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Delineating vineyard zones by fuzzy K-means algorithm based on grape sampling variables

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ABSTRACT

This study describes a method for delineating management zones using interpolated maps of grape characteristics recorded in 2013 and 2014 in a Godello vineyard located in the Bierzo Denomination of Origin (León, Northwest Spain). Ten variables were analyzed and recorded for the sampled vines (50 vines/ha). Interpolated maps reflecting each variable and year were created by spatial interpolation (kriging) from the sampled points. Principal component analysis was used to detect relationships between variables and to select the variables to be used to create the cluster classification. Using the fuzzy k-means classification algorithm implemented in the Management Zone Analyst (MZA v.1.0.0) software, several zones were delineated by combining the studied variables. The results delineated 2 different management areas composed of 3 zones each based on winery objectives: (1) to increase grape production (combining the yield for 2013 and 2014); and (2) to improve grape composition (combining the pH for 2013 and 2014).

1. Introduction

Grape production and quality are not even within the same parcel. Moreover, the spatial variability of the variables that define grape production and quality are not stable between campaigns, although the distribution pattern tends to remain the same (Arnó et al., 2011). One approach to optimize production goals is to delineate homogeneous blocks for separate management (Proffitt et al., 2006). The use of different management zones means better management of cropping practices, including segregated harvests and the establishment of monitoring points (Santesteban et al., 2010). The management zoning approach is usually used in vineyards in Australia, Chile, New Zealand, South Africa and the USA. For Australian vineyards, Bramley and Hamilton (2004) identified zones with similar yield characteristics, and Bramley (2005) identified zones based on maturation and quality variables. For Chilean vineyards, Esser and Ortega (2002) delineated homogeneous zones according to soil characteristics and related these with grape composition, production and vigor variables. In USA, California, Johnson et al. (2001) delineated management zones according to vine vigor. In Spain, Arnó et al. (2005) related yield maps with leaf petiole composition, and González-Fernández et al. (2016) identified homogeneous zones on the basis of a combination of grape composition, production and vigor variables.

Delineating zones with similar characteristics requires an understanding of the spatial stability of the variables that define final grape characteristics (Keller, 2015), such as grape composition and production (Cortell et al., 2005). Grape composition is usually defined by total soluble solids (TSS), which estimates the probable alcohol content of the wine (Alburquerque et al., 2007). pH and titratable acidity (TA) define the acidity of grapes and the organoleptic characteristics of a wine (Blouin and Guimberteau, 2003). Production variables like yield (Y), Mean weight of one cluster calculated from the ratio Y/number of clusters (CW) and the weight of a sample of 100 berries (BW) depict the productive potential of a vineyard. The inverse relationship between grape composition and production variables has been widely documented (González-Fernández et al., 2012). At maturity, grape size

Abbreviations: TA, titratable acidity(kg m^{-3}); BW, weigh of 100 berries(kg 10^{-3}); MI, maturity index(TSS TA^{-1}); CW, cluster weight(kg 10^{-3}); PW, shoot pruning weight(kg $10^{-3}m^{-1}$); RI, Ravaz index (Y PW^{-1}); TSS, total soluble solids(ºBrix); WS, weight of shoots(kg 10^{-3}); Y, yield (kg $10^{-3}m^{-1}$)

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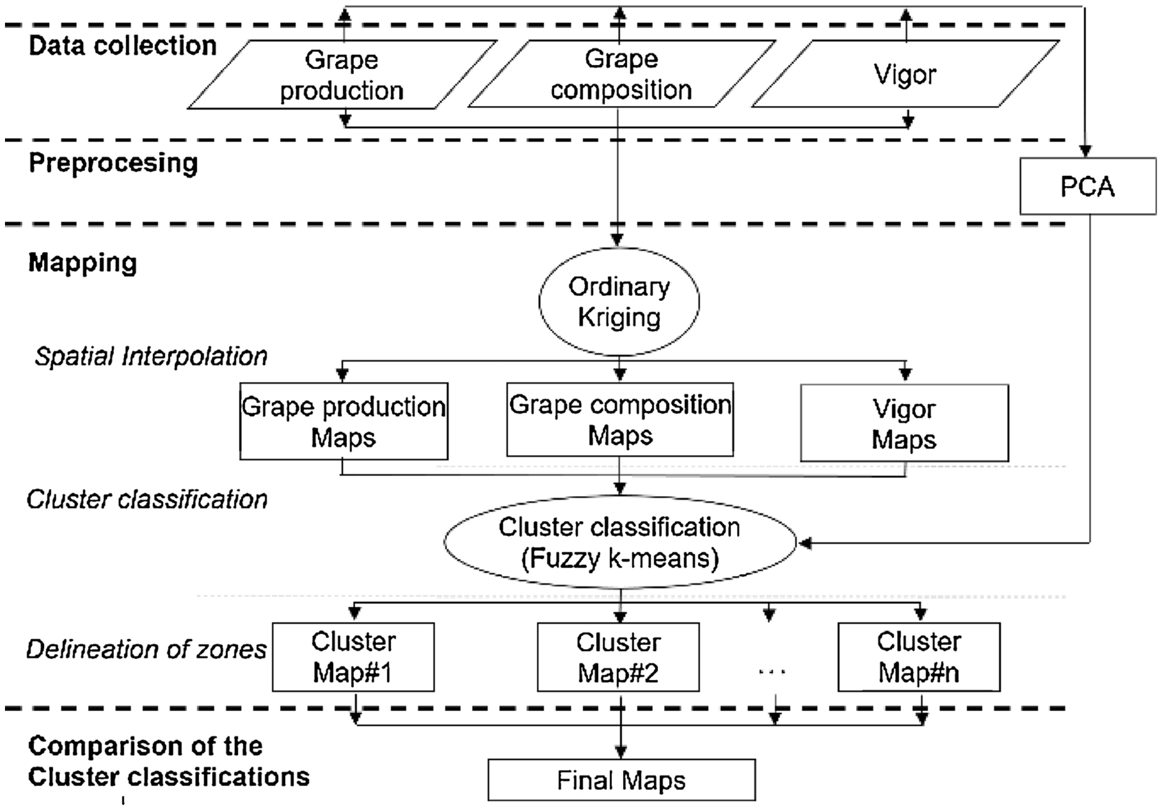

