ASSESSING DEFINITION OF MANAGEMENT ZONES TROUGH YIELD MAPS

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ABSTRACT

The knowledge of the temporal stability of yield is very important in the decision making process, allowing to make more precise estimates of the risks associated with agricultural investments. Therefore, this study aims to check for yield stability in grain crops and define management zones using yield maps. Temporal inconsistencies lead to problems of yield scale, demanding a suitable data normalization, and small spatial inconsistencies pollute the data within a same range of comparison along years, demanding suitable filtering or majority rule within cells. In a first step of the work, for a historical sequence of yield datasets, two normalizations techniques were applied, three distinct filtering procedures were tested, and 11 within cell parameters were extracted for two distinct grids with two distinct cell-sizes (10m and 30m) cells upon the processed data). Pearson correlations along the data series showed higher values for global filtering procedure and 30m cell sizes; but the lower correlations values found for strength filtering procedures, cell classification by majority normalized value and smaller cell-size may suggest that the highest correlation obtained could be due to spatial data pollution which approximates values not spatially but also in time-series. In a second step of the work, yield maps were standardized and then submitted to principal component analysis to reduce the dimensionality of the data and determine the main causes of the variability in each field. The principal components with eigenvalues greater than one were kept and their scores were used to do a cluster analyses by the k-means method, delineating three management zones. The results yield maps of corn showed high temporal stability, suggesting that this crop has a great potential to delineate management zones. The proposed methods were efficient to delineate management zones identifying different yield potential zones an also given an estimate of each zone temporal stability.

Key words: temporal stability, corn, soybean, data filtering, Brazil

INTRODUCTION

The yield maps represent the combined effect of different sources that contribute to yield variability, part of this can be attributed to factors that are constant or vary slowly over time, while others are more dynamic, changing their importance and spatial distribution for each crop.

The use of yield maps for definition of zone management is limited by different seasonal climatic conditions along years and spatial factors, like local attack of pests, errors in yield sensing and existing diversity of genetic materials that may spoil their potential expression.

Carvalho et al. (2001) claim that productivity suffers spatial and temporal influences, which makes inadequate the indiscriminate use too few yield maps for defining management zones, it is necessary to evaluate the temporal maps of the same area and characterize the changes. Thus, the temporal consistency of yield maps is not a rule, but in grain crops, most often it occurs in corn when observed soil and climate conditions which culture was submitted (Kaspar et al., 2003).

Although some studies have found it difficult to observe a clear pattern of spatial distribution of productivity over the years (Blackmore et al, 2003; Milani et al, 2006), there are studies with time series in which the factors determining productivity are constant and allow to differentiate subareas of the field with distinct yield response potential (Molin, 2002; Santi et al., 2013).

In order to do a temporal analysis of the yield data, it is necessary that the productivity of each year are standardized and grouped in cells, since the point by point comparison is not possible. However, the filtering parameters and the determination of the cells size for aggregation or interpolation of yield data must be understood correctly before analysis. The use of too large cells reduces the number and the variability of the data, while the use of very small cells decreases the robustness and stability of the values representing the cell.

It is important to be clear which scales of variability can be managed with each proposed intervention, because if the goal is to guide a specific site treatment, the cell can be larger, on the other hand, if the goal is to determine the micro variability to perform variable rate seeding, it is important that the cells have dimensions appropriate to characterize this small scale variability.

Therefore, this study aims to check for yield stability in grain crops and define management zones using yield maps.

MATERIALS AND METHODS

This work is based on the premises that distinct soil zones in field will continue to express their potential throughout the collected yield measurements along the years.

The scope of this work studies aspects involving the achievement of management zones throughout historical series of yield maps.

Overview of the problem

Two problems regarding the definition of yield potential units studied in here: temporal and spatial inconsistency.

Temporal inconsistency: The different climate conditions (like rainfall and temperature) along the years also alter the expression yield potential of the crops, making impossible the comparison of yield between years. Normalization of the data is needed in a common scale along historical yield data series.

