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Precision viticulture: Tool for production of quality grape

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Abstract
Precision farming is a important tool for promoting sustainable agriculture. The integration of new technologies in vineyard management enhances production efficiency and quality while minimizing environmental impact. Advances in information and geographic sciences offer substantial potential for developing optimized solutions in distributed information systems for precision viticulture. Recent technological progress has resulted in valuable tools for monitoring and controlling various aspects of vine growth. Precision viticulture aims to leverage a wide array of observations to accurately depict spatial variations within vineyards and provide recommendations to enhance management efficiency concerning quality, yield, and sustainability. This review provides a concise overview on various technologies used in precision viticulture, divided into two main sections: monitoring technologies such as geolocation and remote/proximal sensing, and variable-rate technologies including new agricultural robots.

Keywords: Precision viticulture, grape, remote sensing, proximal sensing, variable-rate technology

Introduction

Precision agriculture (PA), a relatively new discipline in agronomy developed in the mid-1980s, has been listed among the top ten developments in agriculture in recent decades (Santesteban, 2017) [38]. PA includes a wide range of techniques and technologies aimed at adapting crop management to field spatial variability. In view of the fact that the main characteristics of a crop production environment, such as water and nutrients, often vary considerably over space and time within a single agricultural area, it is necessary. It is therefore necessary to make management decisions taking into account these changes in order to meet the crop requirements properly. Precision viticulture (PV) corresponds to a part of the PA devoted to vineyard management.

It is also important to distinguish between precision viticulture and digital viticulture. Precision viticulture has a specific application in viticulture derived from precision agriculture (Buss *et al*., 2005) [12]. The more accepted PA definition is as follows: precision agriculture is a management strategy that gathers, processes, and analyzes temporal, spatial, and individual data and combine it with other information to support management decision according to estimated variability for improved resource use efficiency, productivity, quality, profitability, and sustainability of agricultural production (Matese and Di Gennaro, 2015) [30]. In general, PA focuses on the implementation of technological advances in the assessment of spatial and temporal differences within a field. These technologies can assess soil–plant–atmosphere conditions using different approaches, including wireless sensor networks Bramley and Hamilton, 2004 [8]. These proximal sensors can be in direct contact with the soil (soil moisture/salinity sensors), based on the plant trunk (e.g., sap flow sensors, dendrometers, acoustic sensors), at the canopy level (i.e., leaf temperature, psychrometry, and leaf wetness) or within the environment. Most of these proximal and contact sensor technologies offer high temporal resolution data that can be used to assess grapevine growth, water status, irrigation requirements, pest and disease detection, among others (Bramley, 2003; Bramley, 2005) [6, 7]. Precision viticulture optimizes vineyard performance, maximizes grape yield and quality and minimizes environmental impacts and risks. This can be achieved by measuring local variations in factors affecting the yield and quality of grapes (soil,

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topography, microclimate, vine health, etc.) and using appropriate viticulture management practices (trellis design, pruning, fertilizer application, irrigation, harvest timing).

Vineyards are characterized by a high degree of heterogeneity due to structural factors, such as morphological characteristics, as well as other factors such as cultivation practices and seasonal weather. This variability causes a different physiological response of the vine, which directly affects the quality of the grapes. Therefore, a specific agronomic management is required to satisfy the real needs of the crop in relation to spatial variability within the vineyard (Ozdemir *et al*., 2017) [32]. The introduction of new technologies aimed at supporting vineyard management makes it possible to improve the efficiency and quality of production and to reduce environmental impacts.

Objectives of precision farming in grape

1. **Economic Aspect**

- Optimizing production efficiency
- Optimizing quality
- Minimizing financial risk
- Maximize gross margin

2. **Social Aspect**

- Healthy and safety food
- Saving a natural resources
- Reduction of pollution and improving living conditions
- Educational importance for rural areas

3. **Environmental Aspect**

- Minimizing environmental
- Optimal input quantities
- Reduction of pollution

Steps in the precision farming process

1. Assessing variation
2. Managing variation and
3. Evaluation

With the help of the available tools, we can manage the unpredictability that makes precision horticulture practical by providing site-specific agronomic suggestions. Finally, evaluation is a crucial component of every precision farming system. The detailed steps involved in each process are clearly depicted as fallows

Assessing variability

The crucial first step in precision farming is assessing variability. Since it is obvious that one cannot control what they do not know. There are numerous variables that affect crop performance in terms of yield over time and space. The challenge for precision farming is quantifying the variability of these factors and processes and figuring out when and where different combinations are accountable for the spatial and temporal variation in crop yield. Techniques for assessing spatial variability are readily available and have been applied extensively in precision agriculture. Assessing spatial variability is a key component of precision agriculture. There are methods for evaluating temporal variability as well, but the simultaneous reporting a spatial and temporal variation is rare. Both the spatial and the temporal statistics are necessary. We can observe the variation in yield of a crop in space but we cannot predict the reasons for the variation. It requires observations of crop growth and development over the course of the growing season, which is nothing but the temporal variation. To implement precision farming techniques, we therefore require both the space statistics and the time statistics.

