

A software for the delineation of crop management zones (SDUM)

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Abstract

Agricultural management zones (MZs) are economic and environmentally friendly alternatives for the precision agriculture. However, several analyzes and procedures are required for the delineation of MZs, which is being considered a difficult task. The statistical analysis, selection of variables, generation of thematic maps of the selected variables, generation of MZs (empirical or clustering methods), and evaluation of the applied practices are among routine procedures. In order to facilitate the definition and use of MZs, the aim of this paper was to present a software for delimitation of management zones (SDUM). Therefore, we developed a computer tool developed at and UTFPR to facilitate the generation and evaluation of MZs quickly and easily. The software was developed in Java language and can be run on any operating system. It can be downloaded from <http://ppat.md.utfpr.edu.br/sdum/sdum-vm.ova>. We performed tests in an experimental area, generating thematic maps of soil attributes and soybean yield. The software delineated and validated MZs, by assessing all functionalities. The statistical analysis, thematic maps, MZs and the results of MZs evaluation were shown through the graphical interfaces of the software, allowing easy interaction for the users.

Keywords: precision agriculture; software for agriculture; water conservation, soil conservation.

Abbreviations: PA_precision agriculture; MZs_management zones; SDUM_Software for Definition of Management Zones; CV_coefficiente of variation.

Introduction

Technological resources and improvement of data collection devices and methods contribute to the increasing use of suitable techniques for crop management, making it financially and environmentally more attractive. It can be seen by the increasing adoption of the precision agriculture (PA) technologies. The costs of PA are high and studies to reduce it through the use of management zones (MZs) (Fridgen et al., 2004; Tagarakis et al., 2013) make the PA more attractive even for small farmers (Farid et al., 2016; Peralta and Costa, 2013). It usually represents areas of the field (sub-fields or sub-regions) that are similar based on some quantitative measurements. Since each sub-region can be treated differently from the point of view of sampling and management, optimization of these resources protects the environment (Zhang et al., 2013). Besides, it allows the use of conventional equipment, since in each subfield fertilizer applications can be performed at constant rate. Regardless of the considerable number of researches indicating the feasibility of MZs (Fu et al., 2010; Moral et al., 2010; Bazzi et al., 2013; Li et al., 2013; Bazzi et al., 2015; Zhang et al., 2013), the delineation of an area in MZs is not a simple task, considering several attributes that may influence crop yield. In the literature, soil electrical conductivity, elevation and soil texture are among the variables identified as potential

to generate MZs are (Farid et al., 2016; Peralta and Costa, 2013; Schenatto et al., 2016). The computational and statistical techniques are used for the identification of the subfields (MZs) to use in management techniques. The traditional software for data analysis and interpretation are the Minitab (Minitab, Inc., State College, Pa.), ArcGIS (Environmental Systems Research Institute, Redlands, CA), Software R (R CORE TEAM, 2014), Statistica (StatSoftInc, Tulsa, OK, USA), FuzMe (Minasny and Mcbratney, 2002) among others. These packages have not been developed for the agricultural sector. Some others such as MZA - Management Zone Analyst have been specifically developed for agriculture management (Fridgen et al., 2004). Regardless of the software, the proposed methodology could be performed, but it would be necessary for the user to have prior training and/or knowledge in computing sufficient to perform all the steps of the process. In addition, users would probably spend several hours working, while using our proposed software the whole process can run much faster. In this sense, this work aims to introduce the Software for Delineation of Management Zones (SDUM, acronym for Software para Definição de Unidades de Manejo) developed to manage, analyze and process

agricultural data in an easier way, for the delineation, presentation and evaluation of MZs.

Results and Discussion

Since several computational techniques can be used to develop the proposed software, we selected only open source technologies to develop software without additional costs for license or support for each stage of the project. For features representation and documentation generation, a representation language was used - Unified Modeling Language (UML), which is a modeling language (Schach, 2009) used to describe software projects. The modeling was performed in ArgoUML 0.24 tool, being all software requirements graphically represented through UML diagrams. For each functionality, a case was generated for software documentation.

