APPLICATION OF REMOTE SENSING AND GIS IN PRECISION FARMING

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1. Introduction

Historically, agronomic practices and management recommendations have been developed for implementation on a field basis. This generally results in the uniform application of tillage, fertilizer, sowing and pest control treatments at a field scale. Farm fields, however, display considerable spatial variation in crop yield, at the 'within-field' scale. Such uniform treatment of a field ignores the natural and induced continuous variation in soil properties, and may result in zones being under- or over-treated, giving rise to economic and environmental problems associated with this inefficient use of resource inputs. The more substantial of these problems being: economically significant yield losses, excessive chemical costs, gaseous or percolatory release of chemical components, unacceptable long-term retention of chemical components and a less than optimal crop growing environment.

Precision Farming (PF), in the form of Site-Specific Management, offers a remedy to many of these concerns. The philosophy involves matching resource application and agronomic practices with soil properties and crop requirements as they vary across a site. PF has three requirements such as (i) ability to identify each field location, (ii) ability to capture, interpret and analyze agronomic data at an appropriate scale and frequency, and (iii) ability to adjust input use and farming practices to maximize benefits from each field location. Collectively, these actions are referred to as the "differential" treatment of field variation as opposed to the "uniform" treatment underlying traditional management systems. The result is an improvement in the efficiency and environmental impact of crop production systems. It is sometimes called ‘Prescription farming’, site-specific farming’ or ‘variable rate technology farming’.

2. Developments which Prompted Precision Farming

Many technological developments occurred in 20th century led to the development of the concept of precision farming. The success of the precision farming system relies on the integration of these technologies into a single system that can be operated at farm level with sustainable effort. These technological developments are as follows.

2.1 Computer and Internet

The computers and internet are the most important component in enabling the precision farming possible as they are main source of information processing and gathering. The high-speed computer has made faster processing the data gathered during precise management of the land parcel. Internet, which is a network of computers, is the most recent development among all these technologies. The Internet has bridged the gap between the information provider and the user. In agriculture, like any other form of business, internet has the capability to supply timely data about changing conditions.

2.2 Global Positioning System

The development of the publicly available global positioning system (GPS) has opened new doors in opportunities for spatial data. This is a passive positioning system from a constellation of 24 orbiting radio-navigation satellites. They provide continuous position data in two or three dimensional in real-world coordinates.
More recently farmers have gained access to site specific technology though GPS. GPS makes use of a series of satellites that identify the location of farm equipment within a meter of an actual site in the field. The most common use of GPS in agriculture is for yield mapping and variable rate fertilizer/pesticide applicator. GPS are important to find out the exact location in the field to assess the spatial variability and site-specific application of the inputs. GPS operating in differential mode are capable of providing location accuracy of 1 m.

The availability of GPS approaches to farming will allow all field-based variables to be tied together. This tool has proven to be the unifying connection among field variables such as weeds, crop yield, soil moisture, and remote sensing data.

2.3 Remote Sensing Technique

Remote sensing (RS) holds great promise for precision agriculture because of its potential for monitoring spatial variability over time at high resolution (Moran et al., 1997). Various workers (Hanson et al., 1995) have shown the advantages of using remote sensing technology to obtain spatially and temporally variable information for precision farming. Remote sensing imagery for precision farming can be obtained either through satellite-based sensors or CIR video digital cameras on board small aircraft. Moran et al. (1997) in their review paper summarized the applications of remote sensing for precision farming. They have found RS can be used as source of different types of information for precision farming. However, using RS data for mapping has many inherent limitations, which includes, requirements for instrument calibration, atmospheric correction, normalization of off-nadir effects on optical data, cloud screening for data especially during monsoon period, processing images from airborne video and digital cameras (Moran et al., 1997). Keeping in view the agricultural scenario in developing countries, the requirement for a marketable RS technology for precision agriculture is the delivery of information with the following characteristics like low turn around time (24-48 hrs), low data cost (~ 100 Rs./acre/season), high spatial resolution (at least 2m multi-spectral), high spectral resolution (<25 nm), high temporal resolution (at least 5-6 data per season) and delivery of analytical products in simpler format.

2.4 Geographic Information System (GIS)

GIS is a computerized data storage and retrieval system, which can be used to manage and analyze spatial data relating crop productivity and agronomic factors. It can integrate all types of information and interface with other decision support tools. GIS can display analyzed information in maps that allow (a) better understanding of interactions among yield, fertility, pests, weeds and other factors, and (b) decision-making based on such spatial relationships. Many types of GIS software with varying functionality and price are now available. A comprehensive farm GIS contains base maps such as topography, soil type, N, P, K and other nutrient levels, soil moisture, pH, etc. Data on crop rotations, tillage, nutrient and pesticide applications, yields, etc. can also be stored. GIS is useful to create fertility, weed and pest intensity maps, which can then be used for making maps that show recommended application rates of nutrients or pesticides.

