MANAGEMENT ZONES DELINEATION IN BRAZILIAN CITRUS ORCHARDS

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ABSTRACT

Precision agriculture (AP) has been recently introduced in orange production in Brazil. Early research that evaluated variable rate fertilization based on soil grid sampling and yield maps showed good results regarding fertilizer use efficiency. But, areas that present distinguished soil characteristics might not be suited for standardized spatial investigation and prescription and might benefit from different PA strategies like management zones (MZ). Cluster analysis and rich data over soil and yield maps is considered trustful methods for MZ delineation. But often electrical conductivity or grid soil sampling are expensive and not available for citrus growers. At the same time, if dedicated MZ software is not available, the statistical steps of clustering might be limiting for PA practitioners. Gathering data for yield mapping is an inexpensive task for citrus growers and might provide enough data for MZ delineation. Simple procedures for classifying yield points can be used for MZ delineation using easier software kits. The objective of this study is to compare two MZ delineation methods: one based on soil (texture, organic matter, and electrical conductivity) and yield data, using principal component analysis (PCA) and cluster analysis; and the other, based only on normalized yield data and simple classification procedure. Two 25.7 ha orange fields located in São Paulo, Brazil, were used. Both methods resulted similarly in one of the fields. This field presented clear spatial patterns of soil texture and yield. In the second field, the method based on soil and yield data and cluster analyses performed better. This field presents a small area with drainage problems that was successfully detected on EC maps. Also PCA allowed different weights for data that present greater variability. The simpler method might be used when clear patterns are viewed on available yield maps. Otherwise, soil data and more intelligent clustering methods should be applied.

Key words: cluster, normalized yield, yield maps, Brazil

INTRODUCTION

Citrus crops are socially and economically important for Brazil, the world largest producer and exporter of orange juice. Orchards cover extensive areas, especially in São Paulo State. These production systems demand high technology to keep competitiveness and sustainability. Studies about precision agriculture (PA) applied to citrus production in Brazil started in the mid 2000's. Farmers actually started using some PA technology about five years ago, but adoption is still low. Citrus farmers that use some PA technology are limited to variable rate application of lime, P and K based only on soil grid sampling. Yield maps are not yet adopted.

A long term study that evaluated variable rate fertilization based on soil fertility and yield maps was reported by Colaço and Molin (2012) (first two years of evaluation) and Colaço and Molin (2014) (five years of evaluation). Results showed potential on increasing fertilizer agronomical efficiency and improving soil fertility management. Despite the good results, in some cases it is noticed that systematic methods of investigation (grid sampling and yield data) and prescription (standardized prescription equations) are not suited to recognize and treat areas that need different approach regarding soil fertility management.

Management zones (MZ) delineation can distinguish these areas based on spatial data such as soil EC, texture, elevation and sequential yield maps, and provide means for appropriate management strategies. Although MZ have been intensely studied and methods for delineation are fairly well developed (Zaman and Schumann, 2006; Man et al. 2010), validation is still needed in Brazilian citrus orchards. Important questions that need investigation are: what type of attribute (plant, soil, etc) must be used for MZ delineation and what method for clustering data is most effective.

Soil survey might provide enough data for MZ delineation in most crops. But, in citrus, historical yield data is also a key factor in delineating MZ. As a perennial crop, variability might be due to management actions (not necessarily related to soil) carried years ago that might still play important role in yield spatial variability (e. g. disease infection, pruning, replacement of dead trees or affected by disease).

At the same time that yield data is an important layer in MZ delineation, in most cases it is not available since harvest is still predominately manual and appropriate method must be applied to develop yield maps in such harvest type. The current yield mapping method adopted in our experimental orchards is based on georreferencing bags used during hand harvest. These bags are distributed in the field and filled with fruit. Yield is calculated based on distribution of bags in the orchard. This method is based on Schueller et al. (1999), but it was adapted for Brazil citrus production type (Molin and Mascarin, 2007; Molin et al., 2011). Despite its simplicity it is efficient in providing yield maps. Also, it is quite inexpensive and practical.

Regarding methods for MZ delineation, cluster analysis is probably the most accepted. But, in some cases, if dedicated and user friendly software is not available the statistical steps of clustering might not be the best option for PA practitioners. On the other hand, simple methods based on normalized historical yield data might provide reliable MZ in citrus, since yield can represent most of the spatial variability within an orchard.

The objective of this study was to compare two methods of obtaining management zones in citrus orchards, one based on cluster analysis of soil and yield data, and the other based on normalized historical yield data. The first method will be taken as the most reliable, as it counts with more attributes and applies robust cluster analyses. The second method is simpler and more accessible and will be tested against the first one.