Managing variability

Once variation is adequately assessed, farmers must match agronomic inputs to known conditions employing management recommendations. They are site-specific and employ precise application control technology. We can use the technology most effectively. In site-specific variability management we can utilize GPS instrument, so that the site specificity is pronounced and control will be easy and affordable. We must record the sample location coordinates while taking soil or plant samples so that we can use them later for management. This leads to the efficient utilization of inputs and the avoidance of waste, which is what we want.

Steps in Managing the variability

a) Precision Soil Fertility Management
b) Precision Pest Management
c) Crop Management
d) Water Management
e) Soil Management

Evaluation

There are three important issues regarding precision agriculture evaluation
Economics
Environment
Technology transfer

Economics: The most important fact regarding the analysis of profitability of precision agriculture is that the value comes from the application of the data and not from the use of the technology.

Environment: Precision agriculture is frequently advocated for because of potential improvements in environmental quality. Decreased usage of agrochemicals, higher nutrient use efficiencies, increased efficiency of managed inputs, and increased soil yield from deterioration are frequently cited as potential benefits to the environment. Enabling technologies can make precision agriculture feasible, agronomic principles and decision rules can make it applicable and enhanced production efficiency or other forms of value can make it profitable.

Technology transfer: The phrase "technology transfer" may indicate that precision agriculture happens when individuals or firms simply acquire and use the enabling technologies. While using enabling technologies and agronomic principles in precision agriculture does include managing spatial and temporal variability, the essential word here is manage. Much of the attention in what is called technology transfer has focused on how to communicate with the farmer. These issues associated with the managerial capability of the operator, the spatial distribution of infrastructure and the compatibility of technology to individual farms will change radically as precision agriculture continues to develop.

According to numerous prior studies, generally, the implementation of precision agriculture (PA) has shown to increase profits across different crops and with various technologies adopted (Schimmelpfennig and Ebel, 2016; Sumiahadi *et al*., 2019).

There are numerous proven benefits of precision agriculture, which can be summarized as follows.

- Improve crop Yield
- Identification of plant stress
- Constant monitoring of crops with the possibility to implement targeted actions.
- Reduction of intra-field variability
- Lower the environmental impact of agricultural operations
- Give information to make better management decisions.
- Reduction of costs and time of agricultural operations;
- Almost no useful crop production resources are wasted since each must be used specifically according to the needs of the production system.
- Optimization of the use of fertilizers, pesticides and water
- Increase of products quality.

Major constraint in implementation of Precision Farming under Indian Conditions

- Small-scale farming
- Diversity in cropping system
- Obtaining data particular to a site is very expensive
- High initial investment
- Lack of local technical expertise
- Tools and Techniques are complicated, require new skill
- Culture, attitude of farmers including resistance to adoption of new technologies and lack of awareness of environmental problems
- India's farmers need evidence of the effects of precision farming on yields because it is a new concept.
- Uncertainty around the potential returns from investments in new machinery and information management systems

Component of precision farming

Global Positioning System (GPS)

Global Positioning System as a satellite-based radio navigation system which has a full set of at least 24 satellites orbiting the earth in a designed pattern maintained by the US Department of Defense (DoD). This system provides accurate 3 dimensional location data (latitude, longitude, and elevation) globally at any time, in any weather and for no charge with an accuracy of between 100 and 0.01 m. Development of these positioning systems is the main technological milestone, which made precision agriculture concept a reality. Precision farming is made possible by GPS technology since all stages require positional data. GPS is able to offer positioning in a useful and effective way. The precise location of field features, such as soil type, pest occurrence, weed invasion, water holes, boundaries, and impediments, can be found by farmers using GPS. Farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications, and yield mapping are all done with the use of GPS-based applications in precision farming. GPS allows farmers to work during low visibility field conditions such as rain, dust, fog, and darkness. System is not affected by wind.

