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Management zones applied to pear orchard

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Abstract

Precision agriculture has been adapted to become feasible even for small producers whose agricultural area is not so expressive. According to the crop potential of an area, the generation of management zones (MZ) comes as possibility to implement precision agriculture. Using conventional equipments, each sub-region receives a specific recommendation optimizing the input application and reducing the cost. Thus, this research aimed at identifying chemical and textural characteristics of soil as well as altimetric data that influenced a pear orchard yield. The data were collected during two years in an experimental area of 1.49 ha. To select the attributes to be used in the MZ generation, two approaches were used: chemical attributes (less stable) and textural and altitude attributes (more stable). MZ were generated with the Fuzzy C-Means algorithm and subsequently evaluated. When two MZ were generated, there was a reduction on variance of yield sample data in most studied MZ. The best results were recorded when two MZ were generated using data of texture, altitude and yield.

Key words: Precision agriculture, spatial variability, fuzzy clustering, autocorrelation, cross-correlation.

Introduction

Precision Agriculture (PA) can be defined as a set of methods, techniques and technologies applied to the management of small spatial zones of production. Its main principle is the variability management of soils and crops in space and time [1]. The importance to optimize the use of inputs and minimize the prospective negative impacts on the environment and human health is among its main goals [2].

The PA technology has evolved lately, and it has become essential to a successful agriculture. Meetings with cooperating producers and other stakeholders raised following questions [3]: (i) can spatial variation of soil fertility levels and soil properties be characterized across production agriculture fields without costly intensive grid sampling of the soil? (ii) can grain yield and the efficiency of nutrient use be improved by variable-rate application of fertilizers? (iii) does the crop remove nutrients differentially across the field? and (iv) is PA economically viable?

Among the researches that have been developed to obtain an economic viability of PA, the ones that work with definition of management zones (MZ) aim at dividing the producing areas in smaller MZ that must be treated differently, serving as a source of recommendation and analysis. So, in order to define these sub-regions, data of yield, physical and chemical properties of soil, electrical conductivity, topography and their combination are always used, besides the use of a statistical modeling of these attributes [4-6].

MZ is defined as an alternative to make PA economically feasible, since it works as an operation unit to determine where inputs will be applied and as an indicator for soil sampling and crop [7]. Even though there was not an ideal way to carry out this work, several researchers successfully used MZ [7-11].

The most widely used clustering method to define MZ corresponds to the Fuzzy C-Means algorithm [12-16], assuming the minimization of distance between the centroid (center of group) and the variable values.

Although most researches in this field have been working with MZ applied to cereal yield, techniques of production have been adopted and recommended by integrated and organic production systems of fruit and precision horticulture, in accordance with the new trends of Brazilian horticulture [17]. This trend mainly occurs due to the promising consumer market, which makes the horticulture an agricultural alternative of great success.

Among the fruits of mild weather, pear comes as the third most consumed fruit and the most imported one by Brazil. Its current consumption is around 150,000 tons per year. On the other hand, the commercial production of pear is still insignificant, since its production does not reach 10% of total consumption. Based on the amount of Brazilian internal market, there should have some moves to increase national production of this fruit, although it is important to highlight some technological and economic restrictions to achieve such goal. Since the increased production of pears is relevant for the country, as well as its fruit quality and reduction of production costs, this study aimed at evaluating the correlation of pear yield with chemical and physical properties of soil, as well as altitude, and according to the division of the cropped area (1.49 ha) in MZ, to identify if the division can be used as a recommendation and analysis for this fruit yield.

Material and Methods

The studied data were collected in a pear orchard, whose geographic coordinates were 25° 23' 22" S; 52° 34' 15" W and 750 m average altitude in Nova Laranjeiras, PR city, Paraná, Brazil. It is a Latossolo Vermelho Distroférrico, with mesothermal humid subtropical weather and average annual rainfall of 1900 mm. The municipality has an average temperature of 20ºC and average relative humidity of 70%.

The orchard was established in 2000 in an area that was previously cropped with corn, soybeans, oats and sorghum under no-tillage system. The seedlings were from the region of Mafra, SC. Rootstocks are from the hard pear variety (Kieffer), on which Pêra D'água variety has been grafted. The spacing was 8 m between rows and 10 m between plants. The experimental area was 1.49 ha, with 146 cropped pear trees.

