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Delineation of management zones in an apple orchard in Greece using a multivariate approach

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ABSTRACT

Management zone (MZ) delineation is important for the application of Precision Agriculture because farm management decisions are based on it. Several factors were used for the MZ delineation including crop and soil characteristics. In the present paper multivariate analysis was applied to delineate MZs. Soil and crop data, collected over 3 years from a Precision Agriculture project in an apple orchard in Greece, were used. The collected data were categorized in three groups, namely soil properties, yield and fruit quality. All data were analyzed for descriptive statistics and their distribution. Maps of the spatial variability for the 3 years were presented. Data were jointly analyzed for management zone delineation using a combination of multivariate geostatistics with a non-parametric clustering approach, and the orchard was divided in four zones which could be differently managed. However, further research and experimentation are needed before precision horticulture being confidently adopted in Greece.

1. Introduction

Apple is the fourth among the most important tree crops in Greece after olive, citrus and peach (Vasilakakis, 2007). Greek apple orchards are commonly uniformly managed by applying fertilizers and other inputs at the same rate, without taking into account crop and soil variability of the field. Although Greek apple orchards are generally small in size, they show significant spatial and temporal variability in yield, fruit quality and physical and chemical soil properties (Aggelopoulou et al., 2010, 2011). Precision Agriculture (PA) or site-specific management (SSM) of apple orchards could increase yield, improve fruit quality to meet fruit market's requirements, and reduce environmental pollution, caused by an over application of agrochemicals.

An effective way to manage variability is through delineation of management zones (MZs), which are defined as regions or subareas of a field differentiated from the rest for the purpose of receiving individual management (Kitchen et al., 2005). Each zone presents similar properties and should receive the appropriate level of inputs (seed, fertilizer, pesticide, and water), according to the actual plant requirements and soil properties. Management zones can also be used for targeted soil sampling (MacMillan et al., 1998) and for associating production with soil and landscape data in calibration of crop growth models (Fraisse et al., 2001a).

Precision Agriculture application starts from data collection in the field. Several types of data can be collected, such us yield, topography, physical and chemical soil properties, bare soil aerial images, vegetation indices, crop properties, being analyzed to produce thematic maps. Management zones can then be created by using part of the collected properties or by jointly processing all gathered information for a field. Yield data were commonly used in many studies for management zone delineation (Blackmore et al., 2003; Diker et al., 2004; Ping and Dobermann, 2003; Dobermann et al., 2003). Vrindts et al. (2005) created management zones based on association of soil compaction with yield and crop data; Lark and Stafford (1997) used elevation data to delineate management zones; Fleming et al. (2000) created management zones based on soil color, using aerial images of bare soil and the farmer's experience. Many researchers used soil apparent electrical conductivity (EC_a) (Kitchen et al., 1999, 2003; Perry et al., 2007; Johnson et al., 2003; Morari et al., 2009), while Sudduth et al. (1996) and Fraisse et al. (2001b) used a combination of topographic and EC_a data. Long et al. (1994) compared different data (soil maps, aerial photos) and concluded that using aerial photos of developing crops was the best method to create management zones and predict yield.

Precision Agriculture applications in tree crops are rather limited in the literature. Zaman and Schuman (2006) produced nutrient management zones in a citrus crop, based on variation of soil properties and tree performance. Mann et al. (2010) created productivity zones using fruit yield, ultrasonically measured tree

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canopy volume, normalized difference vegetation index (NDVI), elevation and apparent electrical conductivity. In olive trees, Lopez-Granados et al. (2004) created site-specific fertilization maps based on leaf nutrient spatial variability and Fountas et al. (2010) delineated management zones for fertilization, using soil chemical properties. Aggelopoulou et al. (2010) produced fertilization maps for apple trees, based on the amount of nutrients that were removed from the soil with the previous year yield.

Whatever the type of data used, both soil and crop properties are equally important in site-specific management and it needs also to take into account the temporal effects of crop season on spatial variation in yield. However, there are various ways in which orchard classification can be carried out. Cluster analysis procedures have been effectively used to divide a field into potential management zones (Stafford et al., 1998). This methodology groups similar individuals into distinct classes called "clusters" in the N-dimensional character space, defined by the N properties measured for each individual (Irvin et al., 1997; Lark, 1998). At present several algorithm options exist but no unified theory is widely accepted. The Iterative Self-Organizing Data Analysis Technique (ISODATA) (Tou and Gonzalez, 1974) is one of the most widely used unsupervised clustering algorithms, that iteratively groups the data points by minimizing the Euclidean distance (ESRI, 1994). To characterize each class by mean vectors and a covariance matrix, ISODATA requires each variable in the data set to exhibit a Gaussian distribution and all data to have similar variances (Fraisse et al., 2001b).

