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Precision Farming for Sustainable Agriculture

Abhilash Joseph E. [1*], Abdul Hakkim V.M. [2] and Sajeena, S. [3]
[1.] School of Biotechnology, National Institute of Technology, Calicut NIT Campus PO, Kozhikode, Kerala – 673601, India.
[2.] Professor (Soil and Water Conservation Engineering) College of Agriculture, Kerala Agricultural University, Padannakkad (P.O), Kasaragode (Dt.), Kerala - 671314, India.
3. Assistant Professor (Soil and Water Conservation Engineering) Krishi Vigyan Kendra (KVK), Malappuram, KCAET Campus Tavanur (P.O.), Malappuram (Dt.), Kerala – 679573, India.
*Corresponding author email id: abhilashjosephe@gmail.com

***Abstract* – Agriculture faces critical challenges for feeding the growing global population with the limited or depleting fresh water resources. Innovative irrigation practices are essential to enhance water use efficiency and to reduce the environmental burdens. Advanced irrigation systems and technologies allow site-specific application of irrigation water and fertilizers within the field to improve water use efficiency by reducing water wastage for sustainable crop production, especially in arid and semi-arid regions. Precision agriculture uses the inputs most efficiently and judiciously to maximize productivity and profitability with minimum impact on soil and environment. Precision in terms of both time and quantity of inputs and agronomic practices envisages a prospect, which can help in decreasing the cost of production without any adverse effect on soil and environmental health. Thus the intention of precision farming is to match agricultural inputs and practices with the localized conditions within a field to do the right thing in the right place, at the right time and in the right way.**

***Keywords* – Precision Agriculture, Fertigation, Site Specific Farming, Mulching, Protected Cultivation.**

I. INTRODUCTION

Agriculture is the largest consumer of the available fresh water worldwide, as plant growth largely depends on the availability of water in the soil. According to the Food and Agriculture Organization (FAO), current irrigated area throughout the world is approximately 300 million ha, and projection to 2050 suggests growing scarcities of water resources for agriculture. Although water is a renewable resource, irrigation systems have been under pressure with lower supplies of water. This situation has amplified the intensity of food insecurity, climate change, and poverty globally. The greatest challenge to agriculture is to provide food for almost 8 billion people around the world in the advent of depleting freshwater resources [1]. The agriculture sector is undergoing a transformation driven by new technologies, which seems to be very promising as it will enable this primary sector to move to the next level of farm productivity and profitability [2]. Precision agriculture, which consist of applying inputs (what is needed) when and where it is needed, has become the third wave of the modern agriculture revolution i.e., the first was mechanization and the second the green revolution with its genetic modification [3], and nowadays, it is being enhanced with an increase of farm knowledge systems due to the availability of larger amounts of data. The United States Department of Agriculture (USDA) has reported in 2016 that precision agriculture technologies increased net returns and operating profits [4]. With respect to the environment, new technologies are increasingly being applied in the farms to maintain the sustainability of farm production. However, the adoption of these technologies involves uncertainty and tradeoffs.

Innovative Irrigation Practices

Various innovative practices can gain economic advantage while reducing environmental burdens such as water abstraction, energy use, pollutants etc. [5]. Farmers can better adopt extra technologies, enhance their skills in soil and water management, tailor cropping patterns to lower water demand and usage, reduce agrochemical

inputs, etc. Water efficient practices potentially enhance the economic viability and environmental sustainability of irrigated agriculture, without necessarily reducing water usage.

Innovative irrigation technology is generally encouraged for raising water use efficiency along with multiple benefits, but these remain elusive in practice and the practical limitation is the use of water wasting irrigation technologies. There is immense scope for use of new technologies (e.g. soil moisture and canopy sensors) to better match irrigation with pant needs and good agricultural practices, such as conservation tillage, management of soil fertility and water retention capacity, and scheduling of irrigation during night to reduce evaporation [6]. Water use efficiency provides complementary benefits, such as reduced energy needs or other environmental benefits, will also deliver better results. The modernization of irrigation systems has steadily progressed and water productivity has also improved considerably [7]. Improperly managed 'hi-tech' systems can be as wasteful and unproductive as poorly managed traditional systems [8]. When incorrectly applied, irrigation technology 'can cause losses arising on investments made by farmers, thus decreasing the economic water productivity index and the overall sustainability' [9].