Spatial inconsistency: The use of yield maps for definition of zone management is limited by other factors, like local attack of pests, errors in yield sensing and existing diversity of genetic materials that may spoil their potential expression.
The spatial yield data is collected in the form of points, but for comparison of yield potential between years, these points have to be adjusted (and if necessary aggregated) to a common spatial reference which is often in a cell-raster format. Figure 1
Fig. 1 shows an example of points overlaying a grid of cells which (often) averages the value of the points within their respective cell.

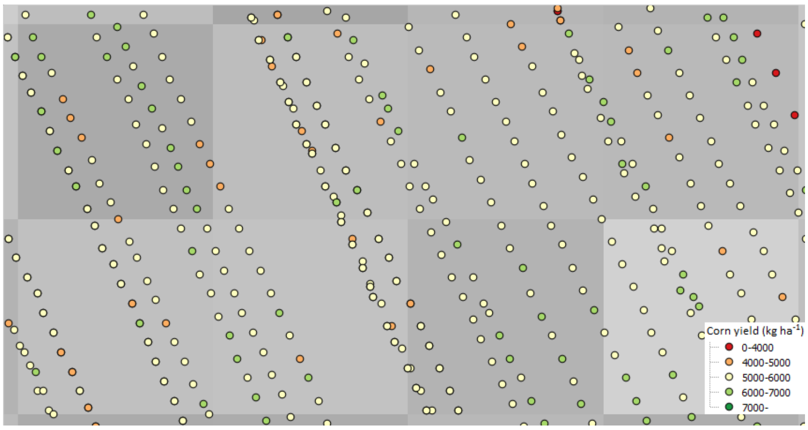

Fig. 1. Yield points overlaying their respective interpolated raster cells (30m)

Figure 1
Fig. 1 shows the variation of point-yields within a cell-range. The variation is composed by inconsistent points that mask true yield potential within one cell, which may affect the similarities between years.

Case study description

The yield data were collected from one field of grain production in Brazil. The studied area ~~studied~~ contain four maps of maize and soybean (Table 1~~Table 1~~). The combine yield monitoring system was calibrated according to the manufacturer recommendation.

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Table 1. Description of location and yield data

Location	Area (hectares)	Combine harvester	Yield data
Maracaju, Mato Grosso do Sul, Brazil	91	John Deere STS 9770 (Greenstar - AMS)	Corn 2007 Corn 2009 Soybean 2010

21°35'46.18"S 55°32'59.76"O		Corn 2010

Assessing parameters for observing consistency along years

A sequence of steps is followed searching for the aspects that may influence in the temporal consistency. These steps are illustrated in the flowchart in Fig. **2** ~~Figure 2~~.

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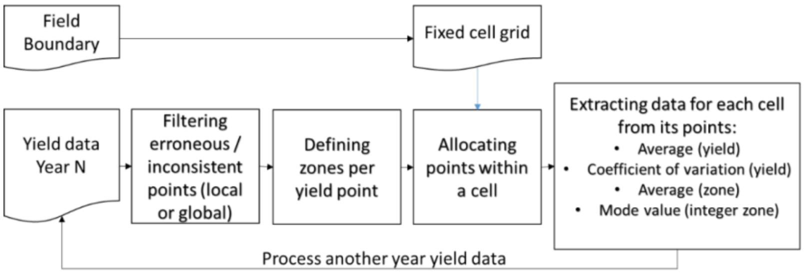

Fig. 2. Conceptual model of the steps used to assess the yield data consistency along time

The steps in Figure 2 are described:

Filtering erroneous/inconsistent points: filtering spatial inconsistency may help to reduce in-cell variability and increase consistency of yield potential along time. Herein two methods are proposed to reduce yield spatial inconsistency:

- A global filtering technique that removes extreme data by lower and upper limits of productivity;
- A modified local filtering method proposed by Spekken et al. (2013), which uses a radius to identify neighboring range of points and a variation criteria to identify outliers within this range. This use of the statistical parameter Coefficient of Variation (CV) proposed by the authors was herein substituted by a local Median (Med) as a classification parameter.

Defining zones per yield point: two normalization procedures are used on each filtered datasets.