MATERIALS AND METHODS

Two 25.7 ha orange fields located in São Paulo State, Brazil, were used in this study. Trees were planted in 2003 and 2004. Varieties are Rubi as canopy and Swingle as rootstock. These fields have been experimentally conduced with PA practices and spatial data are available since 2008.

Available data are the following: soil electrical conductivity (EC), soil texture, soil organic matter and yield, from 2008 until 2011. Soil EC was collected using a Veris instrument (Veris 3000, Veris Technology, Salina, KS, EUA) which acquires data in the 0 – 0.3 m and 0 – 0.9 m depths. EC readings were collected at 1 Hz frequency in every inter row space. Texture and organic matter information was collected by soil grid sampling with density of two samples per hectare. Yield data was gathered using a method presented by Molin and Mascarin (2007) and later applied by Molin et al. (2011). The bags used during harvest are georeferenced and yield is calculated at these points based on bag volume and its representative area.

Data from Veris, soil sampling and yield points were interpolated in a 10 x 10 m pixel grid using either kriging or inverse distance (when spatial dependency was not observed). These maps were arranged in SSToolbox ® 3.4 software (SST Development Group, Stillwater, OK, USA). A descriptive statistics was carried over these data.

Two MZ delineation methods were applied. Method 1 used all available data from soil and yield. The clustering method used in this case was the agglomerative hierarchical cluster based on Ward's minimum variance method. Prior to the cluster analysis, a principal component analysis (PCA) was carried in order to reduce the dimensionality of the data and, as an exploratory way, determine the main causes of the variability in each field. PCA and cluster analysis were carry out using the JMP ® 8 software (SAS Institute Inc. Cary, NC, USA).

Method 2 used only available yield data from 2008 until 2011. This type of spatial data is here considered of easy acquisition and quite inexpensive for citrus farmers. A simple method of grouping data into MZs was used in this case. Interpolated yield maps were lined together and organized in a excel spreadsheet. Yield data given in Mg ha^{-1} was converted into average normalized values (percentage of that year's average yield). This procedure allows the use of yield maps from different years since they are now given in relative values. The average normalized yield from four years and coefficient of variation (CV) were calculated in each pixel. Pixels were then classified into two MZs, one of high yield (over 100 %) and another of low yield (under 100 %). CV was used to assess temporal consistency – low values of CV means that yield performance was consistent over the years.

After classification of points, the resulting maps were processed to eliminate group of points from one cluster that are embedded within another MZ. This procedure was carried for both delineation methods.

To evaluate MZ delineations, maps were compared visually. The author's knowledge over these fields was also considered.

RESULTS AND DISCUSSION

Spatial and descriptive analyses over soil and yield data

Available maps for MZ delineation in field 1 and 2 are viewed in Figures 1 and 2, respectively. Averages and variation on this data can be assessed on the descriptive statistics table (Table 1). Field 1 present a significant one direction (east to west) spatial variation on soil texture, M.O and soil EC (0 – 0.3 m), which is reflected on yield (especially in 2008 and 2009). Clay content in field 2 is lower (average of 14.6 %) and less variable than in Field 1. The maps of soil EC (0 – 30 m) in field 2 showed higher EC values in the southern portion of the area, which matches with a poor drainage region. This small portion of the field frequently present lower yield, easily viewed in 2008 and 2011 yield maps.

