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Sources of information to delineate management zones for cotton

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Abstract. *Cotton in Brazil is an input-intensive crop. Due to its cultivation in large fields, the spatial variability takes an important role in the management actions. Yield maps are a prime information to guide site-specific practices including delineation of management zones (MZ), but its adoption still faces big challenges. Other information such as historical satellite imagery or soil electrical conductivity might help delineating MZ as well as predicting crop performance. The objective of this work was to evaluate the importance of numerous sources of information in predicting the crop development and delineating MZ in cotton. In order to represent the historical data set, 16 variables were chosen, including satellite imagery collected over the 27 years before the crop season, soil electrical conductivity and digital elevation model. Four variables represented the in season data set: satellite and terrestrial-derived NDVI and sensor-derived crop height. Both data sets were resumed to two latent variables from canonical correlation analysis. Historical and in season variables showed to be highly correlated (r=0.87) indicating that in the lack of in season crop development data, historical information can be used to delineate management zones and guide site-specific management strategies.*

Keywords. *Historical satellite imagery; NDVI; Canonical correlation analysis*

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Introduction

Cotton (Gossypium ssp.) is among the most important fiber crops, with approximately 35 million hectares grown throughout the world. The global demand has gradually increased since the 1950s, with an average annual growth of 2%. Brazil produces around 1.7 million tons of cotton lint per year, being placed among the top five global producers. Brazil is the fourth largest exporter achieving the highest yields in non-irrigated fields (Neves and Pinto, 2013).

Cotton production in Brazil is capital-intensive, requiring the input of high amounts of fertilizers and pesticides. Cultivating cotton requires intensive field management, involving application of nitrogen and plant growth regulators to keep the balance between vegetative growth and reproductive development. Using the right amount of these inputs at the right time remains a challenge for growers, especially due to spatial variability of soil conditions and crop development. New practices such as variable rate application are starting to take place in these production systems to help growers dealing with field spatial variability. This management strategy is usually based on crop canopy sensors or previously stablished management zones (MZ). Usually a prime source of information to delineate such management zones is the yield mapping.

In the Brazilian cotton production, few areas have historical and reliable yield maps. There are many factors contributing to this fact, which includes the use of old harvesters without yield monitoring systems, lack of maintenance of yield monitoring systems and lack of calibration of sensors that are in operation. The latter is particularly important when there are more than one harvesting machine in the same field, which is a common situation in Brazil. Even in the machines that have complete and calibrated yield monitoring systems, it is common for the data to be only displayed on the screen and not be saved and organized for later use.

Cultural problems among growers also affects the yield mapping adoption. The importance of such information is often neglected. The difficulty in quantifying the value of this information, the lack of skilled operators, inefficient technical support and the needs associated with data transferring and processing are also important issues.

The progress towards generalized yield mapping adoption in Brazil is going to be slow, and it depends on the development of new yield mapping systems that are more robust and less dependent of user interference. Therefore, there is a need for alternative sources of information that can produce similar results in guiding site-specific practices to those obtained through yield maps. These could include variables that are highly correlated with yield and are less affected by factors that vary greatly from one year to another, such as attack of pests and diseases.

The findings of several authors over different soil and crop variables suggests that soil electrical conductivity (Guo et al., 2012), spectral reflectance indexes (Gutierrez et al., 2012), sensor-based crop height (Shiratsuchi et al., 2005; Portz et al., 2014) and the combination of such variables (Sharma and Frazen, 2014; Sui et al., 2013; Zhou and Yin, 2014) might help explaining and estimate crop performance. These information could be implemented in MZ delineation for site specific management.

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 (Spekken et al., 2014). Yield maps are well recognized and widely used for this purpose, nevertheless, these data are not available for most of the fields in Brazil, which makes it necessary to find other sources of information that could predict the crop development and allow the adoption of site specific management practices. Therefore, the objective of this work was to evaluate the importance of numerous sources of information in predicting the crop development and delineating MZ in cotton producing areas.