Geographic Information System (GIS)

The GIS is an organized collection of computer hardware, software, geographical data, and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information. GIS is considered the brain of Precision Agriculture. Unlike traditional maps, computerized GIS maps have multiple layers of information (such as yield, soil survey maps, rainfall, crops, soil nutrient levels, and pests). Information on field topography, soil types, surface and subsurface drainage, irrigation, chemical application rates, soil testing, and crop production can all be found in a farming GIS database.

Sensor technologies

A range of technologies, including electromagnetic, conductivity, photoelectric, ultrasonic, and others, are employed to measure a variety of environmental parameters, including temperature, humidity, vegetation, texture, structure and physical character. Data from remote sensing is used to track drought, soil, and plant conditions, identify pests and weeds, and distinguish crop types (Di Gennaro *et al*., 2016) [17]. Sensors enable the collection of immense quantities of data without laboratory analysis.

Remote Sensing

It is a group of techniques used to gather data about land, water, object or region without coming into direct contact between the sensor and the subject of analysis. (Remote – Not in contact with an object and Sensing – Getting information). Remote sensing is a multidisciplinary field which encompasses a variety of scientific fields, including optics, spectroscopy, computer, satellite launching, photography and electronics. Remotely sensed data, obtained either by aircraft or satellite, containing electromagnetic emittance and reflectance data of crop can provide information useful for soil condition, plant growth, weed infestation etc. It is a valuable technology for precision agriculture because it can provide information on the field's parameters relatively easily. In general, we perceive the sun's reflected light, which is composed of infrared, red, green, and blue wavelengths as well as ultraviolet wave lengths. The green plants reflect the green and infrared waves while absorbing the red and blue waves (Hall *et al*., 2002) [21]. With multispectral cameras, we can measure the wavelengths that are reflected to determine the vigour of the plants or any problems like illness, nutrient deficiency, water logging, etc. We can relate the organic content, moisture, to the soil color (Hoff *et al*., 2017) [23].

Satellites

Satellites have played a vital role in precision farming for over four decades, starting with the launch of Landsat 1 in 1972. This satellite, equipped with a multispectral sensor, provided imagery with a spatial resolution of 80 meters per pixel and revisited locations approximately every 18 days. Subsequent to this, Landsat 5, launched in 1984, enhanced imaging capabilities by capturing data in multiple spectral bands including blue, green, red, near-infrared, and thermal, at a spatial resolution of 30 meters. The initial utilization of remote sensing in precision agriculture involved analyzing

Landsat imagery of exposed soil to discern spatial variations in soil organic matter content (Mulla, 2013) [31].

VRT

Precision viticulture employs VRT to differentiate agronomic management and dosage inputs in both time and location. Automation technologies are used by modern agricultural machinery to regulate movement in the vineyard, including speed, direction of travel, and steering angle as well as to handle agronomic managements. With this technique, prescription maps created for individual operations can be combined with position data acquired by a GPS module. The agronomic inputs will now be applied based on the actual demands of the vines, which are determined by the vineyard's heterogeneity, rather than in average amounts per hectare. This technology meets the current needs of the food industry, ensuring adequate productivity and profitability in the vineyard. The resulting benefits are a substantial reduction of the work and speeded-up operations. The guidance systems can reduce operating stress, while the VRT provides a rational use of agronomic inputs, with direct impact on costs, quality, and environmental sustainability.

Application of precision viticulture

Precision viticulture, together with other tools such as different global positioning systems (GPS) and geographical information systems (GIS), promotes the capacity of grape and wine producers to acquire detailed geo-referenced information about vineyard performance and to start using this information to tailor the production of both grapes and wine according to expectations of vineyard performance and desired objectives in terms of both yield, quality and environment (Ozdemir *et al*., 2017) [32]. The process of viticulture precision begins with the mapping of yields and the acquisition of complementary information, followed by the interpretation and evaluation of this information, which leads to the implementation of targeted management strategies. It is followed by further observation. As a result, the data acquisition and use process is continuous, and the management improvements are incremental (Arno *et al*., 2017) [3]. At present, various precision viticulture applications help grape growers to produce high-quality grapes (Goldammer, 2015) [19].