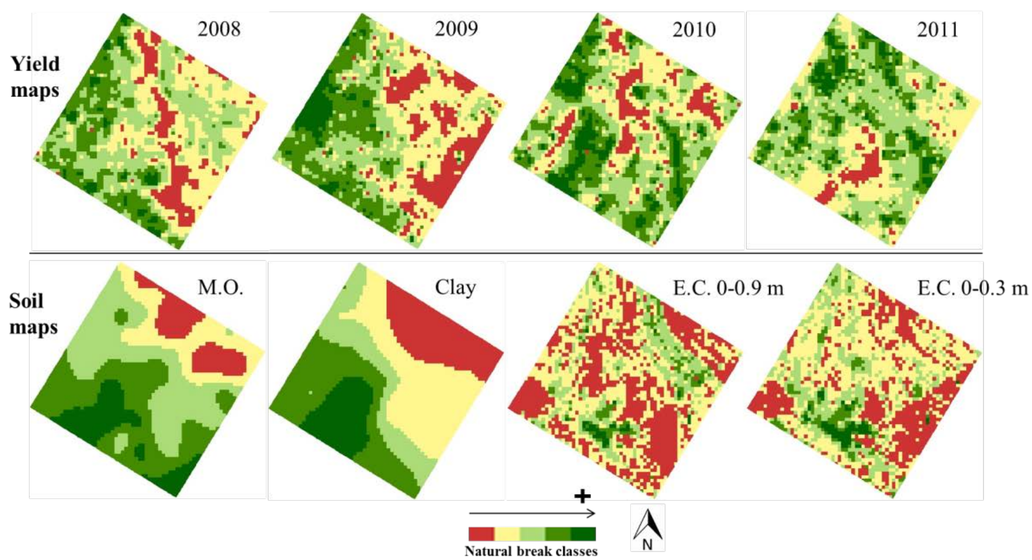

Fig. 1. Yield and soil maps available for MZ delineation in field 1

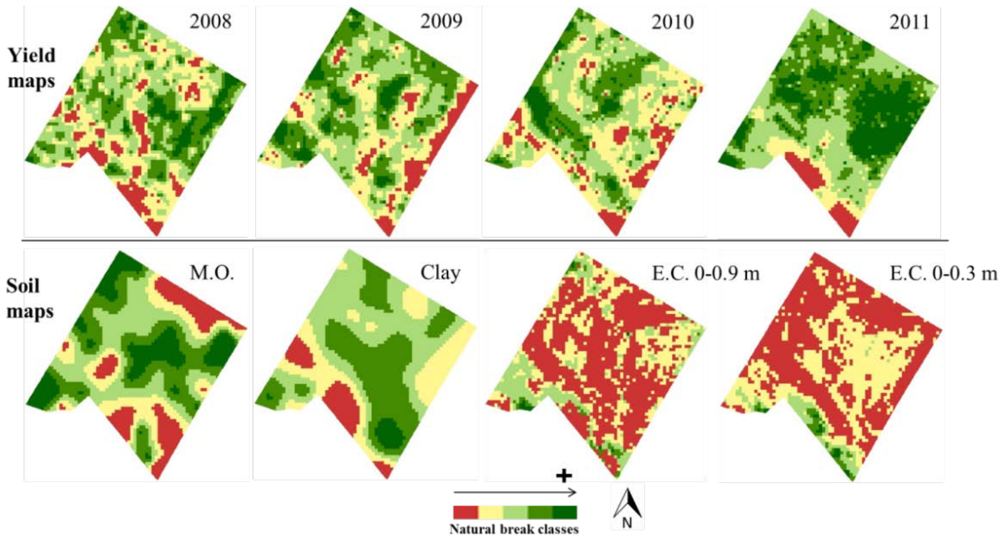

Fig. 2. Yield and soil maps available for MZ delineation in field 2

Table 1. Descriptive statistics over spatial attributes

Field	Atribute	Average	Max.	Min.	Standart Dev.	C.V. (%)
1	E.C. 0-0.3 m (mS m^{-1})	4.65	14.60	1.40	1.50	10.25
1	E.C. 0-0.9 m (mS m^{-1})	3.51	12.80	0.50	1.34	10.47
1	Texture (%)	32.61	50.40	18.40	8.54	16.94
1	M.O. (%)	2.56	3.60	1.50	0.36	10.10
1	Yield 2008 (Mg ha^{-1})	18.68	43.65	5.47	4.11	9.42
1	Yield 2009 (Mg ha^{-1})	41.85	66.98	20.17	6.23	9.31
1	Yield 2010 (Mg ha^{-1})	27.83	46.37	13.98	4.00	8.63
1	Yield 2011 (Mg ha^{-1})	52.80	80.52	28.46	5.41	6.72
2	E.C. 0-0.3 m (mS m^{-1})	1.05	6.00	0.30	0.60	9.96
2	E.C. 0-0.9 m (mS m^{-1})	0.68	3.80	0.00	0.42	10.97
2	Texture (%)	14.61	19.30	10.80	1.26	6.54
2	M.O. (%)	1.71	2.10	1.40	0.14	6.51
2	Yield 2008 (Mg ha^{-1})	14.60	28.42	5.22	2.65	9.34
2	Yield 2009 (Mg ha^{-1})	33.52	47.21	17.97	3.71	7.87
2	Yield 2010 (Mg ha^{-1})	27.73	43.56	16.11	3.47	7.97
2	Yield 2011 (Mg ha^{-1})	52.87	88.14	14.02	9.61	10.90

MZ delineation, method 1

Through interpretation of the dendogram from the agglomerative hierarchical clustering, two management zones were defined in each field (Figure 3). This division agrees with our expectation for these fields. Similar sized clusters were produced in the first field. MZ delineation followed the patterns previously known, as shown if Figure 1. The eastern part of the field was defined as MZ 1 (Figure 4), which presents lower clay, M.O., EC and yield. MZ 1 should then be managed as a low potential yield zone. On the other hand, MZ 2 would be carried as a high potential yield zone.

