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Digital viticulture: Grape farming with smart technologies

Digital viticulture integrates advanced digital tools like AI, IoT, and data analytics into grape farming to optimize production, minimize environmental impact, and enhance crop quality. Key components such as IoT sensors, drone and satellite imagery, and data-driven decision support systems enable real-time monitoring and efficient management of vineyards. These innovations help address significant challenges in Indian viticulture, including water scarcity, pest and disease pressures, climate variability, labour shortages, and inconsistent market prices. Globally, countries like Spain, France, and the U.S. have advanced digital viticulture through innovations in robotics, UAVs, and precision management systems. In India, initiatives by ICAR-NRCG and partnerships with universities have begun exploring intelligent viticulture, emphasizing water-efficient irrigation, automated advisories, and stress detection in vineyards. Despite the potential of digital viticulture, challenges such as high initial costs, technical expertise gaps, data management, and privacy concerns need to be addressed for widespread adoption. Enhanced infrastructure, farmer training, and localized technology solutions are essential to realizing the full benefits of digital viticulture in India.

DIGITAL viticulture can be described as the integration of digital tools, technologies, and data-driven decision-making processes into grape farming. This approach uses artificial intelligence (AI), remote sensing, Internet of Things (IoT) and mobile applications. The key objectives of the digital viticulture are increasing the production efficiency by reducing cost of cultivation, minimizing environmental impact besides improving quality of the produce, sustaining productivity and yield.

Current trends in digital viticulture include collection of sensor-based data for crop and weather monitoring, data analytics for assessment of vineyard health and possible risks, automation of vineyard operations (for example, monitoring, spraying, harvesting etc.). The key components of this system include:

- IoT sensors for monitoring plant health, soil moisture, environmental temperature, relative humidity, rainfall, etc.
- Drone and satellite imagery for high-resolution mapping.
- Data analytics platforms which use machine learning to analyse the data received and provide insights into vineyard health, risk assessment and yield predictions for market intelligence, etc.
- Decision support systems (DSS) developed based on above information in the form of mobile applications in simple language and user interface to guide grape growers for making informed and timely decisions.

Indian viticulture challenges

Water scarcity: Grape cultivation is water-intensive, and Indian vineyards, particularly in Maharashtra and Karnataka where more than 90% of Indian grapes are commercially produced, face water shortages. This is despite the fact that vineyards are mostly under drip irrigation.

Pest and disease problems: The fungal diseases, e.g., powdery mildew, downy mildew, anthracnose, and insect pests including thrips, mealybugs, etc. are the common threats that impact grape yields as well as quality. Some of these insect pests and diseases infest the vineyards after the veraison (berry softening) stage. To control them, farmers apply pesticides, which eventually causes food safety related trade issues on account of pesticide residues.

Climate variability: Grape growth is sensitive to climatic changes, and erratic weather patterns due to climate change make vineyard management increasingly difficult. Untimely rainfall increases downy mildew incidences and rains at the time of harvest cause berry cracking leading to crop failures. In addition, hailstorms have also become a major impediment to grape cultivation in certain major grape growing regions of Nashik and Sangali districts of Maharashtra. Hailstorms damage the grapevines physically, shatter grape berries, and also crack them causing huge losses. The seasonal weather changes can also influence the formation and ratio of sugar and pro-phenols in grapes, thereby affecting the quality of

produce.

Labour shortages: Manual labour-intensive tasks such as pruning, thinning, harvesting, weed control, etc. are becoming harder to manage due to labour shortages and increasing costs.

Price realisation: Grape growers face a lot of problem in getting descent price during peak harvest months of March and April due to market glut.

Potential of digital viticulture

Digital viticulture presents significant opportunities to address these challenges.

Optimizing water use and enhancing water- use efficiency: IoT-enabled soil moisture sensors and precision irrigation systems ensure that water is applied where and when it is needed the most, reducing wastage of water while maintaining grapevine health.

Enhanced pest and disease monitoring: Drones and image analysis powered by AI can detect early signs of diseases or pest infestations, allowing for targeted interventions (e.g. spraying of specific pesticides, biocontrol agents etc.). It can reduce the need for repetitive and broad applications of pesticides and applications of broad-spectrum pesticides, which often cause disease and pest resistance, resurgence and pesticide residue problems.