Terroir Management

Precision agriculture improves terroir management of vineyards (Bouma, 2015). Precision viticulture tools make it possible for growers, wine producers and researchers to understand that vineyard terroir may vary (Jose Maria *et al*., 2017) [24]. In fact, vineyards which produce wines characteristic of a particular region may be able to produce different wines from different areas within the same management unit (Bramley and Hamilton, 2007) [9]. Mobile platforms equipped with proximal soil sensors can be deployed across vineyards to gather geo-referenced soil data, enabling the creation of high-resolution maps that highlight spatial variations in soil properties and topography. This information is crucial for the establishment or redevelopment of vineyards, as noted by Bramley (2010) [10]. Recently, advancements have integrated electromagnetic induction sensors and multispectral imaging to assess variability in vineyard soil and vine vigor, as detailed by Hubbard *et al*. (2021) [22].

Canopy management

Canopy and vigour control are the areas where growers are mostly used for a number of reasons. It is possible to get timely and high-resolution information during the growing period, which may be relevant for canopy management, fertilization, and irrigation (Brunori *et al*., 2022). Remote and proximal sensing technologies have been extensively utilized to assess vine canopy growth and health in commercial vineyards, as highlighted by Darra *et al*. (2021) [16]. Portable fluorescence-based sensors are employed for evaluating leaf nitrogen levels and can be mounted on mobile platforms (Diago *et al*., 2016a) [18]. Additionally, light detection and ranging (LiDAR) technology has demonstrated its effectiveness in rapidly and non-destructively evaluating canopy and leaf characteristics in vineyards (Arno *et al*., 2013) [5]. Arno *et al*. (2017) [3] used mobile terrestrial laser scanners (MTLS) to study the significance of mapping the leaf area index (LAI) for viticulture. According to Luo *et al*. (2016) [27], when harvesting grape clusters, grapes are likely to collide and be damaged by manipulation, binocular stereo vision was used to locate the spatial coordinates of the cutting points on a peduncle of grape clusters for the end-effector and determine the bounding volume of the grape clusters for the motion planner of the manipulator to conduct undamaged robotic harvesting. The cutting-point detection success rate is approximately 87%, indicating that this method can be used on harvesting robots. In order to monitor vineyards, numerous methods have been created. These systems combine a GPS system for data georeferencing with a high-resolution screening of the canopy side across the row. Sensors is called GrapeSense (Lincoln Ventures Ltd, Hamilton, New Zealand), which measures the height and texture of the vines along the row by taking a high-frequency digital picture of the canopy side.

Water management

Given the increasing scarcity and regulation of water, improved management is essential. Variations in soil type and topography within vineyards mean that different blocks have varying water requirements. Advanced irrigation systems have been developed to precisely deliver water where it is needed. Monitoring vineyard water status is crucial for controlling yield and quality, and it directly influences irrigation management. Monitoring stem and leaf water potential at different times of the day has been effectively used to monitor, control, and manage irrigation, showing strong correlations with soil and plant water status as well as vegetation indices (Cancela *et al*., 2017) [13]. Thermal imaging has emerged as a practical tool for managing agricultural water use by providing rapid assessment of canopy surface temperature, which correlates with transpiration and indicates crop water status. Recently, thermal imaging systems have improved in resolution and decreased in weight, facilitating their integration onto Unmanned Aerial Vehicles (UAVs) for civil and agricultural engineering applications. This approach addresses many limitations of on-site thermal imaging by enabling the mapping of plant water status over large areas, accounting for natural or artificially induced variability at field or farm scales. Santesteban *et al*. (2017) [38] investigated the extent to which high-resolution thermal imaging enables the assessment of both instantaneous and seasonal variations in water status within a vineyard.

Disease and insect management

Grape cultivation in India is significantly threatened by various diseases and insect pests. Key fungal diseases include downy mildew, powdery mildew, and anthracnose, while major insect pests such as mealybugs and thrips lead to substantial economic losses. Downy mildew is particularly severe in several horticultural crops, including grapes. The effective management of pests hinges on the precise application of the correct pesticide, at the appropriate dosage, timing, and location. Remote sensing and monitoring technologies have revolutionized the identification of diseases and pests in vineyards, offering precise, swift, cost-effective, and reliable diagnostics compared to the time-consuming, subjective, risky, and expensive methods of visual inspection (Lee and Tardaguila, 2021) [26]. These advancements enable the mapping of pests and diseases across vineyards, facilitating targeted application of fungicides using Variable Rate Technology (VRT) (Chen *et al*., 2020) [14]. Gutierrez *et al*. (2021b) [20] utilized computer vision and deep learning techniques to successfully detect and distinguish between downy mildew and spider mite in commercial vineyards. Oberti *et al*. (2014) [33] researched the automated identification of powdery mildew on grapevine leaves through image analysis. They highlighted that powdery mildew constitutes a significant fungal threat to grapevines (*Vitis vinifera* L.) and other critical specialty crops, leading to substantial damage such as reduced yield and diminished quality of wine or produce. Oberti *et al*. (2016) [34] 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.