To work with a multi-platform tool, the Java programming language was chosen, which is based on the object orientation methodology. For development, Integrated Development Environment (IDE), Eclipse Galileo version 3.4.0 was used. For storage and data management, the Database Management System (DBMS) and PostgreSQL were used. They support georeferenced data through PostGIS spatial extension, and allowed creation of stored procedures using procedural language (PL/pgSQL), which is a key point.

All functions of georeferenced data manipulation were performed in the database, using the PL/pgSQL, which allowed building and storing in database. All functions defined in the analysis stage corresponded to the main functionalities of the software.

Delineation and evaluation of management zones

In addition to mathematical and statistical procedures used to delineate MZs, several procedures are required for the delineation of MZs (Fig 1), while certain functionalities have been implemented. Some steps need to be performed prior to use the software, related to the area of definition, the sampling grid and the field sample referring to soil attributes, relief and crop yield.

Software usage begins with the import of area boundary data and sample data is executed through files in text format (".txt"). An exploratory data analysis looking for outliers was already done. The values that were outside the mean \pm 3 standard deviation (SD) (Amidanet et al., 2005) were removed, to obtain robust variance estimators, even though actual data may belong to this interval. After that, the analysis of variables influencing the on crop yield was carried out. Doerge (2000) indicated that ideally, only stable variables should be used (Table 1), excluding soil chemical properties, satisfying general recommendation of literature (Gavioli et al., 2016; Schenatto et al., 2016). To perform the selection of variables in SDUM, the spatial correlation matrix was created by calculating the statistical Moran bivariate spatial autocorrelation (Czaplewski and Reich, 1993, Driemeier et al., 2016) between each combination of variables. That allows evaluation to determine whether an attribute is spatially correlated with other variables (positively or negatively) or is auto-correlated. Then, the variable were selected using the procedure proposed by Bazzi et al. (2013): (a) elimination of variables with no significant spatial

autocorrelation at 95% significance; (b) removal of the variables that were not correlated with yield; (c) decreasing order of the remaining variables, considering the degree of correlation with the yield; and (d) elimination of variables, which are correlated with each other, preferring to the withdrawal of those with lower correlation with the yield. The remaining variables were used in the delineation of MZs. The selected variables are interpolated by traditional methods used in agriculture (Lopez-Lozano et al., 2010; Ortega and Santibanez, 2007) implemented in SDUM: inverse distance weighting, nearest neighbor or moving average. It is also possible to import data interpolated by Kriging in others software.

The SDUM allows MZs to be generated using empirical methods, concerning the data normalization of several years (Blackmore, 2000) or clustering methods, through K-Means and Fuzzy C-Means algorithms (Mingoti and Lima, 2006; Iliadis et al., 2010; Arno et al., 2011; Jipkate and Gohokar, 2012; Valente et al., 2012; Li et al., 2013; Schenatto et al., 2016b). The mean comparison test (ANOVA) between MZs was performed to identify whether there is significant mean difference in the dependent variable (yield), assuming that in each MZ there is no spatial dependence. Although the evaluation of MZs was performed with yield sample data using ANOVA, it is possible to compare any attribute, serving as an indicator of average nutrients in other soil (Bazzi et al., 2013).

The evaluation of the best method for clustering also includes the visual aspect of the created cluster. Therefore, the smoothness of the boundary curves should be considered, because it facilitates the visual interpretation and application of agricultural inputs. The smoothness index was proposed by Schenatto et al. (2016) to calculate the frequency change of classes in the thematic maps in horizontal, vertical, and diagonal directions, pixel by pixel. It was also adopted in the software.

Software structure

Due the need for working and management of a considerable amount of data, integrity constraints have been implemented towards the management of areas and projects (Sorensen et al., 2010) (Fig 2). The project is characterized by a delimitation of the property or period, to which the work must take place. The areas can be added after being created, in which sample data, thematic maps, and MZs are embedded. The simultaneous work of two projects is not permitted, but certain area or sample can be added to more than one project.