The sampling was done in a 30 m regular spacing grid, based on a GPS. Thirty six points were selected (Fig. 1) and 18 of them were generated from the sampling grid, while 18 points coincided with the first plant on the right (from east to west).

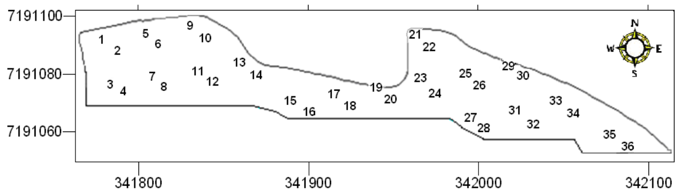

Figure 1. Spatial distribution of the pear trees used in the yield sampling in the experimental area (in UTM).

The yield data from the pears as well as the chemical analysis of the soil (P, C, pH, H^++Al^{3+}, Ca^{++}, Mg^{++}, Al, K, Cu, Zn, Fe, Mn) were collected in 2009 and 2010. Texture data (clay, silt and sand) and altitude were collected only in 2010, since these are attributes that do not undergo significant changes in their structure from one year to another. Chemical characteristics were classified [18].

Data were statistically analyzed by exploratory analysis, by calculating the mean, median, minimum, maximum, standard deviation, coefficient of variation (CV), skewness and kurtosis. The CV was considered low (homoscedasticity) when CV$\leq$10%; but, it was intermediate when 10% < CV$\leq$20%; high when 20% < CV$\leq$30% and it was very high (heteroscedasticity) when CV > 30% [19]. The normality of data at 5% probability was evaluated according to Anderson-Darling and Kolmogorov-Smirnov tests, so that the normal ones have shown normality at least one of the tests.

The data were analyzed separately for 2009 and 2010. Yield data of each year was correlated with the chemical data of the soil that was collected in the respective periods. For both years, the yield was also correlated with clay, silt and sand contents as well as the altimetric data in the area.

The spatial correlation was determined by using the cross-correlation between variables Y and Z [20] (Equation 1).

$$I_{YZ} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij} * Y_i * Z_j}{W\sqrt{m_Y{}^2 * m_Z{}^2}} \quad (1)$$

where I_{YZ} - level of association between the variable YZ, ranging from -1 to 1, as it follows: positive correlation $I_{YZ} > 0$ and negative correlation $I_{YZ} < 0$; W_{ij} - ij[th] element matrix of spatial association, calculated by $W_{ij} = (1/(1+D_{ij}))$, so that D_{ij} is the distance between points i and j; Y_i - value of variable Y transformed at point i. The transformation occurs to obtain a zero mean, by the formula:

$$Y_i = (Y_i - \overline{Y})$$

where $\overline{Y}$ is the sample mean of variable Y; Z_j - the value of variable Z transformed at point j. The transformation occurs to obtain a zero mean by the formula:

$$Z_j = (Z_j - \overline{Z})$$

where $\overline{Z}$ is the sample mean of variable Z. W – the sum of degrees of spatial association, obtained from Matrix W_{ij}, for $i \neq j$. $m_Y{}^2$ - sample variance of variable Y. $m_Z{}^2$ - sample variance of variable Z.

In general, MZ definition comes as a source of recommendation and analysis for several years. It should be used as a stable and predictable source of spatial information, which is correlated with yield [21]. Unstable sources of information can also be used for MZ definition to carry out the adjustment of nutrients in a given year. Thus, there were two evaluations, based on the stable (texture and altitude) and unstable factors (soil chemistry).

For each approach, the following procedure was used as an input source aiming at selecting the variables for Fuzzy C-Means algorithm: 1. Elimination of variables with non-significant spatial dependence at 5% probability level; 2. Elimination of variables that had no correlation with yield; 3. Ordering according to the degree of correlation with yield; 4. Elimination of redundant variables (that are correlated with each other) giving preference to the maintenance of variables that have a higher correlation with yield.

During the thematic maps generation, sampling data relating the variables selected by procedure described were interpolated. The surface was represented by 5 m x 5 m polygons (25 m^2). The inverse-distance interpolation method was used, with a window of interpolation of 10 neighbors.

