to the analysis of dependency on space, weight of seeds per plant, weight of seeds per linear meter, and yield presented strong dependency on space. In contrast, the other agronomic characteristics presented weak dependencies on space (Table 4), based on the parameters proposed by Cambardella *et al.* (1994).

All the geostatistical models of agronomic characteristics were higher than 75 m (Table 4), indicating that the grid used for sampling the plants was appropriate. Moreover, the smallest range calculated was 256 m, determined for the weight of seeds per plant, indicating that the grid sampling of two hectares could be used to monitor the dependency on space variability of agronomic characteristics of soybean plants in this field. Therefore, it is suggested that a 140×140 m grid is adequate for the grid sampling of plants for one seed producer.

The results of productivity and physiological quality are similar to those in Mattioni *et al*. (2011), Mondo *et al.* (2012), Mattioni *et al*. (2013), and Gazolla-Neto *et al.* (2016) also observed variability in fields of soybean seeds.

It is important to note that in the 2015/16 crop season, there was no spatial dependence in all variables (Table 4). These data are the product of randomness and are not dependent on localization or distances between the samples, characterizing a nugget effect. Silva *et al*. (1989)

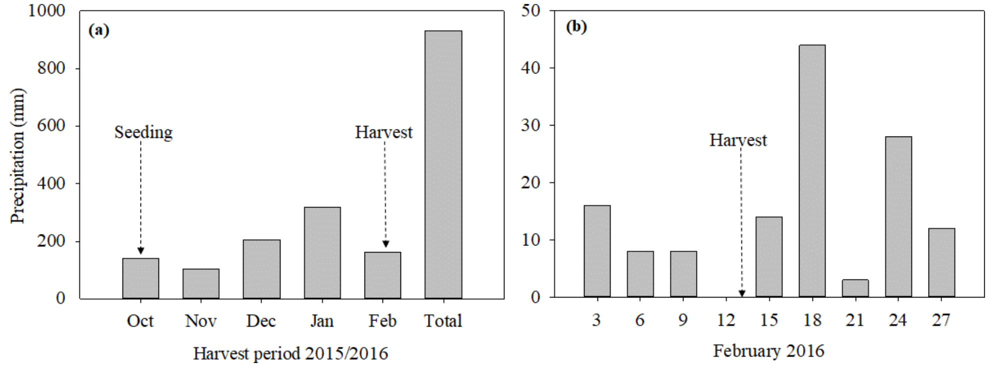
Table 3 – Descriptive statistics for agronomic characteristics of soybean plants and cultivar BMX Desafio RR seeds during two crop seasons.

Attribute	Season	Mean	Median	Value		Standard deviation	Coefficient of variation (%)
				Min.	Max.		
Dens.	2014/15	21.1	21.1	19.1	23.3	1.0	4.6
	2015/16	20.4	23	17	25	1.97	10.0
HPl	2014/15	88.6	89.2	81.3	94	3.5	4.0
	2015/16	70.92	71.36	67	75.71	2.66	3.75
Hei.1° pod	2014/15	15.9	15.9	13.3	18.3	1.1	7.6
	2015/16	10.84	10.71	8.86	12.57	1.23	11.33
NN	2014/15	12	12.1	10.4	13.1	0.6	5.2
	2015/16	12.85	12.86	9.71	15	1.36	10.61
DS	2014/15	6.9	6.9	6.2	7.7	0.3	4.8
	2015/16	6.54	6.37	5.63	7.57	0.56	8.49
EPSP	2014/15	0.5	0.5	0	1.4	0.3	59.0
	2015/16	0.07	0	0	0.29	0.09	143.05
EPL1S	2014/15	2.4	2.4	1.4	3.7	0.5	21.2
	2015/16	1.47	1.57	0.29	2.71	0.63	42.54
EPL2S	2014/15	10.5	10.6	7.6	12.2	0.9	8.5
	2015/16	9.48	9.14	6	12.57	1.86	19.6
EPL3S	2014/15	14.6	15.1	10.1	17.5	1.6	11.0
	2015/16	17.45	16.57	12.86	24.71	3.59	20.58
EPL4S	2014/15	1.6	1.5	0.7	2.4	0.4	22.7
	2015/16	2.07	2	0.43	4.43	1.05	50.6
FPSP	2014/15	29.2	29.6	23.6	33.7	2.3	7.8
	2015/16	30.47	29.86	21.14	42.14	5.76	18.92
SP	2014/15	73.7	74.6	56.3	85.9	6.2	8.4
	2015/16	81.06	79.57	55.43	113.57	16.24	20.03
WTS	2014/15	176.9	177.7	163.2	190.2	5.2	2.9
	2015/16	175.19	175.09	165.55	185.86	4.97	2.83
WSP	2014/15	13	13.2	9.2	15.3	1.2	9.3
	2015/16	14.17	13.83	9.78	18.8	2.64	18.6
WSML	2014/15	274.9	280.2	194.2	341.7	29.8	10.8
	2015/16	289.02	282.2	199.6	383.55	53.77	18.6
Yield	2014/15	6.1	6.2	4.3	7.6	0.7	10.8
	2015/16	6.42	6.27	4.44	8.52	1.19	18.6
P7	2014/15	17.1	16.8	7.3	30.4	5.4	31.4
	2015/16	15.73	13.25	9.83	27.99	5.99	38.09
P6.5	2014/15	48.1	48.4	36.3	65.1	4.2	8.7
	2015/16	51.53	52	46.6	53.81	2.46	4.77
P6	2014/15	28.6	28.3	17.7	39.3	5.3	18.4
	2015/16	27.48	28.35	17.41	35.19	4.81	17.49
P5.5	2015/16	5.5	5	2.1	14.4	2.4	44.0
	2014/15	4.7	4.43	2.07	7.79	1.53	32.5
G	2014/15	83	85	61	96	9.9	12.0
	2015/16	73	72	53	91	11.33	15.49

