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An Overview of Precision Farming

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

With respect to conventional farming precision agriculture increases average yields by limiting the wastage by calculating the exact required quantities of inputs. One major issue in India is the relatively small and scattered landholdings. In India 58% of the cultivable land is less than 1ha

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under single owner. The agricultural production system is the result of a complex interplay between seed, soil, water, and agrochemicals (including fertilizers). As a result, judicious control of all inputs is critical for the long-term viability of such a complex system. Precision agriculture is the use of technology and techniques to control the geographical and temporal variability associated with all aspects of agricultural production to improve output and environmental quality. Precision agricultural success is dependent on an accurate assessment of variability, its management, and evaluation in the space-time continuum of crop production. Precision agriculture's agronomic performance has been highly impressive in sugar beet, sugarcane, tea, and coffee crops. Due to lack of knowledge of space-time continuum the economic benefits environmental and social advantages are not explored yet. Precision agriculture is a relatively new field that integrates cutting-edge geographic technology with farming scenarios to optimize inputs, eliminate waste, and maximize returns. Precision farming systems are intended for use in many sorts of agricultural systems, ranging from row crops to dairy, and the technology has experienced extensive acceptance in the United States and across the globe.

Keywords: precision farming; agricultural production; agrochemicals.

1. INTRODUCTION

Precision farming is fundamentally based on the measurement and understanding of variability; thus, the primary components of a precision farming system must oversee variability. Precision farming technology is information-based and decision-focused, including components such as Remote Sensing (RS), Geographical Information System (GIS), Global Positioning System (GPS), Soil Testing, Yield Monitors, and Variable Rate Technology. Precision farming necessitates the procurement, management, analysis, and dissemination of massive amounts of spatial and temporal data. Mobile computing systems are required in agricultural operations to perform on the go because workstation systems in the farm office were unsuitable. As precision farming is concerned with spatial and temporal variability, which is information-driven and decision-centered. Precision agriculture is assisted by GIS's spatial analytic capabilities. GPS, DGPS has substantially improved precision farming and is crucial for precision farming, especially for guiding and digital assessment modeling position accuracies at the centimeter level are achievable in DGPS receivers.

1.1 Definition of Precision Farming

This term precision farming/ site-specific crop management (SCM) was highlighted in 1994 March at the second international conference on site-specific management for the agricultural system in Minneapolis, Minnesota in the USA. SSCM involves the development of agricultural management system to improve variable management approaches for soil factors or within field-based onsite. This is also popularized by the name such as spatially prescriptive farming, computer-assisted farming or sat farming, site-specific farming, high-tech sustainable agriculture, soil specific crop management, and the widely used term precision farming

Precision farming can be defined broadly as, “an information and technology-based agricultural management system that identifies, analyzes, and manages soil in terms of spatial and temporal variability within a field for maximum profitability, sustainability, and environmental protection”. Precision farming is also referred to, “the precise evaluation of soil and crop management practices to meet the various conditions faced on arable land”.

1.2 Need of Precision Farming

- Increases agricultural productivity
- Prevents soil deterioration
- Reduces chemical use in crop production
- Efficient use of water resources
- Dissemination of modern farming methods to increase product quality, quantity, and cost
- Promoting positive attitudes
- Precision farming is altering farmer’s socio-economic situation

2. PRESENT SCENARIO OF PRECISION FARMING IN INDIA

Underdeveloped nations such as India, face a major issue in adopting these types of systems as are not suitable due to the low economic status of farmers, small and scattered land holdings where farming is just sustenance-based activity. But still, this approach had made significant progress despite such issues in underdeveloped countries. Take into account the following scenario: a farmer approaches his field with a GPS (Global Positioning System)-guided tractor. The GPS detects the tractor's precise position within the field. It transmits signals to the tractor's computer, which comprises of a Geographical Information System (GIS), having the soil nutrient demand map. The GIS, in collaboration with a Decision Support System, would determine the precise amount of fertilizer required for that region. It then instructs a variable rate fertilizer applicator, which is again coupled to the tractor, to administer the appropriate dose at the farm's exact location. However, this is what precision farming means to commercial producers in the world's most developed countries of the world. Though precision farming is often discussed in developed countries, it is still in its initial stage in developing countries such as India. The Space Application Center (ISRO) in Ahmedabad has initiated an experiment at the Central Potato Research Station farm in Jalandhar, Punjab, to test the capabilities of remote sensing in mapping and variability in space and time. Chennai M S Swaminathan Research Foundation has adopted a village cluster at Tamil Nadu's Dindigul district with NABARD to test the efficiency of variable rate input application. The Indian Agricultural Research Institute in New Delhi has turned focus in direction, and Indian farmers in exploiting the potential of frontier technology without jeopardizing land quality.