Material and Methods

The data used refers to an agricultural field (200 ha) located on the municipality of Campo Verde, state of Mato Grosso, Middle West Brazil, centered at coordinates 54°57′54″W and 15°14′19″S. The field had soils with different clay contents (50 – 300 g kg^{-1}) associated with soil types varying from Quartzipsamments to Oxisols. Rainfed cotton was grown in this field during the 2014/15 season, adopting a narrow row cultivation system (0.45 m row width).

A total of 20 variables were used, which were divided into two datasets representing the historical and the in season crop development. The first dataset consisted of 16 variables, all representing sources of information that could be obtained before the crop season, and therefore could be used to predict crop development in the next season. The dataset included NDVI calculated from satellite images collected over the 27 years before the crop season (starting with native vegetation and varying from different crops along the years), topographic indexes and soil apparent electrical conductivity.

The 12 historical NDVI maps were obtained from 10 images acquired by LANDSAT 5 satellite, using bands 3 (660 nm) and 4 (830 nm) of Thematic Mapper (TM) sensor, one image acquired by LANDSAT 8 satellite, using bands 4 (660 nm) and 5 (870 nm) of Operational Land Imager (OLI) sensor and one image acquired by the RapidEye satellite using bands 3 (660 nm) and 5 (810 nm). Elevation data was collected using a Starfire 3000™ (NavCom Technology Inc., Torrance, California, USA) GNSS (Global Navigation Satellite System) receiver, with real time kinematic (RTK) corrections provided by a base station located less than 5 km from the field. Data was recorded at a frequency of 1 Hz, using a vehicle that passed the field every 21.6 m at a travel speed of 2 m s^{-1}. To create a digital elevation model (DEM), the elevation data was kriged to a 5 x 5 m regular grid. This map was used to derive slope and planform curvature as described in Evans (1980). The soil EC map was obtained using the Veris 3100® Soil EC Mapping System (Veris Technologies, Salina - Kansas). Data from the shallow layer (0 – 0.3 m) was recorded at a frequency of 1 Hz, using a swath width of 12 m and speed of 4 m s^{-1}, and kriged to a 5 x 5 m regular grid.

The second dataset consisted of four variables related to cotton development, all taken during the crop season. These included the N-Sensor S1 index, satellite derived NDVI and ultrasonic measured crop height at mid-season and pre-harvest. The S1 vegetation index was obtained at 88 days after emergence (DAE), with a commercial optical reflectance canopy sensor (N-Sensor™ ALS, Yara International ASA, Research Centre Hanninghof, Duelmen, Germany) mounted on the top of a high clearance vehicle that passed the field every 24 m at a travel speed of 5 m s^{-1}. In season satellite derived NDVI was obtained using bands 4 (660 nm) and 5 (870 nm) of Operational Land Imager (OLI) sensor onboard of LANDSAT 8 satellite. The image was acquired on May 5, 2015, when the crop had 103 DAE. Plant height was obtained at 88 and 156 DAE, using four ultrasonic ranging modules (HC - SR04), which measured the distance between the top of the canopy and the sensor, using custom data acquisition system. The measurements were geo-referenced using a GNSS receiver and collected at a frequency of 5 Hz. The sensors were mounted in a high clearance vehicle that passed the field every 24 m at a travel speed of 5 m s^{-1}.

All the satellite data was resampled to a common grid with 5 m of spatial resolution, using the nearest neighbor interpolation. All other data, which were collected as point data, were interpolated by Kriging to the same common grid.

The two sets of data were submitted to canonical correlation analysis. The first latent variable from each set were used to represent the historical crop development data (HCD) and the in season crop development (ISCD). The correlation between each of the 16 variables in the first set and the ISCD was used as criteria to evaluate each variable as a crop development predictor. The HCD was used to delineate management zones for the field using the k-means clustering technique, followed by a spatial filter using the modal cluster value of a 5x5 moving window. A statistical summary of crop development was calculated for each zone, and the amount of variance explained versus the number of clusters was used as criteria to decide the final number of management zones.