Although micro-irrigation systems are considered as 'efficient technologies', to gain the extra benefits of such technology, most important is operation and maintenance, regardless of the irrigation method used [10]. The attainable application efficiencies for different irrigation methods, assuming irrigations are applied to meet the crops' water needs [11, 12]. Micro irrigation has the potential to achieve the highest uniformity (90%) in water applied to each plant, yet poor uniformity and application efficiency can result from various causes inadequate maintenance, low inlet pressure or pressure fluctuations, emitter clogging and inadequate system design [13]. Consequently, micro irrigation technology has on-farm efficiencies varying from 0.7 to 0.95 [11].

The irrigation method is promoted if the technology brings various benefits, farmers seek to maximize net income rather than water productivity. Innovative technologies can achieve the full potential benefits only through appropriate technical advice, and farmers lack a knowledge system for anticipating effects of specific irrigation practices or for retrospectively evaluating their irrigation efficiency.

Tools Used in Precision Farming

Remote Sensing and Sensors for Precision Farming

Remote sensing techniques play an important role in precision farming by providing continuous acquired data of agricultural crops. Precision farming needs information about mean characteristics of small and relatively homogeneous management zones in the agricultural land. This is essential for the acquisition of data about soil, vegetation and other parameters that are amenable for remote sensing. Remote sensors for image of vegetation, which is growing on different soil types with different water availability, substrate, impact of cultivation provide information about the following applications:

Soil properties sensing: soil structure, texture, moisture, nutrients and physical condition.

Crop sensing: plant population, stress and nutrient status in the plant.

Yield monitoring systems: crop yield; harvest swath width; crop moisture.

Variable rate technology systems: fertilizer flow, weed detection, pressure sensors, crop condition assessment, agricultural drought assessment, pests and diseases, land capability and irrigation requirement can al

-so determine with this technology.

Global Positioning System

GPS is a crucial tool of precision farming used in different agricultural processes. The Global Positioning System (GPS) is a collective network of satellites orbiting the earth, which receives and transmits real-time data. This real-time collection of data gives accurate position information about the agricultural land, which in turn leads to efficient analysis and manipulation of large amounts of geospatial data. Precision agriculture is the collection of timely geospatial information on soil and plant requirement and prescribing site specific actions to protect the crops their by increasing agricultural productivity.

Drones

Recently, drones are used in agricultural activity to prevent, cure and detect pests and diseases of the crops. Like any other aerial vehicles, drones also have pilots, which control the equipment from the ground. Drones are attached with different equipment for usage purposes and flown over the farm field captures high-resolution images of any pest, diseases, rogue plant or potential threats to the crop. This aerial imagery helps to manage agricultural activity more effectively. This technology allows farmers to gain oversight of nutritional or protection requirements of crops, using infrared cameras and other visual capturing mediums, potentially saving them time and money by allowing for precision applications of chemicals, fertilizers or crop irrigation. Multispectral and hyper spectral imagery are often used to measure the responses of plants in the visible and near infrared parts of the electromagnetic spectrum to remotely detect plant stress. Sometimes prayers are attached to drones for applying pesticides in the fields and also used to release beneficial insects over crops, which cures and prevents the increase of diseases. Furthermore, stereo vision camera is used as the depth sensing tool to identify different objects easily, which is not possible with ordinary camera.

Spatial Variability of Soil Properties

Management of spatial and temporal variability, through the application of technologies and principles associated with all aspects of agriculture for improving production and environmental quality is termed as precision agriculture. To understand the variability and to give site specific agronomic recommendations, management of variability is essential, for which the available technologies such as Remote Sensing (RS), Geographical Information System (GIS), Global Positioning System (GPS), Soil Testing, Yield Monitors and Variable Rate Technology are widely used.

The cause of nutrient depletion is due to the imbalance occurred between input and output in a soil system. Maintenance of proper nutrient status in soil is the key factor for obtaining high yield quality of the agricultural products. Significant variation in crop growth and yield can be achieved if the management practices are recommended based on the information derived from the GIS Database. Recent research in precision agriculture has focused on use of management zones as a method to more efficiently apply crop inputs such as fertilizers across varying agricultural landscapes. Management zones, in the context of precision agriculture, are field areas possessing homogenous attributes in landscape and soil condition, which can potentially serve as a basis for variable fertilizer application. While using management zones to characterize spatial variability in soil and crop properties in site-specific studies, it is equally important to consider the temporal effects of climate variability on expression of spatial variation in crop yields. To maximize the yield to a great extent, supplying nutrients as

