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PRECISION VITICULTURE TOOLS TO PRODUCTION OF HIGH QUALITY GRAPES

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Abstract

Grapes are the most widely grown commercial fruit crop in the world, and also one of the most popular fruit crops for horticultural production. Grape growers constantly search the ways in order to maximize their profits all over the world. It becomes to be important to use new information technologies to increase to overall returns. Precision Viticulture (PV) refers to the application of new and emerging information technologies to the production of grapes to improve the efficacy of production, maximize the quality of production, minimize the environmental footprint of production and minimize the risk associated with production for the grower and processer. Precision viticulture depends on new and emerging technologies such as global positioning systems (GPS), meteorological and other environmental sensors, satellite and airborne remote sensing, and geographic information systems (GIS) to assess and respond to variability. It can be possible that take under control such as soil fertility, fertilizer application norm, disease, water, weed, harvesting, and environmental management by precision viticulture systems in vineyard. So, to reduce inputs such as fertilizer, water, pesticides and to increase yield and quality of grape berries, we must to increase precision technologies in our vineyards. In this review, Precision Viticulture tools will be demonstrated to producing of high quality grapes. Finally, this study will also help grape growers and government agencies that provide new information and technologies such as Remote Sensing to growers in order to detect some factors affecting to maximize grape production.

Key words: *Geographical Information Systems, Grape, Precision Viticulture, Remote Sensing, Vineyard Management.*

INTRODUCTION

Precision viticulture is precision farming applied to optimize vineyard performance, maximizing grape yield and quality while minimizing environmental impacts and risk (Proffitt et al., 2006; Urretavizcaya et al., 2017). This is accomplished by measuring local variation in factors that influence grape yield and quality (soil, topography, microclimate, vine health, etc.) and applying appropriate viticulture management practices (trellis design, pruning, fertilizer application, irrigation, timing of harvest) (Bramley and Hamilton, 2004; Bramley, 2005).

Among the benefits of precision viticulture reduction of fertilizer costs, reduction of pesticide application costs, minimization of environmental pollution, increase of product yield, more accurate information management due to more efficient information production, operating records required for sales and after sales production periods.

Precision viticulture is based on the premise that high in-field variability for factors that affect vine growth and grape ripening warrants intensive management customized according to local conditions. Precision viticulture depends on new and emerging technologies such as global positioning systems (GPS), meteorological and other environmental sensors, satellite and airborne remote sensing, and geographic information systems (GIS) to assess and respond to variability (Matese and Di Gennaro, 2015).

Several authors have studied precision viticulture in different countries (Bramley et al., 2000; Bramley et al., 2003; Bramley, 2001; Bramley and Williams, 2001; Bramley and Lamb, 2003; Bramley and Hamilton, 2004, 2007; Taylor, 2004; Tisseyre et al., 2001; Arno et al., 2005; Arno, 2008; Penn, 1999; Carothers, 2000; Aho, 2002; Matese and Di Gennaro, 2015).

Vineyards are characterized by a high heterogeneity due to structural factors such as the morphological characteristics, and other dynamics such as cropping practices and seasonal weather (Bramley, 2003).

This variability causes different vine physiological response, with direct consequences on grape quality (Smart, 1985). Vineyards therefore require a specific agronomic management to satisfy the real needs of the crop, in relation to the spatial variability within the vineyard (Proffit et al., 2006). The introduction of new technologies for supporting vineyard management allows the efficiency and quality of production to be improved and, at the same time, reduces the environmental impact.

This paper presents a review of applications used in precision viticulture to production of high quality grapes.

Precision Viticulture Applications

Precision viticulture is still relatively new in that yield monitoring technology for wine grapes has only been commercially available in Australia since the 1000 vintage, and there is still only one brand of grape yield monitor on the market (although at least three others are currently under development). Nevertheless, this technology, along with other tools such as different global positioning systems (dGPS) and geographical information systems (GIS), promotes the capacity for grape and wine producers to acquire detailed geo-referenced information about vineyard performance and to start using this to tailor production of both grapes and wine according to expectations of vineyard performance, and desired goals in terms of both yield, quality and the environment (Figure 2) (Bramley and Proffitt, 1999 and 2000).

