THEMATIC AND PROFITABILITY MAPS FOR PRECISION AGRICULTURE

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ABSTRACT

In the last few years yield maps became economically feasible to farmers with the technological advances in precision agriculture. The evidence of its profitability, however, is still unknown and, yield variability has seldom been correlated to profitable variability. Differently from yield maps, profitable maps can supply additional information related to the economical return for each particular area of the field. So, the objective of the present work was to study the economical viability in four situations, using profitable and profitability maps, as well as to quantify the influence of the interpolator type (inverse of distance, inverse of square distance and kriging) used for data computation in these maps drawing. It can be concluded that profitable and profitability maps are important tools for the diagnosis of spatial variability of economic return, since they assist farmers on the management decision making. The proposed index for the comparison of errors provided easy and non subjective selection of the experimental semivariogram, a necessary tool to use kriging when creating thematic maps. The interpolator inverse of square distance proved more effective than kriging and inverse of the square distance.

Keywords: Precision agriculture, profitable map, interpolator

INTRODUCTION

So important as searching for high yield indexes in the agriculture is the concern with profitability, efficiency, technology, innovation, and working conditions. These can be achieved through the study and rationalization of processes and methods which may transform inputs into products. WILD & COLVIN (2003) reported that profitability is the decisive key-factor of production viability and it is based on the relationship between income and cost. Maps of physical and chemical soil attributes associated to the yield maps can assist in the development of techniques for the attainment of higher yield.

The geoprocessing techniques provide subsidies for the identification and correlation of the variables that affect the yield and consequently the financial viability of areas used for the planting. Countless techniques are appearing, looking for the relationship among yield, the attributes of the soil and of the relief, seeking to identify the main limitations of the production of a certain area or region. Precision agriculture (PA), through the collection and analysis of geospatial data, enables site-specific crop management, with the necessary accuracy and precision, making possible the increase of the profitability and lower environmental impact.

With the technological advances in PA, yield maps became economically accessible to farmers. They can be easily generated after data collection by a yield monitor and integrate the effects of several spatial variables such as: soil properties; fertilizer rates; topographical attributes; atmospheric conditions; and occurrence of diseases and pests infestations. A yield map can be considered, alone or in association with other spatial information, as it is the case of the use of covariates, an essential tool in PA.

This technology has been increasingly adopted. The evidence of its profitability, however, is still unknown. Economical analyses and interviews with farmers suggest that yield mappings are profitable when they reveal yield patterns which can be managed at acceptable cost. The handling of this variability includes not only site-specific application of inputs, but also improvements such as field drainage, field leveling, windbreaks and fences (SWINTON & LOWENBERG-DEBOER, 1998).

The understanding of the spatial variability of grains yield is the first step for the management within variable rates. Geostatistics has been used to characterize the yield spatial variability (BIRRELL et al., 1995; MURPHY et al., 1995; JAYNES & COLVIN, 1997; YANG et al., 1998).

Spatial variability of yield implies in changeable economical return and net profit throughout the field. However yield variability has rarely been correlated to profit variability. Profit maps can be generated from data provided by yield monitors, crop prices, and production costs. Contrarily to yield maps, profit maps can provide additional information related to the economical return for each area within the field, enabling the farmer to take better decisions concerning management (YANG et al., 2002). Profit maps can also be used to identify stands, or even parts of them within a field, which consistently have low production profile. These areas can then be properly used for production of ensilage, for cultivation of other different crops, or fallow.

MASSEY et al., (2008) investigated how the decisions in management options can be improved by transforming database of yield maps of multiple crops from the same field into profit maps indicating profitability zones. This analysis demonstrated how the transformation of yield maps in profit maps can help the producer to analyse and then decide for different management options.

YANG et al. (2002) affirmed that several degrees of spatial variability in the yield in several cultures have been documented. They examined the spatial yield and profit variability in ten areas in the south of Texas. The results indicated that high spatial variability, high production costs and low resale prices result in a significant variability of the profits and low economical return. Unlike a yield map, a profit map can generate additional information focusing financial returns for any field area and enable the farmer to make administrative decisions.

Starting from a base of georeferenced yield data and using a geographic information system (GIS), yield maps can be generated through interpolation. However, one of the aspects still to be elucidated is the influence of the different interpolators types in the elaboration of thematic maps. Many papers were published comparing different interpolation methods in a great variety of data types (JONES et al. 2003). GRIM & LYNCH (1991) and PHILIPS et al. (1997) used atmospheric data. VAN KUILENBURG et al. (1982), LASSLET et al. (1987), LASLETT & MCBRATNEY (1990), BREGT (1992), GALLICHAND & MARCOTTE (1993), BRUS et al. (1996) and DECLERCQ (1996) used data of clay content and soil pH. CREUTIN & OBLED (1982) and TABOIS & ROOMS (1985) used data of rain precipitation. FRANKE (1982), HEINE (1986), JONES et al. (1995) and ZIMMERMAN et al. (1999) used predefined mathematical functions of control. HEINE (1986), ROUHANI (1986), LASLETT (1994) and WEBER & ENGLUND (1994) used elevation data.

WEBER & ENGLUND (1992) and KITANIDIS & SHEN (1996) used chemical data. COELHO et al. (2009) used yield data. All of the studies involved comparisons of two-dimensional methods of interpolation, with exception of the three-dimensional study of JONES et al. (1995). The methods more studied were kriging and inverse of the distance weighted (IDW). Out of the mentioned studies, eight showed kriging as the best (GRIM & LYNCH, 1991; HEINE, 1986; LASLETT, 1994; LASLETT & MCBRATNEY, 1990; LASLETT et al., 1987; PHILIPS et al.; 1997; ROUHANI 1986; ZIMMERMAN et al. 1999). Not all of the analyses included the interpolation IDW, and even when the kriging proved better "in the average", IDW was better under certain circumstances.

Three of the studies proved IDW was better than kriging (WEBER & ENGLUND, 1992; DECLERCQ, 1996, COELHO et al., 2009), and six studies showed a very small difference between kriging and IDW (CREUTIN & OBLED, 1982; VAN KUILENBURG et al., 1982; GALLICHAND & MARCOTTE, 1993; WEBER & ENGLUND, 1994; BREGT, 1992; BRUS et al., 1996). Another fact to be emphasized is that even for situations where the sampling density is high, as it is the case of yield monitors, the choice of the interpolator is an important decision, since most of them are inexact, as they do not reproduce the sampled values, affecting the minimum, maximum and average values, and changing the asymmetry and kurtosis distributions. In the process of choosing the best interpolator, cross validation enables the comparison of the predicted values with the sampled values (ISAAKS & SRIVASTAVA, 1989), and it was the technique that presented the best performance in a comparison made by FARACO et al. (2008) with the Akaike Information and Filiben Criteria, and the maximum value of the log-likelihood function.