Notes: seeding density (Dens.; pl m^{-1}); the height of plant (HPl; cm); the height of insertion of the first pod (Hei.1° pod; cm); the number of nodes per plant (NN); diameter of the stalk (DS; mm); empty pods without seeds per plant (EPSP); pods with seeds per plant (EPL1S); pods with two seeds per plant (EPL2S); pods with three seeds per plant (EPL3S); pods with four seeds per plant (EPL4S); full pods with seeds per plant (FPSP); seeds per plant (SP); the weight of a thousand seeds (WTS; g); the weight of seeds per plant (WSP; g pl^{-3}); the weight of seeds per linear meter (WSML.m^{-1}; g m^{-1}); yield (t ha^{-1}); seeds retained in 7.0 mm sieve (P7; %); seeds retained in 6.5 mm sieve (P6.5; %); seeds retained in 6.0 mm sieve (P6; %); seeds retained in 5.5 mm sieve (P5.5; %); germination (G; %).

Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

Figure 4 – Rainfall between October 2015 to February 2016 (a) and detailed monitoring (accumulation of rain every three days) of February 2016 (b), when the harvest period of the 2015/2016 season took place.



Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

described the nugget effect as a phenomenon in which the variable has an independent spatial and random distribution.

About the germination percentage (Figure 5a), a division of the field into three parts was observed, visualized by tracing imaginary northwest to southeast lines (dotted lines in Figure 5a). The eastern region produced seeds of lower physiological quality. The central region produced seeds of average physiological quality, while seeds of the highest physiological quality were produced in the western region. A similar pattern was observed in the productivity of seeds (Figures 5b and 5c). The eastern region of the field featured a smaller yield, and the yield increased with western advancement, with the maximum productivity found in the center-south region of the field. This behavior was also evidenced in the agronomic characteristics of plant height (Figure 4d), number of nodes per plant (Figure 5e), number of pods with three

Table 4 – Geostatistical models of dependency on space (ADE) of agronomic characteristics of soybean plants and seeds of cultivar BMX Desafio RR.

			2014/2015			
Attribute	Model	Mean (μ)	Nugget Effect ($\tau 2$)	Sill ($\sigma 2$)	Range (Φ)	ADE (%)
HPl	Gaussian	6.26E+11	1.45E+22	2.90E+22	713.00	33.32
NP	Gaussian	11.92	0.25	0.20	650.80	55.02
EPL3S	Gaussian	14.32	1.78	1.56	756.31	53.21
FPSP	Gaussian	28.83	3.59	1.95	583.77	64.88
SP	Spherical	72.22	22.71	17.90	912.00	55.92
WSP	Exponential	12.57	0.35	1.41	256.64	19.89
WSML	Exponential	265.20	192.50	945.00	450.00	16.92
Yield	Exponential	5.88	0.10	0.50	515.11	16.40
G	Gaussian	1.54E+06	2.47E+11	1.93E+11	797.30	56.13
			2015/2016			
			Nugget Effect for all seed and agronomic characteristics			