All data manipulation, including statistical and geostatistical procedures were performed using the R software, version 3.1.3 (R Development Core Team, 2015). The final maps were prepared using QGIS software, version 2.8.1 (QGIS Development Team, 2015).

Results and discussion

The variables used had coefficients of variation varying from 0 to 38%, with soil EC showing the greater variation (Table 1). The variation in most of satellite derived NDVI was in the range of 10 to 15%. The canonical variables HCD and ISCD had a correlation coefficient of 0.87. The coefficient of determination using HCD to predict ISCD was 0.76, meaning that 76% of the variance shown in crop development in this particular season could be explained by de historical data. The four individual variables of in season crop development had also good correlations with HCD. The variables representing historical data more correlated to ISCD were: LANDSAT 5 derived NDVI (pearl millet cover crop) from June, 2009 (r = 0.84), LANDSAT 8 derived NDVI (cotton) from 2014 (r = 0.79), LANDSAT 5 derived NDVI (soybean) from January, 2009 (r = 0.77), Rapid Eye derived NDVI (cotton) from 2014 (r = 0.73) and soil apparent electrical conductivity (r = 0.72). Topographic indexes were not important in this field. The best NDVI maps from a total of 12, including native forest of 27 years before the crop season, various crops and stages of development, were the ones from the last ten years. The analysis of correlation indicates that the spatial variability in this field was consistent over the years and that historical satellite derived NDVI might be used as predictors of the actual crop development.

Table 1. Statistical summary of the data sources used to delineate management zones for cotton in Campo Verde – Mato Grosso – Brazil.

Variable*	Minimum	Average	Maximum	SD	CV (%)	HCD	ISCD
Elevation (m)	650.2	681.7	713.8	12.3	2	-0.22	-0.20
Slope (m m^{-1})	0.017	0.038	0.101	0.00	21	-0.16	-0.15
Curvature	-0.001	0	0.001	0	0	-0.08	-0.07
EC30 (mS m^{-1})	0.29	1.39	5.27	0.53	38	0.83	0.72
L5 1988-01	0.44	0.52	0.59	0.02	4	0.56	0.49
L5 1999-02	0.35	0.45	0.53	0.03	6	0.58	0.51
L5 2001-06	0.20	0.45	0.59	0.05	11	0.21	0.18
L5 2004-06	0.24	0.48	0.61	0.05	11	0.76	0.67
L5 2004-12	0.16	0.47	0.63	0.07	14	0.77	0.68
L5 2005-05	0.31	0.64	0.73	0.06	10	0.81	0.70
L5 2006-05	0.22	0.44	0.58	0.07	15	0.72	0.64
L5 2007-05	0.21	0.43	0.67	0.09	21	0.74	0.65
L5 2009-01	0.37	0.71	0.83	0.08	11	0.86	0.77
L5 2009-06	0.27	0.60	0.77	0.10	16	0.93	0.84
L8 2014-05	0.17	0.24	0.26	0.01	5	0.88	0.79
RE 2014-05	0.02	0.66	0.75	0.09	13	0.79	0.73
NDVI 103 DAE	0.12	0.75	0.91	0.10	13	0.76	0.83
S1 88 DAE	22.5	39.9	54.3	5.4	14	0.83	0.94
Height 88 DAE (cm)	0.0	87.8	148.1	16.4	19	0.71	0.81
Height 156 DAE (cm)	1.1	88.1	160.7	22.5	26	0.80	0.92

*EC30: Soil electrical conductivity in the 0-0.3 m layer; L5: LANDSAT 5; L8: LANDSAT 8; RE: RapidEye; S1: N-Sensor vegetation index; HCD: Correlation with latent variable representing historical data; ISCD: Correlation with latent variable representing in season crop development.