- Unsupervised Fuzzy Classification using the software Management Zone Analyst (MZA) performing a normalization on each in-field referenced point. Four zones attributes were created in each dataset (2, 3, 4 and 5 zones classification).
- Standard score statistic normalization (SSSN) which converted to z-scores using a z-transform method to have zero mean and unit variance, accordingly to the formula:

$$z_i = \frac{x_i - \mu}{\sigma}$$

Where:

z_i is the normalized value added as attribute to each yield-record, ranging in a float scale from -4 and 4;

x_i is the record yield value;

μ is the mean value of the yield data;
σ is the standard deviation of the yield data;

Regarding the properties of the normalization methods, unsupervised classification is capable of classifying data with non-normal distribution, while the simplified standard score statistics may not perform adequately for this same condition. Observations were done for comparisons along years.

Obtaining a cell value from normalized yield points: this step considers two distinct forms to allocate a value to a grid-cell: using the average of the normalized point-values within the cell-area, or using the mode of the point-values found within it (the latter for points classified in integer values through the MZA application).

The use of the mode instead of the average works also as a filtering process, ignoring classified data that disagrees with the majority of points within a cell. As an example, if majority of points within a cell have the normalized value "1", the mode cell value will be "1", while the average cell-value could be "1.3".

Also the cell size will influence in the number of points allocated in within. Small cells may not be overlaid by any recorded-yield-point, thus requiring its value to be estimated by interpolation. A bigger cell-size will likely include points with higher variance among them.

Two cell sizes (squared) where here studied to observe its influence in the correlation along years: 10m and 30m cells.

Fig. 3~~Figure 3~~ illustrates, from a certain range of yield points, the processes herein used to obtain the attributes of one cell.

NAO É BRUT, É RAW YIELD DATA

Brute yield data
4.73
4.59
4.93
6.67
6.43
6.07
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5.04
5.06
5.91
6.99
6.94
5.62
5.19
5.36
4.96
4.18
5.85
4.87
7.18

➡

Yield data filtered
4.73
4.59
4.93
6.67
6.43
6.07
6.51
5.04
5.06
5.91
5.62
5.19
5.36
4.96
5.85
4.87

➡

Classified data

	MZA (Unsupervised Fuzzy Classification)				Std Score
Yield	2 Zones	3 Zones	4 Zones	5 Zones	Normaliz
4.73	1	2	2	3	-0.367
4.59	1	2	2	3	-0.474
4.93	1	2	2	3	-0.212
6.67	2	3	4	5	1.131
6.43	2	3	4	4	0.945
6.07	2	3	3	4	0.669
6.51	2	3	4	4	1.009
5.04	1	2	2	3	-0.131
5.06	2	2	2	3	-0.111
5.91	2	3	3	4	0.542
5.62	2	2	3	4	0.321
5.19	2	2	3	3	-0.008
5.36	2	2	3	3	0.117
4.96	1	2	2	3	-0.188
5.85	2	3	3	4	0.496
4.87	1	2	2	3	-0.262

⬇

Considering all points belonging to a specific cell-range

Average yield	Coeficient of variation	Average of zones (MZA)				Mode of zones (MZA)				Average Std S Norm
		2 Zon	3 Zon	4 Zon	5 Zon	2 Zon	3 Zon	4 Zon	5 Zon	
5.49	12.3%	1.63	2.38	2.75	3.5	2	2	2	3	0.22

Fig. 3. Steps for obtaining the attributes of one cell

The historical map series have their data gathered in overlaying grid cells, with each cell containing the attributes given in Figure 3. The number of parameters simulated is listed.~~:~~

- Filtering: the global filtering process consisted in removal of data located two standard deviations away from the average value in the dataset. The local filtering method was based in two distinct classifications which used respectively 15% and 5% of local median absolute deviation from points located in a radius range of 10m. A total of three filtered datasets are obtained.
- The normalization used for the unsupervised fuzzy classification was applied independently to each filtered dataset, using Mahalanobis measurement of similarity (because of unequal variances and non-zero covariances), with fuzziness exponent of 1.3, convergence criterion of 0.0001 into four zone ranges added as attributes to each record of the datasets with one additional attribute representing the standard score statistical normalization. A total of five normalization attributes will be obtained for every dataset.
- Data was merged in cells of two sizes (10 m and 30 m) created upon the field, extracting for all the point within each cell: the average yield value, the coefficient of variation of the yield, the average of the zone classified values, the mode of the zone classified values (the latter two for all four zone-ranges obtained by the MZA classification). For each cell 11 attributes are obtained (Fig. 3~~Figure 3~~).