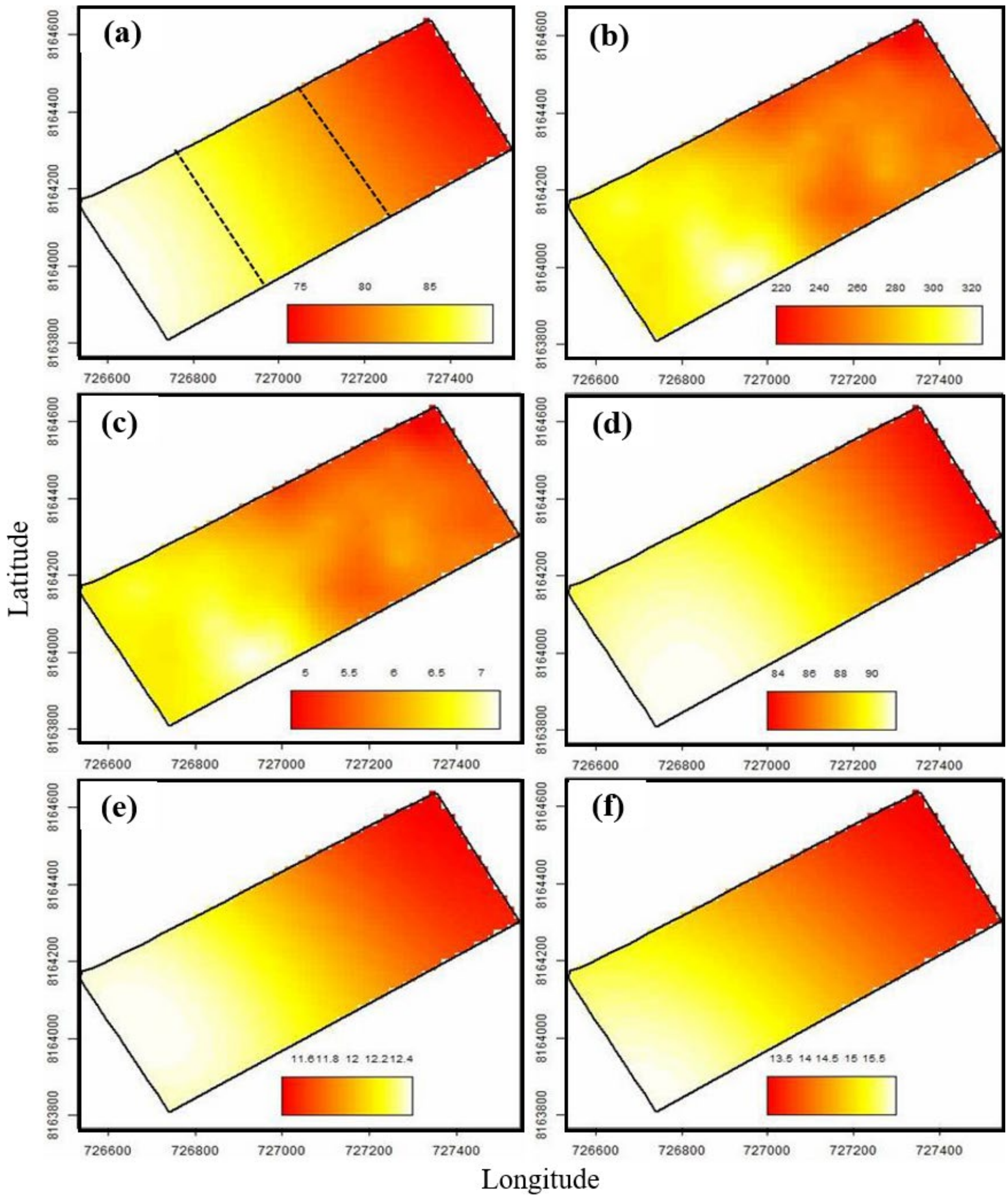
Notes: height of plant (HPl; cm); nodes per plant (NP); pods with three seeds per plant (EPL3S); full pod with seeds per plant (FPSP); seeds per plant (SP); the weight of seeds per plant (WSP; g pl^{-1}); the weight of seeds per linear meter (WSML.m^{-1}; g m^{-1}); yield (t ha^{-1}); germination (G;%).

Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

seeds per plant (Figure 5f), number of pods with seeds per plant (Figure 6a), number of seeds per plant (Figure 6b), and weight of seeds per plant (Figure 6c). From these maps, it can be seen that the eastern region was less productive than the western.

