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Review Paper

Current Approaches in Viticulture Mechanization

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Abstract

Viticulture, known as grape cultivation, has a rich history spanning thousands of years. Grapevine is one of the oldest fruit species cultivated in the world and is still one of the most basic agricultural activities today. Throughout the centuries, techniques in vineyard management have evolved following advances in technology and machinery. In recent years, especially the wine industry has been experiencing a significant transition to viticulture mechanization due to increasing productivity, cost reduction and the gradual decrease of skilled labour force. This transition allows cultural processes in vineyard cultivation to be carried out more effectively both in a timely manner and in accordance with its purpose. In addition, with the introduction of technology, this mode of production becomes more attractive for the young population, which tends to move away from agricultural activities. In this article, prominent mechanization applications in grape cultivation and current approaches on a global scale are examined.

Introduction

Viticulture is an important economic sector in global agriculture and a cultural heritage in many regions of the world. Additionally, it is a labor-intensive and demanding form of cultivation that requires significant effort throughout the entire production season. As vineyards are not annual, the operations carried out during the production season have an impact on the yield in subsequent years. Increasing production and quality in vineyards depend on various inputs such as the availability of high-yielding vine varieties, plantation of vineyard, soil cultivation, maintenance, fertilization, irrigation and pest control. Furthermore, it relies on the proper recognition and optimal use of agricultural tools, machinery, and tractors required by the vineyard technique (Uz et al., 1984; Uz, 1984; Eker et al., 1988). Mechanization techniques are being developed in many countries where viticulture is practiced. However, even with existing techniques, many producers still rely on manual labor and fail to fully benefit from available technologies. This situation leads to decreased productivity in vineyard areas.

Today, the need to manage large vineyards under increasingly limited labor conditions can only be met through mechanization. Hence, there is a growing need to engage in farming with fewer people, at a more affordable cost, and within the appropriate timeframe. The most labor-intensive tasks in vineyards are winter and summer pruning, as well as harvesting, and mechanization applications for these methods have garnered significant interest from researchers, machinery manufacturers and growers. As growers become accustomed to mechanqical harvesting and pruning, they have started seeking other methods to mechanize additional cultural operations such as leaf removal in shoot and fruit zones, cluster thinning and others.

The existing vineyard mechanization equipment reduces the need for seasonal manual labor for specific tasks but does not eliminate it entirely. The extent to which hand labor can be reduced depends on factors such as the region where cultivation takes place, the grape variety, and the number of cultural practices that the grower can perform (whether it's only harvesting or pruning and other practices as well). Additionally, vineyard mechanization relies heavily on informed decision-making, so growers require fewer but more skilled human resources for optimal vineyard management.

New and emerging technologies can play a critical role in the future of viticulture and winemaking. Climate change, increasing ambient temperatures, variability in precipitation, and the rise in climatic risks pose a threat to the future of viticulture and the wine industry. Moreover, the increase in climate anomalies such as floods, frost, and wildfires during the vegetation period directly affects grape yield and wine quality. Therefore, the use of Artificial Intelligences-supported technological applications is of great importance in reducing risk levels in the future of viticulture and winemaking.

Pruning, canopy management, and harvesting are increasingly performed by machines in grape production. The effectiveness of these practices significantly influences fruit yield and quality. Additionally, mechanization applications offer time savings, efficiency in work quality, and cost advantages in production.

The use of mechanization in grape cultivation has some other advantages besides product efficiency and time savings. With the applied techniques, it is possible to reduce the spread of disease in the vineyard and to increase the fruit quality with effective canopy management. Reducing the intensive labour force ensures occupational health and safety, and time and human resources are managed more effectively.

Mechanization Applications for Growing Technique

Soil cultivation is done for different purposes in the vineyards. The general purposes of tillage can be counted as increasing the water holding capacity of the soil, controlling weeds, ensuring that the precipitation is retained by the soil, mixing with the soil to obtain the necessary benefit from the fertilizer and facilitating other cultural processes. Microorganisms activate in the cultivated soil, breaking down organic materials, and increasing the fertility of the soil by creating the soil, water and air balance. In tillage, machines such as ploughs, cultivators, rotary plows and subsoilers can be used between rows. On the rows, soil cultivation is carried out at the by using vine-sensing machines.

For reasons such as protecting the environment, making production more economical, controlling erosion and maintaining moisture, it is becoming increasingly important to use conservative tillage methods, in which the soil is processed without overturning, instead of traditional tillage methods in viticulture. In this context, applications such as the use of secondary tillage tools such as cultivators in tearing the soil, and the cultivation of mulch plants between rows and laying them on the soil surface with grass conditioners can be considered in order to protect the physical, chemical and biological properties of the soil.

Weeds growing between rows in vineyards pose a major problem. While these weeds can be removed with grass mowers, it is possible to control them and increase the organic matter content of the soil, especially in recent years, by planting and growing annual or perennial cover crops between rows with suitable sowing machines.