This work aimed at studying the economical viability in four situations, using profitable and profitability maps, as well as quantifying the influence of the interpolator type (inverse of distance, inverse of square distance and kriging) used for data computation in these maps drawing.

MATERIAL AND METHODS

The corn and soybean yield of crops of four areas located in the rural area of the city of Cascavel (24 57' S and 53 27' W, average elevation of 750 m), state of Parana, Brazil, were evaluated. The harvest was performed using a combine New Holland® TC 57, equipped with yield monitor AgLeader® PF 3000. After data collection, the elimination of sampling points that presented very high or very low yield was done, following the procedure adopted by BLACKMORE & MOORE (1999). These points were probably influenced by sources of errors, such as: timing delays; loading and unloading times; GPS positioning; and actual width of harvesting smaller than that presented by the monitor. Data with very low or very high water content due to moisture sensor reading errors were also eliminated.

The maps were elaborated using data collected for each area (Table 1), having a sampling density higher than 175 points ha^{-1}. Despite this density sampling being well above the minimum necessary of 2.5 points ha^{-1} to build a thematic map (WOLLENHAUPT & WOLKOWSKI, 1994), the influence of the type of interpolator used in the elaboration of the yield map was evaluated.

Table 1 Metadata collection and filtering

Culture/Havest	Simbology	Area (ha)	Average Speed (km h^{-1})	Time* (s)	Gross Total Points	FinalTotal Points	Point number reduction	Sampling Density (points ha^{-1})
Soybean - 2002/2003	Soybean/03	14.8	5.3	1.00	19,351	18,306	5.4%	1,237
Corn – 2003/2004	Corn/04	30.3	4.0	3.00	14,693	13,738	6.5%	453
Soybean – 2005/2006	Soybean/06	45.3	5.5	3.00	8,089	7,960	1.6%	176
Soybean – 2006/2007	Soybean/07	30.0	5.7	3.00	6,037	5,246	13.1%	175

*Time - collection period between the two samples in seconds.

The data were statistically analyzed through exploratory analysis computing the mean, median, quartile, minimum, maximum, standard deviation and coefficient of variation (CV). The coefficient of variation was considered low when CV ≤ 10% (homoscedasticity); medium when 10% < CV ≤ 20%; high when 20% < CV ≤ 30%; and very high when CV > 30% (heteroscedasticity) (PIMENTEL-GOMES & GARCIA, 2002). The sampling coefficients of asymmetry and kurtosis were compared with the confidence intervals generated for different sizes of samples, indicating normal distribution of probability (JONES, 1969). The Anderson-Darling and Kolmogorov-Smirnovs were the tests used to verify data normality at 5% probability. Data were considered with normal distribution when fitting, at least, one of the tests. The outliers were verified through box-plot graphs.

The software ArcView 9.2 was used in the process of interpolating and construction of thematic maps. In the geostatistical analysis, the theoretical models spherical, exponential and Gaussian were adjusted to a semivariogram using the method of parameter estimation OLS (ordinary last square), default for the software used. The data were interpolated using the structure of variability estimated in interpolation by ordinary kriging. Cross-validation was used as a tool of choice for the most appropriate model of theoretical semivariogram, as well as in the comparison of interpolators.

Among the estimates supplied by the software to assess the quality of interpolation we have the mean error (ME, equation 1), the standard mean error (SME, equation 2), the standard deviation of mean errors (SDME, equation 3) and standard deviation of reduced mean errors (SDRME, equation 4). For deterministic methods (inverse of the distance (ID), and inverse of the square distance (ISD)), which do not provide a measure for the prediction uncertainty, only ME and SDME are calculated. However, in the choice between models adjusted to the experimental semivariogram, in order to avoid a situation in which those estimates suggest different models, a new estimate was proposed called index for comparison of errors (ICE, equation 5), which in the selection of j models provides lower values the closer to zero the SME is and the closer to 1 the SDRME is. Therefore in the choice between various models, the one having the lowest ICE is considered the best model.

$$ME = \frac{1}{n}\sum_{i=1}^{n} Z(s_i) - \hat{Z}(s_{(i)}) \quad [1]$$

$$SME = \frac{1}{n}\sum_{i=1}^{n} \frac{Z(s_i) - \hat{Z}(s_{(i)})}{\sigma(\hat{Z}(s_{(i)}))} \quad [2]$$

$$SDME = \sqrt{\frac{1}{n}\sum_{i=1}^{n} Z(s_i) - \hat{Z}(s_{(i)})} \quad [3]$$

$$SDRME = \sqrt{\frac{1}{n}\sum_{i=1}^{n} \frac{|Z(s_i) - \hat{Z}(s_{(i)})|}{\sigma(\hat{Z}(s_{(i)}))}} \quad [4]$$

where $\sigma(\hat{Z}(s_{(i)}))$ is the standard deviation of kriging in point s_i, without considering the observation $Z(s_{(i)})$.

$$ICE_i = A + B \quad [5]$$

where:

$$A = \begin{cases} \dfrac{ABS(SME)i}{MAX(ABS(SME))}, & when\ MAX(ABS(\overline{ER})) > 0 \\ 1, & when\ MAX(ABS(\overline{ER})) = 0 \end{cases} \quad [6]$$

$$A = \begin{cases} \dfrac{ABS(SDRME)i}{MAX(ABS(SDRME))}, & when\ MAX(ABS(S_{ER})) > 0 \\ 1, & when\ MAX(ABS(S_{ER})) = 0 \end{cases} \quad [7]$$

where ICE_i is the index for the comparison of errors for the model *i*.

The degree of spatial dependence was classified in accordance with the spatial dependency index (SDI, equation 8). CAMBARDELLA et al. (1994) proposed the following intervals: SDI $\leq$ 25% - strong spatial dependence; 25 % < SDI < 75% - moderate spatial dependence and SDI $\geq$ 75% - weak spatial dependence.

$$SDI = \frac{C_0}{C_1 + C_0} x 100 \qquad [8]$$

where: C_0 is the nugget effect and C_1 is the spatial contribution.

Since agricultural prices frequently undergo fluctuations, mainly due to seasonal variations, the best economical moment for the harvest sale is difficult to be predicted and it will occur when the profit (Eq. 9), difference between the gross income and total cost, is the maximum (DEBERTIN, 1986).

$$P = \text{Pr} * PP - \text{Pr}_C \qquad [9]$$

where: P = profit; Y = yield (kg/ha); PP = sale price of the product (US$ ton^{-1}); Pr_c = production cost (US$ ha^{-1}).

Production cost (Table 2) and sale prices of the product (Table 3 and 4) in the month of harvest and in the subsequent five months were used to study the dependence of profit on the selling season.