The cell-grids for each historical year will be gathered compared trough Pearson correlation to observe how each of the attributes correlate along time.

This is performed for each of the three filtering classifications proposed. In the end three distinct filtering procedures, two cells sizes, and 11 parameters per cell were obtained.

Creation of management zone maps

After analyzing the results of the first step of this study, we decided to use the simplest method to delineate the management zones. This consisted of obtaining yield potential maps by selecting filtered maps from the global filtering process, using standard score statistic normalization in each map and interpolating these using inverse distance interpolation in 10 m cells. Temporal consistency was retrieved trough Pearson correlation.

Instead of aggregating the data to 30 m cell grid, which showed greater correlations, we decided to use interpolation and a 10 m cell grid, to make a better use of the information and characterize the variability in smaller scales.

Principal Component Analysis (PCA) was applied to the filtered, normalized and interpolated data in order to reduce the dimensionality of the data and, as an exploratory way, determine the main causes of the variability in each field, graphically showed in biplots (Gabriel, 1971).

The principal components with eigenvalues greater than one were kept and their scores were used to do a cluster analyses by the k-means method. The number of clusters was chosen to be three for all fields analyzed.

RESULTS AND DISCUSSION

The number of cells created to cover the field was of: 12132 and 1232 cells respectively for 10m and 30m size cells. Cells without yield points within its range in any of the years of data collection were excluded from the analysis to allow a consistent comparison. No interpolation was done within this step of the study.

Table 1. General properties of the datasets after filtering of yield points and their distribution in grid-cells

Filtering procedure	Fraction of removed points from original dataset (%)	Average number of points within the cells (30 m cells)	Average number of points within the cells (10 m cells)	Average CV of the points within the cells (30m cells)
		2007 Corn		
Global 2st dev	5%	22.82	2.55	54%
Local 15% Med	9%	21.74	2.45	44%
Local 5% Med	37%	15.43	1.98	27%
		2009 Corn		
Global 2st dev	2%	23.77	2.85	80%
Local 15% Med	15%	20.89	2.59	52%
Local 5% Med	47%	13.46	1.92	30%
		2010 Corn		
Global 2st dev	4%	22.23	2.85	56%
Local 15% Med	11%	20.65	2.70	46%
Local 5% Med	42%	13.71	2.04	27%
		2010 Soybeans		
Global 2st dev	5%	26.59	3.71	47%
Local 15% Med	11%	27.44	3.52	44%

Local 5% Med	42%	18.16	2.57	24%

Table 2 shows the intensity of removal of points and the final distribution of these in the grid-cells, the higher removal of the local filtering procedures leaded also to an expected lower variation of the yield within the cells. The low number of points located in the smaller cell size didn't allow to obtain a robust CV, which was not added to Table 2~~Table 2~~.

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Table 2. Pearson correlation found between years for points submitted to global filtering process and with values merged in 30m cells

Pairs of years	Number of zones for unsupervised fuzzy classification								
	2	3	4	5	2	3	4	5	SSSN
	Average values within cells				Mode values within cells				
2007C - 2009C	0.73	0.76	0.78	0.79	0.56	0.67	0.68	0.71	0.80
2007C - 2010C	0.59	0.59	0.57	0.58	0.46	0.48	0.49	0.50	0.56
2007C - 2010S	0.25	0.37	0.38	0.38	0.14	0.28	0.31	0.31	0.40
2009C - 2010C	0.66	0.69	0.68	0.68	0.52	0.58	0.59	0.59	0.66
2009C - 2010S	0.29	0.36	0.39	0.40	0.20	0.30	0.33	0.31	0.41
2010C - 2010S	0.17	0.21	0.22	0.22	0.11	0.15	0.17	0.14	0.22
Average between all yield crop data	**0.45**	**0.50**	**0.50**	**0.51**	**0.33**	**0.41**	**0.43**	**0.43**	**0.51**
Average between corn yield data	**0.66**	**0.68**	**0.68**	**0.68**	**0.51**	**0.58**	**0.59**	**0.60**	**0.67**