such in the soil will not serve, as the whole quantity of applied nutrients are not supplied to the plants and the requirement varies with different zones in the soil. Therefore it is a must to analyse the soil nutrient status in various zones and the nutrients are to be supplied according to the site specific requirement. Soil fertilizer recommendations in modern crop production rely on laboratory analysis of representative soil samples. The accuracy and precision of the fertilizer recommendation can be improved by considering the factors influencing nutrient variability. The fertilizer and water management varies with different zones, which plays a vital role in determining the yield and quality of farm produce. The term "fertility" refers to the inherent capacity of a soil to supply nutrients to plants in adequate amounts and in suitable proportions. The term "nutrition" refers to the inter-related steps by which a living organism assimilates food and uses it for growth and replacement of tissue. Previously, plant growth was thought of in terms of soil fertility or how much fertilizer should be added to increase soil levels of mineral elements. Most fertilizers were formulated to account for deficiencies of mineral elements in the soil. The amount of fertilizer, lime, and other amendments recommended for soil improvement should allow optimum growth without undue risk of polluting the natural run-off. It is important not to apply more than is recommended; this will assure greatest plant response with the least chance of plant damage or drainage water pollution. The purpose of a soil test is to supply enough information to make a wise fertilizer and soil amendment choice. When the fertilizer is applied in right dose based on soil test results, the crop response will be excellent. Plant nutrition management studies are highly helpful to the farming community, since they provide information on optimum requirement of nutrition to cultivate a crop. It also minimizes the wastage of fertilizer application to a greater extent.

II. WATER CONSERVATION

Efficient use of available irrigation water is essential for increasing agricultural productivity for the alarming global population. Efficient management of water resources is essential to meet the increasing competition for water between agricultural and non-agricultural sectors and the present day share of 80 per cent of water used for agriculture is anticipated to be reduced by 70 per cent in the coming decade. This necessitates scientific management of available water resources, particularly in agricultural sector. Sustainability of any system requires optimal utilization of resources such as water, fertilizer and soil. Apart from the economic considerations, the adverse effect of non-judicious use of water and fertilizers on the environment can have far reached implications. There is a need to develop agro technologies, which will help in sustaining the precious resources and maximize the crop production, without any detrimental impact on the environment. Water availability for irrigation is going to be a major constraint for agriculture in the near future. Efficient management of available water resources is hence necessary for expanding the area under irrigation. Bringing more area under irrigation would depend largely upon efficient use of water. In this context, micro irrigation has most significant role to achieve not only higher productivity and water use efficiency but also to have sustainability with economic use and productivity. Fertilizer management is the most important agro-technique, which controls development, yield and quality of a crop. Fertilizer use efficiency is only 50 per cent in conventional practice of soil application. Location specific fertilizer management practices are essential for increasing fertilizer use efficiency for optimizing the fertilizer input and maximizing the productivity.

Precision agriculture uses the inputs most efficiently and judiciously to maximize productivity and profitability with minimum impact on soil and environment. Precision in terms of both time and quantity of

inputs and agronomic practices, envisages a prospect, which can help in decreasing the cost of production and not having any adverse effect on soil and environmental health. Thus the intent of precision farming is to match agricultural inputs and practices to localized conditions within a field to do the right thing in the right place, at the right time and in the right way. Precision farming basically depends on measurement and understanding of variability. The accuracy in assessment of the variability, its management and evaluation in space-time continuum in crop production decides the success in precision farming.

Although water is a renewable resource, its availability in appropriate quality and quantity is under severe stress due to increasing demand from various sectors. Agriculture is the largest user of water, which consumes more than 80% of the country's exploitable water resources. The overall development of the agriculture sector and the intended growth rate in GDP is largely dependent on the judicious use of the available water resources. While the irrigation projects (major and medium) have contributed to the development of water resources, the conventional methods of water conveyance and irrigation, being highly inefficient, has led not only to wastage of water but also to several ecological problems like water logging, salinization and soil degradation making productive agricultural lands unproductive. It has been recognized that use of modern irrigation method like drip irrigation is the only alternative for efficient use of surface as well as ground water resources. Hence, this scheme on Micro Irrigation (MI), which aims at increasing the area under efficient methods of irrigation. Apart from the economic considerations, the adverse effect of injudicious use of water and fertilizers on the environment, can have far reached implications. There is a need to develop agro-technologies, which will help in sustaining the precious resources and maximize the crop production, without any detrimental impact on the environment. Water availability for irrigation is going to be a major constraint for agriculture in the near future. Efficient management of available water resources is hence necessary for expanding the area under irrigation. Bringing more area under irrigation would depend largely upon efficient use of water. In this context, micro irrigation has most significant role to achieve not only higher productivity and water use efficiency but also to have sustainability with economic use and productivity. Fertilizer management is the most important agro-technique, which controls development, yield and quality of a crop. Fertilizer use efficiency is only 50 per cent in conventional practice of soil application. Location specific fertilizer management practices are essential for increasing fertilizer use efficiency for optimizing the fertilizer input and maximizing the productivity.