In the second field, clustering analysis successfully recognized the poor drainage and low yield area (Figure 4), located in the southern portion of the field. This area is represented in MZ 1, which is a low potential yield zone. MZ 2, the high potential zone, covers the rest of the field. The first principal component resulted from the PCA represented mainly the variability from 2008 and 2011 yield maps. EC (0 – 0.3 m) is also an important variable in the second principal component. These maps were given higher weights during clustering, which is reflected on the final generated MZ.

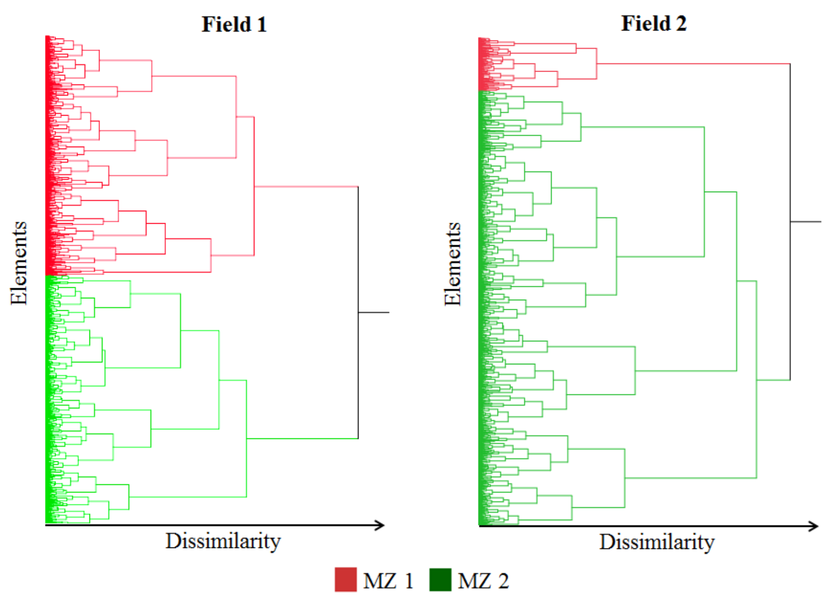

Fig. 3. Dendograms resulted from agglomerative hierarchical clustering

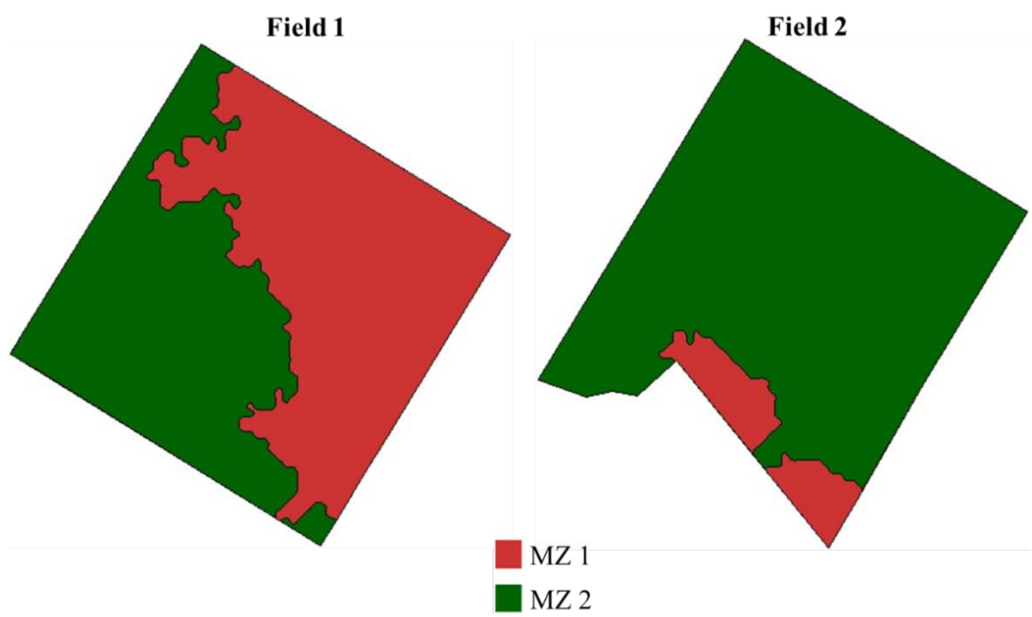

Fig. 4. Management zones generated by method 1

MZ delineation, method 2

MZ generated by the second method is viewed in Figure 5. In both fields two MZ were created. In the first field MZ are fairly similar to the ones resulted from the hierarchical clustering. The high potential yield zone is located in the western portion of the field, which agrees with the patterns found in the original soil and yield maps. CV map showed that most of the field presented consistent yield performance (CV < 15 %). CV values over 15 % are spread along the field, showing no significant spatial pattern. In the second field, MZ of low yield (MZ 1) is larger than the one from the first cluster method. Also, MZ 1 concentrates instable yield data. CV values over 15 % reveals that low yield performance in this region was not consistent along the years.