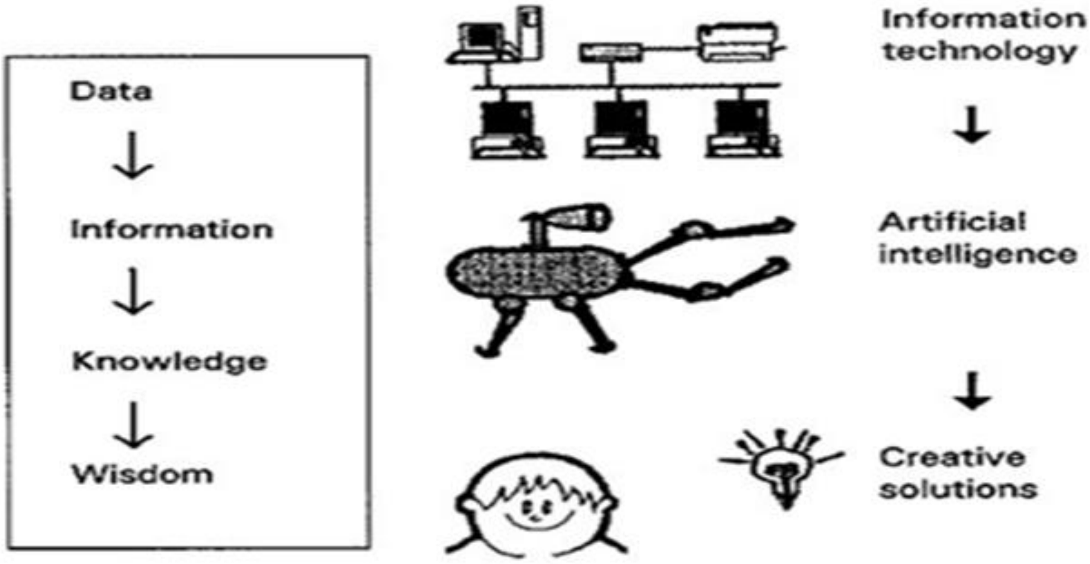
In addition, the Project Directorate for Cropping Systems Research (PDCSR), Modipuram and Meerut (UP), in partnership with the Central Institute of Agricultural Engineering (CIAE), Bhopal, initiated variable rate input use in various cropping systems. Precision farming may help Indian farmers get the benefits of cutting-edge technology without risking land quality in the future years.

2.1 Principle of Precision Farming

Under Precision farming, a large field is divided into a limited number of sub-Plots, which are designed to make input-based adjustments based on data so obtained. Ideally, this reduces the associated risks and allows for the maximum possible return on investment without environmental degradation.

2.2 Components of Precision Farming and its Methods

The development of system technology for precision farming is displayed in Picture 1. Primarily, it is important to understand and describe the diversity within and across fields. The use of GPS-enabled field sensors and machine monitors ease the step. The next step consists of creating remotely controlled devices.



Picture 1. Development of precision farming Technologies

To properly understand and use precision farming, the following fundamental concepts must be defined:

1. Global positioning system (GPS)
2. Remote sensing
3. Geographic information system (GIS)
4. Yield monitoring:
5. Variable rate technologies (sensors, controllers, and others)

2.3 Global Positioning System (GPS)

The GPS these days use 24 orbiting satellites for determining the exact location by accurately transmitting the radio signals from that location to the receiver and it allows the instantaneous analysis of the information related to soil and plant of that particular location. For this, the GPS device can be manually taken into the field or can be fitted to the machine/ equipment working at that location by this the user can return to the exact problematic location again. It is very essential to take precise location for data collection into account under precision agriculture. In agriculture diversity of activities such as precision sowing, irrigation, managing insect pests, diseases, etc. are undertaken in terms of internal variation under each field plot. The use of GPS in agriculture is minimal but still significant enough to find its wider utility in the near future. For instance, a GPS enabled helicopter has been developed for precision crop dusting has been innovated to enable its usage in an area as small as 4 m^2.

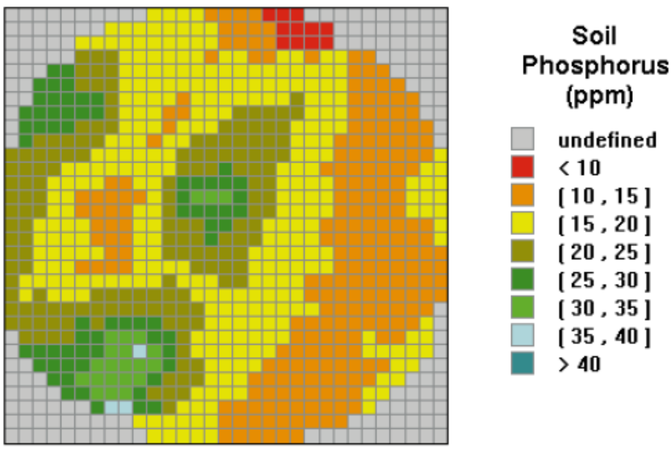
Some farmers have started using GPS for observation recording In a few years Indian farmers would be earning lucrative returns after using this futuristic technology without hampering the land quality.

2.4 Remote Sensing Technique (Rs)

Remote sensing technology has enabled us to collect the field-related data from the ease of sitting at a place. Under precision farming, remote sensing is an approach used to collect field information such as internal information of field plots for making decisions related to crop growth habits, plant status, and spatial variability information. Continuous research being carried out from the past 3 decades has made precision farming near to perfect levels. Remote sensing finds its use in various daunting tasks such as monitoring of soil moisture, crop nutrient analysis, management of agriculture disease and pest, analyzing the status of crop growth, crop yield estimates, and many others such tasks. So remote sensing turnouts to be the most important source for collecting information required for precision agriculture.

2.5 Geographical Information System (Gis)

GIS is a computer hardware and software method that enables maps production by combining feature attributes and location data. The storage of layers of information, such as yield, soil survey maps, remotely sensed data, and so on, is an important feature of agricultural GIS. This platform exchanges information, with other systems or users. In general, the information service primarily consists of the services of information management, message exchange and update, decision analysis, and information release.