In India, the primary insect pests affecting grapes, ranked by economic impact, include mealybugs, thrips, flea beetles, leafhoppers, stem borers, and mites. Excessive pesticide use not only escalates cultivation costs but also poses environmental and human health risks. Therefore, effective pest management in viticulture should adopt an integrated approach encompassing optimal farming practices, advanced forecasting models, decision support systems (DSSs), biological controls, and judicious use of chemical sprays to minimize pesticide usage (Pertot *et al*., 2017) [37]. Chougule *et al*. (2019) [15] developed "PDMGrapes," a decision support system for grape crop protection in India's hot tropical regions, employing ontology, semantic web rule language, and image processing techniques to manage insect pests and diseases effectively.

Crop load monitoring

In order to ensure a uniform production of high-quality fruits and mature wood, it is necessary to manage the volume of crops in vineyard. “Crop load” is the ratio of the exposed leaf area to fresh fruit weight. A large quantity of leaves contributes to shading and reduces the quality of the fruit and, in some cases, the bud fruit. Too little leaf space per unit of fruit delays ripening and reduces the size of vines. Measurements of crop load are useful for growers to assess the success of vineyard management. The Ravaz index is a common metric used for estimating crop load according to the ratio of yield to pruning weight. Current and future research on precision viticulture has many different priorities, such as environmental economics, production quality assessment methods and new technologies for crop monitoring (Arno *et al*., 2009) [4].

Berry quality monitoring

NDVI image is an excellent tool for designing quality sampling zones based on NDVI classification. The source-to-sink size ratio, i.e. the relative abundance of photosynthetically active organs (leaves) relative to photosynthate-demanding organs (mainly bunches), is widely known to be one of the main drivers of grape oenological quality (Kavak *et al*., 2014) [25]. However, precision viticulture (PV) has been mainly based on within-field zone delineation using vegetation indices due to the difficulty of remote sink size estimation. This approach has given only moderately satisfactory results for discriminating zones with differential quality. Urretavizcaya *et al*. (2017) investigated an approach to delineate within-vineyard quality zones that included an estimator of sink size in the dataset set. We performed zone delineation using normalized difference vegetation index (NDVI), soil apparent electrical conductivity (ECa), and bunch number (BN) data.

Harvest management

During grape harvesting, the measurement of yield is commonly achieved by weighing berries as they pass over load cells integrated into mechanical harvesters (Taylor *et al*., 2015) [39]. Recently, computer vision systems have been employed to estimate grape yields based on factors such as cluster density (Palacios *et al*., 2019) [35], berry count per cluster (Aquino *et al*., 2018) [2], cluster weight (Liu *et al*., 2020b) [29], and berry size (Roscher *et al*., 2014). The proper ripening of grapes is the key to obtain a high-quality wine and another grape product. The spatial distribution of the vineyard and planted variety, in addition to uncontrollably occurring climate conditions, affects the ripening of grape. It is a multifaceted process that cannot be characterized by a single parameter; instead, the profile of the grape's components is altered (Aquino *et al*., 2015) [1]. Several Android-based applications, including vitisFlower® (Aquino *et al*., 2015) [1], vitisBerry® (Aquino *et al*., 2015) [1], and 3DBunch® (Liu *et al*., 2020a) [28], have been developed to measure parameters related to flowers, berries, and bunches. For large-scale commercial vineyards, mobile vehicles equipped with automatic RGB image capturing devices are utilized to capture images, and grape yield predictions are generated using computer vision technology (Palacios *et al*., 2020) [36].

Conclusion

Precision viticulture is a new technology in India. Hoverer, recently, precision viticulture has been received much attention in grape growing countries. Various applications of precision viticulture utilizing advanced technologies like GPS, meteorological sensors, satellite imagery, and GIS have assisted grape growers in enhancing grape quality. These technologies enable precise management of soil fertility, fertilizer application rates, disease control, water usage, weed management, harvesting, and environmental factors. Increasing the adoption of precision technologies in our vineyards can potentially reduce inputs such as fertilizers, water, and pesticides while boosting grape yield and quality.

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