It was impossible to identify a relationship between the spatial variability of phosphorus, organic matter, and CEC of soil (Figure 3) and the spatial variability of the attributes of plants and seeds in soybeans (Figures 5 and 6) cv. BMX Desafio RR. The absence of a relationship could

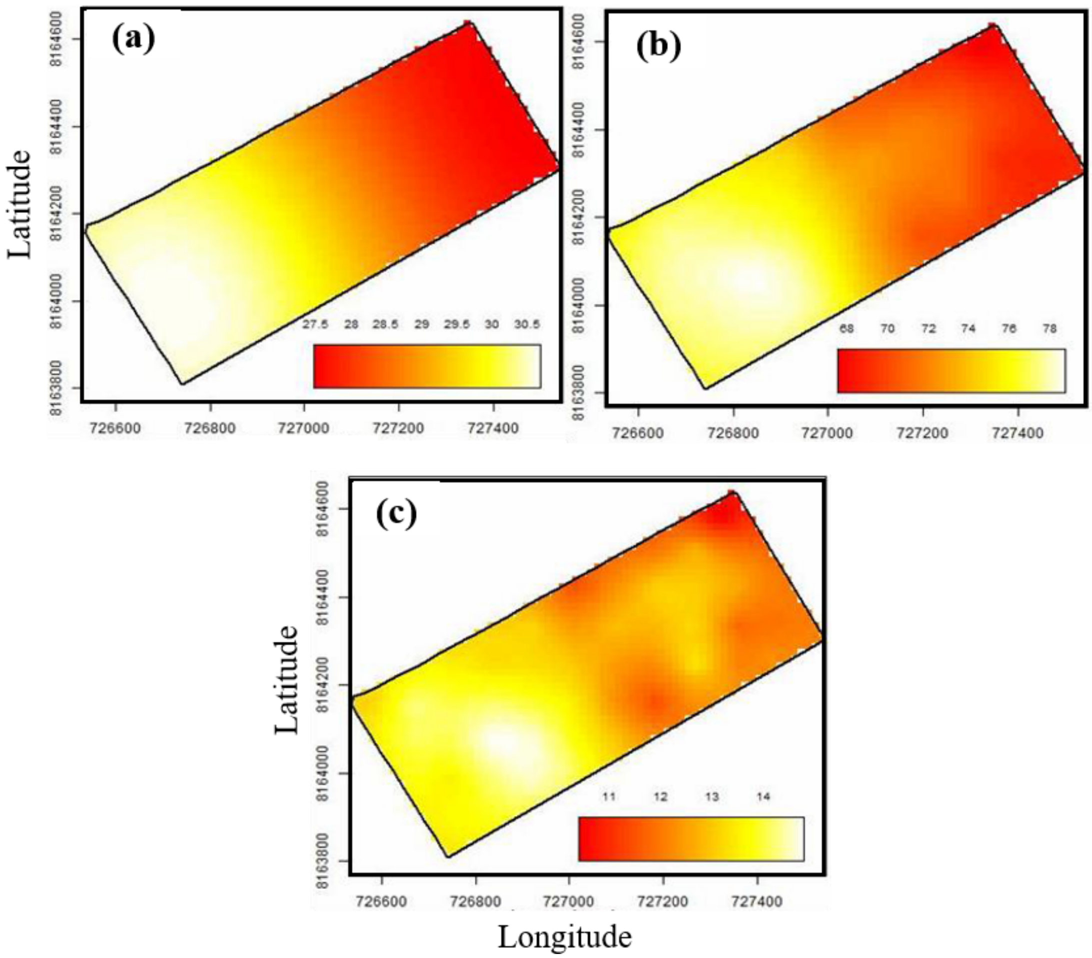
Figure 5 – Digital models obtained by kriging analysis of agronomic characteristics.



Notes: A) the percentage of germination in seeds; B) weight of seeds per linear meter (g m^{-1}); C) yield (t ha^{-1}); D) height of plants (cm); E) the number of nodes per plant; F) the number of pods with three seeds per soybean plant. BMX Desafio RR was produced in one field in commercial production, 2014/2015 harvest.

Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

Figure 6 – Digital models obtained by kriging analysis of agronomic characteristics.



Notes: A) the number of pods with seeds per plant; B) the number of seeds per plant; C) the weight of seeds per plant (g pl^{-1}) in soybeans. BMX Desafio RR was produced in one field in commercial production, 2014/2015 harvest.

Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

have occurred because the management in the seed field was based on high fertilization, and it was justified by the data from the second crop season showing that the nugget effect occurred (Table 4).

