REVIEW ARTICLE

Precision horticulture a modern approach to smart farming: A review

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Sharma S, Lal B, Verma AK, et al. Precision horticulture a modern approach to smart farming: A review. AGBIR.2024;40(2):945-948.

A number of important elements, including social justice, economic sustainability and environmental health, are integrated into precision farming. In order to achieve this, it emphasizes the precise management of crops through the use of state-of-the-art technologies such as Remote Sensing (RS), Geographic Information Systems (GIS) and Global Positioning System (GPS) in conjunction with ground equipment like yield monitors, Variable Rate Applicators (VRA) and computer systems with the necessary software. Precision agriculture is essentially a systematic strategy that aims to restructure the entire agricultural system in order to adopt a farming model that is high-efficiency, low-input and sustainable. Prioritizing technology-driven horticulture precision farming as a potential solution is becoming more and more necessary in light of the escalating challenges presented by an expanding global population and unexpected environmental fluctuations. This approach holds great potential for addressing these pressing issues and ensuring the future sustainability of agriculture.

Key Words: *Precision farming; Sustainability; Global positioning system; Remote sensing*

INTRODUCTION

As the global population continues to grow, urbanization accelerates and natural resources weaker, farmers must undergo a fundamental shift in their mindset. This shift involves transitioning from an exclusive focus on production to a broader emphasis on productivity and profitability. The contemporary challenges faced in agriculture primarily revolve around diminishing land availability and the depletion of critical resources, particularly water. To address these challenges, it is imperative to promote farmer-friendly, location-specific production management technologies in a concerted effort. This approach seeks to propel vertical growth in horticultural production while ensuring the quality of produce and enhancing financial returns per unit of land area. Central to this endeavor, precision farming plays a pivotal role by facilitating the efficient utilization of resources over specific periods and land areas to attain the targeted production of horticultural crops.

Professor Pierre C. Robert, often regarded as the pioneer of precision farming, provided a defining perspective on this approach. He emphasized that precision agriculture represents not merely the incorporation of new technologies but rather an information-driven revolution made possible by these innovations, leading to a more refined and precise farm management system. Fundamentally, it involves the application of the right treatments in the right quantities, at the right time and location within a field [1]. Precision farming harnesses modern technologies, including remote sensing. However, in countries like India, where the majority of farmers have small land holdings averaging between 1 to 2 acres, using aerial remote sensing to access detailed information about natural resources, especially soil data, has proven to be a challenge. Advancements in remote sensing particularly increased spatial resolution have enabled the application of precision farming methods even on smaller land areas [2].

This scientific approach leverages Information Technology (IT) and satellite-based technologies to identify, analyze and manage the spatial and temporal variations in agronomic parameters such as soil quality, diseases, nutrients and water within fields [3]. It achieves this by precisely applying the necessary inputs to optimize profitability and sustainability while minimizing environmental impact [4]. Current research, such as the study on "Integrating farmer knowledge, precision agriculture tools and crop simulation modeling to evaluate management options for underperforming areas in crop fields", holds significant promise, particularly for a country like India [5]. In India, there are relatively developed regions that can serve as incubators for novel ideas and sophisticated technologies tailored to domestic conditions.

LITERATURE REVIEW

Techniques for precision farming

Precision farming is the management and understanding of variability over time and space. This system is based on use of information generated through survey to manage this variability by matching inputs to conditions within field using site-specific inputs like such as computer system, GPS system, GIS system, RS system, VRA system, yield mapping technology, soil and crop sensing technology, DRIS and SSNM for precision farming in horticulture and waste management in context to precision horticulture in specific site.

Computer system

Computers have help to define precision farming in terms of management strategy that uses information technologies for decision making [6]. Precision farming requires the acquisition, management, analysis and output of large amount of spatial and temporal data. Computer software in precision agriculture has become better with time for precision farming, the knowledge needed is that for managing variability on the farm, knowledge that is requisite for decisions making. Therefore, in this system, computers and related software have become capital inputs [7].