Table 2. Production cost of the crops (US$ ha^{-1})

Culture/Harvest	Soybean/03	Corn/2004	Soybean/06	Soybean/07
Production cost	270.90	366.90	641.28	632.35

Source: SEAB/PR (2009)

Table 3. Selling price of corn (US$ ton^{-1})

Year	July	August	September	October	November	December
2004	88.00	85.00	87.67	83.00	82.33	79.83

Source: SEAB/PR (2009)

Table 4. Selling price of soybean (US$ ton^{-1})

Year	March	April	May	June	July	August
2003	188.50	199.66	189.00	192.83	182.17	184.33
2006	181.83	180.00	173.33	191.00	188.17	186.33
2007	232.50	223.00	233.67	242.33	245.33	256.50

Source: SEAB/PR (2009)

Departing from the profit, the profitability (P%, Eq. 10), which indicates the earnings percentage obtained on the production costs, can be estimated.

$$P\% = \frac{P}{\text{Pr}_c} * 100 \qquad [10]$$

where: Pr_c - production cost (US$ ha^{-1}).

Since yield is a variable usually with spatial dependence and both profit (*P*) and profitability (*P%*) are functions of yield, it can be concluded that *P* and *P%* usually presented spatial dependence, and their maps are important tools of economic analysis. In this work, the inverse of the distance (ID), inverse of the square distance (ISD) and kriging (KRI) were the interpolation methods used to generate the values for sites not sampled, which are necessary for the elaboration of thematic maps, using the software ArcView 9.2. These are the most used interpolators (JONES et al., 2003), having good accuracy and reliability. In addition to evaluating the performance of these interpolators, the interest is whether the use of kriging, considered the best interpolator, but with implementation more complicated and laborious, is justified.

In the comparison of the effect of the interpolator in the yield map the coefficient of relative deviation (CRD, Equation 11), proposed by COELHO et al. (2009) was used. This coefficient expresses in modules the mean percentage difference of the values interpolated in each map, considering one of them as the standard map. This coefficient, however, cannot be used when the variable in the analysis assumes null values, as in the case of profit and of profitability. In these cases, the mean absolute difference (MAD, Equation 12), which computes the mean value of the difference among each interpolation method, divided by the field area, was used. For each variable in the analysis (yield, profit and profitability) three comparisons were used (between KRI and ISD; between KRI and ID; and between ISD and ID).

$$CRD = \sum_{i=1}^{n} \left| \frac{P_{ij} - P_{iSt}}{P_{iSt}} \right| * \frac{100}{n} \qquad [11]$$

where: n = number of points; P_{iSt} = yield in the point i for the standard map (kg/ha); P_{ij} = yield in the point i for the map j to be compared (kg/ha).

$$MAD = \frac{\sum_{1}^{n} \left| (VR_{ij} - VR_{iSt}) \right|}{n} \qquad [12]$$

where: n = number of points; VR_{iSt} = value of the response variable (yield, profit, and profitability) in the point i for the standard map; VR_{ij} = value of the response variable in the point i for the map j to be compared.

RESULTS AND DISCUSSION

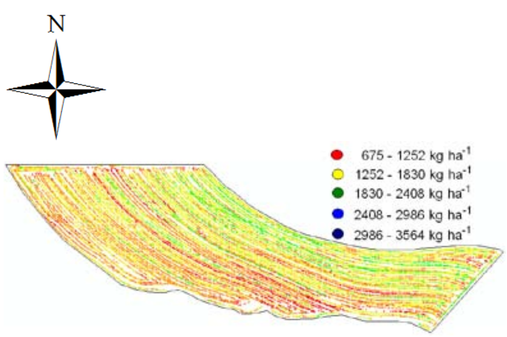
The descriptive analysis of data (Table 5) showed that the four sets of data (one for each field) did not have normal distribution, but presented negative symmetrical and mesokurtic distribution. The values of yields showed medium (soybean/06, CV = 16.2 %; and soybean/07, CV = 13.1 %) and high (corn/04, CV = 28.3 %; and soybean/03, CV = 24.3 %) heterogeneities. The maximum value ranged from 220% (soybean/07) to 556% (corn/04) of the minimum value, which corroborates the premise that even in small areas, in the specific case of 15 ha (soybean/03) to 45 ha (soybean/06), the data variability is very large (YANG et al., 2002).

Table 5. Descriptive statistics for the yield data

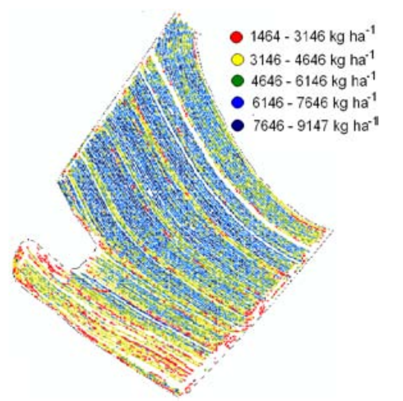
Culture	Minimum (kg ha^{-1})	Mean (kg ha^{-1})	Median (kg ha^{-1})	Maximum (kg ha^{-1})	StDev (kg ha^{-1})	CV (%)	Amplitude (kg ha^{-1})	Skewness	Kurtosis	N*
Soybean/03	675	1,903	1,836	3,564	540	28.3	2,889	0.56 c	0.01 A	No
Corn/04	1,646	5,549	5,667	9,147	1,350	24.3	7,501	-0.60 c	-0.12 A	No
Soybean/06	2,061	3,741	3,788	5,422	610	16.2	3,361	-0.26 c	-0.09 A	No
Soybean/07	2,414	3,852	3,872	5,314	500	13.1	2,900	1.27 c	11.2 A	No

Skewness: symmetric (a), positive skewness (b), negative skewness (c);
Kurtosis: mesokurtic (A), platykurtic (B), leptokurtic (C);
StDev – Standard deviation; CV – Coefficient of Variation;
* Normality tested with Anderson-Darling and Kolmogorov-Smirnovs tests.

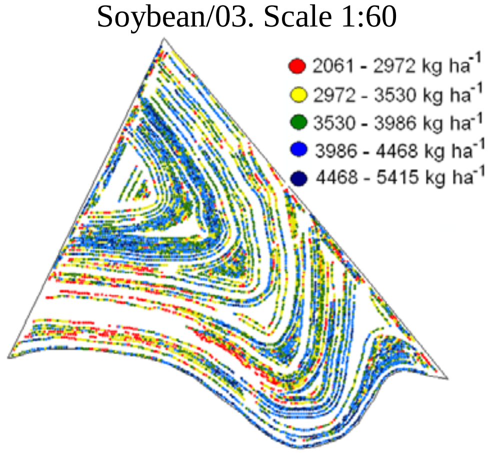
The local yields maps relating to soybean/06 and soybean/07 (Figure 1) presented gaps in the data survey, contrary to the soybean/03 and corn/04. However this fact may be offset by the data interpolation.