The correlation between the latent variables can be observed in the maps showing their spatial distribution (Figure 1). The variability patterns are very similar, although the spatial resolution and number of layers produced a smoother spatial distribution in HCD. The spatial variability from in season assessment was consistent with spatial patterns from the past. Both maps have smaller values in the northeast and northwest regions, contrasting with higher values in the center and south regions of the field. The clear contrast between these regions suggests that this field could benefit from a division into smaller MZ.

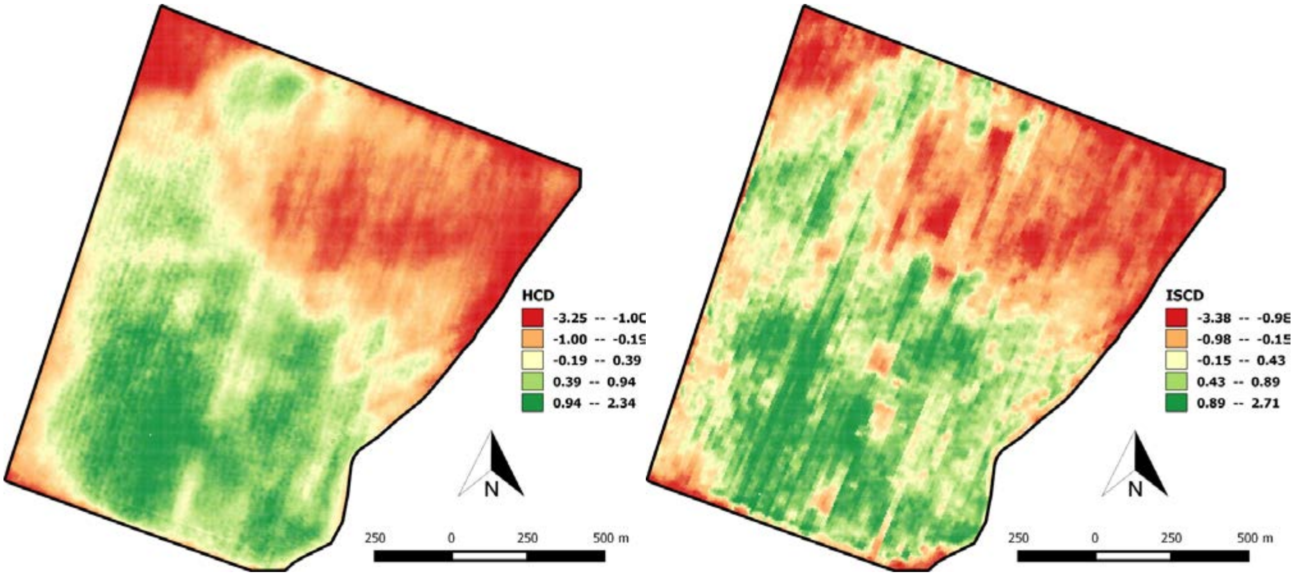

Figure 1. Maps of the first pair of latent variables from the canonical correlation analysis, representing historical crop development (HCD) and in season crop development (ISCD) for a cotton field in Campo Verde – Mato Grosso – Brazil.

The HCD was used to delineate management zones for the field and the average standard deviation was calculated for each number of zones. The results revealed the division of the field into five MZs would produce the best results (Figure 2), because incrementing the number of zones from 4 to 5 still reduced the average standard deviation, while the use of more than five MZ produced almost the same values of average standard deviation.