Materials and Methods

To evaluate all the software features and to confirm the methodology applied to it, data from an experimental area of 15 ha, located in Céu Azul/PR/Brazil, with central geographical location of 25°06'32" S and 53°49'55" W and the average elevation of 460 m was used (Fig 3). The demarcation of the area was carried out with a GNSS (Geo Explorer XT 2005, Trimble Navigation Limited, Sunnyvale, CA, USA) device using PathFinder software (Trimble Navigation Limited, Sunnyvale, CA, USA).

The soil was classified as typical DYSTROPHIC RED LATOSOL (EMBRAPA, 2006) and cultivated under no-tillage system

Table 1. Identification of the variables (attributes) and data acquisition periods for each experimental area.

Variables	2012	2013	2014
SPR 0.0 - 0.1 m (MPa)	X	X	X
SPR 0.1 - 0.2 m (MPa)	X	X	X
SPR 0.2 - 0.3 m (MPa)	X	X	X
Elevation (m)	X		
Slope (°)	X		
Soil Density (g cm ⁻³)	X		
Sand (%)	X		
Silt (%)	X		
Clay (%)	X		
OM (%)	X		
Soybean yield (Mg ha ⁻¹)	X	X	X

SPR – Soil Penetration Resistance; OM – Organic Matter; X - represents the available data.

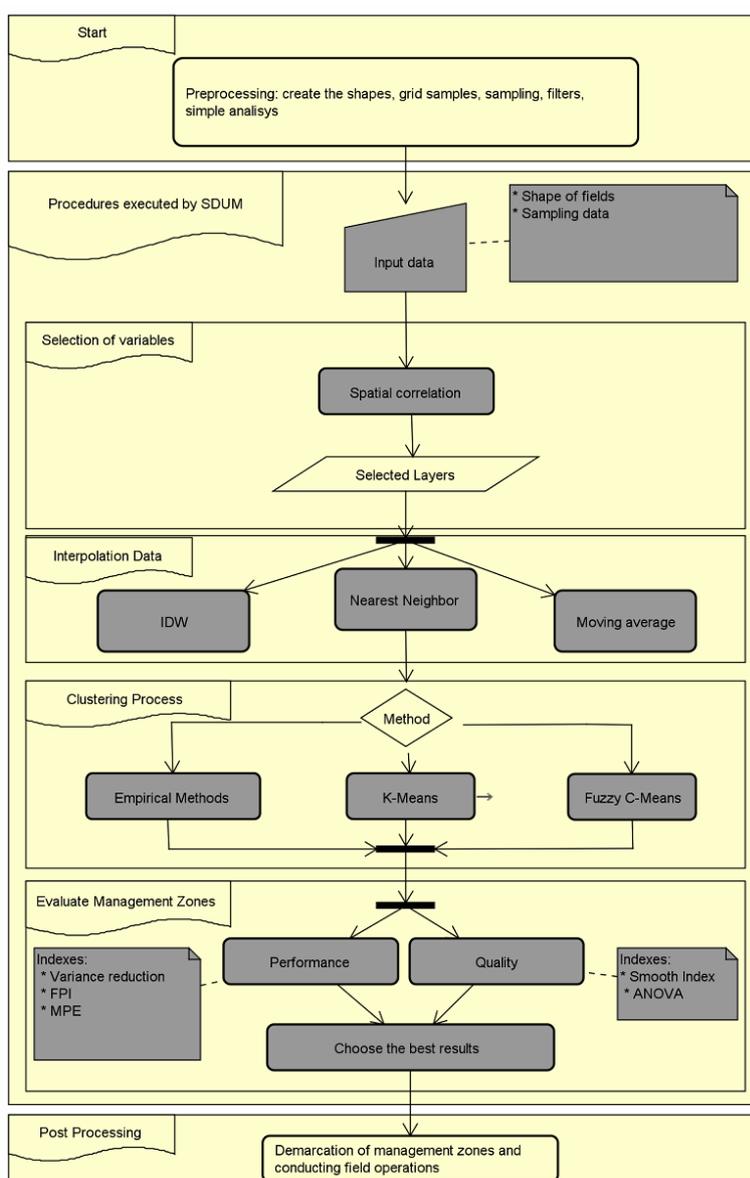


Fig 1. Flowchart for use agricultural management zones (MZs) definition using SDUM.