Viticulture precision process (Figure 1) begins with yield mapping and the acquisition of complementary information followed by interpretation and evaluation of the information leading to implementation of targeted management. This is followed by further observation. The process of data acquisition and use is therefore continuous, and improvements to management, incremental. Over time, data collected during the observation stage take on a predictive value (Bramley, 2001; Arno et al., 2017).

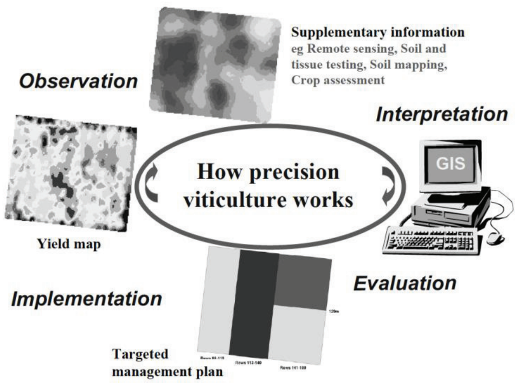

Figure 1. The process of precision viticulture (Bramley, 2001)

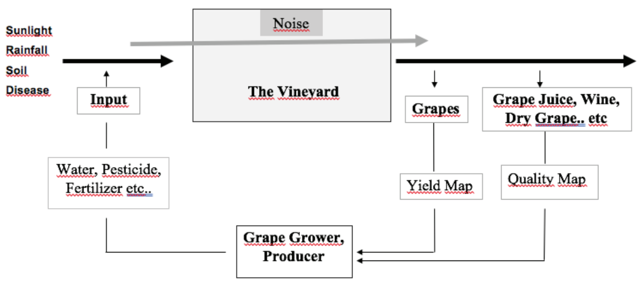

Figure 2. Viticulture input and output process

Nowadays different precision viticulture applications have helped grape growers to produce high quality grapes (Goldammer, 2015).

Terroir Management

Precision agriculture suitability to improve vineyard terroir management (Bouma, 2015). The tools of Precision Viticulture enable both growers, winemakers and researchers to see that terroir may vary within vineyards. Indeed, vineyards producing wines that are deemed characteristic of a region, may in fact be capable of producing contrasting wines from different areas within the same management units (Bramley and Hamilton, 2007).

According to Urretavizcaya et al. (2017) the early definition of within vineyard zones combining NDVI, ECa and BN data was successful, since the zones delineated allowed a differentiation of grape batches with different characteristics at harvest. Interestingly, the inclusion of a variable related to sink size (in this case the number of bunches per plant) provided the most efficient classification, which makes its consideration highly advisable for any PV work aimed at zone delineation for grape quality estimation.

Canopy Management

Canopy and vigor monitoring is the area of greatest adoption by the growers and the wineries for several reasons. It is possible to get timely, high-resolution information during the growing period, which may be relevant for canopy management, fertilization, and irrigation.

Arno et al. (2017) studied mapping the leaf area index (LAI) by using mobile terrestrial laser scanners (MTLS) is of significance for viticulture. Three different row length sections of 0.5, 1, and 2 m have been tested. Data analysis has shown that models required to estimate LAI differ significantly depending on the scanned length of the row; the model required to estimate LAI for short sections (0.5 m) is different from that required for longer sections (1 and 2 m).

According to Luo et al. (2016), grapes are likely to have collisions and be damaged by manipulations when harvesting grape clusters. For this reason, to conduct an undamaged robotic harvesting, they attempted locating the spatial coordinates of the cutting points on a peduncle of grape clusters for the end-effector and determining the bounding volume of the grape clusters for the motion planner of the manipulator using binocular stereo vision. As a result of the study, they found that cutting point detection success rate was approximately 87% and this method that it could be used on harvesting robots.

According to Berenstein et al. (2010) while much of modern agriculture is based on mass mechanized production, advances in sensing and manipulation technologies may facilitate precision autonomous operations that could improve crop yield and quality while saving energy, reducing manpower, and being environmentally friendly. They focused on autonomous spraying in vineyards and presented four machine vision algorithms that facilitate selective spraying. Researchers tested all image-processing algorithms on data from movies acquired in vineyards during the growing season. Results showed that 90% accuracy of grape cluster detection leading to 30% reduction in the use of pesticides (Gatti, et al., 2009; Goldammer, 2015).