Need for Efficient Irrigation

Efficient use of irrigation water is an important means for increasing the productivity. The surface irrigation methods, which are widely, practiced leads to enormous loss of water through seepage and evaporation. This is due to poor distribution of water in farm as a result of inadequate land preparation and lack of farmer's knowledge in the application of water, which leads to excess application and deep percolation loss. Generally, under surface irrigation methods, only less than one half of the water released reaches the plants. The unscientific use of water has resulted not only in wastage of water but also has caused soil erosion, salinization and water logging, which ultimately degraded the quality of the two basic natural resources - soil and water.

Components of Precision Farming

Micro Irrigation

To bring more area under irrigation, it has become necessary to introduce new irrigation techniques for econ-

-omizing the use of water and to increase productivity per unit of water. Micro irrigation is a method of delivering slow, frequent applications of water to the soil near the plants through a low pressure distribution system and special flow control outlets. It can be considered as an efficient irrigation method, which is economically viable, technically feasible and socially acceptable. It is the slow and regular application of water directly to the root zone of the plants through a network of economically designed plastic pipes and low discharge emitter. It enables watering the plants at the rate of its consumptive use thereby minimizing the losses such as deep percolation, runoff and soil evaporation. Micro irrigation can be classified into drip irrigation, spray jets, bubbler irrigation, micro sprinklers and foggers, all of which have similar design and management criteria.

These systems deliver water to individual plants or rows of plants. The outlets are generally placed at short intervals along small tubing and unlike surface or sprinkler irrigation, only the soil near the plant is watered. The outlets include emitters, orifices, bubblers and sprays or micro sprinklers.

Advantages of Micro Irrigation

Micro irrigation has lot of advantages over traditional irrigation such as, water saving, enhanced plant growth and yield, uniform and better quality of agricultural products, efficient and economic use of fertilizers, less weed growth, no soil erosion, flexibility in operation, easy installation, labour saving, suitable to all types of land terrain, saving of land as no bunds are required and minimum diseases and pest infestation.

Scientific method of cultivation and judicious use of all the inputs, especially of water, is called upon to become cost competitive. Keeping in view acute water scarcity in many basins, efforts were made to introduce most efficient micro irrigation system at farms around 1970. Through the good management of micro irrigation systems, the root zone water content can be maintained near field capacity throughout the season providing a level of water and air balance close to optimum for plant growth. In addition, nutrient levels, which are applied with water through the system (fertigation), can be controlled precisely. Fertigation gives successful results in terms of yield, saving in fertilizer and improvement in quality of the produce. During the dry season in humid areas, micro irrigation can have a significant effect on quantity and quality of yield, pest control and harvest timing.

Fertigation

Efficient crop production requires efficient utilization of soil water and soil fertility. Placement of fertilizers in the correct zone of moisture availability is important to maximize fertilizer efficiency. Fertigation is the method of application of soluble fertilizer with irrigation water. Fertigation is a prerequisite for drip irrigation. Since the wetted soil volume is limited, the root system is confined and concentrated. The nutrients from the root zone are depleted quickly and a continuous application of nutrients along with the irrigation water is necessary for adequate plant growth. Fertigation offers precise control on fertilizer application and can be adjusted to the rate of plant nutrient uptake.

Advantages of Fertigation

1. Saving of energy and labor.
2. Flexibility of application (nutrients can be applied to the soil when crop or soil conditions would otherwise

prohibit entry into the field with conventional equipment).

3. Convenient use of compound and ready-mix nutrient solutions containing also small concentrations of micro nutrients which are otherwise very difficult to apply accurately to the soil.
4. The supply of nutrients can be more carefully regulated and monitored.
5. The nutrients can be distributed more evenly throughout the entire root zone or soil profile.
6. The nutrients can be supplied incrementally throughout the season to meet the actual nutrition requirements of the crop.
7. Soil compaction is avoided, as heavy equipment never enters the field.
8. Crop damage by root pruning, breakage of leaves, or bending over is avoided, as it occurs with conventional chemical field application techniques.
9. Less equipment may be required to apply the chemicals and fertilizers.