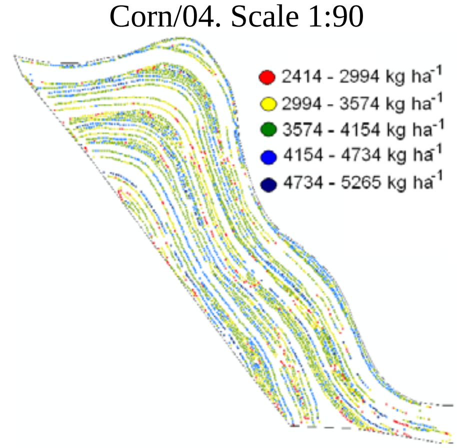
Soybean/03. Scale 1:60



Corn/04. Scale 1:90



Soybean/06. Scale: 1:130



Soybean/07. Scale: 1:120

Figure 1. Local yields maps.

The average yield of each harvest (Table 6) was higher than the respective averages presented in the city (Cascavel), in the state and in the country, with exception of the harvest of soybean/03.

Table 6. Comparison between the local, state and Brazilian yields, for each harvest.

Culture	Measured yield (kg ha^{-1})	Average yield in Cascavel (kg ha^{-1})	Average yield in the State of Paraná (kg ha^{-1})	Average yield in Brazil (kg ha^{-1})
Soybean/03	1903	3236	3016	3025
Corn/04	5549	4548	3017	3187
Soybean/06	3741	2413	2397	2405
Soybean/07	3852	3204	2981	2995

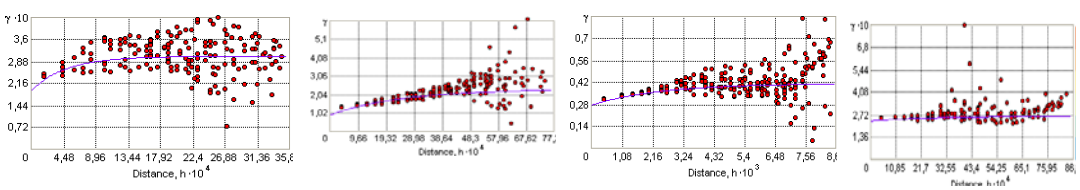
Source: SEAB (2008)

In the geostatistical analysis (Table 7), the method cross-validation showed the exponential model as the best fitting model to the semivariograms (Figure 2), since it provided the lowest ICE in all cases. The data presented mostly medium spatial dependence because for most of the cases the spatial dependence index (SDI) varied in the interval from 25 to 75% (CAMBARDELLA et al., 1994).

Table 7. Models and parameters of the semivariograms for each harvest

Variable	Model	Co	C_1	Sill (C_0+C_1)	Range (m)	SDI	SME	SDRME	ICE
	Gaussian	0.2292	0.0731	0.3023	120.4	75.8%	-0.00427	0.8712	2.00
Soybean/03	Exponential	0.1912	0.1128	0.3040	142.6	62.9%	-0.00030	0.9098	1.40
	Spherical	0.2148	0.0871	0.3019	138.3	71.1%	-0.00374	0.8839	1.77
	Gaussian	1.2588	1.3694	2.6282	653.9	47.9%	0.00079	0.82	1.75
Milho/04	Exponential	0.9033	1.4391	2.3424	748.2	38.6%	0.00099	0.9405	1.27
	Spherical	1.0609	1.4770	2.5379	748.2	41.9%	0.00105	0.8814	1.66
	Gaussian	0.3010	0.0942	0.3952	410.1	76.2%	-0.00617	0.9069	2.00
Soybean /06	Exponential	0.2728	0.1400	0.4128	727.6	66.1%	-0.00472	0.9359	1.45
	Spherical	0.2826	0.1109	0.3935	461.8	71.8%	-0.00524	0.9257	1.65
	Gaussian	0.2419	0.0248	0.2667	846.5	90.7%	0.00322	0.9034	1.91
Soybean /07	Exponential	0.2327	0.0297	0.2624	846.5	88.9%	0.00337	0.9168	1.86
	Spherical	0.2375	0.0261	0.2636	846.5	90.0%	0.0033	0.9099	1.95

* C_0 - Nugget Effect; C_1 - Contribution; Sill - C_0+C_1; SDI - Spatial Dependence Index; SME - standard mean error; SDRME - standard deviation of reduced mean errors; ICE - index for comparison of errors.



Soybean/03 Corn/04 Soybean/06 Soybean/07

Figure 2. Experimental semivariograms.

For each set of data, three yield maps were generated (Figure 3), using the interpolation methods inverse of the distance (ID), inverse of the square distance (ISD) and kriging (KRI). The kriging was the method that visually provided better separation of productivity classes.