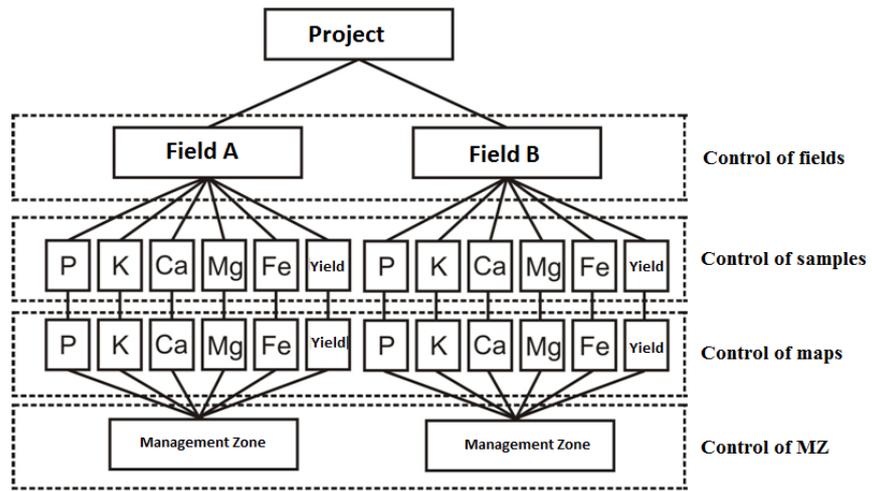


Fig 2. SDUM structure for management data into the project.



Fig 3. Shape of the agricultural field located in Céu Azul/PR/Brazil used to collect data and create management zones.

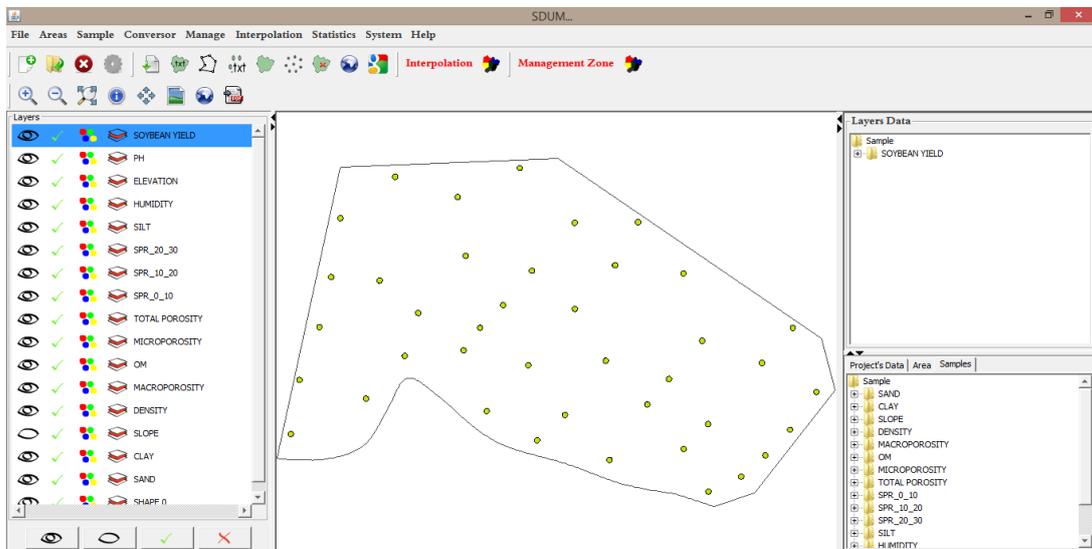


Fig 4. SDUM's main screen when executed. In this case, the software is showing data from experimental field and samples of soybean yield.