However, existing traditional clustering techniques are aimed at gaining insight into inherent structure of the data and producing natural groupings of the data only in the character space, without any reference to geographical position. According to this paradigm, clusters are defined as discrete, non-overlapping multi-dimensional hypervolumes. These clusters are "crisp", because the cluster to which any individual is assigned is unambiguous and is linked, by a legend, to the centroid attributes and their standard deviations. At the boundaries of the clusters the observed differences in properties are expected to be greater than elsewhere, therefore most of total variation is represented by between-unit variation. Variation within the classes is still recognized but described as homogeneous and completely random. This approach does not account for spatial correlation between observations and takes little account of gradual change, either from one class to another or within any one class. The reason for this is that the variability of most properties is assumed to be less within – clusters than between – clusters. In most cultivated fields this model of spatial variation will be quite artificial, because soil and crop may vary gradually rather than abruptly, therefore in such conditions it is very difficult to unambiguously draw the borders of MZ. The application of fuzzy set theory (Burrough, 1989) to clustering algorithm has allowed researchers to better account for the continuous variability in natural phenomena. It may then be more realistic to consider any individual possibly bearing some similarity to more than one of the clusters. The degree of resemblance of an individual to a cluster is measured by its membership in the cluster. Of course, for practical reasons it may be necessary to assign each individual to a unique class using the one of maximum membership, a process called "defuzzification" (Guastaferro et al., 2010).

Moreover, many properties in an agricultural field may show spatial dependence over many scales, therefore geostatistics is preferred to describe spatial variation. According to geostatistical paradigm any soil or crop attribute is considered as a random regionalized variable, varying continuously, and its gradual geographical variation is described by a spatial covariance function. In geostatistical applications classes are unnecessary, nevertheless in precision farming it may be sound to divide the field in a restricted number of practical management zones. Therefore a clustering algorithm, that is also spatially constrained in order to ensure spatial contiguity, is needed. Most current clustering methods (Sarle, 1982), as the previously described, based on least-squares criterion are biased, because they tend to find clusters with roughly the same number of observations or equal variance. Such methods generally produce compact, roughly hyperspherical clusters and are incapable of detecting clusters with highly elongated or irregular shapes. Conversely, the methods based on nonparametric density estimation are the ones with the least bias (Silverman, 1986; Scott, 1992). According to such an approach, a cluster is defined as a region surrounding a local maximum of probability density function or a connected set of local maxima and, given a large enough sample, clusters of unequal size and dispersion and with highly irregular shapes can be detected. The utility of density estimation in Precision Agriculture derives firstly from the possibility to extend the concept of continuous variation from geographical space to attribute space to delineate management zones (Castrignanò et al., 2006).

The objectives of the work presented in this paper were: (1) to study spatial variability of soil, yield and fruit quality in an apple orchard over three consecutive years and (2) use multivariate analysis as a tool to delineate management zones.

2. Materials and methods

2.1. Study area

The present study was carried out in the Agia area (22°35′33″E, 39°40′28″N and 160 m above sea level) of central Greece, in a 5-ha apple orchard over the years 2005, 2006 and 2007. The main variety was Red Chief and the pollinator was Golden Delicious. The tree spacing was 3.5 m × 2 m and the trees were trained as free palmette.

2.2. Soil properties measurements

To assess the variability of some soil physical and chemical properties, 20 soil samples were taken at two sampling depths, 0–0.30 m and 0.30–0.60 m in the orchard in December 2005, before winter crop fertilization. The sample positions were recorded using a hand-held computer equipped with GPS (Trimble, model Trimble pathfinder, Sunnyvale, CA). The samples were air-dried, passed through a 2 mm sieve and analyzed for the following properties: soil texture (% sand, % silt and % clay), pH, nitrate nitrogen (NO_3–N), ammonium nitrogen (NH_4–N), phosphorus (P), exchangeable calcium (Ca), exchangeable sodium (Na), exchangeable potassium (K), exchangeable magnesium (Mg), available iron (Fe), available zinc (Zn), available manganese (Mn), available copper (Cu) and organic matter (OM) content. Soil texture was measured with Bouyoukos densimeter; soil pH was determined in a 1:1 water solution (McLean, 1982); for the determination of NO_3–N and NH_4–N, 1:1 and 1:5 soil/water extracts (McLean, 1982) were analyzed using Ion Chromatography (DIONEX, model DIONEX ICS-1500, Sunnyvale, CA); P concentration by Olsen method (Olsen and Sommers, 1982); exchangeable K, Na, Ca and Mg by ammonium acetate (CH_3COONH_4) method; available Fe, Zn, Mn and Cu by atomic absorption spectrometry and OM content by Walkley–Black method (Nelson and Sommers, 1982).

Apparent electrical conductivity (EC_a) was measured up to two depths (0–0.30 m and 0–0.90 m) by using a Veris machine (Veris Technologies Inc., model Veris 3100, Salina, KS), pulled through the field at a speed of 7 km h^{-1} onparallel transects with a 7-m line spacing, while data were recorded every 1 s. The EC_a data were georeferenced using a GPS connected to the recording unit.