The correlations displayed in Table 3~~Table 3~~, which were similar to any of the parameters tested, showed higher inconsistency between any of the corn and soybean grid-cells. The level of significance between the correlations for the different normalization methods isn't yet retrieved, but strong similarity of maps obtained using SSSN and unsupervised classification suggest the first to be a useful simple option for users. The SSSN may have performed worse in the 2010C maps because of the more abnormal distribution of the yield values in this harvest-season.

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Table 3. Average Pearson correlation values found for points submitted to different filtering procedures in two cells sizes

Filtering procedure	Number of zones for unsupervised fuzzy classification								SSSN
	2	3	4	5	2	3	4	5	
	Average values within cells				Mode values within cells				
	30m cells - average between all datasets								
Global 2std dev.	0.49	0.53	0.54	0.55	0.36	0.44	0.46	0.47	0.55
Local 15% Median	0.47	0.52	0.53	0.54	0.37	0.44	0.46	0.48	0.52
Local 5% Median	0.43	0.50	0.51	0.53	0.35	0.43	0.44	0.48	0.51
	30m cells - average between corn datasets								
Global 2std dev	0.69	0.70	0.70	0.71	0.54	0.60	0.62	0.64	0.71
Local 15% Median	0.67	0.69	0.69	0.69	0.55	0.59	0.60	0.63	0.69
Local 5% Median	0.62	0.67	0.67	0.68	0.53	0.59	0.60	0.63	0.68
	10m cells - average between all datasets								
Global 2std dev	0.36	0.41	0.42	0.43	0.31	0.37	0.38	0.40	0.44
Local 15% Median	0.36	0.41	0.43	0.44	0.32	0.39	0.40	0.41	0.44
Local 5% Median	0.32	0.42	0.43	0.45	0.32	0.39	0.40	0.43	0.45
	10m cells - average between corn datasets								
Global 2std dev	0.55	0.59	0.60	0.61	0.49	0.54	0.54	0.55	0.62
Local 15% Median	0.55	0.59	0.60	0.61	0.50	0.54	0.56	0.57	0.63
Local 5% Median	0.51	0.57	0.57	0.59	0.48	0.55	0.54	0.57	0.62

The type of filtering does not suggest an increasing correlation between datasets along years, being the global filtering slightly superior in consistency along years. The more intense local filtering showed to decrease the correlation. The cell size surprisingly showed a more significant factor, herein defeating the idea that narrower cell sizes may find higher correlation along historical yield maps. Extracted mode values of the normalized values for the cells decreased the correlation along years but in less extend for the harsher filtering (5% median), suggesting that the harsh local filtering is indeed bringing yields to a same level.

Fig. 4Figure 4 displays the cells size effect for two distinct years in a 3 zone classification (fuzzy unsupervised, taking the average of points within cells). The correlation between these specific two years increased from 0.62 to 0.74 with the cell increase.

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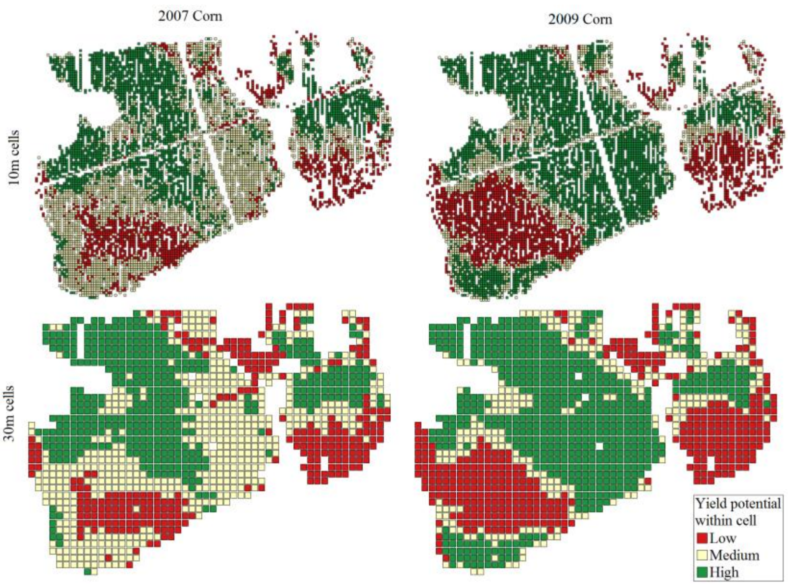