Tang et al. (2016) conducted a study on non-productive vine canopy estimation through proximal and remote sensing. They asserted that non-productive canopy detection in a vinicultural block is a key factor in reducing the drain on infrastructure and improving management practices and current methods are significant in cost, biased, and do not provide information on location of non-productive canopy. Researchers announced that results indicate the success of semi-supervised method in providing a useful measure of non-productive canopy at the phenological stage of veraison; laying the groundwork for improved methods in this area. They also stated that these methods provide practical outputs that lay the foundations for improving management decisions in an automatic and low-cost manner at different times in the season.

Reis et al. (2012) states that one of the most demanding tasks in wine making is harvesting, even for humans, the environment makes grape detection difficult, especially when the grapes and leaves have a similar color, which is generally the case for white grapes. In this reason, they proposed a system for the detection and location, in the natural environment, of bunches of grapes in color images. In this study, they stated that system is able to distinguish between white and red grapes, and at the same time, it calculates the location of the bunch stem. They also reported that system achieved 97% and 91% correct classifications for red and white grapes, respectively.

Escola et al. (2013) developed and tested an orchard sprayer prototype that running a variable-rate algorithm to adapt the volume application rate to the canopy volume in orchards on a real-time. They divided prototype was into three parts: the canopy characterization system (using a LiDAR sensor), the controller executing a variable-rate algorithm, and the actuators. As a result, they observed a strong relationship between the intended and the sprayed flow rates (R^2 = 0.935) and between the canopy cross-sectional areas and the sprayed flow rates (R^2 = 0.926). In addition, they state that when spraying in variable-rate mode, the prototype achieved significantly closer application coefficient values to the objective than those obtained in conventional spraying application mode.

Gil et al. (2013) announced that the structural characteristics of the canopy are a key consideration for improving the efficiency of the spray application process for tree crops. However, they state that obtaining accurate data in an easy, practical, and efficient way is an important problem to be solved. Researchers developed and tested a sprayer prototype for the suspension plant for this purpose. They electronically measured variations in canopy width along the row crop using several ultrasonic sensors placed on the sprayer and used to modify the emitted flow rate from the nozzles in real time; the objective during this process is to maintain the sprayed volume per unit canopy volume. As a result, they estimated that 21.9% less pesticides could be used compared to traditional pesticide applications. In addition, they announced that this result is in accordance with the results of similar research on automated spraying systems.

Llorens et al. (2010) compared two different spray application methods during different crop stages of three vine varieties. A conventional spray application with a constant volume rate per unit ground area was compared with a variable rate application method designed to compensate electronically for measured variations in canopy dimensions. An air-blast sprayer with individual multi-nozzle spouts was fitted with three ultrasonic sensors and three electro valves on one side, in order to modify the emitted flow rate of the nozzles according to the variability of canopy dimensions in real time. As a result, they obtained the better leaf deposits and 58% saving in application volume with variable rate method.

Crop Load Monitoring

Crop load management in vineyards is important for the consistent production of both quality fruit and mature wood. “Crop load” is the ratio of exposed leaf area to fresh fruit weight. Too much leaf area promotes shading and reduces fruit quality and sometimes bud fruitfulness. Too little leaf area per unit of fruit delays ripening and reduces vine size. Measures of crop load are useful to growers in evaluating success of vineyard management practices. The Ravaz index which uses the ratio of yield to pruning weight to estimate crop load is one common metric (Figure 3).

Research into PV is still in its infancy, and to date relatively little has been published in this field. Current and future research into PA (PV) have many of different priorities: environmental economics, production quality assessment methods and new technologies for crop monitoring (Arno et al., 2009).

In the context of precision viticulture, remote sensing in the optical domain offers a potential way to map crop structure characteristics, such as vegetation cover fraction, row orientation or leaf area index, that are later used in decision support tools. Weiss and Baret (2017) studied to Using 3D Point Clouds Derived from UAV RGB Imagery to Describe Vineyard 3D Macro-Structure.