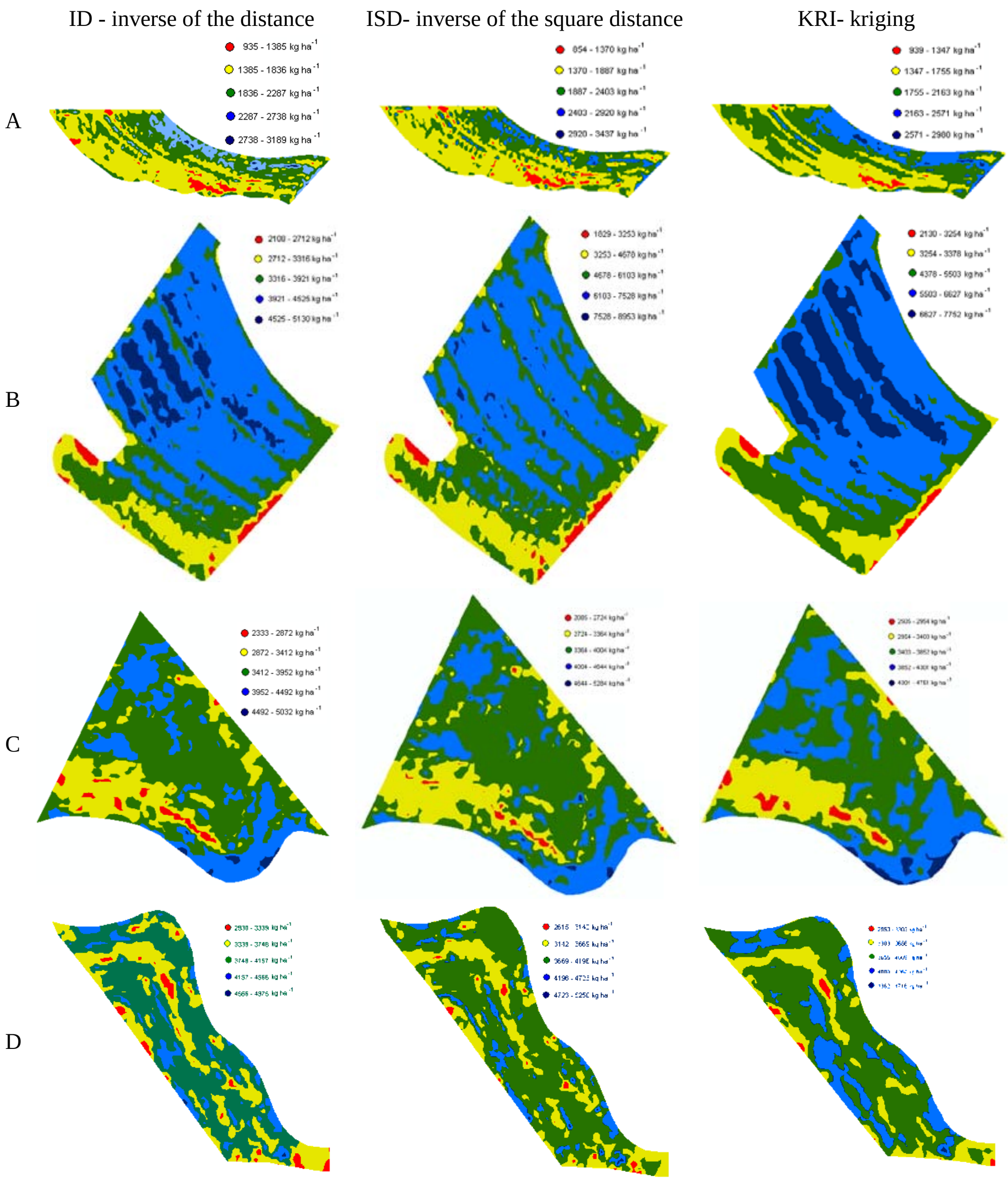


Figure 3. Yield maps for the harverst soybean/03 (A), corn/04 (B), soybean/06 (C), and soybean/07 (D).

The data interpolated with ISD presented the highest CV and amplitude (Table 8), indicating that the estimation of values performed by this interpolator provided the highest dispersion. Kriging was the method which presented the lowest CV, indicating that this interpolator was the one which produced the smoothest data

(Table 9). This data smoothing is due to the inexact nature of the interpolators. The data predicted are smoothed, in a higher or lower degree, and the resulting surface rarely passes through the input points. With this, an increase in the minimum values and a reduction of the maximum values of yield was verified, with consequent decrease in amplitude (Figure 4). Furthermore a decrease in the standard deviation and the CV occurred.

Table 8. Descriptive statistics of the yield data after interpolation

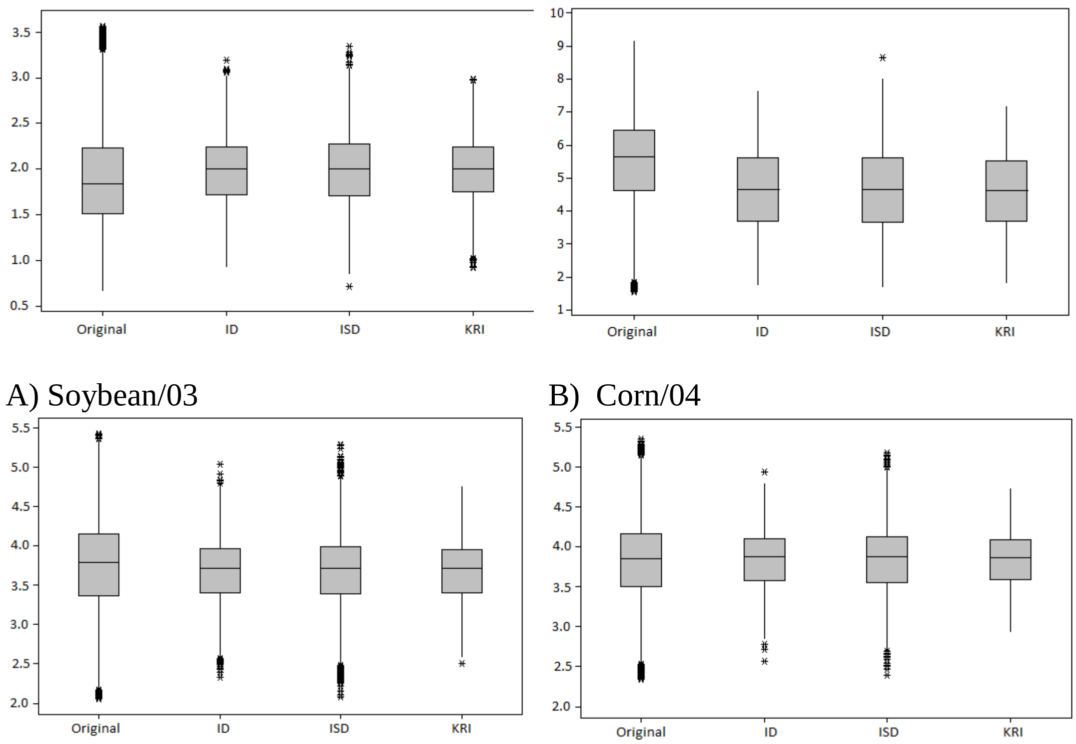
Culture	Interpo-lator	Minimum (kg ha^{-1})	Mean (kg ha^{-1})	Median (kg ha^{-1})	Maximum (kg há$^{-1}$)	StDev (kg ha^{-1})	CV (%)	Amplitude (kg ha^{-1})	Skewness	Kurtosis	N*
Soybean/03	ID	936	1,995	1,997	3,190	370	18.5	2,254	0.11 (c)	-0.42 (A)	No
	IQD	716	1,997	2,000	3,341	398	19.9	2,625	0.06 (c)	-0.39 (A)	No
	KRI	925	1,998	2,003	2,980	340	17.0	2,056	0.03 (c)	-0.44 (A)	No
Corn/04	ID	1,774	4,647	4,677	7,632	1,268	27.3	5,858	-0.16 (c)	-0.87 (B)	No
	IQD	1,713	4,637	4,657	8,649	1,309	28.2	6,937	-0.09 (c)	-0.85 (B)	No
	KRI	1,834	4,579	4,621	7,810	1,233	26.9	5,977	-0.13 (c)	-0.83 (B)	No
Soybean/06	ID	2,333	3,680	3,714	5,032	432	11.7	2,699	-0.17 (c)	-0.37 (A)	No
	IQD	2,086	3,679	3,714	5,285	459	12.5	3,199	-0.17 (c)	-0.33 (A)	No
	KRI	2,505	3,677	3,716	4,751	411	11.2	2,246	-0.24 (c)	-0.42 (A)	No
Soybean/07	ID	2,627	3,865	3,893	4,915	334	8.7	2,288	-0.17 (c)	-0.72 (B)	No
	IQD	2,463	3,865	3,897	5,148	359	9.3	2,684	-0.17 (c)	-0.51 (A)	No
	KRI	2,996	3,854	3,879	4,718	328	8.5	1,722	-0.17 (c)	-0.68 (B)	No

ID - inverse of the distance; ISD - inverse of the square distance; KRI = kriging;
Skewness: symmetric (a), positive skewness (b), negative skewness (c);
Kurtosis: mesokurtic (A), platykurtic (B), leptokurtic (C);
StDev - Standard deviation; CV - Coefficient of Variation;
* Normality tested with Anderson-Darling and Kolmogorov-Smirnovs tests.