Picture 2. Soil phosphorus level from the remote sensing photograph

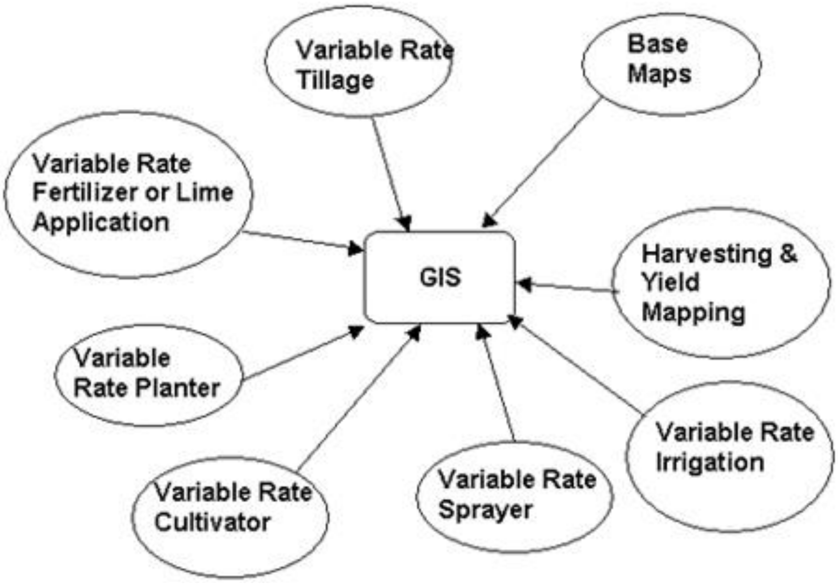


Fig. 1. Application of Geographical Information System (GIS)

2.6 Yield Monitoring

"Yield monitoring and mapping are key components of precision farming, and they were originally the most commonly utilized components of precision farming [1]. Yield monitoring offers the most thorough measure of regional yield variability in agricultural fields, allowing farmers to examine how management skills and environmental variables influence crop output" [2]. "Yield monitoring enables the farmer with quick and important feedback which in turn helps to make better management choices, his evaluation supplies the farmer with rapid and essential input, helping us to make better management decisions" [3]. Such feedback is included but is not only limited to yield and moisture maps, digitally flagged pest records, immediate yield and moisture recording, and data classifications by year, farm, field, load, and crop. Monitoring yield for a longer period generates a single GIS database which enables the farmer to assess the yield fluctuations within a field, make better variable-rate decisions, and develop a spatial field data history. In crops such as potato, onion, sugar beet, and tomato are being studied and marketed using this approach.

2.7 Variable Rate Technology (Vrt)

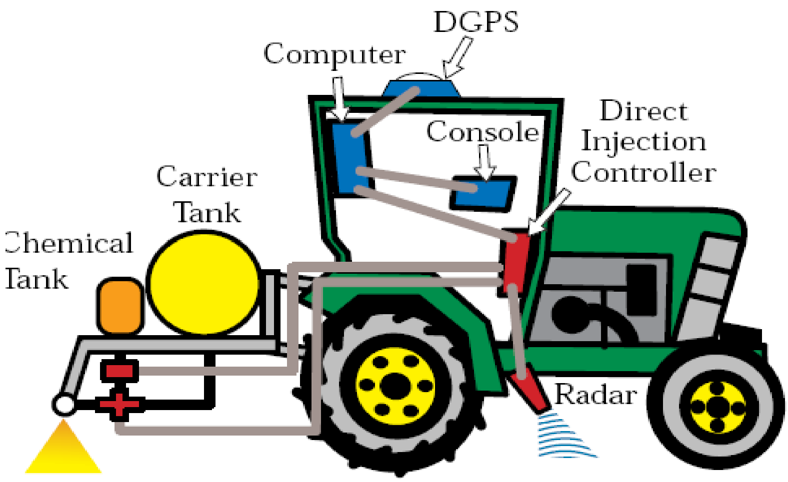
Variable-rate technology (VRT) is used to modify agricultural inputs based on the site-specific needs of each portion of the field. If machines are utilized, variable-rate equipment is required. Inputs can be applied manually on small farms. Variable-rate applications require a) precise field positioning; b) accurate location information; and c) farm machinery equipped with VRT controllers typically have a DGPS receiver to identify the precise location of spatial variability in the field and automatically control the rate of application based on pre-derived input application maps. VRT technology has a variety of uses in the management of site-specific cropping systems. Some of the most extensively used VRT applications are listed below. The most extensively utilized precision agricultural technology is variable-rate application equipment. There have been around 1,600 sales of flotation fertilizer-application systems, map-driven variable-rate technology (VRT) systems, and on-the-go sensor tractor-based application systems. Thirteen percent of those surveyed.

2.8 Basic Steps in Precision Farming

The basic step in precision farming is

i. Assessing variation
ii. Managing variation and
iii. Evaluation

The available technologies allow us to identify variability and control it by providing site-specific agronomic recommendations, which makes precision agriculture feasible. Finally, assessment must be a component of any precision farming system. A diagram clearly illustrates the different steps involved in each process.



Picture 3. Components of VRT chemical applicator

2.8.1 Assessing variability

he first step in precision farming is to assess variability. Because one cannot manage what one does not understand. Factors and mechanisms that govern or affect crop yield performance vary in location and time. Precision agriculture has the challenge of quantifying the variability of these aspects of a system and establishing when and where various combinations are responsible for spatial and temporal variation in crop production. Techniques for measuring spatial variability are widely accessible and have been widely employed in precision agriculture. The majority of precision agriculture is concerned with measuring spatial variability. Techniques for measuring temporal variability exist as well, however reporting both spatial and temporal variance at the same time is rare. We need both geographical and temporal statistics. We can see agricultural production variability in space, but we cannot forecast the causes of the variability. It requires observations of crop growth and development throughout the growing, which is nothing more than temporal variation. As a result, to employ precision agricultural methods, we require both spatial and time data. However, this is not true for all of the variables/factors that influence crop productivity. Some documents are variables more in space than in time, making them more suitable for present techniques of precision management.