Finally, a MZ generation was carried out by Fuzzy C-Means clustering technique. Three thematic maps were generated and classified according to the division in MZ, considering, respectively, 2, 3 and 4 sub-regions in a plot. Physical, chemical and yield of soybean data were used to evaluate MZ in order to identify if the generated zones have shown significant difference for each characteristic. Two parameters were used for the evaluation: 1. Relative Efficiency (RE): evaluates whether there was a reduction of the total variance of the evaluated variable with the division in MZ (Equation 2). The grouping will be considered appropriate when RE > 1 and the higher the RE, the more efficient it will be;

$$RE = \frac{S^2_{AREA}}{S^2_{MZ}} \quad (2)$$

where S^2_{MZ} is the sum of the yield variance of each management unit, calculated separately, whereas the proportion of total area that represents the management zone; S^2_{AREA} - variance of yield that refers to the whole area.

2. Analysis of Variance (ANOVA): There is an evaluation to observe if the MZ's are associated with attributes statistically different, assuming that internally, within each sub-region, the data have normal distribution and are independent.

Results and Discussion

Yield data from pear (Table 1) were classified as very high CV for both studied harvests, but only the 2010 harvest showed normality in data [19]. The high CV usually occurs in this kind of crop, considering climatic factors, disease infestation, among others. The skewness was classified as positive for both harvests and kurtosis was classified as platkurtic in 2009 and leptokurtic in 2010. After evaluating yield in its time aspect, it was observed that there was some instability on production, besides, the average yield in 2009 was superior to the one in 2010. Attributes as H^{+}+Al^{3+} and Ca^{++}, although they are collected in the same sampling grid, showed differences in CV classification from one year to another, so that H^{+}+Al^{3+} changed from intermediate (2009) to high (2010) and Ca^{++} changed from high (2009) to very high (2010). The skewness also changed its classification in 2009 and 2010 concerning C, H^{+}+Al^{3+}, K and Zn attributes, from positive to negative skewness as well as for Cu which changed from positive to negative skewness. Kurtosis was also changed from platkurtic to leptokurtic for P attribute and from leptokurtic to platkurtic for attributes as C, Cu and Zn (Table 2).

Only P and Mn attributes did not show normality for both sampling years, and for Al and Zn, the normality was registered only in 2009 and for Fe only in 2010.

In 2009, 80% of P samples were classified as an intermediate content (Table 3). In 2010, 83% of samples were classified as low level, but 58% of organic matter may be composed of carbon and was ranked as high in 94% (2009) and in 91% (2010) of samples; it could be observed that this nutrient showed a high content to the plants. With similar values, Ca showed high content in most samples, and this may be related to soil classification (clayey)[22]. Each kind of soil can also be related to the high Mg^{++} content, considered high for all samples.

Potassium (K) was classified as very high at 91% and 55% of sampling points in 2009 and 2010, respectively. The high content of Cu (100% of sampling points), may be related to pH (which showed maximum values of 5.9). When pH is low, there is an increase of this nutrient content.

Despite there is a decrease in the representativeness of sampling points, classified as medium level for the year 2010 when compared to 2009, Zn was classified as so in 91% (2009) and 50% (2010) of sampling points. This is related to the high rate of C and consequently the organic matter that may contribute to the lack of Zn [23].

In latosol, Fe is usually present with high content [24], but in this research, it has average contents in most sampling points (85% in 2009 and 89% in 2010).

On the other hand, high contents of Mn were recorded in most sampling points (100% in 2009 and 84% in 2010), and for this kind of soil (clayey), it is considered as high levels when they are superior to 30 mg dm^{-3}.

The texture and elevation data (Table 4) were normally distributed and kurtosis was classified as leptokurtic. The sand and altitude data showed positive skewness, but clay and silt presented negative skewness. Only sand was classified with high CV, and for the other attributes, the CV was classified as low [19].

With the spatial correlation matrices (one generated for chemical attributes and the other for the textural ones and altitude for each year), the layers were classified as candidates to be used for MZ generation.

Table 1. Descriptive statistics for the pear yield data (kg ha^{-1}) in a pear orchard, Nova Laranjeiras, PR.