Table 9. Effect of interpolators on the data sets

Culture	Interpolator	Variation of the minimum Yield (%)	Variation of the mean Yield (%)	Variation of the maximum Yield (%)	Variation of the StDev (%)	Variation of the CV (%)	Variation of the Amplitude (%)	Assimetry		Kurtosis	
								before	after	before	After
Soybean /03	ID	38.7%	4.9%	-10.5%	-31.5%	-34.6%	-22.0%	Ass.	Sim.	mês.	Mes.
	IQD	6.1%	4.9%	-6.3%	-26.3%	-29.7%	-9.1%	Ass.	Sim.	mês.	Mes.
	KRI	37.0%	5.0%	-16.4%	-37.0%	-39.9%	-28.9%	Ass.	Sim.	mês.	Mes.
Corn /04	ID	7.8%	-16.2%	-16.6%	-6.1%	12.3%	-21.9%	Ass.	Sim.	mês.	Pla.
	IQD	4.0%	-16.4%	-5.4%	-3.0%	16.0%	-7.5%	Ass.	Sim.	mês.	Pla.
	KRI	11.4%	-17.5%	-14.6%	-8.7%	10.7%	-20.3%	Ass.	Sim.	mês.	Pla.
Soybean /06	ID	13.2%	-1.6%	-7.2%	-29.2%	-27.8%	-19.7%	Sim.	Sim.	mês.	Mes.
	IQD	1.2%	-1.7%	-2.5%	-24.8%	-22.8%	-4.8%	Sim.	Sim.	mês.	Mes.
	KRI	21.6%	-1.7%	-12.4%	-32.6%	-30.9%	-33.2%	Sim.	Sim.	mês.	Mes.
Soybean /07	ID	8.8%	0.3%	-7.5%	-33.2%	-33.6%	-21.1%	Ass.	Sim.	Lep.	Pla.
	IQD	2.0%	0.3%	-3.1%	-28.2%	-29.0%	-7.4%	Ass.	Sim.	Lep.	Mes.
	KRI	24.1%	0.1%	-11.2%	-34.4%	-35.1%	-40.6%	Ass.	Sim.	Lep.	Pla.

Despite the asymmetry presented in the collected data sets, after the interpolation, all showed symmetric distribution, indicating that the interpolator influenced the form of the data distribution. The interpolators caused the data to be closer to the average, considering that there was a decrease in maximum yield and an increase in minimum yield, and the kriging was the one which caused the highest influence and ISD the one which caused the lowest influence in this factor. This influence can be perceived by analyzing the data amplitude, and for the soybean/07 data set there was a decrease in amplitude of 40.6% in the interpolation by kriging.



A) Soybean/03 B) Corn/04

C) Soybean/06 D) Soybean/07

Figure 4. Data sets Boxplot before (originals) and after the interpolation using the interpolation methods inverse of the distance (ID), inverse of the square distance (ISD) and kriging (KRI).

The interpolator less biased (more centered on the values measured) was kriging (Table 10), as supported by the literature (CRESSIE, 1990), corresponding to the values of mean error (ME) closer to zero (two out of four cases). However the standard deviation of mean errors (SDME, Table 10) showed the interpolator ISD as more effective, in all cases, in conformity with the findings of WEBER & ENGLUND (1992), DECLERCQ (1996), and COELHO et al. (2009). It was found that the most significant errors corresponded to the interpolator kriging, which confirms the largest data smoothing of this interpolator (Table 10 and Figure 4).

Table 10. Statistics mean error (ME) and standard mean error (SME), for each interpolator

	Soybean/03		Corn/04		Soybean/06		Soybean/07	
Interpolador	ME	SME	ME	SME	ME	SME	ME	SME
ID	0.00058	0.38	0.0055	0.85	0.0034	0.47	0.0002	0.42
ISD	-0.00055	0.34	0.0010	0.83	0.0036	0.46	-0.0022	0.40
KRI	-0.00185	0.41	0.0001	0.88	-0.0031	0.50	0.0013	0.45

Value closer to zero Minimum value Maximum value

The profit for each area was simulated using the three interpolators in a sale scenario that starts in the harvest month and ends in the sixth subsequent month

(Figure 5). In all cases the maximum and minimum values were found for the interpolator ISD, which has been the interpolator that presented the highest amplitude (less smoothing, Table 11). This amplitude was found to be very high and expresses the large spatial variability in the profit, as supported by BIRRELL et al. (1995), MURPHY et al. (1995), JAYNES & COLVIN (1997), YANG et al. (1998), and YANG et al. (2002). The soybean area of the harvest 2003 (Table 11 and Figure 5) presented regions with loss of up to U$$ 140.44 ha^{-1} (interpolator ISD in 5^{th}/2003) and profit of up to U$$ 396.40 ha^{-1} (interpolator ISD in 2^{th}/2003).

Table 11. Minimum and maximum profit (US$ ha^{-1}) as a function of a six-month sale scenario

Culture	Inter-polator	Month											
		1^{th}		2^{nd}		3^{rd}		4^{th}		5^{th}		6^{th}	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Soybean/03	ID	-94.41	330.59	-83.97	366.16	-94.07	331.76	-90.42	344.20	-110.23	276.68	-98.43	316.78
	ISD	-135.86	359.14	-127.87	396.40	-135.59	360.37	-132.80	373.40	-140.44	337.76	-138.94	344.77
	KRI	-96.55	291.04	-86.24	324.27	-96.21	292.13	-92.60	303.76	-102.46	271.97	-100.52	278.23
Corn/04	ID	-210.84	304.36	-215.99	282.23	-211.35	302.20	-219.57	266.83	-220.81	261.49	-225.31	242.16
	ISD	-216.28	393.79	-221.24	368.71	-216.76	391.34	-224.70	351.27	-225.90	345.21	-230.23	323.30
	KRI	-205.64	264.61	-210.96	243.78	-206.16	262.57	-214.66	229.30	-215.94	224.28	-220.58	206.09
Soybean/06	ID	-216.91	273.90	-221.16	264.76	-236.75	231.13	-195.48	320.11	-202.06	305.94	-206.38	296.63
	ISD	-261.92	319.79	-265.72	310.19	-279.66	274.87	-242.77	368.32	-248.65	353.44	-254.34	338.99
	KRI	-185.63	222.77	-190.18	214.14	-206.93	182.38	-162.62	266.40	-169.68	253.01	-174.31	244.22
Soybean/07	ID	-21.63	510.40	-46.67	463.54	-18.66	515.97	4.15	558.65	12.08	573.48	41.41	628.36
	IQD	-59.64	564.46	-83.12	515.39	-56.85	570.30	-35.46	614.99	-28.02	630.52	-0.52	688.00
	KRI	64.31	464.62	35.74	419.64	67.78	469.97	93.73	510.94	102.77	525.17	136.23	577.86

Minimum value Maximum value

The corn area of the harvest 2004 (Table 11 and Figure 5), shows regions with loss of up to U$$ 230.23 ha^{-1} (interpolator ISD in 6^{th}/2004) and profit of up to U$$ 393.79 ha^{-1} (interpolator ISD in 1^{th}/2004).