Climate resilience: Advanced weather forecasting tools and decision support systems enable grape growers to prepare for extreme weather events and adjust practices in real-time to mitigate risks. For example, one month forecast of presence or absence of rain can help grape growers to take decision on forward pruning dates to avoid downy mildew period coinciding with rains. Accurate hailstorm forecast can help grape growers to cover their vineyards with hail nets.

Labour efficiency: Most of the operations in vineyards are time-dependent and need specialised skills as well as availability of skilled labour to carry out timely operations. Automation in pruning, thinning, irrigation, disease and pest management, and harvesting can reduce dependence on scarce labour, making timely vineyard operations possible.

Yield predictability and market intelligence: Data analytics platforms can enable better forecasting of grape yields based on historical data, weather conditions, and current vineyard health, reducing variability and improving market planning and intelligence.

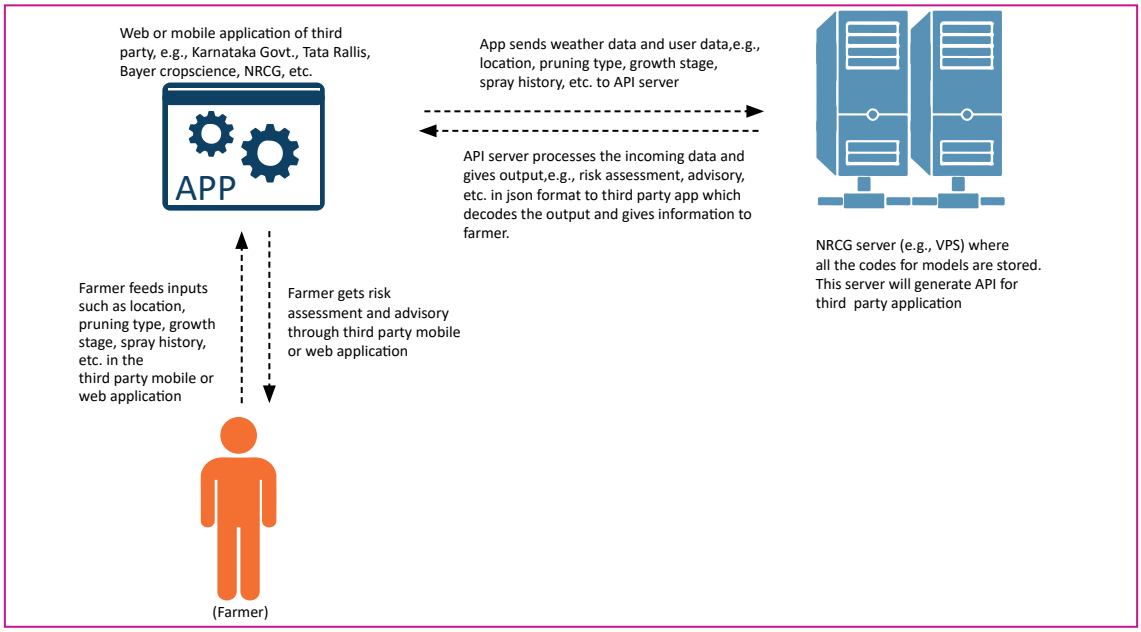
Global status

Globally, countries including Spain, France, Australia, the United States of America and many other countries have made significant strides in digital viticulture. Among ground-based monitoring platforms, 'Televitis mobile lab' is a manually driven vehicle developed by the Televitis Research Group, University of La Rioja in Spain. It is a portable sensing platform equipped with various sensors, including an RGB camera, a near-infrared sensor, hyperspectral imaging, and a thermal camera. These sensors are linked to a GPS and an industrial computer, allowing for real-time data or image collection, while the platform moves at speeds ranging from 2 to 7 km/h. This platform was used to access various vineyard parameters, such as cluster compactness, canopy porosity, bunch and leaf exposure by image analysis. It enhances decision-making in precision viticulture, benefiting the wine industry. Televitis in collaboration with SMEs from Rioja, Spain has developed vitis Flower® app, which uses machine vision to estimate the number of flowers per grapevine inflorescence through image analysis. Autonomously driven ground robots have also been developed for navigation in vineyards, Bakus robot models by Vitibot of France.