In commercial vineyards where mechanization is used, many spraying applications are made during the vegetation period (Marucco et al., 2019). Intensive use of chemicals every year causes undesirable effects on grapes due to pesticide residues. In addition, when the sprayer is not adjusted properly during spraying applications on the vine, some of the applied chemical is lost before reaching the target (Biglia et al., 2022). This situation shows how important it is to use the sprayer in accordance with agro-technical demands in the vineyard, both in terms of environment and production efficiency.

Various researches are carried out in the world to make spraying more effective in viticulture. Among these research topics is the use of drones and unmanned aerial vehicles for agricultural spraying. The use of drones in the control of diseases and pests provides the advantage of reaching the vineyard quickly and performing the process in a short time, as well as eliminating the problems related to compaction of the soil or wrinkling of the plants. In addition, there is a risk of poisoning by the people who spray in the use of sprayers working with back or tractor. On the other hand, having a higher cost compared to ground equipment, low storage capacity, limited engine power, and short flight distances can be shown as disadvantages. These negativities can be eliminated with new designs (Ezin, 2021).

In cases where the need for frequent spraying arises in areas where grapes are grown and receive heavy rainfall, the oversaturation of the soil with water limits the opportunities for entry to the land and the work efficiency. In these cases, the use of drones provides significant advantages. However, unlike the effective use in field crops production, there is a need for more studies to increase the efficiency of use in the vineyard due to reasons such as the condition of the plant and the canopy structure.

In viticulture, it is necessary to keep the productivity of the vineyard soils at the highest level in order to obtain maximum and good quality products from the unit area. For this reason, in order to meet the nutrient needs of the vineyard soils, to increase the soil fertility or at least to maintain the current situation, it is necessary to meet the nutrients removed from the soil through fertilization. The machinery and equipment to be used for this purpose should be selected according to the fertilization method. Centrifugal mineral fertilizer spreading machines and underground fertilization machines are mostly used in fertilization.

Pruning is an important cultural process in vineyard management that has an impact on quality and plant health. Pruning, which has traditionally been a labor-intensive process, is greatly facilitated by mechanization. Automatic pruning systems precisely prune vines according to defined parameters using sensors and robotic arms. These machines can move between rows of grapes, identify suitable shoots for pruning and perform cuts with accuracy. Plant arrangement works such as leaf removal and shoot thinning can also be mechanized using special equipment. In this case, it provides better aeration, disease prevention and more effective use of daylight for the grapes.

Mechanical winter pruning is facilitated when done in high wire trellises with free-growing plant parts at the top of the cordon. Both cultivation systems, characterized by a self-supporting free canopy that does not involve the use of a fixed cord and support wires, are particularly suitable for winter pruning mechanization because the cutting bars are unobstructed and can work as close to the cord as possible (Allegro et al., 2022) .

In mechanical pruning it is possible to use different techniques like box pruning and pre-pruning (Figure 1) (Kurtural and Fidelibus, 2021).

A pruning robot was developed by Botterill et al (Botterill et al.,2017). This robot is a mobile platform. Images are taken with three cameras while on the move. The computer detection system creates a three-dimensional (3D) model of the vines, and the artificial intelligence (AI) system decides which branches to prune.

A pruner is shown in action at the vineyard at French Camp Vineyards, Santa Margarita, California (Figure 2). This configuration allows the tractor towed unit to trim the facing edges of adjacent rows (Morris,2008).

Figure 1. Examples of pruning machines A. Box pruning B. Pre-pruning

Figure 2. An example of a pruning machine

Harvest Mechanization

Harvesting in viticulture is one of the most challenging and timeliness processes. Unlike many fruits, grapes do not continue to ripen after being picked, so the grapes are harvested when they reach the desired level in terms of color, appearance, flavor and taste. In our country, harvesting is commonly done by hand using vineyard shears. Machine harvesting practices are more common in some developed countries, especially in wine grape growing (Figure 3).

In most countries where labor is scarce and expensive, mechanization is being adopted in vineyards. The adoption of this form of technology is extremely important for wines to compete in both domestic and international markets (Domingues and Aguila, 2016).

Over time, different types of harvesting machines have been developed. In the current technology, two separate systems are used that work by beating or shaking the grapevine. Both systems aim to selectively separate the clusters. The fruits are then collected on a conveyor passing by a blower that removes the leaves and transferred to a bin (Cristescu et al., 2019).

Mechanical harvesting of wine grapes was developed in the 1950s and extensively studied in the United States in the 1970s. The practice was widely accepted in Italy as early as 1980. The primitive technology of the first mechanical harvesters caused mechanical stress on the fruit and could not adequately remove material other than grapes during harvest. The amount of mechanical stress the grapes are subjected to during harvest depends on several factors, such as the degree of maturity and the general condition and health of the fruits at the time of harvest. Technologies in mechanical harvesting have improved over the last four decades, especially with the addition of sorting techniques to remove material other than grapes (Sun et al., 2022).