2.5 Spatial Decision Support Systems (SDSS)

Spatial decision support systems (SDSS) are designed to help growers to solve complex spatial problems and to make decision concerning to irrigation scheduling, fertilization, use of crop growth regulators and other chemicals. Spatial decision support systems have evolved in parallel with decision support systems (DSS). In addition, in order to effectively support decision-making for complex spatial problems, a SDSS will need to:
i. provide for spatial data input
ii. allow storage of complex structures common in spatial data
iii. include analytical techniques that are unique to spatial analysis
iv. provide output in the form of maps and other spatial forms

GISs stand alone fall short of the goals of SDSS for a number of reasons:

i. analytical modeling capabilities often are not part of a GIS
ii. many GIS databases have been designed solely for cartographic display of results - SDSS goals require flexibility in the way information is communicated to the user
iii. the set of variables or layers in the database may be insufficient for complex modeling
iv. data may be at insufficient scale or resolution
v. GIS designs are not flexible enough to accommodate variations in either the context or the process of spatial decision-making

SDSS provide a framework for integrating: 1) analytical modeling capabilities 2) database management systems 3) graphical display capabilities 4) tabular reporting capabilities 5) the decision-maker's expert knowledge. GISs normally provide 2), 3) and 4). The addition of 1) and 5) create a SDSS.

2.6 Yield Mapping

Yield mapping and soil sampling tend to be the first stage in implementing PF. Yield maps are produced by processing data from an adapted combine that has a vehicle positioning system integrated with a yield recording system. Massey Ferguson were the first company to produce a commercial yield mapping combine. This combine has a Differential Global Positioning System (DGPS) fitted to it that can be identified by the GPS receiver on the roof of the cab and the differential aerial above the engine. The output from the combine is a data file that recorded every 1.2 seconds the position of the combine in longitude and latitude, with the yield at that point. This data set can then be processed by various geo-statistical techniques into a yield map.

2.7 Crop Simulation Models (CSMs)

However, although significant technical advances have been made in measuring and displaying variation in crop yields across a field, it is not always clear how to determine the best management practice for each part of a field in order to achieve these goals. For example, does a farmer apply more fertilizer to the lower yielding areas to try and raise yields to the average or are these low-yielding areas at their potential yield already, and would he therefore be advised to apply more to the high yielding areas, believing they are able to make better use of it. Answers to these questions are not clear cut, but can be found using optimization techniques based on knowledge of the marginal yield response to a unit of the input in question for all the different regions of a field. The marginal yield response can be obtained from the curve describing yield response to the level of particular input for each homogenous region are unlikely to be known. While mini-experiments on each homogenous region with a range of application levels of the input will provide this information, this approach in time-consuming, labour-intensive, and results are likely to be specific to that field only. An alternative, and perhaps complementary, approach is to use crop simulation models to predict the likely yield response to different levels of a particular input. Such models offer a cost effective way in which agronomic knowledge accumulated from
numerous previous experiments, usually with treatments of uniformly applied inputs on small and relatively homogenous plots, can be extended to larger spatially-variable fields.

Crop simulation models are needed to help consultants, researchers, and other farm advisors determine the pattern of field management that optimizes production or profit. However, the effective use of these tools requires their evaluation in fields to be optimized, their integration with other information tools such as GIS, geostatistics, remote sensing, and optimization analysis.

Crop simulation models like CERES (maize, wheat, rice, sorghum, barley, and millet) CROPGRO (soybean, peanut, dry bean, and tomato), SUBSTOR (potato), CROPSIM (cassava), and CANEGRO (Sugarcane) models has been developed by researchers from several countries. These models respond to weather, soil water holding and root growth characteristics, cultivar, water management, nitrogen management, and row spacing/ plant population. Also decision support system like, DSSAT incorporates crop/soil/weather models, data input and management software, and analysis programs for optimizing production or profit for homogenous fields. DSSAT also includes links to GIS and remote sensing information, which allows mapping of spatially variable inputs across a field and mapping of predicted outputs from the models, such as yield, nitrogen leaching, water use, etc. The site specific yield potentials can be estimated determining spatial pattern crop and land information and using it in above simulation models.