Mulching

Mulching is an ancient agricultural practice, "perhaps as old as agriculture itself". It affects water conservation through water capture and retention. With respect to water capture, mulches protect the soil surface against raindrop impact, thereby minimizing aggregate dispersion and surface sealing. If porous, such mulches allow direct water infiltration into soil or retard water flow across the surface, thereby providing more time for infiltration. Different materials have been used as mulches [14]. Mulches of crop residues and other plant materials (straw, stover, leaves, corn cobs, cotton gin trash, wood chips, and sawdust) are inexpensive, often readily available, and porous, thus allowing water to readily enter soils. Other porous materials used a mulch are gravel, rocks, coal, bitumen, and similar granular materials. In general, mulch effectiveness for increasing water capture increases with the amount on the soil surface [14].

Plastic film mulches are used extensively for agricultural crops in many countries and have increased crop yields by 44 to 165% as compared with yields on unmulched areas. Their main benefit with respect to water conservation is reduced evaporation, but they do provide water capture benefits if provisions exist for water to enter the soil. The increase was attributed to improved water conservation through both an improved water supply to plants and reduced evaporation [15]. In addition, they result in improved water retention by reducing weed competition for water because they effectively control weeds. Rapid channeling of water into soil is achieved by vertical mulching, which provides a slot in soil filled with crop residues (or other porous materials) that is open to the surface. Use of vertical mulching substantially increases soil water storage (up to 41%) under some conditions. A variation of vertical mulching is slot mulching (mentioned previously), which has been shown to reduce runoff from frozen soil [16].

Advantages of Mulch

There are many benefits to using plastic mulch in vegetable production. Although its use does not guarantee each benefit, the following advantages are generally realized.

1. Earliness. Earlier plant growth and earlier crop production are two of the primary benefits of using black and clear plastic mulches. Black plastic mulch can result in an earlier harvest (7 to 14 days) while clear pla-

-stic can mean a 21-day earlier harvest in many conditions.

2. Reduced evaporation. Soil water loss is reduced under plastic mulch. As a result, a more uniform soil moisture is maintained and irrigation frequency may be reduced. Plant growth on mulch can be twice that of unmulched soil. Because these larger plants will require more water, mulching is not a substitute for irrigation.
3. Complete elimination of weed problems. Black and white-on black mulches will reduce light penetration to the soil. Weeds generally cannot survive under the mulch.
4. Reduced fertilizer leaching. Excess water runs off the impervious mulch. Fertilizer beneath the mulch is not lost due to leaching, so fertilizers are optimally used and not wasted.
5. Reduced soil compaction. Soil under the plastic mulch remains loose, friable and well-aerated. Roots have access to adequate oxygen and microbial activity is enhanced.
6. Root pruning eliminated. Cultivation is eliminated, except for the area between the mulched strips. Weed growth in these areas can be controlled by a labeled herbicide.
7. Cleaner product. The edible product from a mulched crop is cleaner and less subject to rots because soil is not splashed on the plants or fruit. Note: This is accomplished by a bed that is firm and tapered away from the row center and plastic that is tight to encourage water runoff. There should be no puddles on the mulched beds.
8. Increased growth. Mulch film is nearly impervious to carbon dioxide, which is necessary for photosynthesis. Research has shown that high levels of carbon dioxide may build up under the plastic. Because the film does not allow the gas to penetrate, it has to escape through the holes punched for the plants. This creates a "chimney effect," resulting in abundant CO_2 for the actively growing leaves.
9. Aids fumigation. Mulches increase the effectiveness of soil fumigant chemicals. Because of the impervious nature of the plastic mulch, it acts as a barrier to gas escape and keeps gaseous fumigants in the soil.
10. Reduction in drowning of crops. Water is shed from the row area by the tapered bed; excess water runs off the field, reducing drowning and other excess soil water stresses.

Protected Cultivation

Protected cultivation is the most modern approach that has been spread extensively world over in the last few decades. It is a controlled environment agriculture with highly productive, conservative of water and land and also protective of the environment [17]. The technology involves the cultivation in a controlled environment of temperature, humidity, light, soil, water, fertilizers etc. manipulated to attain maximum productivity [18]. Protected cultivation technology has been growing rapidly throughout the world and particularly in India due to unpredictable weather pattern, global warming, biotic and abiotic stress related symptoms prevailing and affecting our entire agriculture habitat.

