G Model
AGWAT-4663; No. of Pages 8
ARTICLE IN PRESS
Agricultural Water Management xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Agricultural Water Management
journal homepage: www.elsevier.com/locate/agwat

Discrimination of irrigation water management effects in pergola trellis system vineyards using a vegetation and soil index

J.J. Cancela*, M. Fandiño, B.J. Rey, J. Dafonte, X.P. González

GI-1716, Department of Agroforestry Engineering, University of Santiago de Compostela, Campus Universitario, 27002 Lugo, Spain

ARTICLE INFO

Article history:
Received 30 June 2016
Received in revised form 24 October 2016
Accepted 4 November 2016
Available online xxx

Keywords:
Apparent electrical conductivity
NDVI
Soil water content
Stem water potential
Precision viticulture

ABSTRACT

This research aims to test the discrimination of homogenized areas in traditional Galician vineyards of *Vitis vinifera* (L.) cv. Albariño, using a vegetation index and soil electrical conductivity and their relations with plant and soil measures (stem water potential and soil water content) and productivity and quality parameters. The study was conducted in a 4.8 ha commercial vineyard (*Vitis vinifera* L., cv. Albariño) located in Galicia (Spain). The trellis system was 'emparrado', typical in this region, at 1.8 m in elevation; the vines were trained to quadrilateral cordons leaving 6–8 buds per spur. Several irrigation treatments – irrigation from flowering to harvest and irrigation from budburst to harvest- were conducted during the 2015 season, where a rainfed treatment was used as the control. Images acquisition – R, G and NIR bands – was developed in veraison using an unmanned aerial vehicle. Moreover, apparent electrical conductivity (EC_a) was measured in winter using a soil electrical conductivity metre (EM38) in a horizontal dipole. Soil water content measurements during veraison showed statistical significance differences between irrigation treatments (p-value = 0.014) but none in the stem water potential (p-value = 0.19). No significant differences were observed for production parameters. However, random forest models allowed a good estimation of stem water potential and quality parameters using topographic, soil and plant variables. NDVI details analysed, using a spherical buffer showed significant differences between treatments, especially for minimum and average NDVI pixel values. The process applied showed the capacity to discriminate between different quality grapes areas in a pergola trellis vineyards. This allows to winegrowers to have a selected vintage for several wine purposes as well as, a tool for irrigation management.

1. Introduction

Climate conditions have an important influence on crop management, mainly in relation to crop water requirements. Humid and temperate regions are increasing their use of irrigation practices due to the effects of the heterogeneity in climate in recent years (higher evapotranspiration demand and irregular precipitation distribution) (Trigo-Córdoba et al., 2015). Irrigation management is directly related to soil and plant within-field variability and to final purpose for winemakers (Arnó et al., 2009). Precision viticulture required information about spatial variability of soil properties, vegetative growth and topographic data (Morari et al., 2009; Rossi et al., 2013) to achieve similar status areas within plots in which to apply a differential practices management. Vineyard water status is a key aspect to reach a control about yield and quality parameters (Urretavizcaya et al., 2016) and is linked to irrigation system management. Stem and leaf water potential, in several day times, was used for monitoring, controlling and managing irrigation with good correlations with soil and plant water status (Cancela et al., 2015) and with the vegetation index (Williams and Araujo, 2002, Rodríguez-Pérez et al., 2007).

Advances in the acquisition of multispectral images with a remote piloted aircraft (RPA) has allowed development studies to determine the relationship between vineyard water status and different vegetation indexes (Baluja et al., 2012; Pôças et al., 2015), and using multispectral images (Rodríguez-Pérez et al., 2007), has allowed the zoning of vineyards (Bellvert et al., 2012). The normalized difference vegetation index (NDVI) is one of the most employed, and presents contradictory results between studies.

Soil characteristics are the main component in the 'terroir' concept applied in viticulture. To evaluate within field variability, classical techniques of sample and analysis need great effort (time and labour) and are high in cost, making it impossible to achieve good results (Morari et al., 2009). For this reason, the electrical conductivity (EC) is the property that has a material to transmit or conduct electrical current, and could be used as the overall

* Corresponding author.
E-mail address: javierjose.cancela@usc.es (J.J. Cancela).

http://dx.doi.org/10.1016/j.agwat.2016.11.003
0378-3774/© 2016 Elsevier B.V. All rights reserved.

soil parameter. The apparent soil electrical conductivity (EC_a) is a measurement of the bulk electrical conductivity of the soil and is influenced by various factors such as soil porosity, concentration of dissolved electrolytes, texture, quantity and composition of colloids, organic matter, and water content in the soil (Rhoades et al., 1976). Recent research found that apparent soil electrical conductivity, using electromagnetic sensors, can be used at field scales to map the spatial variation of several edaphic properties. These include soil salinity, clay content or depth to clay-rich layers, soil water content, the depth of flood deposited sands, and organic matter. In addition, EC_a has been used at field scales to determine a variety of anthropogenic properties: leaching fraction, irrigation and drainage patterns, and compaction patterns due to farm machinery (Corwin and Lesch, 2005). In summary, it is widely accepted that the main factors that influence EC_a in non-saline soils are soil texture, SWC, and cation exchange capacity (Sudduth et al., 2001). Thus, measurements of apparent soil electrical conductivity (EC_a) can be used to define specific management zones.

Several authors have used apparent soil electrical conductivity (EC_a) to characterize vineyards (Morari et al., 2009, Fulton et al., 2011, Priori et al., 2013, Rossi et al., 2013, Tagarakis et al., 2013, Urretavizcaya et al., 2016), and the two main methods for measuring soil EC_a are electromagnetic induction and direct contact.