Figure 3. (A) Spectron. (B) Multiplex hand device sensors for grape quality proximal monitoring, which allows quality maps to be realized (Matese and Di Gennaro, 2015)

Berry Quality Management

The NDVI image is an excellent tool to design quality, sampling zones based upon the NDVI classifications.
Source to sink size ratio, i.e.: the relative abundance of photosynthetically active organs (leaves) with regards to photosynthate demanding organs (mainly bunches), is widely known to be one of the main drivers of grape oenological quality. However, due to the difficulty of remote sink size estimation, Precision Viticulture (PV) has been mainly based on within-field zone delineation using vegetation indices. This approach has given only moderately satisfactory results for discriminating zones with differential quality. Urretavizcaya et al. (2017) investigate an approach to delineate within-vineyard quality zones that includes an estimator of sink size in the data-set. Zone delineation was performed using Normalized Difference Vegetation Index (NDVI), soil apparent electrical conductivity (ECa) and bunch number (BN) data.
Irrespective of the seasonal factors which affect the mean concentration of berry rotundone, variation in the land (soil, topography) underlying the vineyard is a consistent driver of within-vineyard variation in this important grape-derived flavour and aroma compound (Bramley et al., 2017).

Harvest Management

The proper ripening of grapes is the key to obtain a high-quality wine and another grape product. Ripening is a temporal process that is influenced, in addition to uncontrollable climate factors, by the spatial distribution of the vineyard and planted variety. It is a complex process that cannot be characterized by a single parameter; rather, it is a modification of the profile of the compounds of the grape. Melendez et al. (2015) analyzed the joint evolution of twelve physicochemical parameters determined in red grapes from four different varieties, in sixteen representatives (in both geographical and edaphic point of view) plots belonging to the Qualified Designation of Origin (DOC) Rioja. Samples were collected in September 2009 during four consecutive weeks prior to harvest.

Disease Management

Disease from insects, pathogens, and other infectious organisms can become a serious problem. In some cases, disease development on grapevines occur rapidly and results in entire vineyards incurring injury to various degrees. For example, grapevines are susceptible to powdery mildew infection early in the growing season. Patricia et al. (2009) studied to field monitoring for grapevine leafroll virus and mealybug in pacific northwest vineyards.
Oberti et al. (2014) conducted a study on the automatic detection of powdery mildew on grapevine leaves by image analysis. They announced that powdery mildew is a major fungal disease for grapevine (*Vitis vinifera* L.) as well as for other important specialty crops, causing severe damage, including yield loss and depreciation of wine or produce quality. According to researchers proximal optical sensing is a major candidate for becoming the preferred technique for identification of foci for powdery mildew in grapevine and other specialty crops, but detection sensitivity of symptoms in the early-middle stage can yield largely limited results due to the combination of small dimensions, low density, and spatial arrangement of thin fungal structures. They processed multi-spectral images from different angles of vine leaves under laboratory conditions. As a result, researchers found that detection sensitivity generally increases as the view angle is increased, with a peak value obtained for images acquired at 60°.
Oberti et al. (2016) developed an agricultural robot equipped with a new precision-spraying end-effector with an integrated disease-sensing system based on R-G-NIR multispectral imaging. Researchers tested the robotic system

on four different replicates of grapevine canopy plots prepared in a greenhouse setup by aligning potted plants exhibiting different levels of disease. They announced that the results indicated that the robot could automatically detect and spray from 85% to 100% of the diseased area within the canopy and to reduce the pesticide use from 65% to 85% when compared to a conventional homogeneous spraying of the canopy.

Water Management

With water becoming a more scarce and managed commodity, better management is required. Most vineyard blocks do not have the same water requirements due to differences in soil type and topography within the same vineyard. Irrigation systems have been developed that can apply the correct amount of water where it is needed.

Vineyard water status is a key aspect to reach a control about yield and quality parameters 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 and with the vegetation index (Cancela et al., 2017).