Year	Minimum	Mean	Median	Maximum	SD	CV(%)	Skewness	Kurtosis	N*
2009	1.626	5.443	5.006	10.738	2.067	38.0 (vh)	0.84 (b)	0.37 (B)	No
2010	765	3.032	3.026	6.085	1.375	45.4 (vh)	0.30 (b)	-0.36 (C)	Yes

*Anderson-Darling and Kolmogorov-Smirnov Test of normality; standard deviation (SD), coefficients of variation (CV) - very high (vh). Skewness: symmetric distribution (a) positive skewness (b) negative skewness (c); kurtosis: mesokurtic (A), platkurtic (B), leptokurtic (C)

Table 2. Descriptive statistics for the data of soil chemistry in a pear orchard.

Attribute	Year	Minimum	Mean	Median	Maximum	SD	CV(%)	Skewness	Kurtosis	N
P (mg dm^{-3})	2009	2.60	4.03	3.50	7.60	1.22	30.36 (vh)	1.24 (b)	1.04(B)	No
	2010	1.00	1.88	1.60	4.10	0.97	51.78 vh)	0.94 (b)	-0.22(C)	No
C (g dm^{-3})	2009	19.87	27.62	28.05	35.84	4.36	15.78 (m)	-0.09 (c)	-0.89(C)	Yes
	2010	14.03	26.40	25.71	36.62	3.62	13.09 (m)	-0.61(b)	4.41 (B)	Yes
pH	2009	4.7	5.22	5.20	5.90	0.33	6.36 (l)	0.21 (b)	-0.44(C)	Yes
	2010	4.60	5.03	5.00	5.70	0.30	6.10 (l)	0.27 (b)	-0.99(C)	Yes
H^{+}+Al^{3+} (cmolc dm^{-3})	2009	3.97	6.06	6.21	9.01	1.13	18.69 (m)	0.36 (c)	0.03(C)	Yes
	2010	3.97	6.36	5.76	9.01	1.54	24.11 (h)	0.24 (b)	-1.22(C)	Yes
Ca^{++} (cmolc dm^{-3})	2009	3.44	6.68	7.03	9.39	1.70	25.41 (h)	-0.33 (c)	-0.82(C)	Yes
	2010	2.57	6.18	6.31	9.89	2.02	32.61 (vh)	-0.22 (c)	-0.72(C)	Yes
Mg^{++} (cmolc dm^{-3})	2009	1.01	2.15	2.205	3.20	0.59	27.31 (h)	-0.27 (c)	-0.74(C)	Yes
	2010	0.89	2.40	2.50	3.55	0.67	28.06 (h)	-0.26 (c)	-0.59(C)	Yes
Al (cmolc dm^{-3})	2009	0.00	0.03	0.00	0.20	0.05	204.52(vh)	2.00 (b)	3.29 (B)	Yes
	2010	0.00	0.09	0.00	0.53	0.16	174.62(vh)	1.73 (b)	1.91 (B)	No
K (cmolc dm^{-3})	2009	0.18	0.80	0.86	1.14	0.32	40.42 (vh)	-0.39 (c)	-1.23(C)	Yes
	2010	0.09	0.36	0.34	0.82	0.20	56.63 (vh)	0.31 (b)	-0.85(C)	Yes
Cu (mg dm^{-3})	2009	6.30	10.09	9.75	14.20	1.97	19.48 (m)	0.51 (b)	-0.19(C)	Yes
	2010	6.10	9.94	10.00	14.00	1.72	17.27 (m)	0.04 (c)	0.51(B)	Yes
Zn (mg dm^{-3})	2009	2.70	4.96	5.05	8.00	1.50	30.31 (vh)	0.28 (c)	-0.92(C)	Yes
	2010	0.80	4.39	3.40	15,50	3.33	75.77 (vh)	2.18 (b)	5.28(B)	No
Fe (mg dm^{-3})	2009	20.00	37.17	34.50	94.00	14.7	39.71 (vh)	2.57 (b)	7.73 (B)	No
	2010	14.00	28.50	27.00	60.00	9.91	34.76 (vh)	1.41 (b)	2.55 (B)	Yes
Mn (mg dm^{-3})	2009	66.00	127.83	108.50	230.00	45.8	35.85 (vh)	0.62 (b)	-0.87(C)	No
	2010	24.00	62.11	53.00	119.00	28.2	45.33 (vh)	0.63 (b)	-0.82(C)	No

*Anderson-Darling and Kolmogorov-Smirnov Test of normality; standard deviation (SD), coefficients of variation (CV) - very high (vh); high (h); low (l); moderate (m). Skewness: symmetric distribution (a); positive skewness (b); negative skewness (c). Kurtosis: mesokurtic (A), platkurtic (B), leptokurtic (C)

Table 3. Levels of interpretation of chemical properties contents of soil with their respective representation in a pear orchard.