Global positioning system

Many satellite constellations assist the positioning system in its operation. Precision agriculture is now a reality because to advancements in positioning systems. These developments represent the primary technological milestone. For the field use of variable rate technology, GPS offers a precise locating system [8]. It allows for the precise positioning of farm equipment to within inches, controls the administration of inputs by machinery and prescribes fertilizer and pesticides based on the characteristics of the soil. The US Department of Defense (DOD) created the Global Positioning System (GPS). The Russian Global Navigation Satellite System (GLONASS) location system is comparable [9]. There is debate over the European Global Navigation Satellite System (GNSS) or "Galileo" hence, a definition study supported by the European Union (EU) and the European space agency is underway [10,11]. For every task in GPS, all location data should be distributed and stored from a single system located at a central vehicle (such the tractor) [4]. According to Spilker [12], the primary benefit of a central system is that position data are computed based on the application and sent straight to the location where they will be utilized. Kinematic GPS (KGPS), a more precise positioning technology with centimetric accuracy, is not utilized in precision agriculture because of cycle ambiguity issues [13]. Double differencing is a

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Received: 16-Feb-2024, Manuscript No. AGBIR-24-127689; **Editor assigned:** 19-Feb-2024, Pre QC No. AGBIR-24-127689 (PQ); **Reviewed:** 04-Mar-2024, QC No. AGBIR-24-127689; **Revised:** 11-Mar-2024, Manuscript No. AGBIR-24-127689 (R); **Published:** 18-Mar-2024, DOI:10.35248/0970-1907.24.40.945-948

technique employed by Real-Time Kinematic (RTK) and Differential Global Positioning System (DGPS), which can be utilized for in-depth topography mapping. Elevation accuracy with the RTK method can reach up to 5 cm. This is made feasible by the fact that RTK systems analyze the GPS signal's carrier wave to extract additional information. To determine the spatial influence of topographical factors on apple yield, one study was conducted [14].

Geographic information system

An essential tool for efficiently capturing, storing, updating, manipulating, analyzing and displaying all types of geographically referenced information is the Geographic Information System (GIS), which consists of an organized collection of computer hardware, software, geographic data and human resources [15]. The field of GIS science encompasses modeling and data management, allowing for a transition from mapping to spatial reasoning. According to Miller and Paice [16] GIS is used to apply recommended rates of nutrients or pesticides because it contains base maps of topography, soil type, nutrient level, soil moisture, pH, fertility and weed and pest intensity. It can also integrate all types of information and interface with other decision support tools.

Remote sensing

Remotely sensed data, acquired using satellite or airplane, that includes crop electromagnetic emittance and reflectance data can offer valuable insights into several aspects such as soil health, plant development and weed infestation. Programs for crop management that are site-specific can greatly benefit from this kind of information, which is also reasonably priced [17]. Precision agriculture can benefit from this technology since it provides field parameters with relative ease. Generally speaking, we see the sun's reflected light, which is made up of infrared, visible (red, green and blue) and ultraviolet wave lengths. The green plants reflect the infrared and green wavelengths while absorbing the red and blue wavelengths. We can assess the health of the plants and any issues they may be facing, such as illness, nutrient shortages, water logging, etc., by measuring the reflected wavelengths using multispectral cameras. We can relate the color of the soil to its organic matter, moisture content, etc. Vegetation indices, which are derived from light reflection from the sun or artificial light sources, have been employed in precision agriculture. The Normalized Vegetation Index (NDVI) is the most widely utilized of them. There are various indices that can be computed and applied that have good agreement with certain crop attributes. There is a correlation between crop yield and quality and NDVI. Plant reflectance can be measured using land devices, aircraft or satellites. These maps derived NDVI data were transformed into a Leaf Area Index (LAI) map, which demonstrated the ability to support irrigation and canopy management decisions [18]. The retrieval performances for LAI were improved by smoothing the residual errors related to each individual observation for maize crop, primarily through the use of a simple semi-mechanistic Canopy Structure Dynamic Model (CSDM) in conjunction with a Radiative Transfer Model (RTM) to estimate the spatial and temporal variation of LAI based on multi-temporal remote sensing observations. Furthermore, this technique made it possible to continuously describe the LAI time course from a small number of observations made throughout the growth cycle [19,20]. These studies used the NDVI of the vines at vaireson as a measure of the quality of the grapes and divided the product into lots that produced high-quality and low-quality wine. The farmer reaped benefits and made money thanks to the idea's success. In Chile, Best et al., [6] discovered strong correlations ($r2>0.7$) between the NDVI and vineyard yield and quality, as well as between the NDVI and LAI (r2). Any item that emits electromagnetic radiation at a temperature higher than absolute zero does so. This is utilized in thermal cameras that identify temperature variations in plants. Precision agriculture has employed thermal cameras to monitor crop water status and control irrigation ($r2>0.75$). Investigated the relationships between yield and grape characteristics and spectral pictures. The fruit anthocyanin and phenolic content, berry size and yield were all substantially associated with the predicted canopy area and canopy density. However, correlations for total soluble solids were not constant.