For the soybean of the harvest 2006 (Table 11, Figure 5), it was verified regions with loss of up to U$$ 279.66 ha^{-1} (interpolator ISD in 3^{th}/2006) and profit of up to U$$ 368.32 ha^{-1} (interpolator ISD on 4^{th} /2006).

Finally, for soybean of the harvest 2007 (Table 12, Figure 11), the best results of profit were verified, with only small regions with loss. The maximum loss was U$$ 83.12 ha^{-1} (interpolator ISD in 2^{th}/2006) and the maximum profit was U$$ 688.00 (interpolator ISD in 6^{th}/2007).

Table 12. Average profit per hectare (US$ ha-1) as a function of a six- month sale scenario

Culture	Inter-polator	Month											
		1^{th}		2^{nd}		3^{rd}		4^{th}		5^{th}		6^{th}	
Soybean /03	ID	105.2	(99.6%)	127.4	(99.7%)	105.9	(99.6%)	113.7	(99.6%)	71.55	(77.1%)	96.66	(99.6%)
	IQD	103.5	(98%)	125.3	(98.1%)	104.2	(98.0%)	111.9	(98%)	91.0	(98%)	95.1	(98.0%)
	KRI	105.6	(100%)	127.8	(100%)	106.3	(100%)	114.1	(100%)	92.8	(100%)	97.0	(100%)
Corn /04	ID	42.20	(100%)	28.61	(100%)	40.87	(100%)	19.15	(100%)	15.87	(100%)	4.0	(100%)
	IQD	41.31	(97.9%)	27.7	(97.0%)	39.9	(97.8%)	18.3	(95.6%)	15.0	(94.7%)	3.1	(79.7%)
	KRI	36.1	(85.6%)	22.7	(79.4%)	34.8	(85.2%)	13.4	(70.0%)	10.1	(64.1%)	-1.5	-(38.0%)
Soybean /06	ID	27.8	(100%)	21.2	(100%)	-3.3	-	61.6	(100%)	51.3	(100%)	44.4	(100%)
	IQD	27.7	(99.4%)	21.0	(99.3%)	-3.5	-	61.4	(99.7%)	51.1	(99.7%)	41.0	(92.3%)
	KRI	27.39	(98.2%)	20.71	(97.7%)	-3.85	-	61.14	(99.2%)	50.78	(99.0%)	43.98	(98.9%)
Soybean /07	ID	264.2	(99.3%)	227.6	(99.3%)	268.5	(99.3%)	301.8	(99.2%)	313.4	(99.2%)	356.2	(99.3%)
	IQD	266.2	(100%)	229.3	(100%)	270.5	(100%)	304.1	(100%)	315.8	(100%)	358.9	(100%)
	KRI	263.7	(99.1%)	227.0	(99.0%)	268.1	(99.1%)	301.5	(99.2%)	313.2	(99.2%)	356.2	(99.3%)

Minimum value Maximum value

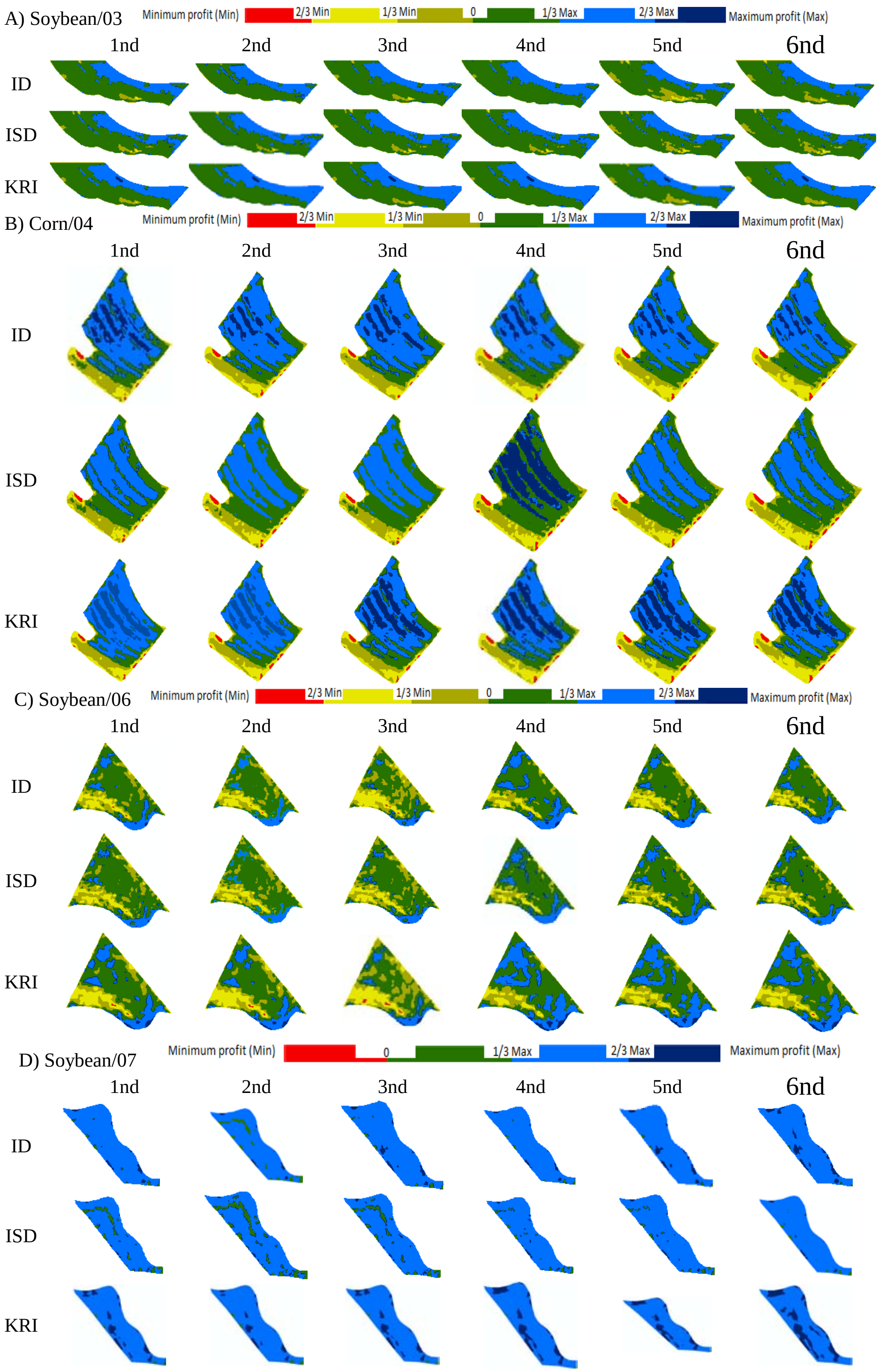


Figure 4 Profit maps for the haverst soybean/03 (A), corn/04 (B), soybean/06 (C), and soybean/07 (D) as a function of a six- month sale scenario.