2.8.2 Managing variability

Farmers must match agronomic inputs to the status of the respondents for implementing management guidance once variability has been correctly calculated. These are site-specific and involve precise application management systems. We can make the greatest use of technology in the management of site-specific variability. We may employ a GPS sensor to identify the site's uniqueness, making administration straightforward and cost-effective. We must capture the sample location coordinates while taking soil/plant samples so that we may utilize them for management later. This leads to more efficient exploitation of resources and considerably less wastage, which is the ultimate objective. Precise soil fertility management is an attractive, but mainly untested, alternative to uniform field management owing to the prospect for improved accuracy in soil fertility management paired with higher precision in application control. Precision soil fertility management demands that within-field variability exists and is appropriately detected and frequently evaluated, and that variability affects crop production, crop quality, and the environment for effective implementation. As a consequence, inputs may be applied effectively. The more a controllable soil property's spatial dependence, the bigger its capability for precision management and the higher its potential usefulness. The degree of difficulty grows as the time component of spatial variability increases.

Applying this paradigm to soil fertility would corroborate the hypothesis that Phosphorus and Potassium fertility are very susceptible to precision control owing to their low temporal variability. In some instances, the temporal component of variability in N could be bigger than the geographical component, making accurate N control substantially more complex.

2.8.3 Evaluation

Precision agriculture evaluation targets the following three important issues:-

1. Economics
2. Environment
3. Technology transfer

“The most underlying reality about the profitability of precision agriculture is that the value comes from the use of data rather than the use of technology. Precision agriculture is often cited as a basis for potential improvements in environmental quality. Reduced pesticide usage, greater nutrient use efficiencies, increased efficiency of regulated inputs, and enhanced soil productivity from degradation are all frequently mentioned as possible environmental benefits. Precision agriculture may be made feasible by enabling technology, driven by agronomic principles and decision rules, and economical due to increased production efficiency or other types of value. The notion of technology transfer may indicate that precision agriculture occurs when individuals or businesses simply buy and use enabling technologies. While precision agriculture does include the use of enabling technologies and agronomic principles to control spatial and temporal variability. Much of the emphasis in what is known as technology transfer has been shifted on how to interact with farmers. These difficulties regarding the operator's management skills, the geographical distribution of infrastructure, and the compatibility of technology with particular farms will alter dramatically as precision agriculture advances” [4].

2.9 Technology Transition

Precision farming is considered in the acquisition of variability in product quantity or quality. If this diversity does not exist, the same management system is the cheapest and most effective management method, then precision farming is useless. Thus, “output diversity and equal opportunity for quality” in precise farming. Having said that, the nature of the variance is also important in assessing the strength of the PA system. For example, the amount of variability may be too small to be economically manageable. Otherwise, diversity may be more random across the entire production system, making management of existing technologies ineffective. Finally, variability may be the result of an uncontrolled Factor. Therefore, the ability of current flexible technologies (VRT machines/technologies that allow for a different management of the production system) to deal with highly volatile areas and the inability of the economy to produce returns from low-density variables using precise farming limits the implementation of accurate farming. (VRT). Because of these limitations, PA is now operating locally instead of the site-specific base. The minimum administrative space required for the effective use of PA will decrease as VRT progresses and the greater costs of installing PA are reduced until it is entirely possible for a site-specific management system. Until this happens, it is necessary to be able to assess both the variability of the production system and the size of the small controlled area (MMZ). If the production system instability requires fewer control areas than MMZ, PA means nothing to the system yet (but it may be in the future). It will be interesting to see how the concept of the administration progresses and how it relates to the concept of terroir.

If the yield monitor indicates a lot of variabilities, it implies that there is a lot of variability in the field. During such circumstances, the farmer is usually aware of the problematic regions but not always. Although it might be obvious that yield is low in specific areas, you may not know how low it is and what the major causes of the variability are. Variability in yield may be attributed to several factors, including:

- Water stress in an unirrigated or under the irrigated spot of a field
- Lack of nutrients for good plant growth and production
- pH imbalance for poor release of available nutrients
- Weed pressure competing with the crop for water, nutrients, and sunlight
- Disease pressure reducing leaf area for production
- Insect pressure reducing leaf area for production
- Poor drainage (topography and soil texture)
- Shaded areas if present