Attribute	Year	Level				
		Very low	Low	Medium	High	Very high
P (mg dm^{-3})		--	≤ 3.0	3.1- 6.0	6.1 – 9.0	> 9.0
	2009	--	12%	80%	8%	--
	2010	--	83%	17%	--	--
C (g dm^{-3})		< 9	9.0 – 14.0	14.1 – 20.0	21.0 – 35.0	> 35.0
	2009	--	--	3%	94%	3%
	2010	--	--	6%	91%	3%
Ca^{++} (cmol$_c$ dm^{-3})		--	< 2.00	2.10 – 4.00	> 4.00	--
	2009	--	--	6%	94%	--
	2010	--	--	19%	81%	--
Mg^{++} (cmol$_c$ dm^{-3})		< 0.40	0.41 – 0.60	0.61 – 0.80	> 0.80	--
	2009	--	--	--	100%	--
	2010	--	--	--	100%	--
K (cmol$_c$ dm^{-3})		--	< 0.10	0.11 – 0.20	0.21 – 0.30	> 0.30
	2009	--	--	3%	6%	91%
	2010	--	17%	14%	14%	55%
Cu (mg dm^{-3})		--	< 0.8	0.8 – 1.7	> 1.7	--
	2009	--	--	--	100%	--
	2010	--	--	--	100%	--
Zn (mg dm^{-3})		--	< 3.0	3.0 – 7.0	> 7.0	--
	2009	--	3%	91%	6%	--
	2010	--	36%	50%	14%	--
Fe (mg dm^{-3})		--	≤ 15.0	15.0 – 40.0	≥ 40.1	--
	2009	--	--	85%	24%	--
	2010	--	3%	89%	8%	--
Mn (mg dm^{-3})		--	< 15.0	15.0 – 30.0	>30.0	--
	2009	--	--	--	100%	--
	2010	--	--	16%	84%	--

* Reference values: Costa and Oliveira (2001).

Table 4. Descriptive statistics for texture data and altitude in a pear orchard, Nova Laranjeiras, PR.

Attribute	Minimum	Mean	Median	Maximum	SD	CV (%)	Skewness	Kurtosis	Normal
Clay (%)	62.0	71.2	72.0	77.0	3.78	5.3 (l)	-0.89(c)	0.16(C)	YES
Silt (%)	14.0	16.9	17.0	20.0	1.50	8.9 (l)	0.20(c)	-0.20(C)	YES
Sand (%)	8.0	11.9	11.0	18.0	2.93	24.6 (h)	0.57(b)	-0.71(C)	YES
Altitude (m)	680	687	687	693	3.00	0.44 (l)	-0.01(b)	-0.51(C)	YES

*Anderson-Darling and Kolmogorov-Smirnov Test of normality; standard deviation (SD), coefficient of variation (CV) - very high (vh); high (h); low (l); moderate (m). Skewness: symmetric distribution (a); positive skewness (b); negative skewness (c). Kurtosis: mesokurtic (A), platkurtic (B), leptokurtic (C)

Considering the unstable variables: For 2009 (Fig. 2), all the layers showed a significant spatial correlation at 5% probability, although Cu, P and K layers were eliminated because there was no significant correlation with pear yield. After the other layers had been arranged in decreasing order according to the correlation with pear yield, the C layer was selected for MZ generation. The other layers have been removed whereas correlate with each other.

In 2010 (Fig. 3), due to the lack of spatial autocorrelation, Cu, Zn, Fe, P, and C layers were eliminated, as well as Al due to the lack of its correlation with pear yield. The remaining variables were arranged in decreasing order according to the degree of correlation with yield, and then pH layer was selected for the generation of MZ's during that year.

Considering the stable variables: For 2009, all the attributes presented spatial autocorrelation, and silt layer was eliminated due to its non-correlation with pear yield. After the arrangement in decreasing order according to the correlation of attributes with yield, altitude and clay layers were selected to generate MZ's to this approach (Fig. 4). In 2010, altitude was the only attribute that was correlated with yield, which is selected for MZ generation (Fig. 5).