The differences between MZ methods in the second field might be due to several factors. After PCA in the first method, different weights were given to the attributes according to the variability of each data. In that case, yield from 2008, 2011 and EC (0 – 0.3 m) had higher influence on the final MZ. In the normalized yield method, all four yield maps got equal weights during calculation of average yield. Besides, the second method did not considered soil attributes. EC mapping provided rich information about that field's most important limitation (poor soil drainage), but it was not used as guidance for MZ delineation in the simpler method. Because yield was not sufficiently stable and did not present clear variability pattern, MZ did not perform as expected.

Further analyses are expected to carefully evaluate MZ delineation methods. Uniformity within MZ and disparity between MZ will be assessed in next steps, as well as comparison between maps through kappa index.

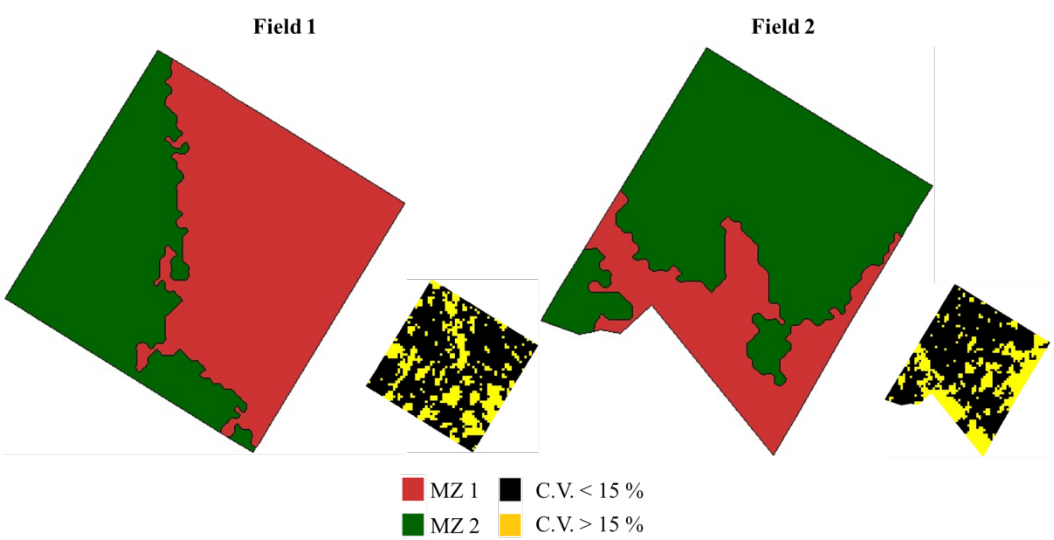

Fig. 5. Management zones generated by method 2

CONSLUSION

MZ were delineated in two orange fields is São Paulo State, Brazil. Two approaches were used. The first method count with soil and yield maps as data layers for cluster analysis. PCA and agglomerative hierarchical clustering was applied. The second method was based only on normalized yield data. Average normalized yield in each pixel were classified as either high or low potential yield zone.

Method one resulted as expected, according to fields characteristics. Field one was divided into two similar sized MZ that followed soil texture gradient. In the second field, a small portion of the area was separated in a low potential yield zone. This area presents drainage problems that limits yield. The second method produced similar MZ in field 1. But in field 2, MZ of low yield was larger, overpassing areas with drainage problem.

In the first field a simple method of delineation, based only on normalized yield data and easy classification procedure was sufficient to generate reliable MZ. The clear spatial variability pattern found on yield maps allowed good results for this method. This approach can be used by PA practitioners with available yield maps, as long as spatial patterns are clear.

In the second field, important information provided by EC measurements was not considered in the simpler method. EC maps indicated problematic areas which should be separated from the rest of the field for appropriate management strategies. Yield maps did not show this variability pattern sufficiently. Yield data was considered not stable enough to create reliable MZ through the simpler method. Better results might be possible by gathering yield data for longer periods and selecting out years with unusual spatial variation. In this field, PCA and hierarchical clustering showed good results since they use more intelligent data processing.

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