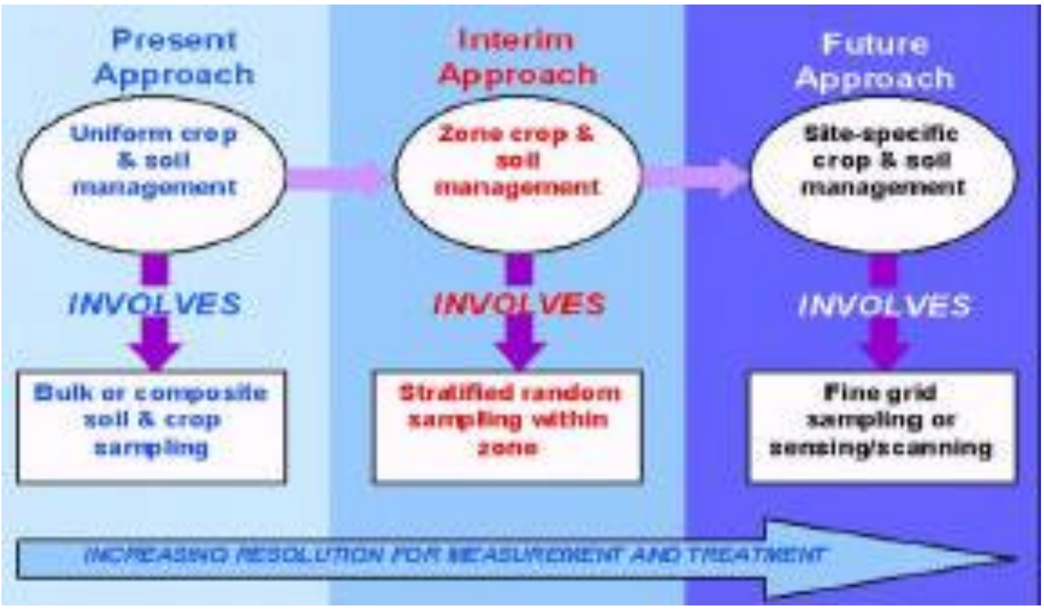


Fig. 2 (a). Precision Agriculture: Transition

Fig. 2(b). Precision Agriculture: The Concept Wheel

Yield reduction may also be within the control of the farmer in other ways. Equipment and/or operator error can cause:

- Planting problems which may cause plant stand problems, reducing yield potential
- Soil ameliorant spreader missing some spots and over-application on others, which affects the pH balance, nutrient balance
- Faulty nozzle(s) on herbicide, insecticide, or fungicide applicator, leaving some plants vulnerable.

3. METHOD TO USE PRECISION FARMING

3.1 Decision Support System

The database system, model base system, knowledge base system, and method base system constitute the DSS. Its primary function is to organize and manage data using a computer, simulate the decision process using a decision model, and provide users with a variety of referenced scenarios. In the context of vegetable crop production, the farm management DSS of precision agriculture may deliver intelligent and visual information to the producer, manager, and scientific and technical workers. The correlated field information may be inquired and processed statistically using this DSS system. Many decisions, such as sowing, fertilizing, managing plant diseases and insect pests, regulating growth phases, and changing and controlling crop yields, may be assisted by the DSS system.

3.2 Site-Specific Nutrient Management

VTR approach is being used for many years and is being explored for different cropping systems. This is mostly used for Variable-rate fertilizer application [5]. Under-fertilization may result in the production of lower yield, whereas, excessive fertilizer application may be toxic to the plant and hazardous to the environment. Due to the rapid development of VRT, it is now possible to manage soil nutrient variations across a field with the precise amount of fertilizer applications. Precision farming also is effective useful under Indian conditions to assist farmers to manage nutrient stress management. The majority of cultivated soils in India are acidic, with substantial geographical variance in pH. The use of remote sensing for identifying nutritional deficiency and integrating data in a GIS may enable site-specific applications of fertilizers and soil remedial measures such as lime, manure, compost, gypsum, and sulfur. Which results in enhanced fertilizer use efficiency and lower nutrient loss.

3.3 Site-Specific Weed, Pest, and Disease Management

Farmers have used herbicides in a continuous broadcast or band application for decades to prevent yield loss due to weed competition, reduce weed seed contamination, and increase crop harvesting ability. In a century highlighted by rising concern about environmental challenges and the potential for increased input efficiency, uniform usage of chemical herbicides may be replaced with site-specific herbicide applications. Pressure to minimize food, soil, and water contamination, as well as relatively high herbicide costs, have encouraged the need for precision technology to more effectively target herbicide use. As a result, herbicide usage may be regulated to a larger extent. Pests and diseases cause massive agricultural losses in India. If remote sensing may assist to identify small problem areas caused by diseases, the timing of fungicide or pesticide treatments can be optimized.

3.4 Site-specific planting

Seed placement and planting rate are site-specific applications. The right location and population of seeds are required for site-specific planting to obtain optimal yield and quality. Spatial variations in yield, crop quality, soil qualities, seed spacing, and plant population are all known to have connections. Monitoring these differences allows for the planting of diverse crops on a geographically selective basis.

3.5 Parallel swath navigation

Parallel swath navigation is a navigation process that includes GPS to guide equipment while reducing over-application and skips. This revolutionary method enables fertilizer and chemical applications to be performed throughout the day and/or night without the risk of expensive skips or overlaps. It also improves yield monitor accuracy in drilled soybean harvest. When adopting precision agricultural technology, it is necessary to generate precise application maps. Several ways are being evaluated to determine which method of calculating agricultural input application is the most efficient and profitable.

4. SENSORS AND SYSTEM APPROACHES IN HORTICULTURE

4.1 Non- destructive Testing in Pre and Post-harvest Operation

To fulfill customers' requirements and quality standards, fresh agricultural goods must be harvested at the appropriate time, handled carefully, and sorted. Many fruits, such as pears, stone fruits, and tropical fruits such as mango and avocado, are often picked when physiologically mature but unripe, and they subsequently ripened during storage. These fruits will not ripen in storage if harvested prematurely and will remain inedible. This entails that fruit maturity should be monitored too, preferably while the fruit is still on the tree. Several symposia and workshops are being conducted to address the state of the art in sensor research and its practical application [6]; Proceedings from the Sensors for Nondestructive Testing International Conference, 1997). Several outstanding contributions on the use of image processing for quality inspection of fruits and vegetables can be found in the literature. There are several commercial systems available. However, much more detailed visual inspection systems that can identify and combine information on shape, surface deterioration, blemishes, color distribution, and so on are required.