Elevation	0.176 (*)																	
Sand	-0.142 (*)	0.129 (*)																
Clay	0.091 (*)	-0.108(*)	0.105 (*)															
Slope	-0.045 (NS)	0.052(*)	-0.061 (*)	-0.001 (NS)														
Density	0.062 (*)	-0.051 (*)	0.046 (NS)	-0.048 (*)	0.020 (*)													
Macroporosity	-0.057 (*)	0.058 (*)	-0.074 (*)	0.056 (*)	-0.022 (NS)	0.002 (NS)												
OM	0.010 (NS)	0.007 (NS)	-0.14 (NS)	0.032 (*)	-0.032 (*)	0.051 (*)	0.005 (NS)											
Microporosity	0.018 (NS)	-0.015 (NS)	0.028 (NS)	-0.054 (*)	0.028 (NS)	-0.026 (NS)	-0.034 (*)	-0.006 (NS)										
Total_Porosity	-0.054 (*)	0.058 (*)	-0.066 (*)	0.020 (NS)	-0.001 (NS)	-0.021 (NS)	0.034 (*)	-0.039 (*)	-0.060 (*)									
SPR_0-10	-0.079 (*)	0.029 (NS)	0.015 (NS)	-0.017 (NS)	0.014 (NS)	-0.042 (*)	-0.018 (NS)	0.036 (NS)	-0.019 (NS)	0.049 (*)								
SPR_10_20	-0.011 (NS)	-0.020 (NS)	0.049 (*)	-0.054 (*)	0.015 (NS)	-0.035 (NS)	-0.007 (NS)	0.021 (NS)	-0.024 (NS)	0.024 (NS)	-0.001 (NS)							
SPR_20_30	-0.012 (NS)	-0.031 (NS)	0.068 (*)	-0.068 (*)	0.026 (NS)	-0.055 (*)	-0.025 (NS)	0.036 (*)	-0.035 (*)	0.053 (*)	0.025 (NS)	0.041 (*)						
SILT	0.034 (*)	0.006 (NS)	-0.020 (NS)	0.027 (NS)	-0.008 (NS)	0.041(*)	0.010 (NS)	-0.024 (NS)	0.028 (NS)	-0.058 (*)	-0.047 (*)	-0.060 (*)	0.021 (NS)					
Moist. Cont.	0.023 (NS)	-0.041 (NS)	0.051 (*)	-0.027 (NS)	0.017 (NS)	-0.007 (NS)	-0.016 (NS)	0.008 (NS)	-0.001 (NS)	0.040 (*)	0.033 (NS)	0.042 (NS)	-0.025 (NS)	-0.020 (NS)				
PH	-0.081 (*)	0.084 (*)	-0.057 (*)	0.023(NS)	-0.021 (NS)	0.040 (*)	-0.012 (NS)	-0.006 (NS)	0.044 (*)	0.029 (NS)	-0.001 (NS)	-0.001 (NS)	-0.015 (NS)	-0.037 (*)	0.014 (NS)			
Soybean_Yield	0.106 (*)	-0.081 (*)	0.043 (NS)	-0.013 (NS)	0.022 (NS)	0.003 (NS)	0.008 (NS)	-0.007 (NS)	-0.002 (NS)	-0.059 (*)	-0.019 (NS)	-0.026 (NS)	0.031 (NS)	-0.007 (NS)	-0.034 (NS)	0.030 (NS)		
	Elevation	Sand	Clay	Slope	Density	Macroporosity	OM	Microporosity	Total_Porosity	SPR_0-10	SPR_10_20	SPR_20_30	SILT	Moist. Cont.	PH	Soybean_Yield		

Fig 5. Spatial correlation matrix among all stable variables and yield with 5% of significance, used to select layers to define MZs using Fuzzy C-Means technique.