Thermal imaging can become a readily usable tool for crop agricultural water management, since it allows a quick determination of canopy surface temperature that, as linked to transpiration, can give an idea of crop water status. In the last years, the resolution of thermal imaging systems has increased and its weight decreased, fostering their implementation on Unmanned Aerial Vehicles (UAV) for civil and agricultural engineering purposes. This approach would overcome most of the limitations of on site thermal imaging, allowing mapping plant water status at either field or farm scale, taking thus into account the naturally existing or artificially induced variability at those scales. Santesteban et al. (2017) studied to evaluate to which extent high-resolution thermal imaging allows evaluating the instantaneous and seasonal variability of water status within a vineyard. The information provided by thermal images proved to be relevant at a seasonal scale as well, although it did not match seasonal trends in water status but mimicked other physiological processes occurring during ripening. Therefore, if a picture of variations in water status is required, it would be necessary to acquire thermal images at several dates along the summer.

Cancela et al. (2017) studied to test the discrimination of homogenized areas in traditional Galician vineyards of *Vitis vinifera* (L) cv. Albarifio, 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.

Environmental Monitoring

Manually monitoring environmental parameters (e.g., humidity, temperature, soil moisture etc.) in the vineyard is not only time consuming but difficult to respond to in a timely manner when conditions change rapidly over space and time. Wireless sensor networks (WSNs), have been found to be suitable for collecting real time data for different parameters pertaining to weather, crop, and soil in developing solutions for vinicultural processes related to growing grapes. The development of wireless sensor applications in viticulture has made it possible to increase efficiency, productivity, and profitability of vineyard operations (Goldammer, 2015).

Wireless Sensor Networks

Wireless Sensor Networks (WSNs) have existed for many years and had assimilated many interesting innovations. Advances in electronics, radio transceivers, processes of IC manufacturing and development of algorithms for operation of such networks now enable creating energy-efficient devices that provide practical levels of performance and a sufficient number of features (Dziadak et al., 2016).

Wireless sensor networks deployed in vineyards is used for monitoring site conditions such as temperature, wind speed, wind direction, rainfall, solar-radiation, relative humidity, soil-moisture, soil-temperature, sap flow, and leaf wetness, for management decision making purposes. For example, Wireless sensor networks is used in the following applications:

A wireless sensor network for precision viticulture (Figure 4): The NAV (Network Avanzato per il Vigneto – Advanced Vineyard Network) system is a wireless sensor network designed and developed with the aim of remote real-time monitoring and collecting of micrometeorological parameters in a vineyard. The system includes a base agrometeorological station (Master Unit) and a series of peripheral wireless nodes (Slave Units) located in the vineyard. The Master Unit is a typical single point monitoring station placed outside the vineyard in a representative site to collect agrometeorological data. It utilizes a wireless technology for data communication and transmission with the Slave Units and remote central server (Matese et al., 2009).

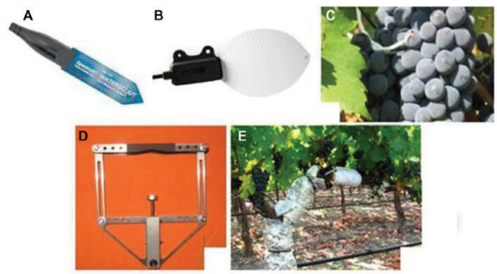

Figure 4. Some sensors employed in wireless sensor networks for proximal sensing in vineyards. (A) Soil moisture (Spectrum Technologies Aurora, IL, USA). (B) Leaf wetness (Decagon Devices Inc. Pullman, WA, USA). (C) Grape temperature. (D) Dendrometer (GMR Strumenti SAS Scandicci, Italy). (E) Sap Flow (Fruition Sciences Inc., Montpellier, France) (Matese and Di Gennaro, 2015).