Precision Viticulture

The concept of precision agriculture, as a general approach, can be defined as giving the inputs needed by the plant in agricultural production at the lowest level and in the most effective way by making use of technological opportunities. With this type of agriculture, it is

Figure 3. A self-propelled harvester that works by biting into an apple (http://agriculture.newholland.com)

possible to contribute to environmental protection by obtaining higher yields from the unit area, making a more economical production and minimizing the use of chemical inputs.

Precision agriculture includes many information communication technologies such as Global Positioning System (GPS), Variable Rate Technologies (VRT), Geographic Information Systems (GIS), Remote Sensing Technologies (UAT), Yield Mapping Systems (VHS), electronic measurement and control systems (Arslanoğlu et al., 2016).

In viticulture, precision farming techniques are used to improve the efficient use of inputs, predict yields, selective harvesting of grape quality, and meet the actual needs of each plot in the vineyard. New technologies have been developed for vineyard management, monitoring and control of vine growth. Remote and proximal sensors are becoming reliable tools for revealing the general condition of vineyards, and they are essential to describe the spatial variability of vineyards in high resolution and to obtain recommendations for improving management efficiency (Sassu et al., 2021).

Remote sensing techniques quickly provide a description of the shape, size and vigor of the grapevine and allow for the assessment of variability within the vineyard. This is an image acquisition from a distance at different resolution scales, which can identify the bond by detecting and recording sunlight reflected from the surface of objects on the ground.

In proximal sensing applications, there are many equipment carried by moving vehicles for continuous measurements or devices for precise observations made by an operatör (Figure 3). With the help of these sensors, many plant and soil properties can be measured and monitored (Matese and Gennaro, 2015).

Climate change, water scarcity and the need for sustainable agricultural practices have increased the importance of precise irrigation and fertilization systems in viticulture. It is clear that smart irrigation contributes to improving water use efficiency, controlling vine growth vigor, and improving fruit composition (Chaves et al. 2007). In particular, the adoption of regulated restricted irrigation (RDI) strategies has been widely used to improve grain composition characteristics as well as water conservation strategy in red grape varieties (Bellvert et al., 2021). In precise fertilization, in the vineyard, as in other fruit types, giving fertilizer at variable rates with machines specially designed in accordance with the pre-determined needs in the parcel can provide both input savings and yield increases.

Conclusion

While the use of mechanization is more common in operations such as tillage, irrigation, fertilization and spraying in viticulture, human labor and small hand tools are mostly used in operations such as pruning and harvesting. The intensive use of human labor in viticulture

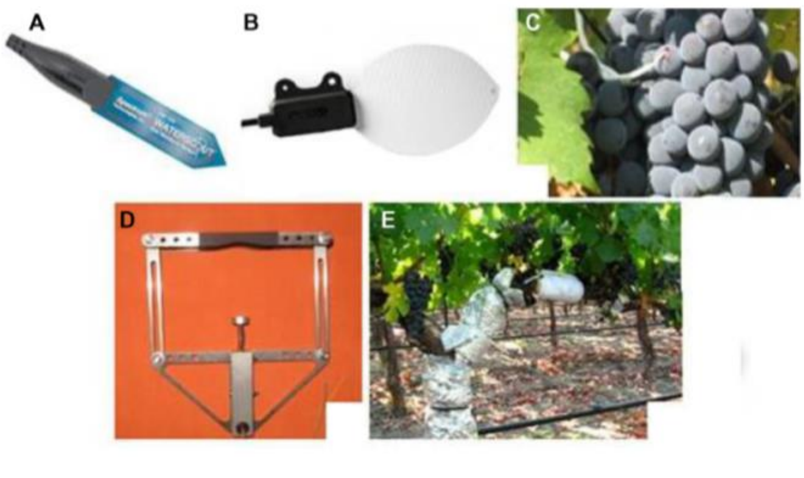

Figure 3. Some sensors used in viticulture **A**. Soil muisture **B**. Leaf wetness **C**. Grape temperature **D**.Dendrometer E**.** Sap flow

increases the cost and prevents the processes from being carried out on time and as required.

In general, there are many ways to improve viticulture production through technology. But the use of technology and robots is not common in vineyards around the world. These new approaches are difficult on a commercial and practical level. In addition to technical challenges such as the reliability and safety of autonomous vehicles that operate for several hours without human intervention, there are economic barriers arising from the need to use the latest technology in a product that must compete on price. The farmer population is getting older and the acceptance and understanding of these technologies by this ever-aging population is one of the major challenges ahead.

However, increasing costs and decreasing farm labor potential in important grape growing regions are increasing interest in mechanization. Currently, machines are available to mechanize the most demanding cultural practices used in grape production, including pruning, canopy management and harvesting. Making the most of these machines can increase the production efficiency in viticulture. Although the use of mechanization and technology in viticulture is concentrated in certain processes, research should be conducted to ensure that mechanization is used in other growing processes and new vineyards should be established in accordance with the data of these studies.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

Author Contribution

EYC conducted literature research and data compilation. EK made language arrangements in addition to literature review.

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