Fig. 1. Flowchart of the most suitable variables for delineating zones identified by the fuzzy k-means algorithm.

increases due to water accumulation in the berry; however, if water accumulation is excessive, the concentrations of the components that determine quality drop, although the quantities remain the same (Walker et al., 2005). Production variables are directly related to vine vigor variables like mean shoot weight (WS) and total pruning weight (PW). Production variables are directly related to vine vigor variables like mean shoot weight (WS) and total pruning weight (PW). To produce quality wine, some authors (Cortell et al., 2005) recommend ensuring vine balance, estimated using the Ravaz index (RI), which is the ratio between Y and PW (Ravaz, 1911). The recommended RI range is between 4 and 10 (Champagnol, 1984).

For financial and practical reasons, determination all variables related to production and quality for all vines in a vineyard is not possible. One solution is to select a sample of vines from a plot and interpolate the data to the whole area. Goovaerts (1999) indicated that the value of a variable studied in 2 different locations will be more similar for nearer locations. Of several interpolation techniques available (inverse distance, triangulation, etc.), kriging is widely used because it considers data variability from the variogram and usually results in lower error than other techniques (Brooker, 1986).

Several multivariate analysis methods are available to delineate management zones. A useful tool for delineating management zones is cluster classification analysis, which classifies individual data into different classes (clusters). The individuals belonging to each homogeneous cluster are grouped according to proximity criteria defined by a distance function (Urretavizcaya et al., 2014). One of the most widely used cluster algorithms is fuzzy k-means, which groups data into k classes whose centroid reflects the minimum Euclidean distance from each data point (Tagarakis et al., 2013). In a study of management zone delineation according to yield, Arnó et al. (2011) compared the k-means and fuzzy k-means algorithms, concluding that fuzzy k-means led to more compact and balanced zones over time. Baluja et al. (2013) used fuzzy k-means classification to identify management zones for the production of different types of Spanish wines. For a study of Greek vineyards, with yield and grape composition as the reference variables, Tagarakis et al. (2013) used fuzzy k-means to delineate homogeneous blocks according to the vegetation index and soil characteristics. Urretavizcaya et al. (2014) used fuzzy k-means to investigate the importance of early berry sampling in defining management zones.

Our aim was to optimize the management of the plot by delineating management zones according to grape composition, production and vigor variables using the fuzzy k-means algorithm. The novelty of this study in relation to previous studies is that input are grape composition and production variables using variables measured by winegrowers that do not require specific additional variables for delineation.

2. Materials and methods

2.1. Study site and experimental layout

The study was conducted in a vineyard cv. Godello (rootstock SO4: *Vitis berlandieri* and *Vitis riparia*) measuring 22,704.3 m^2, located in the Bierzo Denomination of Origin (León, Northwest Spain; 42.606 N, 6.692 W (WGS84)). The vineyard, planted in 1992 in a 1.1 m x 3.0 m pattern, is formed of bilateral cordons and vertical shoots positioned with 2 pairs of wires. Cultivation practices (weed control, fertilization, tillage, phytosanitary treatments, etc.) are the same for the whole plot.

To create the management zones, 50 vines/ha were sampled by choosing 1 line in 5 and 1 vine in 10 in each line. Each sampled vine was geo-referenced using a centimeter-precision Topcon Hiper + GPS receiver (Topcon Corporation, Tokyo, Japan) with real-time kinematic correction. The vineyards were sampled in 2013 and 2014 in order to characterize grape composition, production and vine vigor variables.

2.2. Workflow

The methodology involved 3 main steps: (1) data collection (physical and chemical analyses of grape composition, production and vine