Fig. 4. Grid-cell maps of zone classification between years and cell sizes

The variation of values (coefficient of variation) within cells can be spatially visualized between filtering methods in Fig. 5Figure 5 for the 2009 corn yield. The maps “a”, “b” and “c” are respectively the global filtered method and the 15% and 5% of local deviation tolerated from the median.

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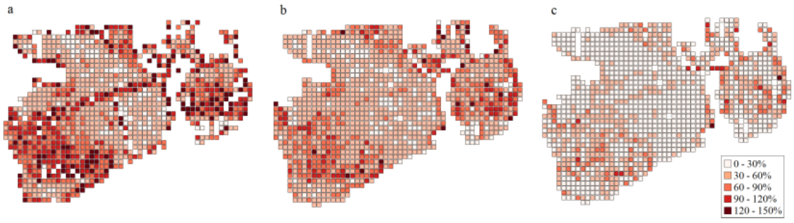

Fig. 5. Grid-cells of the coefficient of variation within cells for the three filtering procedures

In general, strengthening the filtering didn't increase the correlation along data series, in fact leading to an inverse situation. The question that is to be further studied if the lower correlation is indeed the real situation, and if spatial variant data are inducing it to be more alike along harvests.

Management zone maps

Analyzing the descriptive statistics for the yield (Table 2~~Table 2~~) we can see that the mean values of yield for the same crop in the same field may differ approximate 2000 kg ha^{-1}, which is mainly a reflex of climate conditions that vary between years. There is a good similarity between the mean and the median in most crops, which is an indicator that the data is symmetrically distributed.

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Table 2. Descriptive statistics of yield data after filtering and interpolation

Yield map	Mean	Median	Minimum	Maximum	S.D.	CV
Corn 2007	5055	5125	998	9336	1249	25
Corn 2009	3790	4213	698	8578	1479	39
Soybean 2010	3490	3526	1311	4807	358	10
Corn 2010	5700	5992	988	10713	1385	24

The spatial distribution of yield showed clear patterns and similarity along the seasons, with low yield zones close to field limits and high yield in the center (Fig. 6~~Figure 6~~). The most visual difference between maps occur on the soybean, although some parts are similar, the central portion of field demonstrated a different comportment than corn.

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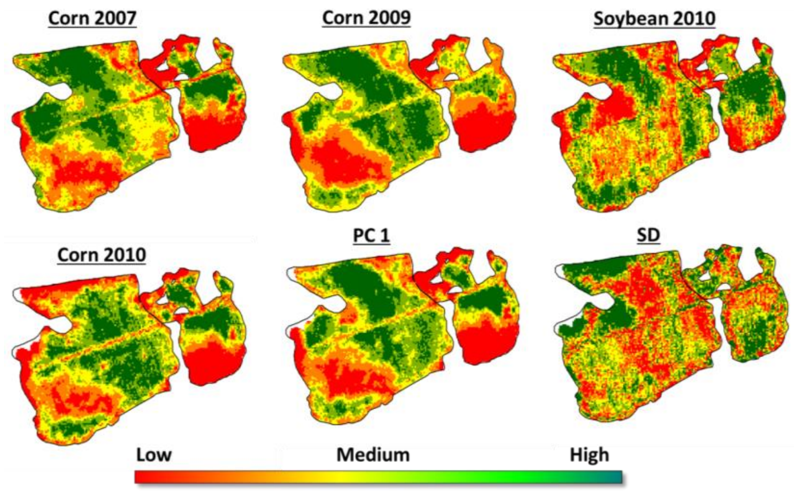

Fig. 6. Yield data of four seasons, first principal component and standard deviation maps of the study area

The first principal component was strongly correlated with the yield data from the three years of corn, expressing 65% of the total variance. The second principal component was correlated with the soybean yield data and expressed 18% of the total variance. All corn variables are in similar directions along the x axis, forming an angle close to 90º with the soybean variable, which implies weak correlation between ~~this~~these two groups of variables (Fig. 7~~Figure 7~~).