Yield	0.071*												
Cu	0.036*	0.200*											
Zn	0.157*	0.163*	0.324*										
Fe	0.068*	0.067	0.049	0.088*									
Mn	0.104*	0.216*	0.320*	0.060*	0.341*								
P	-0.050	-0.062	-0.170*	-0.023	-0.176*	0.146*							
C	-0.159*	-0.231*	-0.284*	-0.128*	-0.296*	0.095*	0.406*						
pH	0.083*	0.088*	0.197*	0.041	0.186*	-0.148*	-0.159*	0.099*					
H^++Al^{3+}	-0.120*	-0.117*	-0.238*	-0.055*	-0.233*	0.166*	0.234*	-0.138*	0.194*				
Ca^{++}	0.123*	0.093*	0.279*	0.049*	0.245*	-0.185*	-0.224*	0.158*	-0.208*	0.237*			
Mg^{++}	0.122*	0.107*	0.301*	0.065*	0.279*	-0.224*	-0.227*	0.198*	-0.240*	0.278*	0.318*		
Al	-0.119*	-0.061*	-0.208*	-0.039	-0.204*	0.189*	0.186*	-0.167*	0.216*	-0.226*	-0.244*	0.237*	
K	0.019	0.055	0.134*	-0.021	0.116*	-0.050	-0.052	0.048	-0.067	0.080	0.091*	-0.072	0.065*
	Yield	Cu	Zn	Fe	Mn	P	C	pH	H^++Al^{3+}	Ca^{++}	Mg^{++}	Al	K

(*)significant

Figure 2. Spatial correlation matrix for yield data and chemical data of soil in 2009 in a pear orchard.

Yield	0.018												
Cu	-0.118*	-0.027											
Zn	0.049*	-0.057*	0.053										
Fe	-0.004	0.032	0.005	-0.030									
Mn	0.087*	-0.074*	0.032	-0.033	0.163*								
P	0.144*	0.011	0.023	-0.025	0.054	-0.023							
C	0.052	0.014	0.075*	0.044	-0.023	0.030	0.039						
pH	0.100*	-0.008	-0.009	-0.027	0.135*	0.010	-0.048	0.101*					
H^++Al^{3+}	-0.070*	0.033	0.016	0.036	-0.144*	-0.021	0.062*	-0.125*	0.149*				
Ca^{++}	0.099*	-0.045	0.071*	-0.035	0.159*	0.033	-0.010	0.102*	-0.124*	0.159*			
Mg^{++}	0.070*	-0.030	0.034	-0.029	0.123*	0.002	-0.037	0.088*	-0.114*	0.123*	0.105*		
Al	-0.049	0.037	-0.032	0.026	-0.120*	-0.014	0.031	-0.099*	0.121*	-0.134*	-0.109*	0.094*	
K	0.076*	-0.070*	0.056	-0.030	0.165*	0.075*	-0.012	0.140*	-0.145*	0.170*	0.125*	-0.129*	0.128*
	Yield	Cu	Zn	Fe	Mn	P	C	pH	H^++Al^{3+}	Ca^{++}	Mg^{++}	Al	K

(*)significant

Figure 3. Spatial correlation matrix for the yield data and chemical data of soil in 2010, in a pear orchard.

Yield	0.071*				
Sand	0.080*	0.158*			
Clay	-0.081*	-0.140*	0.135*		
Silt	0.048	0.046	-0.063	0.069*	
Altitude	0.115*	0.130*	-0.061	-0.099*	0.408*
	Yield	Sand	Clay	Silt	Altitude

(*)significant

Figure 4. Spatial correlation matrix for the yield data, textural and altimetric data in 2009, in a pear orchard.

Yield	0.018				
Sand	-0.045	0.158*			
Clay	0.024	-0.140*	0.135*		
Silte	0.029	0.046	-0.063	0.069*	
Altitude	-0.047*	0.130*	-0.061	-0.099*	0.408*
	Yield	Sand	Clay	Silt	Altitude

(*)significant

Figure 5. Spatial correlation matrix for the yield data, textural and altimetric data in 2010, in a pear orchard.