4.2 The Firmness Problem in Testing Fruit Quality

"Fruit and vegetable mechanical attributes, such as hardness could serve as an excellent indicator of maturity, degree of ripeness, and estimated shelf-life. As a result, methods for evaluating mechanical characteristics have been evaluated which helped in developing sorting techniques. A few of these approaches depend on the vibrational behavior of fruit and provide an overall sense of firmness" [7,8,9]. "The impact force of kiwi is used to determine fruit firmness in a pre-commercial fruit firmness grader for kiwi" [10]. "Several other researchers have been or are currently very active in this field, but no commercial non-destructive equipment for pre-harvest selection or online sorting of fruit based on internal qualities such as firmness is readily available or approved at this moment. The firmness of fruit is related to other fruit qualities such as chlorophyll fluorescence" [11,12] and NIR spectroscopy [13,14].

The key problem with all of these non-destructive technologies is that in the fruit industry, there is an established and commonly accepted firmness index based on the destructive penetrometer. Although it has been shown that non-destructive procedures are more reliable and repetitive than penetrometers, it will take more time to change the mindset of traders and supermarkets about the introduction of non-destructive firmness techniques. If it is successful, the possibility of evaluating fruit properties on the tree, analyzing each fruit on the sorting line, monitoring fruit properties during long-term storage under controlled atmosphere, and final quality control before marketing is. All of these measures will be non-destructive

4.3 Physiology, Sensors, and Consumers

To achieve the goals of providing fresh products of the highest quality to customers, a collaborative effort of fruit physiologists and engineers should be made. First, a quantitative definition of fruit maturity should be developed, followed by the identification of measurable features of maturity. Then, nondestructive techniques for assessing these properties can be developed to define the proper harvest time before harvest, and after harvest, to identify the total quality, degree of ripeness, and expected shelf-life of the product during storage and transportation to the consumer. Xray, NMR, volatile detection, vibration and acoustic emission analysis, ultrasonic testing, NIR spectroscopy, electrical impedance, image analysis, and other approaches are being investigated or developed. The obstacles include determining the physiological significance of the measurement parameters and linking them to customers' highly subjective, sensory assessments of quality. The radiation emitted by the fruit's surface may include one or more of the following components: regular reflectance, body reflectance, transmittance, and emissions (fluorescence, phosphorescence, and delayed-light emission). The qualities of the radiation that leaves the product's surface are determined by the product's characteristics and the incident radiation. As a result, identifying such optical qualities of an agricultural product might provide information on the product's quality attributes.

It has been discovered through the analysis of near-infrared reflectance and transmittance characteristics of numerous agricultural products that radiation in the near-infrared region of the spectrum may offer information about several quality aspects of agricultural products. The utilization of optical fibers and small optical components may enable on-tree reflectance spectroscopy of fruit to be used as a platform for harvest time prediction in the future. Combining optical and firmness data may improve prediction performance.

The reflection of light from an item is determined by its absorption capabilities as well as the material's scattering capabilities. The cell structure and cell wall integrity of the surface tissue of fruits and vegetables have a significant impact on light scattering. As a result, reflection at a slightly absorbed wavelength in the NIR may give a sensitive probe for the produce's near-surface qualities such as bruising or texture.

Fruits and vegetables undergo numerous changes throughout maturity, and the proportions of water, oil, and/or sugar gradually fluctuate as the fruit matures. The mobility of water, oil, and sugar hydrogen nuclei may also change. Furthermore, the concentration and mobility of water, oil, and sugar in fruits and vegetables are often associated with a multitude of other quality variables, including mechanical damage, tissue degradation, over-ripeness, decay, worm damage, and frost damage. NMR can identify many quality variables in fruits and vegetables since it can detect the differences in the concentration and mobility of water, oil, and sugar.

4.4 Kinetics of Respiration

Sugars, primarily sucrose, lipids, organic acids, and, on occasion, proteins are the major substrates involved in fruit respiration, and since they constitute the major food reserves of fruits, their gradual consumption possibly causes a loss of quality and a decline in shelf life. As a result, the rate of respiration is a reliable indicator of a fruit's shelf life in general. Knowledge and control of the respiration rate may be used to establish the appropriate storage conditions for fruits and, as a result, to prolong their storage life. Lowering respiratory activity is frequently associated with a slower rate of deterioration in fruits. Many factors influence the respiration rate, including cultivar, age, environmental variables (temperature, relative humidity, atmospheric composition), injuries, and so on.

Analyzing the cooling efficiency when a product is placed in large containers in stores and trucks can provide useful information about where excessive losses due to hot or low temperatures may occur. Unfavorable storage conditions cause stress in the produce, even after harvest, which might express as changed chlorophyll fluorescence. Quality change and shelf-life prediction models may integrate information on the physiological mechanisms involved in repetitions. When sensors for some of the metabolites involved in these processes become accessible, strong support for enhanced monitoring and process control would be laid. This is the foundation of a 'speaking fruit' technique to dynamic storage conditions.

5. SYSTEMS FOR QUALITY MAINTENANCE DURING LOADING TRANSPORTATION AND STORAGE

To ensure good quality at the time of consumption various intermediate handling and storage processes are required. Transporting multiple loads of fruits as well as vegetables together adds to the challenge of transport. The combination of discrete (packing) and continuous processes (climate, product quality) cannot be segregated under such conditions. Combined model development in packaging, temperature control, distribution, product quality change, route planners, and real-world tests resulting in a decision support system for traders and exporters to manage their transit. The goals are to fulfill the customer's expectations, load the containers for the highest possible space utilization, accomplish the best possible product quality at the right delivery time, and reduce transportation costs.

Researchers were also encouraged by the enzymatic processes involved in respiration to generate specifically designed enzymatic markers which may be simply deciphered. These time-temperature-integrators (TTI) [15] may then indicate any potentially faulty or improper storage conditions that may have occurred during handling.