The average profit per hectare (US$ ha^{-1}, Table 12) presented a significant variance during the period of six months after the harvest. With the exception of corn/04, the difference between the interpolation methods was lower than 2.3%. With the exception of soybean/03, kriging presented results of average profit below the other interpolators. This fact is in agreement with the descriptive statistics of yield interpolated data (Table 8) in which kriging presented the lowest average yields, again with the exception of soybean/03.

The highest profit found corresponds to the year 2007, for which notwithstanding the relatively high production cost (US$ 632.35 ha^{-1}), the sale price was satisfactory (of US$ 223.00 to 256.50 t ha^{-1}). For the soybean/03, satisfactory results were obtained despite the low sale price (of US$ 182.17 to US$ 199.66 t ha^{-1}), since the production cost (US$ 270.90 ha^{-1}) was much lower than the cost of the other seasons.

With respect to profitability (P%, Table 13), which indicates the gain percentage obtained on production costs, it was observed that the two worst years were 2004 and 2006, considering that there was a relatively high production cost and reduced profit. The methods of interpolation showed differences in profitability between 0.03 % (soybean/06) and 0.56 % (corn/04).

Table 14. Profitability for each area cultivated (%)

Culture	Interpolator	Month					
		1th	2nd	3rd	4th	5th	6th
Soybean/03	ID	10.38%	12.57%	10.45%	11.22%	9.05%	9.53%
	ISD	10.21%	12.37%	10.28%	11.04%	8.98%	9.38%
	KRI	10.42%	12.61%	10.49%	11.26%	9.16%	9.57%
Maximum difference		0,21%	0.24%	0.21%	0.22%	0.18%	0.19%
Corn/04	ID	3.87%	2.62%	3.75%	1.76%	1.45%	0,37%
	ISD	3.79%	2.54%	3.66%	1.68%	1.38%	0.29%
	KRI	3.31%	2.08%	3.19%	1.23%	0.93%	-0.14%
Maximum difference		0,56%	0.54%	0.56%	0.53%	0.52%	0.51%
Soybean/06	ID	2.01%	1.53%	-0.24%	4.45%	3.70%	3.21%
	ISD	2.00%	1.52%	-0.25%	4.44%	3.69%	2.96%
	KRI	1.98%	1.49%	-0.28%	4.41%	3.66%	3.17%
Maximum difference		0,03%	0.04%	0.04%	0.04%	0.04%	0.25%
Soybean/07	ID	19.32%	16.65%	19.64%	22.08%	22.92%	26.05%
	ISD	19.47%	16.77%	19.79%	22.24%	23.10%	26.25%
	KRI	19.29%	16.60%	19.61%	22.06%	22.91%	26.05%
Maximum difference		0.18%	0.17%	0.18%	0.18%	0.19%	0.20%

Minimum value   Maximum value

Considering the prices of the market in the month of the product harvest, the methods of interpolation showed differences in the percentage of area that presented profit (Table 14) between 0.1 % (soybean/07) and 3.6 % (soybean/03).

Table 14. Percentage of area with profit

Crop	Type of interpolator			Maximum difference
	ID	IQD	KRI	
Soybean/03	6.3%	8.0%	4.4%	3.6%
Corn/04	32.8%	33.6%	35.4%	2.6%
Soybean/06	34.4%	35.5%	33.4%	2.2%
Soybean/07	0.0%	0.1%	0.0%	0.1%

Minimum value   Maximum value

In the comparison of the interpolator effect in yield map the coefficient of relative deviation (CRD, Table 15) ranged from 1.6 (ISD_ID) and 5.9 % (KRI_ISD), indicating that the methods ID and ISD were more similar. Nevertheless the mean absolute difference (MAD, Table 15) varied from 0.06 to 0.20 t ha^{-1} for yield, from 8.62 to US$ 30.23 for profit, and from 1.99 to 7.03 % for the profitability, always presenting the highest differences in the comparison of the methods ID and ISD.

Table 15. Coefficient of relative deviation (CRD) and mean absolute difference (MAD) for the comparisons between KRI_ISD, KRI_ID, and ID_ISD

		Culture	KRI_ISD	KRI_ID	IQD_ID
CRD (%)	Yield	Soybean/03	7.37	5.97	2.12
		Corn/04	7.53	6.26	2.02
		Soybean/06	4.74	3.87	1.27
		Soybean/07	3.80	3.23	1.20
		Average	5.86	4.83	1.65
MAD	Yield (t ha^{-1})	Culture	KRI_ISD	KRI_ID	IQD_ID
		Soybean/03	0.146	0.120	0.039
		Corn/04	0.323	0.257	0.093
		Soybean/06	0.172	0.140	0.045
		Soybean/07	0.144	0.123	0.046
		Average	0.20	0.16	0.06
	Profit (US$)	Culture	KRI_ISD	KRI_ID	IQD_ID
		Soybean/03	27.54	22.58	7.45
		Corn/04	28.44	22.63	8.18
		Soybean/06	31.36	25.55	8.25
		Soybean/07	33.58	28.52	10.61
		Average	30.23	24.82	8.62
	Profitability (%)	Culture	KRI_ISD	KRI_ID	IQD_ID
		Soybean/03	10.17	8.33	2.75
		Corn/04	7.75	6.17	2.23
		Soybean/06	4.89	3.98	1.29
		Soybean/07	5.31	4.51	1.68
		Average	7.03	5.75	1.99

Minimum value   Maximum value

Conclusions

The proposed index for the comparison of errors provided easy and non subjective selection of the experimental semivariogram, a necessary tool to use kriging when creating thematic maps.

The interpolator inverse of square distance proved more efficient (lower standard deviation of mean error, ME) than kriging and inverse of the distance;

The influence of the interpolator type (inverse of distance-ID, inverse of square distance-ISD and kriging-KRI), used for data interpolation in the drawing of thematic maps, was considered small, ranging from 1.6 (between ISD_ID) and 5.9 % (KRI_ISD), indicating that the methods ID and ISD were more similar;

The mean absolute difference (MAD) varied between 0.06 and 0.20 t ha^{-1} for yield, between 8.62 and US$ 30.23 for profit, and between 1.99 and 7.03 % for the profitability, always presenting the highest differences in the comparison of the methods ID and ISD.

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