2.8 Variable Rate Technology

The variable rate technology (VRT) is the most advanced component of PF technologies, provides "on-the-fly" delivery of field inputs. A GPS receiver is mounted on a truck so that a field location can easily be recognized. An in-vehicle computer, which contains the input recommendation maps, controls the distribution valves to provide a suitable input mix by comparing to the positional information received from the GPS receiver. Current commercial VRT systems are either map-based or sensor-based (NRC, 1997). The map-based VRT systems require a GPS/DGPS geo-referenced location and a command unit that stores a plan of the desired application rates for each field location. The sensor-based VRT systems do not require a geo-referenced location but include a dynamic control unit, which specifies application through real time analysis of soil and/or crop sensor measurements for each field location. New VRT systems like the manure applicator being developed at Purdue University may soon enable precise application of manure in cropping systems. There are two methods of VRT. The first method, Map-based, includes the following steps: grid sampling a field, performing laboratory analyses of the soil samples, generating a site-specific map of the properties and finally using this map to control a variable-rate applicator. During the sampling and application steps, a positioning system, usually DGPS (Differential Global Positioning System) is used to identify the current location in the field. The second method, Sensor-based, utilizes real-time sensors and feedback control to measure the desired properties on-the-go, usually soil properties or crop characteristics, and immediately use this signal to control the variable-rate applicator.

3. Precision Farming Components and Framework

Precision Farming, basically, is characterized by reduced cost of cultivation (through optimization of inputs), improved control and increased resource use efficiency, through appropriate applications of Management Information System (MIS). While the reduced cost of cultivation is achieved through optimization of agricultural inputs taking into account economic push and environmental pull related factors, the control mechanisms are introduced by the help of VRT systems, model outputs and conjunctive use of remote sensing, GIS and
GPS. The MIS comprises Decision Support Systems (DSS), collateral inputs and associated GIS databases on crops, soils & weather. Dynamic remote sensing inputs on in-season crop conditions, crop simulation model outputs on the potential production under the different constraining scenario, and the networks of labs and farms, form the essential ingredients of MIS. Increased efficiency does not employ only efficient resource use but also reflects in terms of less waste generation, improved gross margin and reduced environmental impact.

Precision Farming thus calls for the use of appropriate tools and techniques, within a set of the framework as mentioned, to address the micro-level variations between crop requirements and applications of agricultural inputs. Inevitably, it integrates a significant amount of data from different sources; information and knowledge about the crops, soils, ecology and economy but higher levels of control require a more sophisticated systems approach. It is not simply the ability to apply treatments that are varied at the local level but the ability to precisely monitor and assess the agricultural systems at a local and farm level. This is essentially to have sufficient understanding of the processes involved to be able to apply the inputs in such a way as to be able to achieve a particular goal not necessarily maximum yield but to maximize financial advantage while operating within environmental constraints.

4. Precision Farming in India

PF technologies may be relatively new to India, but the concept of precision management is not. Indian farmers have long known that soil conditions, fertility, moisture, etc. vary widely across a single field and that various parts within fields responded to different types of inputs, and cultural practices. The small size of their farms often permitted such an effective monitoring of spatial and temporal yield variation and variable application of inputs mainly by manual means.

4.1 Limitations

Although precision farming is a proven technology in many advanced countries of the world but its scope in India (also in other developing countries) are limited. Different scientists have reported certain constraints, which limited the scope for site-specific farming in India, are as given follows:

i. Small farms size, heterogeneity of cropping systems, and land tenure/ownership restrictions High cost of obtaining site-specific data
ii. Complexity of tools and techniques requiring new skills
iii. Culture, attitude and perceptions of farmers including resistance to adoption of new techniques and lack of awareness of agro-environmental problems
iv. Infrastructure and institutional constraints including market imperfections
v. PF as new story to Indian farmers needs demonstrated impacts on yields
vi. Lack of local technical expertise
vii. High initial investment
viii. Uncertainty on returns from investments to be made on new equipment and information management systems, and
ix. Knowledge and technological gaps including
   ▪ Inadequate understanding of agronomic factors and their interaction,
   ▪ Lack of understanding of the geostatistics necessary for displaying spatial variability of crops and soils using current mapping software, and
   ▪ Limited ability to integrate information from diverse sources with varying resolutions and intensities.
4.2 Opportunities

Though farm size is the major limitation in adoption of PF technologies in India, contiguous field with same crop and mostly under similar management practice in states like Haryana, Punjab and Rajasthan can be considered as potential site for precision farming. Punjab and Haryana states in India, where farm mechanization is more common than in other states, are likely to be the first to adopt precision farming on a large scale. Rice, wheat, sugar beet, onion, potato, and cotton among the field crops, and apple, grape, tea, coffee and oil palm among horticultural crops are perhaps the most relevant for precision farming. Some have a very high value per acre, making excellent cases for site specific management. For all these crops, yield mapping is the first step to determine the precise locations of the highest and lowest yield areas of the field, and to analyze the factors causing yield variation.