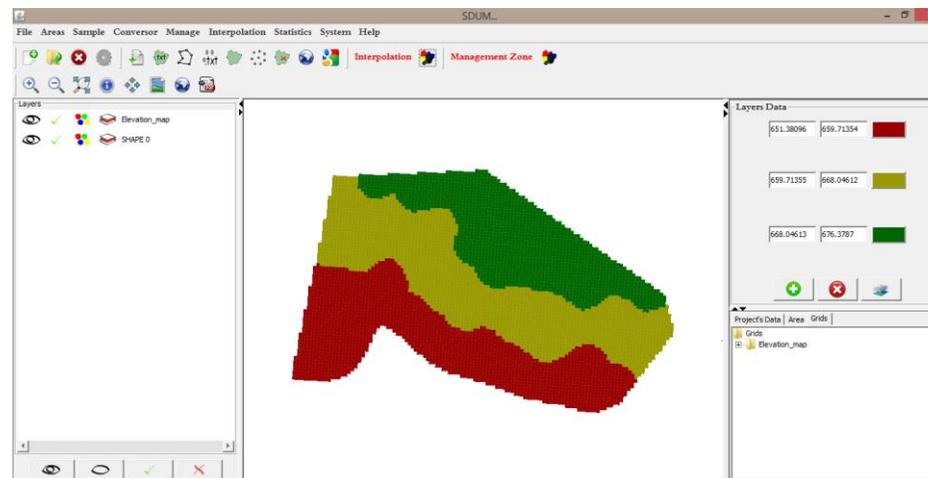


Fig 6. SDUM showing the elevation map with three classes of our experimental field. The green color is the higher elevation.

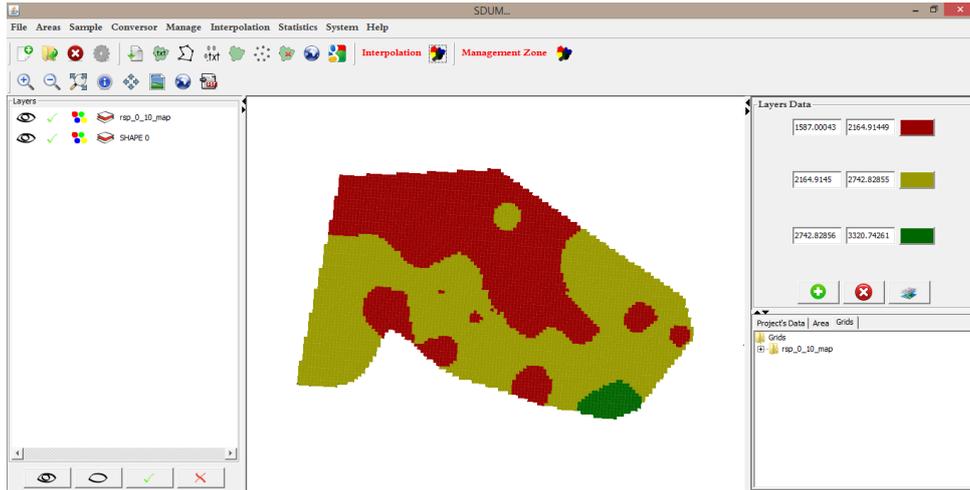


Fig 7. SDUM showing the soil penetration resistance from 0 to 0.1 m (SRP 0-0.1 m) with three classes. The red color represents the lower SRP.

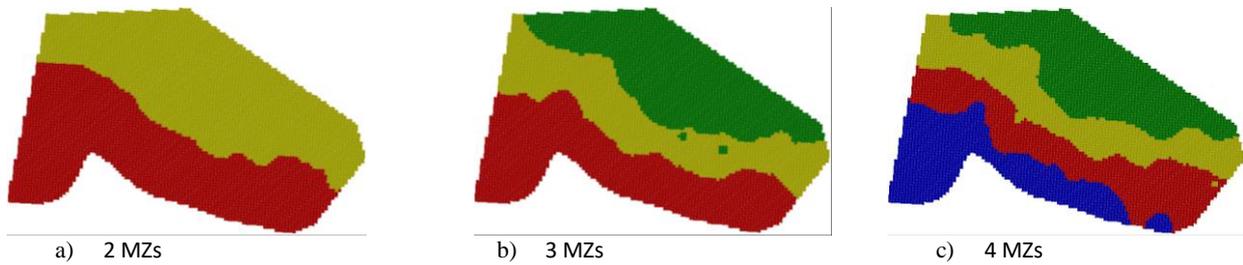


Fig 8. Maps representing the MZs generated by SDUM using the variables elevation and SPR_0_10.