The colors of the points represent the zones to which they belong, it is clear the x axis (PC1) was the most decisive to determine the cluster membership, therefore the soybean yield data have almost no importance in the process of management zone delineation in this area. In this case study, yield maps of corn showed high temporal stability and correlation between themselves, similar results were found by Schepers et al. (2004) and Kaspar et al. (2003) using five and six seasons of corn yield data.

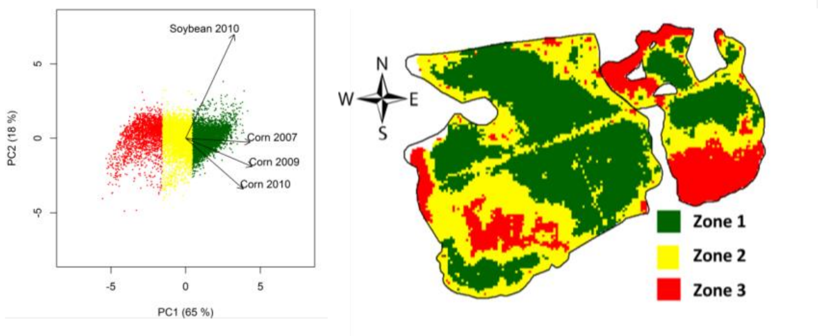

Fig. 7. Biplot of the first two principal components (left) and map of the management zones (right)

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In practice, this management zones are valid to apply site specific management strategies related to corn production, although they may also be used to make recommendations for soybean production in this area, it should be done carefully. More years of data collection could improve this processes and be used to understand how climate changes and soil-culture interactions affect yield and what would be the best decisions in each scenario.

The delineated zones show clear differences in potential yield (Table 4~~Table 4~~). Zone 1 has a low yield potential and is mostly present close to the boundary of the field and in the southwest portion of the field (Fig. 7~~Figure 7~~). Zone 2 is a transitional zone, with an average yield potential and a characteristic spatial distribution around Zone 1. Zone 3 has a high yield potential, producing twice to three times as much as the Zone 1 in some years and is concentered in the centers of the field.

Table 4. Mean of yield in each management zone

Yield Map	Zone		
	1	2	3
Corn 2007 (kg ha^{-1})	3266	4790	5927
Corn 2009 (kg ha^{-1})	1511	3363	4969
Soybean 2010 (kg ha^{-1})	3150	3420	3670
Corn 2010 (kg ha^{-1})	3826	5385	6642
Standard Deviation	0.688	0.653	0.536

The mean of the standard deviation in each Zone can be used as an indicator of temporal stability (Blackmore et al., 2003). In this area, the first two zones had similar mean standard deviation, meaning that the Zone 2 had similar temporal stability, despite lacking spatial contiguity. The third zone had the smallest mean standard deviation, which means this area not only has the high yield potential but also a higher stability, being less affected by climate conditions.

The knowledge of the temporal stability of yield is very important in the decision making process. It is also important in estimating the risks associated with agricultural investments. The more stable is a field, more likely are to succeed practices of risk mitigation and management.

CONCLUSION

Differently than expected, simpler methods of filtering, larger cells and averaging values within cells retrieved a higher correlation of yield zones along years. Deeper studies are now needed to validate that these higher consistent results are indeed more reliable or if spatial polluting data is, contrasting, approximating zone classified cells more.

Yield maps of corn showed high temporal stability, suggesting that this crop has a great potential to delineate management zones.

The proposed methods were efficient to delineate management zones identifying different yield potential zones an also given an estimate of each zone temporal stability.

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