Normalized Difference Vegetation Index

Agricultural remote sensing products are frequently based on so-called spectral vegetation indices (SVIs), formed as various combinations of visible and near-infrared (NIR) spectral channels of digital imagery. SVIs are radiometric variables that are useful for mapping relative variations in canopy density. One common SVI is the normalised difference vegetation index (NDVI), formulated as (NIR-red)/(NIR+red). Many commercial wine grape growers in coastal California are now using NDVI imagery, generally acquired at maximum foliar expansion, to delineate management zones, identify problems, and re-develop properties. Agricultural remote sensing products are frequently based on so-called spectral vegetation indices (SVIs), formed as various combinations of visible and near-infrared (NIR) spectral channels of digital imagery. SVIs are radiometric variables that are useful for mapping relative variations in canopy density. One common SVI is the normalised difference vegetation index (NDVI), formulated as (NIR-red)/ (NIR+red). Many commercial wine grape growers in coastal California are now using NDVI imagery, generally acquired at maximum foliar expansion, to delineate management zones, identify problems, and re-develop properties (Johnson, 2003).

By measuring the health and vigor of vegetation, NDVI can help vineyard managers fine-tune irrigation patterns. NDVI is directly related to the amount of photosynthetically active radiation that a plant may absorb (Kavak et al., 2014).

Soil Mapping

Soil electrical conductivity (EC) has been widely used to interpret soil spatial variability. Initially used to assess soil salinity, the use of EC in soil studies has expanded to include: mapping soil types; characterizing soil water content and flow patterns; assessing variations in soil texture, compaction, organic matter content, and pH; and determining the depth to subsurface horizons, stratigraphic layers or bedrock, among other uses. Variation of conductivity across soil types is the one of the main advantages of using this technology.

Weed Control

Typical vineyards may be infested by up to 20 weed species, of which three or four are dominant in terms of number of plants and land area covered. The distribution of weed species across a vineyard is “patchy” in nature. Some areas will be densely populated by weed while others will have few or no weeds. Densely populated patches often occur along vineyard edges, but may be found anywhere in the vineyard where the environment and management have favored the establishment and survival of weeds. The composition of weed species varies across a vineyard, and different patches may be dominated by different species. In addition to weed density varying spatially in a vineyard, it also may vary temporally and can be strongly influenced by weather (Goldammer, 2015).

Yield Monitoring

Grape yield maps are of fundamental importance for the development of PV (Arno et al., 2009). Yield monitoring refers to the "on-the-go" collection of both yield and positional data by the yield monitor and DGPS as the harvester travels along. The output in the form of yield maps allows growers and wine producers the ability to identify areas of different crop yield, and in some cases, different fruit quality attributes, within individual vineyard blocks. Yield maps do not require ground trothing since they represent actual as opposed to surrogate measures. Ground trothing is the process of gathering data in the vineyard that either complements or disputes remote sensing data collected by aerial photography or satellite (Gatti et al., 2009).

Kicherer et al.(2017) studied automatic image-based determination of pruning mass as a determinant for yield potential in grapevine management and breeding. Researchers calculated the mass of dormant pruning wood with the assistance of an automated image-based method for estimating the pixel area of dormant pruning wood. The evaluation of digital images in combination with depth map calculation and image segmentation is a new and non-invasive tool for objective data acquisition.

According to Aquino et al. (2015) one of the main challenges being faced by the scientific community in viticulture is early yield prediction. They have announced that flowering as well as fruit set assessment is of special interest since these two physiological processes highly influence grapevine yield. In addition, reported that an accurate fruit set evaluation can only be performed by means of flower counting. For this purpose, they presented a new methodology for segmenting inflorescence grapevine flowers in digital images. Thus, they found that values for Precision and Recall were 83.38% and 85.01%, respectively.

CONCLUSIONS

Precision viticulture is very new technology in Turkey. Hoverer, recently, precision viticulture has been received much attention in vineyard in the developed country. Different precision viticulture applications have been using and helped grape growers to produce high quality grapes. Precision viticulture depends on new and emerging technologies such as global positioning systems (GPS), meteorological and other environmental sensors, satellite and airborne remote sensing, and geographic information systems (GIS) to assess and respond to variability. It can be possible that take under control such as soil fertility, fertilizer application norm, disease, water, weed, harvesting, and environmental management by precision viticulture systems in vineyard. So, to reduce inputs such as fertilizer, water, pesticides and to increase yield and quality of grape berries, we must to increase precision technologies in our vineyards.

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