After the MZ's were generated, they were evaluated according to the pear yield data in order to identify the optimal number of MZ for each approach and year of study. Thus, the relative efficiency was calculated and tests of average comparisons were carried out to identify variance reduction and if average yield was different for each management zone (MZ) (Table 5). The division in two MZ's was best for all approaches (variance reduction through the RE and significant average difference for pear yield data), except for the approach using chemical attributes of 2010, division of which into three MZ's has shown the best answer.

When the area was divided into three MZ's, it was observed that RE was less than 1 for the approach using textural attributes and altitude in 2009. This indicates that there was no reduction of variance. For the other approaches, in order to divide the area into three MZ's, there was a reduction of variance. Despite this fact, at least two averages of yield were similar (ANOVA) for all cases on the division of three and four MZ's.

The best approach was selected for each division to evaluate the chemical and physical attributes of soil: two MZs with chemical attributes of 2009, three MZs with chemical attributes of 2010 (Fig. 6), two MZ's with textural attributes and altitude of 2009 and two MZ's with textural attributes and altitude of 2010 (Fig. 7). The selected MZs were used to evaluate texture and chemical properties of soil (Table 6). It was registered that for the approach with two MZs using textural attributes (clay), altitude and yield in 2009, only P, pH and silt attributes showed no significant difference in average, although pH had shown some variance reduction. For the approach with two MZs using chemical attributes of 2009, it was only possible to identify significant average difference between MZs by ANOVA for attributes as: C, H + Al, Cu, Fe and Mn. All of them showed some reduction of variance. For attributes

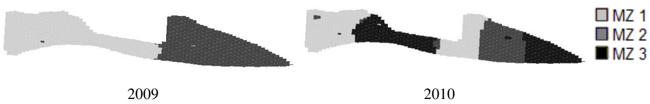

Figure 6. Thematic maps corresponding to the division into two (2009) and three (2010) MZ's to approach unstable data, in a pear orchard, Nova Laranjeiras, PR.

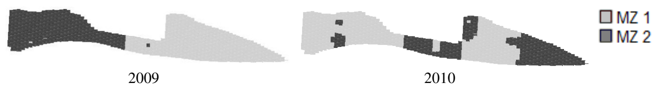

Figure 7. Thematic maps corresponding to the division into two (2009) and two (2010) MZ's to approach stable data, in a pear orchard.

Table 5. Evaluation of management zones (MZ's) generated by the pear yield, in a pear orchard.

Approach	Statistics	2 MZ's		3 MZ's			4 MZ's			
Chemical attributes of 2009	Average	4.62 a	6.47 b	6.63 a	5.55 ab	4.69 b	4.91 a	4.57 a	4.37 a	8.79 b
	RE	1.15		1.11			2.63			
Textural attributes and altitude of 2009	Average	6.07 a	4.56 b	2.53 a	3.30 a	3.12 a	4.32 a	5.94 ac	4.66 b	7.37 c
	RE	1.15		0.99			1.31			
Chemical attributes of 2010	Average	3.25 a	2.83 a	3.25 a	1.55 b	3.87ac	1.61a	2.08 a	4.05 b	3.93 b
	RE	0.99		1.67			2.45			
Textural attributes and altitude of 2010	Average	2.35 a	4.11 b	1.96 a	3.84 b	3.65 b	3.,88 a	4.05 a	1.48 b	3.17 a
	RE	1.62		1.63			1.96			

Note: Observe the best division in MZ for each approach.

Table 6. Evaluation of management zones (MZ's) generated by chemical, textural and altitude attributes of soil in a pear orchard.