5.1 Mechanical Damage of crops

Mechanical handling or harvesting may result in damage to the crops. It may also impose additional reinforcement or connecting force limitations on plant systems. In recent years, breakthroughs have been accomplished in understanding the varied roles of tissue structure, intercellular connection type, and cell wall mechanics about the elastic and failure behavior of vegetative tissue. Growing and storage circumstances influence these crops' attributes, but they are also genetically determined. In certain instances, there are indications that the genetic code has a role in tissue mechanics or product shape. This may result in crops that are more resistant to mechanical stressors during harvest, as well as possessing texture and meatiness characteristics that are preferred by either consumers or processors.

“At that point, biological markers may be employed per field to identify the sensitivity to injury in that field, and the machine action would be altered appropriately. This would be in addition to the present utilization of instrumented spheres to minimize damage during harvest and handling” [16,17].

5.2 Total Quality Assurance in Crop Production

The record of crop status during growth, as well as all treatments, into a geographical information system, may create significant data for management. Similarly, it can be observed that post-harvest conditions and treatments are also maintained for a management system. Making full use of these large datasets needs sophisticated data analysis technology, which is associated with the concept of data mining.

Furthermore, buyers, processors, and distributors of agricultural goods are increasingly being required to guarantee quality to their consumers. These producers will very definitely be required to ensure specific qualities, such as manufacturing, storage, and handling conditions, as well as health aspects. This may be done by maintaining digital records throughout the production process, as well as electronic IDs and recorders that remain with the product after harvest. These electronic devices may be accessible regularly to verify product conditions, even during transit. It is essential to agree to guarantee the confidentiality and reliability of this data.

5.3 Studies of Precision Farming Techniques in Fruit Crops

1. Gebbers et al. [18] developed a method for capturing Spatio-temporal crop and soil data in apple orchards on heterogeneous soils using optical and geo-electrical sensors.

   - Fruit spectra were recoded with NIR.
   - Geo-electric soil mapping was done with the resistivity meter
   - Water stress zones were identified by correlating soil electro-conductivity and water content.

2. Zhi et al. [19] applied Hyper Spectral remote sensing technology to monitor and forecast peach crop yields and reported that the technique can be used for yield mapping and VRT input application.
3. In southern Brazil, Neto and Miranda [20] used high spatial resolution satellite imagery to count orange trees in an orchard and determine canopy volume.
4. At harvest time, Zaman et al. [21] placed a 10 MP 25-bit DSLR camera with a tripod at a height of 1m from the ground for assessing the blueberry yield. In a custom image produced by computer software, the blue pixels were analyzed and results were found to be equal to the yield estimate through the quadrant method.
5. Jarnagin [22] utilized short-range RADAR technology to detect tree foliage in control of an Air Blast Orchard Sprayer.
6. Ayyasomayajula et al. [23] used highly advanced picometer and analysis tools like Feature Analysis and Picometery Aerial Imagery Software to perform automated tree counting from ortho and oblique pictures and estimate tree height using oblique images.
7. Waldo and Schuman [24] investigated the geographical variability of soil water under the canopy of citrus trees in Central Florida. By Installing 'Volumetric Soil Water Monitoring Sensors' in the root zone of the tree canopy.
8. Pfenning et al. [25] used 'Passive Sensor Technology' with a Leica S1 Pro Digital Imager to standardize the timing and dosage of N fertilizer treatment to tomatoes To fine-tune the rate of N application, optical reflectance in the reading was used.
9. Lee et al. [26] used a 3CCD Progressive Scan Digital Color Camera to develop a vision-based citrus yield mapping system for a canopy shake and catch harvester.
10. Kohono et al. [27] devised a grading and harvesting robot with two machine vision, a NIR system, GPS, and a driving mechanism for yield mapping, harvesting, and grading citrus fruits. Fruit color, size, shape, defects, sugar content, tree leaf color, and canopy size can all be precisely measured and entered into a database corresponding to the tree's location.
11. Molin et al. [28] compared precision agriculture approaches like yield mapping and variable rate fertilizer application to conventional fertilizer application. Fields fertilized using VRT technology were shown to be considerably high yielders than their conventional models.
12. Miglioli et al. [29] designed a precision harvester equipped with GPS, two receptacles, and NIR sensors to harvest grapes of the highest possible quality for winemaking.
13. Kondo et al. [30] commercialized Grading Robots for apples, peaches, pears, and other deciduous fruits at SI Seiko Co. Ltd. These robots are equipped with digital image cameras, auditory devices, NIR/NMR sensors. Before harvesting, the fruits are thoroughly inspected in 4D.

5.4 Hurdles in Implementing Precision Farming

- Some field plots are fragmented, making even modest mechanization impossible.
- GIS and GPS facilities are yet to reach the hands of even the rich farmers.
- User culture and beliefs - Because farmers in underdeveloped nations are often economically poor, high-tech farming approaches are not widely adopted.
- The soil and other analytical facilities are also a limiting factor.
- The majority of inputs, such as water-soluble fertilizers, hybrid seeds, annual fruit seeds, and seedlings, are expensive, and only a few farmers can afford them.
- Existing post-harvesting infrastructure and market chains are imperiled and unable to store or transport the produce.
- High cost of sophisticated machines/equipment also acts as a limiting factor.
- Small farm size
- Lack of success stories
- Heterogeneity of cropping systems and market imperfections
- Land ownership, infrastructure, and institutional constraints
- Lack of local technical expertise
- Knowledge and technical gaps
- Data availability, quality, and costs

5.5 Precision farming Development Center (PFDC)

Under the National Horticulture Mission, around 17 PFDCs have been built in various agro-climatic areas (NHM). Greenhouse construction, mulching, shade netting, and plastic tunnels are also encouraged.