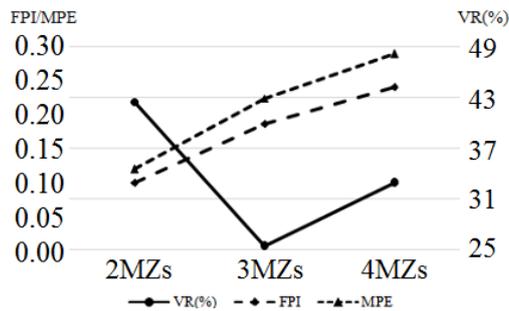


Fig 9. Statistical graphs of variance reduction (VR), Fuzzy performance index (FPI) and modified partition entropy index (MPE).

with sequence of soybean, wheat, corn and oats for more than 10 years. In Forthe delineation of MZs, only variables that considered stable were used (Table 1); consequently, excluding soil chemical properties, satisfying general recommendation of literature (Doerge, 2000; Gavioli et al., 2016; Schenatto et al., 2016a). We used a non-uniform dense sampling grid (2.67 points ha⁻¹), defined considering the central imaginary line between the contour lines of the

area. The area elevation was obtained using a total station (GPT-7505, Topcon Corporation, Tokyo, Japan). The soil penetration resistance (SPR) was determined using an electronic penetrometer (PenetroLOG, Falker, Porto Alegre, Brazil). The soil samples were collected at a depth of 0-0.2 m. The soybean yield data were determined using a harvester-mounted yield-monitoring system (Grain harvester CASE AFS PRO 600, Case IH, Brazil). To meet the

stability requirement of yield data which is strongly influenced by the weather and rainfall, soybean yield data and SPR were normalized, using the normalization technique of standard score, generating a single variable of the attribute yield. Importing data The main screen of SDUM (Fig 4) displays the main menu, where the user has access to all software features and a shortcut menu, through which the user has access to create projects, to insert the border of fields and data of samples, thematic maps generation and MZs delineation. At the center of the main page, the georeferenced data are displayed. In the left side, there are variables that are being used and on the right side the metadata. The data import was performed through files in ".txt" format, organized in columns separated by semicolons (;), comma (,), tab (TAB) or pipe (|). The default file format for the outline of the areas corresponds to two columns, indicating the coordinates of the points that delimit the area in the format "Longitude and Latitude" (Datum default is WGS84). For the sample data, the files must contain a further column with the variable data.

Selecting variables to create management zones

To select the variables that should be used to delineate the MZs, the spatial correlation matrix is generated (Fig 5), which must be evaluated by the user to define which variables must be used. The matrix presents bivariate spatial autocorrelation statistics of Moran's between each variable, including the data of the main diagonal, allowing evaluation of the spatial autocorrelation of the variables. In this study, we configured the significance test (default 0.05 or 5%) and the number of iterations (999 permutations) before the generation of spatial correlation matrix. There were sample grids with number of samples and distinct placements, considering a variable as standard. Therefore, momentarily grids similar to samples were created and the mismatched points interpolated by inverse distance considering ten neighbors. The mismatched points to the standard grid are eliminated after the creation of the new grid to perform the statistical calculation.

Initially, the slope, density, macroporosity, OM, microporosity, SPR_10_20, SPR_20_30 and silt were discharged since they did not present spatial autocorrelation. There were also eliminated the variables clay and total_porosity due to the fact of not having spatial correlation with the yield. The variables elevation, sand and SPR_0_10 were previously selected in descending order regarding the correlation level with the yield. Since the variable sand presented spatial correlation with elevation, it was also discarded. The variables then were used as an input parameter to delineate the MZs.

Creating thematic maps

After the variables elevation and SPR_0_10 were selected, thematic maps were generated (Fig 6 and 7), using the interpolation of inverse-distance weighting. The software allows the user to adjust the settings for generation of thematic maps, such as the pixel size (longitude and latitude), the radius of coverage or number of neighbors, and also allows grids to be generated from polygons or points.