Advantages of Protected Cultivation

The following are the different advantages of using the green house for growing crops under controlled environment:

1. Throughout the year crops can be grown in a greenhouse due to availability of required plant environmental conditions.
2. The productivity of the crop is increased considerably.
3. Superior quality produce can be obtained as they are grown under suitably controlled environment.
4. Gadgets for efficient use of various inputs like water, fertilizers, seeds and plant protection chemicals can be well maintained in a green house.
5. Effective control of pests and diseases is possible as the growing area is enclosed.
6. Percentage of germination of seeds is high in greenhouses.
7. The acclimatization of plantlets of tissue culture technique can be carried out in a green house.
8. Agricultural and horticultural crop production schedules can be planned to take advantage of the market needs.
9. Different types of growing medium like peat mass, vermiculate, rice hulls and compost that are used in intensive agriculture can be effectively utilized in the greenhouse.
10. Export quality produce of international standards can be produced in a green house.
11. When the crops are not grown, drying and related operations of the harvested produce can be taken up utilizing the entrapped heat.
12. Greenhouses are suitable for automation of irrigation, application of other inputs and environmental controls by using computers and artificial intelligence techniques.

Advantages of Precision Farming

The most prominent problems faced by the agriculture sector are low or non-availability of an efficient and productive workforce in developed as well as in developing countries. More precise and effective utilization of inputs can be introduced in agriculture with mechanization and can work without fatigue and more accuracy. Many agricultural researchers are trying to develop robots which can take care of plants as human do; i.e., from planting to harvesting they perform all other agricultural activities too. Various types of robots were designed for harvesting apple, strawberry and citrus fruits. Robots occupy the position of human and perform the task with more perfection. Using technological advancements in precision agriculture will definitely aid in boosting the yields of crops. Various plant diseases, insects as well as weeds would be noticed with the help of sensors and can also minimize the human interference. Pesticide spraying in required amounts at required locations can be mechanized in precision agriculture. The information from sensors can be collected by humans and analyzed for different further studies. Due to the ever increase in demand for food and shortage of labour, farmers are increasingly relying on precision agriculture for their necessity. Such advancement in systems enables labour and time saving, along with increased crop yield.

Future Prospects

Conventional farming follow a group of prescribed manuals or guidelines during fertilizer application. The development of crop sensors will change his scenario, as sensors will provide site specific information on the

precise amount of nutrient requirement for a farm. Tons of fertilizers and pesticides can be saved and also conserve valuable soil resources. With draining soil fertility levels and increasing urbanization, land for farming tomorrow is going to be costlier than before. The vertical farming technique using soil less medium and using artificial lights are the long term solutions. This technique will reduce cost, produce more, protect crops from inclemency and ultimately produce food which is safe and healthier. Labourers will be replaced by agricultural robots with sensors for collecting real time information in the agriculture fields. The data recorded will be shared to the cloud, analyzed and automatic reports are generated in terms of excess moisture, nutrient deficiency and many more insights of the farm. Storing and analysing lakhs of data will help real time decisions making very quickly and with greater accuracy and precision. Feedback on various plants such as their height colour and diseases and their life span will help to increase productivity in a particular farm or field or area.

III. CONCLUSION

Precision farming is one of the most scientific and modern approaches to sustainable agriculture, which has gained momentum towards the end of 20th century. Precision farming actually is the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production. It is a system for better management of farm resources. Precision farming offers a variety of potential benefits in profitability, productivity, sustainability, crop quality, food safety, environmental protection, on farm quality of life and rural economic development. This scenario forces us to think about efficient irrigation system like micro irrigation combined with fertigaion to have more crop per drop. Precision farming is essential for serving dual purpose of enhancing productivity and reducing ecological degradation and is a system for better management of farm resources. To make reliable soil interpretations and accurate predictions of soil performance at any particular location, complete knowledge of the variability of soil properties is a must, which forms the basic step for precision agriculture development.

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AUTHOR'S PROFILE

First Author
Abhilash Joseph E., Adhoc faculty, School of Biotechnology, National Institute of Technology, Calicut NIT Campus PO, Kozhikode, Kerala – 673601, India.

Second Author
Abdul Hakkim V.M, Professor (Soil and Water Conservation Engineering) College of Agriculture, Kerala Agricultural University, Padannakkad (P.O), Kasaragode (Dt.), Kerala – 671314, India.

Third Author
Sajeena S., Assistant professor (Soil and Water Conservation Engineering) Krishi Vigyan Kendra (KVK), Malappuram, KCAET Campus Tavanur (P.O.), Malappuram (Dt.), Kerala – 679573, India.