There was a relationship between the spatial variability of sand and clay content and the spatial variability of the percentage of germination in seeds, seed weight per linear meter (g m^{-1}), yield (t ha^{-1}), plant height (cm), number of nodes per plant, and number of pods with three seeds per soybean plant. The areas that were more productive and produced seeds of greater physiological quality were located in the regions where the sand content was more significant and the clay content was smaller than the lower quality. Equally, it was observed that in the eastern region of the field, which had more clay content, the organic matter and CEC contents were the lowest in the field, with the lowest seed productivity and germination. Lark *et al*. (1999) concluded that yield and soil maps are great tools for defining management zones. Molin (2002) more explicitly considered that establishing three zones with a range of MZ 1: <95% of yield; MZ 2: between 95 and 105%, and MZ 3: >105% of yield is a great tool to help farmers make decisions.

Based on data discussed previously and Molin (2002), using R software, it was possible to define three management areas in the study field (Figure 6a). Figures 5a and 6a show straight lines to visualize the zones; the field shown in Figure 1 had been harvested in straight lines as well. The zones in this study are defined based on the characteristics of the field area plane (Brazilian Cerrado). The first is located in the east of the field, considered to offer little value because germination and productivity present the lowest values. The middle zone is located in the center of the field and offers average yield, where the values observed for germination and productivity were average. The third zone is located in the west of the field, where the highest values for productivity and germination of soybean seeds were observed, and offering good yield.

Finally, Figure 7b presents the digital model where p≥0.8, as seeds had minimum germination of 80% (colored yellow), the minimum percentage established for commercialization of soybean seeds in Brazil (BRASIL, 2013). That region comprises an area of 12.2 (37.1% of the field), indicating the area that can provide one aggregate value to the product and offer seeds of more outstanding quality to the marketplace; the seed producer would benefit from harvesting the most significant physiological quality seeds in this area separately.

The map works as a technical tool that the seed company can use at harvest time, thus improving harvest and postharvest processes and generating many seeds of different physiological qualities, which can generate good returns.

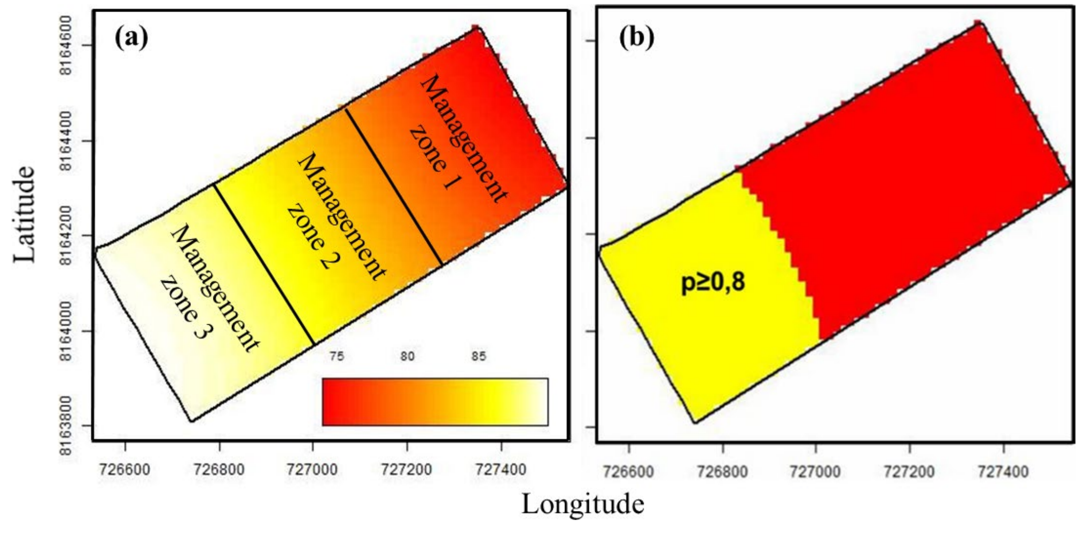
Conclusions

The field study featured variability in its soil characteristics in phosphorus and organic matter content, cation exchange capacity, sand, and clay content, and agronomic characteristics of soybean plants cv. BMX Desafio RR, including its income components productivity and germination.

The productivity of seeds presented a strong spatial dependency, while germination presented a moderate spatial dependency.

Three areas of agronomic management were defined, where the spatial variability of the soil affected productivity and the germination of seeds.

Figure 7 – Management zones defined in the study field, representing the spatial variability of agronomic characteristics (a) and the digital model where p≥0.8 (b), as soybean seeds cv. BMX Desafio RR had a minimum germination of 80%. Seeds were commercially produced in one field in the 2014/2015 crop season.



Source: Elaborated by Bruno Cesar Ivan Suares Castellanos (2017).

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