Attribute		2 MZ's with chemical attributes and yield of 2009		2 MZ's with Textural attributes, altitude and yield of 2009		3 MZ's with chemical attributes and yield of 2010			2 MZ's with altitude and yield of 2010	
P	AVG	4.09 a	3.96 a	4.19 a	3.91 a	2.10 a	1.66b	1.78c	2.02 a	1.67 a
	RE	0.9683		0.98148		0.9859			0.9934	
C	AVG	30.66 a	23.81 b	31.09 a	25.14 b	26.93 a	24.50 b	27.17c	26.21 a	26.71 a
	RE	2.5975		1.8396		1.0526			0.9603	
pH	AVG	5.18 a	5.27 a	5.13 a	5.28 a	4.75 a	5.13 b	5.32 b	5.01 a	5.07 a
	ER	0.9869		1.0218		3.0797			0.9846	
H^++Al^{3+}	AVG	6.38 a	5.66 b	6.52 a	5.73 b	7.85 a	5.65 b	5.03 b	6.45 a	6.22 a
	RE	1.1053		1.1002		3.3798			0.9816	
Ca^{++}	AVG	6.36 a	7.08 a	5.98 a	7.17 b	4.66 a	6.35 b	7.97c	6.20 a	6.16 a
	RE	1.0591		1.1003		1.9447			0.9741	
Mg^{++}	AVG	2.04 a	2.29 a	1.90 a	2.32 b	1.88 a	2.54 b	2.95 b	2.33 a	2.51 b
	RE	1.0489		1.1184		1.8781			0.9915	
Al	AVG	0.04 a	0.01 a	0.04 a	2.01 b	0.09 a	0.08 a	0.11 a	0.09 a	0.10 a
	RE	1.1203		1.0107		0.94845			0.9753	
K	AVG	0.82 a	0.77 a	0.73 a	0.85 b	0.24 a	0.32 a	0.54 b	0.33 a	0.40 a
	RE	0.9789		1.0049		1.691			0.9936	
Cu	AVG	9.18 a	11.24 b	9.01 a	10.87 b	10.35 a	10.11 a	9.31 a	10.13 a	9.65 a
	RE	1.2969		1.2691		1.0333			0.9832	
Zn	AVG	4.62 a	5.38 a	3.97 a	5.66 b	4.83 a b	3.08 a	4.84 b	4.8 a	3.75 a
	RE	1.0954		1.4371		0.9931			0.9772	
Fe	AVG	32.45 a	43.06 b	32.93 a	40.19 b	33.07 a	28.88 a b	22.5 b	30.77 a	24.92 a
	RE	1.02		1.0699		1.2267			1.0499	
Mn	AVG	109.1 a	151.25 b	99.93 a	147.76 b	45.73 a	52.22 a	90.00 b	60.00 a	65.43 a
	RE	1.1705		1.3698		1.9118			0.9859	
Sand	AVG	11.2 a	12.75 a	10.00 a	13.24 b	12.13 a	12.56 a	11.08 a	11.91 a	11.86 a
	RE	1.0377		1.4359		0.9811			0.9731	
Clay	AVG	71.95 a	70.38 a	73.4 a	69.71 b	70.67 a	70.89 a	72.25 a	70.91 a	71.79 a
	RE	0.9953		1.3107		0.9813			0.9829	
Silt	AVG	16.85 a	16.88 a	16.60 a	17.05 a	17.2 a	15.56 a	16.66 a	17.18 a	16.35 a
	RE	0.9683		0.991		0.9871			1.0392	

as pH, Ca^{++}, Mg^{++}, Al, Zn and sand, although they have shown a RE > 1, ANOVA showed that the averages can be considered equal at 5% probability level.

In the approach with two MZs using altitude and yield of 2010, Mg^{++} was the only nutrient to present significant difference of average and only Fe and silt had RE > 1, indicating a reduction of variance. For the approach with three MZs, with chemical attributes of 2010, it was possible to identify significant average difference among the three averages only for P, C and Ca^{++} although for pH, H^++Al^{3+}, Mg^{++}, K, Cu, Fe and Mn, there was some reduction of variance. It is important to observe that for pH, H^++Al, Mg^{++}, K, Zn, Fe and Mn, it was possible to register that the three generated data sets (one for each MZ), at least two of them showed the same averages and should be used as a single management zone in an input application, differing from the remainder of the field.

The best results on correlations and evaluations occurred in 2009, and this fact may be related to climatic factors, which may have affected yield in spite of good plant growth.

Conclusions

·The chemical, textural and altitude attributes were more correlated with pear yield in 2009, and in this year, yield was more expressive and showed spatial autocorrelation among samples.

·The division of the area in two management zones (MZ) provided some reduction of variance in three of the four studied approaches. This fact did not occur in 2010, when chemical and yield data were used, when it was necessary to divide into three MZ.

·The average comparison tests have shown to be effective for the evaluation of MZ, thus, the results were more reliable than the statistics of relative efficiency, which, although they have shown some reduction in total variance, the attributes showed equal averages in at least two MZ.

·The best results were recorded for 2009, when the area was divided in two MZ, using clay, altitude and yield data, since the division provided a reduction of variance in 14 of the 16 studied attributes.

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