Creating management zones

To create the MZs, the SDUM allows the use of empirical methods (normalization by the average or standard deviation) and clustering methods (making use of the K-Means and Fuzzy C-Means algorithms). As the variables have different metric units, the SDUM performs data normalization by the range method (Equation 1; Mielke and Berry, 2007).

$$P_{in} = \frac{P_i - Median}{Range} \quad (1)$$

Where; P_i is the value of the pixel i to be normalized and P_{in} is the value obtained as result of the normalization of P_i .

After the procedures for MZs delineation are executed, the SDUM generates thematic maps (Fig 8), containing the divisions performed by the used methodologies. The MZs are represented in different colors, aiming to visual identification.

The best statistical results reported for VR, FPI and MPE corresponded to division into two MZs, since the highest VR (42.5%) and lowest FPI (0.0988) and MPE (0.0198) were obtained. In addition, we verified that when two MZs were generated, the ANOVA indicated distinct yield potential for each zone (Fig 9).

Software availability

The SDUM can be freely downloaded on [www.ppat.com.br](http://www.ppat.com.br/projects/menu), projects menu (Software: <http://ppat.md.utfpr.edu.br/sdum/sdum-vm.ova>). The same menu allows the download of the booklet about the software, explaining all functions. The user can choose the language (English, Portuguese or Spanish) selecting the System menu.

The SDUM was developed using Java language and PlpgSQL with PostgreSQL database and Postgis extension. For convenience, the software was installed and configured in a virtual machine (.ova file) and the user just need import and run this file. A dataset is available in the virtual machine (c:/sdum/Data) and can be used as example.

In evaluation of the optimal number of clusters, SDUM provides the possibility of three different evaluation indexes: 1. Variance Reduction – VR (Xiang et al., 2007):

$$VR = 1 - \frac{\sum_{i=1}^n W_i * V_{um_i}}{V_{field}} * 100 \quad (2)$$

Where; n – sample size for the entire area; W_i – proportion of the area on each management unit; V_{um_i} – data variance of each management unit; V_{field} – variance of the data sample for the whole field;

2. Fuzzyperformance index– FPI (Fridgen et al., 2004):

$$FPI = 1 - \frac{c}{(c-1)} \left[1 - \sum_{j=1}^n \sum_{i=1}^c (u_{ij})^2 / n \right] \quad (3)$$

Where; c – number of clusters; n – sample size for the whole area (number of observations); u_{ij} – element ij of the relevance Fuzzy matrix.

3. Modified partition entropy index– MPE (Fridgen et al., 2004):

$$MPE = \frac{-\sum_{j=1}^n \sum_{i=1}^c u_{ij} \log(u_{ij})/n}{\log c} \quad (4)$$

Where; n – number of clusters; N – sample size for the whole area (number of observations); u_{ij} – element ij of the relevance Fuzzy matrix.

It is important to note that both the FPI and the MPE are statistics obtained from the clustering process of Fuzzy C-Means and is presented only when used this algorithm to perform the management zone division. In assessing the quality of the clustering process, the ANOVA and the smoothness index can be used.

Conclusion

The methodology implemented in the software and used for generation and evaluation of MZs was suitable for the used data set. This method has already been used with satisfactory results by other authors in several crops, indicating that the tool has a great potential to be explored with different data types and crops and can be used to define places with environment and distinct crop potentials in the same field. In this sense, in each place of the field, different management and inputs can be adopted, reducing the environment impact and increasing the yield. The software SDUM showed to be a suitable environment for delineation of management zones (MZs), considering that it allowed to managed fields and sample data, generated thematic maps and MZs in an organized and straightforward way to perform. The structure for management and analysis of data in precision agriculture showed to be adequate from a methodological point of view, considering that it allowed managing fields and sample data, generating thematic maps and MZs in an organized and easy way to perform. The SDUM provides a multiplatform interface since it had been developed in Java, and is available in 3 languages (English, Portuguese and Spanish) for free. These options are attractive making this software to be used not only by researchers but also by farmers, increasing the use of precision agriculture technology.

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