Variable rate technology

Field equipment already in place that has an additional Electronic Control Unit (ECU) and onboard GPS can meet the variable rate input requirement. Patch spraying has been done using spray booms, a spinning disc applicator with an ECU and GPS [2]. All information gathered should result in a better management of the formed zones. Variable Rate (VR) means that the appropriate rates of inputs will be applied leading either to reduced inputs, costs and environmental effects or improved yields and quality. Two methods are used to apply VR. The first called map based, is based on historical data (previous or present year). Process control technologies allow information drawn from the GIS (prescription maps) to adjust fertilizer application, seeding rates and pesticide selection and application rate, thus providing for the proper management of the inputs. The second, named sensor based, uses sensors that can adjust the applications rates on the go. The sensors detect some characteristics of the crop or soil and adjust the application equipment. VRA can be applied to all inputs. Both systems have advantages and disadvantages. Probably using a mixture of both will offer most advantages in the future. Variable fertilizer applications in vineyard could help minimizing variability in vine growth as well as fruit quality Shah and Mansoodi [20] and Davenport et al., [21] applied VR fertilizer in a vineyard for four years. They have analyzed the nutrient content of the soil and concluded that N and K applications benefited the field as they reduced variation but not the Phosphorus (P) application where the Coefficient of Variation (CV) remained high. Based on management zone delineation and historical data prescription maps can be produced defining the specific requirements of each zone. The prescription map is imported to the controller of the application machine and changes the adjustment as the machine moves through the field.

Yield mapping technology

The most accurate measure of how many agronomic factors vary across the field is yield. Thus, yield mapping, together with its interpretation and linkage with the temporal and spatial variability of several agronomic indicators, aids in the construction of crop management plans for the following growing season. Current yield monitors provide a time-periodic record of the amount of crop harvested for that period by measuring the volume or mass flow rate Schachtl et al., [17]. The most popular color-coded theme map is produced by synchronizing time-periodic yield data with the location address acquired from the onboard GPS system [22]. Yield mapping can be carried out easily in mechanized crops. By using either loading cells that weighed the crop passing on a conveying belt or an array of sonic beam mounted over the grape discharge chute to estimate the volume and the tonnage of fruit harvested. The results showed 8-10-fold difference of yield between parts of the same parcel Bramley [23]. Research in arable crops Blackmore et al., [24] and Fountans et al., [25]. Showed that the trends after the third year are cancelling out and we can only define areas of stable high and low yielding and unstable yielding. Tree crops seem to have more stable yield found in vineyards after five year's data [26]. Ampatzidis et al., [7] have mapped the yield of peaches. They used Radio-Frequency Identification (RFID) or bar code tags on the bins. A weighing machine was combined with a tag reader and a GPS to record the weight and the place of each bin. The data collected was used to produce yield maps of the orchard have mapped the yield of a 1.6 ha pear orchard. They measure the yield of each tree harvested in three passes. Instantaneous combine yield monitors generally provide good results if careful attention is paid during calibration, maintenance and as well as to manufacturer's instruction [21].

Soil and crop sensing technology

Traditional extraction of soil sample and plant tissue sample and analysis in laboratory is time and cost intensive. In recent years many instruments have been invented based on direct contact and proximate remote sensing technology Tiwari and Mondal [10]. Three instruments have already got widespread acceptance, namely infrared spectrometer, soil inductance meter and leaf chlorophyll meter. Plant water status can be determined by infrared spectro meter using a grid sampling and analysis of an olive orchard defined the soil maps and the amount of Phosphorus (P) and Potassium (K) fertilization for each tree [25,27,28].

RESULTS AND DISCUSSION

Diagnosis and recommendation integrated system and site-specific nutrient management for precision farming in horticulture