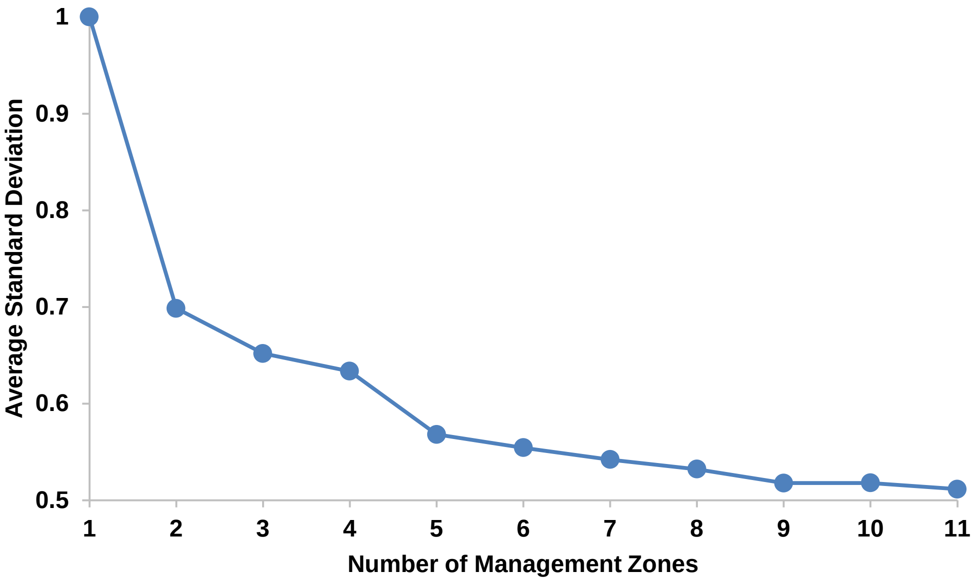

Figure 2. Relationship between average standard deviation and number of management zones.

Due to their spatial configuration, two MZs were further subdivided, resulting in the delineation of seven MZ (Figure 3). This field subdivision accounted for 70% of the variance present in ISCD. The average standard deviation in the MZs for the ISCD was 0.54, compared to a whole field standard deviation of 1. This results confirm that historical data can be used to divide the field into MZ since in season crop parameters also varied accordantly with the produced MZ.

The implementation of MZ could be used to guide appropriate management within each zone, such as adequate plant population, nitrogen and plant regulator inputs.

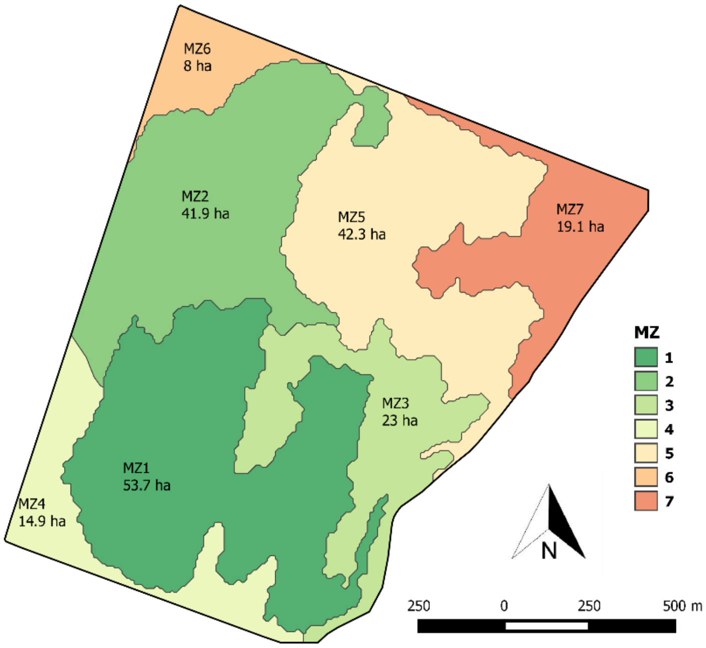

Figure 3. Map of the management zones delineated for a cotton field in Campo Verde – Mato Grosso – Brazil.

Conclusions

Due to the consistency of this field's spatial variability over time, the use of historical data to delineate management zones was a successful approach. Considering the correlation of the first pair of canonical variables for this field, 76% of the variance in crop development could be predicted by data taken before the season, and the remaining 24% could only be explained by in-season data. We conclude that in the absence of yield maps or in-season data, satellite imagery of crops in mid-season development from previous seasons and soil electrical conductivity could be used to predict cotton development.

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