Robotics is no longer limited to crop monitoring and tasks that require heavy labour, like pruning, precision harvesting, etc. are becoming central topics in viticultural robotics. The GRAPE (Ground Robot for Vineyard Monitoring and Protection) project involves the automated distribution of pheromone dispensers for mating disruption in vineyards. This is achieved using an autonomous ground robot equipped with a robotic arm. The project primarily focuses on developing the robot's on-board intelligence and the necessary algorithms, while utilizing commercially available hardware.

Satellite imagery and GIS mapping have made possible for Australian grape growers to monitor vineyard variability and optimise labour and machinery usage. This data-driven approach not only reduces production costs but also enhances crop quality. Integration of Unmanned Aerial Vehicles (UAVs) with advanced hyperspectral and multispectral sensors was also done to enhance the existing surveillance methods, including human inspections and insect traps, for detecting grape phylloxera in Victorian vineyards in Australia. The Efficient Vineyard (EV) Project in United States of America gives spatial data, research and information to grape growers, which helps them to increase grape yield and quality. It uses a precision viticulture approach with three key methods viz. measure,

Sensors installed in a vineyard for monitoring vineyard micro-climate



Decision support system for grapes

model, and manage. Sensors collect spatial data, which the EV software processes to guide informed management decisions, like variable-rate fertilization based on vineyard conditions.

Indian scenario

In India, the adoption of digital viticulture is still in its early stages, but there have been notable efforts.

ICAR-National Research Centre for Grapes (NRCG) has initiated studies on intelligent viticulture, focusing on the use of ground-based sensors and satellite imagery to monitor the vineyards for mapping grapevine health and developing automated advisory system. In collaboration with MIT-ADT University, NRCG has trained machine learning models using transfer learning for identification of biotic and abiotic stress conditions on grape leaves and berries. NRCG and MIT-ADT have also developed two prototypes of vineyard monitoring devices with automated trigger, namely Offline Device and Cloud Based Camera enabled Wireless Sensor Network (CWSN) for capturing time-series grapevine image data.

NRCG has developed and commercialized a Decision Support System (DSS) for grapes, which provides farm-specific advisory for irrigation and nutrition management, pest and disease risk assessment and advisories.

A few large vineyards in Maharashtra have begun using IoT and precision irrigation to optimize water use.

Government initiatives like Digital India and various agricultural technology (AgTech) startups are setting the foundation for more widespread adoption of digital viticulture in the coming years.

Challenges and drawbacks of digital viticulture

While digital viticulture holds immense promise, it is not without its challenges.

High initial investment: The cost of sensors, drones, and other digital tools can be prohibitive, especially for small-scale farmers. Drone pilot training is also costly and may not be available in every state.

Technical expertise: Implementing and maintaining these technologies requires technical know-how, which may be lacking in rural farming communities. For example, interacting with software for using ground or air-based surveillance systems for monitoring and interpretation & understanding results may require the farmers to be tech-savvy.

Data overload: Managing and interpreting large volumes of data can be overwhelming without proper infrastructure and analytic platforms. The recurrent data collection especially image data by surveillance systems may require huge cloud storage. The old data may not be deleted as it will help in analysis over time-series and therefore, data pile-up increases rapidly.

Data privacy: As more data is collected about farms and practices, there are concerns about how this data will be used and who will have access to it. The surveillance systems and digital solutions are most likely to be provided by private firms or start-ups to farmers. This data may be sold to input suppliers or traders for market intelligence and therefore, there is a need for protection of user data.

SUMMARY

Digital viticulture offers the potential to address some of the most important challenges faced by Indian grape farming. By optimising water use, improving pest and disease management, automation of vineyard operations and making vineyards resilient to climate change and untimely weather events, digital viticulture can help secure a sustainable and profitable future for grape farmers. However, to fully realize these benefits, investments in infrastructure, training, and localised technology solutions will be essential.

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