In India, a few researchers in the private sector initiated studies on precision agriculture in high value crops like cotton, coffee and tea. In cotton, remote sensing coupled with GIS can assist in improved precision of insect pest management and harvesting. Testing of precision farming technologies for sustainable rice and wheat cropping system at the research farm level is in progress at Indian Agricultural Research Institute, New Delhi. Space Application Centre (SAC, ISRO), Ahmedabad in collaboration with Central Potato Research Institute, Simla has started experiment in Central Potato Research Station Farm at Jalandhar, Punjab to study the role of remote sensing in mapping the variability. The National Bank for Agriculture and Rural Development (NABARD) with collaborative partnership with MS Swaminathan Foundation, Chennai and Arava R&D Centre in Israel has established Resource Centre for Precision Farming for developing and spreading production technologies based on integrated natural resources management. Project Directorate of Cropping System Research, Modipuam, in collaboration with SAC and National Remote Sensing Centre (NRSC) in collaboration with ICRISAT, CRIDA and ANGRAU are involved in precision farming research for capturing variability and variable rate input application. There is also great opportunity of PF for grape and tea to start as pilot project in Nashik district of Maharastra and Assam respectively, where these crops grown in concentrated area.

Nutrient and water stress management is another area where precision farming can help Indian farmers. Detecting nutrient stresses using remote sensing and combining data in a GIS can help in site-specific applications of fertilizers and soil amendments such as lime, manure, compost, gypsum, and sulfur, which in turn would increase fertilizer use efficiency and reduce nutrient losses (Sawyer, 1994). In semi-arid and arid tropics, precision technologies can help growers in scheduling irrigation more profitably by varying the timing, amounts and placement of water. For example, drip irrigation, coupled with information from remotely sensed stress conditions (e.g., canopy-air temperature difference), can increase the effective use of applied water thereby reducing runoff and deep percolation (Das and Singh, 1989).

Pests and diseases cause huge losses to crops. If remote sensing can help in detecting small problem areas caused by pathogens, timing of applications of fungicides can be optimized. Recent studies in Japan show that pre-visual crop stress or incipient crop damage can be detected using radio-controlled aircraft and near-infrared narrow-band sensors. Likewise, airborne video data and GIS have been shown to effectively detect and map black fly infestations in citrus orchards, making it possible to achieve precision in pest control (Everitt et al., 1994). Perennial weeds, which are usually position-specific (Wilson and Scott, 1982) and grow in concentrated areas, are also a major problem in precision agriculture. Remote sensing combined with GIS and GPS can help in site-specific weed management.

Although thorough cost-benefit analysis has not been done yet, the possible use of precision technologies in managing the environmental side effects of farming and reducing pollution is
appealing. The technologies need not be limited to input application. They can be used in (a) implementing spatially-varied farm operations such as tillage, seeding, harvesting, etc., (b) on-farm testing of agronomic practices to evaluate alternative management practices, (c) plant breeding programs to test the performance of improved varieties, and in (d) re-evaluations of trial procedures.

4.3 Strategies

Precision farming needs to go from a technology-push to application-driven approach. As no single agency can take on the entire PF process, it is essential that various agencies join together and give a participatory approach for effective implementation of PF technologies. Small farm size will not be a major constraint, if the technologies are available through consulting, custom and rental services. For instance, by renting the equipment, manufacturers can enable early adapters to avoid the risks associated with purchasing costly machinery.

The role of agricultural cooperatives is important in dissemination of precision farming technologies to small farmers. If precision farming is considered a series of discrete services: map generation, targeted scouting, etc., it is possible to fit these services within the structure of a progressive agricultural cooperative. Since PF technology requires many costly implements farmers’ cooperative no the single farmer can afford to procure them. Again, cooperative farming will solve the limitation of small field size to take PF.

Changes in agricultural policies are also necessary to promote the adoption of precision farming. There are basically two policy approaches: regulatory policies, and market-based policies. The former refer to environmental regulations on the use of farm inputs, and the latter refer to taxes and financial incentives aimed at encouraging growers to efficiently utilize farm inputs. In India, the lack of penalties for pollutant generation has partly contributed to an excessive use of inputs. Subsidies on inputs and outputs, and mechanisms that prevent the price system from rationing limited resources are also common. The latter include state-guaranteed crop prices, tariffs, import quotas, export subsidies, etc.

5. Conclusion

Precision farming is essential for serving dual purpose of enhancing productivity and reducing ecological degradation. The success stories pertaining to Precision Agriculture have mainly drawn from the developed countries; wherein Agriculture is characterized by highly mechanized and automated systems, and is driven by market forces and has been professionally managed enterprise. Taking into account the predominance of fragmented land holdings, heterogeneity of crops and livestock and concept of farm families in the rural conditions, the model of Precision Agriculture representing the typical Indian Agricultural scenario is yet to evolve. Although it is recognized that agriculture is a major polluter of the environment, farmers will not adopt precision farming unless it brings in more or at least similar profit as compared to traditional practice. While the ecological integrity of farming systems is an imperative need, it is equally important to extend the access of information and market to the small and marginalized farmers. The Precision Agriculture model for India while addressing these issues would provide an innovative route for sustainable agriculture in globalised and liberalized economy.
References