As a function of crop yield, the Diagnosis and Recommendation Integrated System (DRIS). (DRIS) represents a comprehensive approach to the mineral nutrition of the crop and influences the integrated set of norms representing calibration of plant tissues, soil composition, environmental parameters and farming practices. This allows for the diagnosis of the crop's conditions and the isolation of the factors most likely to be limiting growth and production. The DRIS technique offers two main advantages: it can identify agricultural problems at any stage of growth and can identify which nutrients are limiting crop productivity. An integrated diagnosis and suggestion system has been developed in order to meet the needs of the leaf analysis's diagnostic and predictive applications. Conditions are produced that raise the possibility of a higher yield and better quality by optimizing these variables. DRIS employs a survey methodology whereby a vast number of randomly selected places are selected around the region. Samples of soil and leaves are taken from each location for analysis and details regarding the manures and fertilizers used are recorded [29]. Site-specific management differs from the traditional approach of total field management. Whole field management employs management strategies based on the typical characteristics of a farm or field. Under site-specific management, fields are divided into management zones, also called grids. Every zone has its own quantification and upkeep. In order to execute a comprehensive management strategy, producers wishing to use site-specific management must have access to the necessary data and resources. The availability of moisture, pest populations, crop diseases, field topography and the chemical and physical characteristics of the soil are among the requirements for spatial information. Soils sometimes lack certain critical elements like Nitrogen (N), Phosphorus (P), Iron (Fe), Manganese (Mn) and Zinc (Zn), because they are usually descended from basaltic parent material [8]. Because of this, the standard nutrition management approach which mostly focuses on applying macronutrients has demonstrated to be ineffective at raising the productivity level in orchards [8]. Soil test-based Site-Specific Nutrient Management (SSNM) can be used to address these nutritional constraints and maximize the productive potential of specific orchard locations.

Waste management in context to precision horticulture

Horticulture produce undergoes spoilage at the time of harvesting, handing, storage, marketing and processing resulting in huge wastage. Efficient management of this wastage can help preserving essential nutrient of our food and feeds bringing down the production cost of processed product, besides minimizing the pollution hazard and purifying the environmental condition. Recycling the horticultural waste is one of the most important aspects of utilization it in a number of new way to yield new products and meeting the requirement of essential products requirement to mankind.

Nutritional composition of different horticultural wastes has been quoted by Singh et al., [30]. They reported that waste is rich source of vital constituent like carbohydrate, fat, protein, minerals and fibre etc., mango seed kernel is rich in carbohydrate, fat, protein, minerals. Orange, pumpkin, melon seed can provide fat and mineral maters. Possible by products from the waste of processing units have been described by Speckmann [13].

Could help to developed by-products on the basis of availabilities of waste. Maini [31] reported that maximum pectin yield jelly grade was obtained from peel of citrus Giles et al., [32]. Mango seed kernel contains essential oil, which is used in manufacture of soap and other cosmetic products. Fresh apple pomace used at 10.2 kg per day per animal as a partial replacement of fodder without any detrimental effect on health and milk yield of the animals. Some of the fruit wastes can be usefully diverted for biogas generation and making manure. Fruit are not suited for active fermentation in generators due to acidic in nature. Neutralizing agent like lime slurry has to be added along with fruit wastage for the continuous active fermentation and to maintain the efficiency of gas generators [13].

Future strategy for precision farming

To successfully implement precision agriculture in India, a comprehensive strategy should address several key challenges, including land fragmentation, the absence of advanced technical centers for precision farming, the need for specific software tailored to Indian agriculture and the financial constraints faced by Indian farmers. Precision agriculture in small farms necessitates a paradigm shift where each individual farm is considered a management zone within a larger field, with a centralized entity providing cooperative information to farmers. The issue of high costs associated with positioning systems for small fields can be mitigated by adopting a "dead reckoning system". This system, well-suited for small, regularly shaped fields, relies on in-field markers, such as foam, to maintain consistent application. By doing so, it offers farmers a reliable and cost-effective approach to make informed decisions about the spatial management of their fields. Crop and weed characteristics vary from region to region, even from country to country. Therefore, there is a pressing need to develop software and hardware solutions tailored specifically to the unique needs of Indian agriculture. These tailored packages will not only be suitable for developed countries but can also be applied effectively in developing countries if implemented correctly. These innovations have the potential to bring about significant improvements in farm management through more efficient machinery use and resource management.

CONCLUSION

In conclusion, precision horticulture has the potential to completely transform the agriculture sector by increasing profitability, sustainability and production. Farmers can effectively manage their crops, reduce risks and help ensure a more sustainable future for food production by utilizing technology and data-driven insights. Precision horticulture is set to become a crucial part of contemporary agriculture, guaranteeing food security and environmental stewardship for future generations, as technology develops and its usage soars. A contemporary take on smart farming, precision horticulture makes use of data-driven techniques and state-of-the-art technologies to maximize agricultural practices. Precision horticulture makes use of precise application of resources like pesticides, fertilizers and water to optimize crop yields while reducing waste and environmental effect. In order to monitor crop health, soil conditions and environmental elements in real-time, this technique incorporates multiple technologies, including sensors, drones, GPS and data analytics. This enables farmers to make informed decisions and modify their management strategies accordingly.

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