6. PDFC AT SOLAN

PDFC has been engaged in the construction of Drip irrigation, sprinkler irrigation, fertigation, in-situ moisture conservation, anti-hail nets, anti-bird nets, shade nets, protected vegetable cultivation, and LDPE water storage tanks. Drip irrigation tests on numerous economically valuable crops, including crop geometry research in vegetables, are being done through this facility to reduce the cost of drip irrigation installation. Under protected cultivation, a study has been undertaken on the cultivation, mulching, and multiplication of vegetable crops in polyhouse environments, shade in ornamental plants, and hail protection in fruit crops. The center has given detailed recommendations on drip irrigation and plastic mulching in pea and tomato harvests; crop geometry in pea, tomato, capsicum, and cauliflower crops; and fertigation in pea and tomato crops. For economically useful vegetables, the Precision Farming Development Centre has released 24 suggestions in crop geometry, plastic mulching, micro-irrigation, protected cultivation, and anti-hail nets.

7. PDFC AT IARI, NEW DELHI

12 field tests were conducted, including testing of modified design of an energy-saving greenhouse, comparison of various shade nets, a performance assessment of different filters, and a comparative study of alternative greenhouse designs using simulation and modeling. Furthermore, the PFDC would perform crop-specific studies on potato, okra, and garlic utilizing greenhouse, fertigation, shade net, drip, and GIS. Awareness and training seminars for farmers, officials, and others are being conducted in areas near Delhi such as Ghaziabad and Gurgaon. Technology demonstrations are carried out on both research farms and farmers' fields.

7.1 Strategies for Implementing Precision Farming in India

“The current situation of precision agriculture in India is limited by the lack of sufficient measurement and analysis methodologies for agronomically important facets” (National Research Council, 1997). To support both research and production, high-precision sensing and data management technologies must be created and verified. Data quality/availability constraints have become a key barrier to the demonstration and implementation of precision techniques. Precision agriculture requires a collaborative effort on the part of scientists, farmers, and the government. The following methods might be used to put precision farming into practice in the nation.

1. To expand and standardize precision agriculture there is a need to create a team of scientists from different fields like engineers, manufacturers, and economists to work together.
2. Establishment of farmer’s co-operatives because many of the precision agricultural

instruments are quite expensive (GIS, GPS, RS, etc). (GIS, GPS, RS, etc.).
3. Government laws prohibiting farmers from using agricultural inputs haphazard inputs andso generating ecological/environmental imbalance will encourage the farmer to seek an alternate strategy.
4. Pilot studies need to be conducted in farmer's fields to illustrate the effects of precision agriculture implementation.
5. Creating awareness amongst farmers about the effects of applying unbalanced dosages of agriculture inputs like irrigation, fertilizers, insecticides, and pesticides.

With the assistance of the Government of India's Department of Space, we are promoting awareness and making available the potential of space technology in precision farming. Pilot studies were now undertaken in agricultural farms of the ICRISAT, the Indian Council of Agricultural Research, and the Agricultural Universities, as well as in farmers' fields, this must be promoted within the farming community. The pilot studies are primarily aimed at delineating homogeneous zones in terms of soil fertility and crop yield, estimating potential yield, conducting yield gap analysis, monitoring seasonally-variable soil and crop conditions using optical and microwave sensor data, and matching farm inputs to bridge the potential-to-actual yield gap using Spatial Decision Support Systems (SDSS). The test sites are located throughout a very extensive region of the Indian subcontinent, covering a cross-section of agro-climatic zones and several major crops such as wheat, rice, sorghum, pigeon pea, chickpea, soybean, and peanut. If the outcomes of the pilot research are extrapolated using a bigger database of farming conditions, it may be possible to bring a greater region under precision farming.

8. CONCLUSION

It is said, *"Precision agriculture is a phrase that captures the imagination of many concerned with the production of food, feed, and fiber."* Precision farming is a technologically advanced way of application of GIS, GPS, and computer-aided techniques. It may be difficult for resource-poor farmers to gain access to and utilize this technology to enjoy the benefits. However, the strategy has the potential to decrease the productivity of high-value crops, crops cultivated under contract, and crops farmed in vast contiguous regions.

There are numerous criteria for nondestructive (or destructive) sensing of quality or, more precisely, one or more quality parameters for a particular product. Some of these sensing technologies have been produced as generic versions, but they still require considerable adjustment and testing before they can be utilized successfully on varied products. It would be highly advantageous to have sensing devices that can forecast product quality in the future. A method for achieving this objective is to utilize models that represent the biological mechanisms that influence quality improvement. There has been a lot of improvement in this field. Because of the complexity of biological-physiological processes and their interplay with external environmental elements, extensive use of experimental or empirical models is necessary. It suggests that greater work in sensor information and models is necessary. In approach to international commerce and market potential, a systems approach to quality management is gaining favor. Bringing all information on biological and technical processes, as well as the function of sensors and sensory assessment, together in a holistic management and control method, remains a difficult task. Several pieces of information may still be needed. However, in the end, it may benefit producers, trade groups, and consumers in having a more direct interaction to offer the market things of the best quality.

The key method for progress is concurrent engineering in biology, mechanics, electronics, and other domains. This is a one-of-a-kind challenge to develop innovative art based on knowledge and understanding of living and non-living things. Precision farming in horticulture can arise from such an attempt, in which items of precisely specified quality are created and given to the market using precision processes throughout growth, harvest, storage, and handling.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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