Tree based methods for regression involve stratifying or segmenting the predictor space into a number of simple regions (James et al., 2013). Random forests (Breiman, 2001) are an ensemble learning algorithm that can be used for classification, that is predicting a categorical response variable. They can also be used for regression that involves predicting a continuous response variable. Random forest involves producing multiple trees that are then combined to yield a single consensus prediction. A large number of trees can often result in dramatic improvements in prediction accuracy (James et al., 2013). A random forest method was used for regression in an agricultural field (i.e., Everingham et al., 2016).

Combining all the issues previously mentioned (climate and crop management, precision viticulture, soil water status, leaf water potential, apparent soil electrical conductivity, and regression tree based methods), it is a novelty in vineyard discrimination of soil, plant and must quality aspects to pergola trellis system.

The objectives of this study were: (a) to evaluate irrigation effects on production and quality parameters; (b) to provide tools for discriminatory irrigation treatments to cv 'Albariño' conducted in a pergola trellis system using multispectral images; and (c) to achieve the best regression methodology that allows for predicting critical parameters for irrigation management and quality parameters. The main objective is to develop a methodology that permits winegrowers to know within-field variability using topographic, vegetation index and soil parameters, obtained with geophysical methods and to develop a selected harvest according to the winery strategy in their wine production.

2. Materials and methods

2.1. Site description

The experiment was carried out during the 2015 growing season in an 'Albariño' vineyard planted in 1999 on 110-Richter at a spacing of 4 × 3 m (1667 vines ha^{-1}) with 4.8 ha in total. The vineyard is located in O Rosal (Pontevedra, NW Spain) within the Rías Baixas DO (41° 56′ 19" N, 8° 49′ 09" W, average elevation 54 m), with a slight slope of 5.8%. The trellis system was pergola ('emparrado', typical in this region) at 1.8 m in elevation; the vines were trained to quadrilateral cordons leaving 6–8 buds per spur, oriented in the NE-SW direction. The soil depth was 1.0 m, which presented a sandy-loam texture, with an available water capacity of 190 mm m^{-1}, which was determined using minimum and maximum values of soil water content, achieved during several years of previous studies in the same plot. Vineyard floor vegetation was cut several times during the growing season, both in row and in line of vines.

2.2. Experimental design and irrigation treatments

Three treatments were established using complete rows per repetition, with seven vineyards studied per row in a transect (Fig. 1). The treatments were rainfed (RA) (two rows), drip irrigation (DI) from pre-flowering to harvest (DI-H) (eight rows) and drip irrigation from flowering to harvest (DI-I) (eight rows) (Fig. 1). Both irrigation seasons are managed using the Baggiolini phenological scale (Baggiolini, 1952), where H corresponds with separate flower buds and I with complete flowering. The DI pipes were in the vineyard row at 1.8 cm above the soil, with one emitter of 2.1 L h^{-1} per vine. The irrigation management was established applying water from Monday to Saturday, from 15th May to 30th August in DI-H, and from 1st June to 30th August in DI-I. Average daily irrigation depth was 0.41 mm, usually applied 1 h per day in the morning. Depth irrigation was determined with reference evapotranspiration (ET_o), calculated as referred by Allen et al. (1998) using data from an agro-meteorological station, property of the winery, and the average crop coefficient (K_c) 0.65 achieved by Fandiño et al. (2012) to rainfed conditions in a near site and for the same cultivar and practice management. The total irrigation depth was 34 and 30 mm in DI-H and DI-I, respectively. During these seasons, the number of irrigation events was 83 and 73 for DI-H and DI-I, respectively. Irrigation and climate data are included in the Supplementary material for better understanding (Fig. S1).

2.3. Growing season measurements: soil, plant, yield, must and pruning weight parameters

During the growing season phenological stages (Baggiolini, 1952) were observed to trigger the irrigation system, as referred above. From May to harvest in 2015 and in February 2016, the soil water content (SWC) was monitored with a TDR100 (Campbell Scientific), which operates in the field using PCTDR software with a flexible connector (Souto et al., 2008). Observations were performed at a 60 cm depth. The equation of Topp et al. (1980) relating the volumetric water content (θ) with the measured bulk dielectric constant (ε_{eff}) was used since it has proven successful in soils that do not contain substantial amounts of bound water, e.g., most sandy and loamy soils (Robinson et al., 2003). This equipment was used for 9 days of measuring, about one measurement every two weeks. The number of measurements per treatment and date was RA: 6, DI-H: 23 and DI-I: 16.

Measurements of midday stem water potential (ψ_{stem}) were carried out with a Scholander pressure chamber (PMS Model 600, Albany, OR, USA) (Scholander et al., 1965). Leaf sampling and measuring were done considering the precautions suggested in Martínez et al. (2013). Midday ψ_{stem} were performed every two weeks, and these measurements were carried out on healthy mature leaves from the middle third of the shoots, all of them at similar growth stages and with no alterations and exposed to direct solar radiation in 6, 24 and 18 plants in RA, DI-H and DI-I, respectively. For determining the ψ_{stem}, leaves were previously covered with a plastic bag and aluminium foil 1 h prior to the measurement (Williams and Araujo, 2002).

Harvest was done on September 9th. Measurements of the number of bunch per vine, average weight per vine and yield per vine were taken (RA: 14, DI-H and DI-I: 56 vines). Moreover, berry samples per treatment were crushed with a small hand press to determine basic parameters of must: Total soluble solids (TSS), pH, titratable acidity and key metal compounds (potassium, calcium,