# Precision farming – The emerging concept of agriculture for today and tomorrow

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Agriculture is the backbone of our country and economy, which accounts for almost 30 per cent of GDP and employs 70 per cent of the population. Though this is a rosy picture of our agriculture, how long will it meet the growing demands of the ever-increasing population? This is a difficult question to be answered, if we depend only on traditional farming. Agricultural technology available in the 1940s could not have been able to meet the demand of food for today's population, in spite of the green revolution. Similarly, it is very difficult to assume that food requirement for the population of 2020 AD will be supplied by the technology of today. To meet the forthcoming demand and challenge we have to divert towards new technologies, for revolutionizing our agricultural productivity.

Green revolution succeeded in India to increase the farmer's income, yield of major crops and made India self-reliant in food production, with the introduction of high-yielding varieties and use of synthetic fertilizers and pesticides[1]. In the post-green revolution period agricultural production has become stagnant, and horizontal expansion of cultivable lands became limited due to burgeoning population and industrialization. In 1952, India had 0.33 ha of available land per capita, which is likely to be reduced to 0.15 ha by the end of year 2000 (ref. 2). As the availability of land has decreased, application of fertilizers and pesticides became necessary to increase production. The major effect is that our agriculture became chemicalized. In this situation, it is essential to develop eco-friendly technologies for maintaining crop productivity.

Since long, it has been recognized that crops and soils are not uniform within a given field[3]. The farmers have always responded to such variability to take actions, but such actions are inappropriate and less frequent. Over the last decade, technical methods have been developed to utilize modern electronics to respond to field variability. Such methods are known as spatially variable crop production, geographic positioning system (GPS)-based agriculture, site-specific and precision farming (PF). The term 'spatially variable crop production' seems to be more accurate and descriptive than the term PF.

## Precision farming

PF is a management philosophy or approach to the farm and is not a definable prescriptive system[4]. It identifies the critical factors where yield is limited by controllable factors, and determines intrinsic spatial variability. It is essentially more precise farm management made possible by modern technology. The variations occurring in crop or soil properties within a field are noted, mapped and then management actions are taken as a consequence of continued assessment of the spatial variability within that field. Development of geomatics technology in the later part of the 20th century has aided in the adoption of site-specific management systems using remote sensing (RS), GPS, and geographical information system (GIS). This approach is called PF or site-specific management[5–7]. It is a paradigm shift from conventional management practice of soil and crop in consequence with spatial variability. It is a refinement of good whole field management, where management decisions are adjusted to suit variations in resource conditions. Statistically, the precision farming $P = 1 - \mathrm{SD}$, where, SD is standard deviation; $P = 1$, indicates highly homogeneous field and $P = 0$, is a complex system, which describes maximum variability of field.

The responses to variability are identified by Schueller[8] as *homogeneous* – the entire field is uniform and *temporally separate variability* – where crop yield and soil nutrient status is variable, which is measured, recorded and mapped to decide appropriate future measures as cropping pattern. PF requires special tools and resources to recognize the inherent spatial variability associated with soil characteristics, crop growth and to prescribe the most appropriate management strategy on a site-specific basis. It offers a potential step change in productive efficiency[4]. Fundamentally, PF acknowledges the conditions for agricultural production as determined by soil, weather and prior management across space and over time[9]. Considering this inherent variability, management decisions should be specific to time and place, rather than rigidly scheduled and uniform.

Conventional agriculture is practiced for uniform application of fertilizer, herbicide, insecticides, fungicides and irrigation, without considering spatial variability. To alleviate the ill-effects of over and under usage of inputs, the new concept of PF has emerged. Site-specific management to spatial variability of farm is developed to maximize crop production and to minimize environmental pollution and degradation, leading to sustainable development. Current costs for PF are estimated at US \$9 to 23 per acre; future costs are likely to drop[9]. The recommendations of production inputs for each variable portion of the field could be adjusted to optimize output according to the agronomic, economic[5] and environmental goals through minimization of production cost. Spatially variable crop production has been commercialized in USA[10].

## Technology for precision farming

Spatially variable crop production to a large extent is technology-driven[10]. The new tools applicable to this PF are the advances in electronics and computers such as RS, GPS and GIS. Technologies used in PF cover three aspects such as data collection, analysis or processing of recorded information and recommendations based on available information. Technologies required are as follows:

### *Mapping*

The generation of maps for crop and soil properties is the most important and first step in PF. These maps will measure spatial variability and provide the basis for controlling spatial variability. Data collection occurs both before and during crop production and is enhanced by collecting precise location coordinates using the GPS. The data collection technologies are grid soil sampling, yield monitoring, RS and crop scouting[9]. During crop production, the data are collected through sensing instruments such as soil probes, electrical conductivity and soil nutrient status. Optical scanners are used to detect soil organic matter and to recognize weeds[9]. Then these data generated through mapping are recorded and stored in a computer system for future action and generated maps used for acquisition of information and for making strategic decisions to control variability. Mapping can be done by RS, GIS and manually during field operations.

### *Remote sensing*

It is the acquisition of information about an object from a distance, with precision, without coming into contact with the same. Although the use of RS is a decade old, its relevance to agriculture in spatial variability management is relatively new. RS measures visible and invisible properties of a field or a group of fields and converts point measurements into spatial information, to monitor temporally dynamic plant and soil conditions. The visual observations are recorded through a digital notepad and geo-referenced to GIS database, the most commonly used RS device, but aerial photography and videography are also used in PF[5]. Satellite RS has provided a tool for acreage estimation one month in advance, with more than 95% accuracy and in mono-crop area yield estimation with more than 90% accuracy ten days in advance[11]. The most popular procedure is to take images from satellites such as LANDSAT or SPOT[10]. Finally, images are used for generating maps and calibration of the measurement, assuming that measurements are taken in field to ground-truth accuracy. These images allow mapping of crop, pest and soil properties for monitoring seasonally variable crop production[12], stress, weed infestation and extent[5] within a field.

RS can be used for PF in a number of ways for providing input supplies and variability management through decision support system. The point data of soil test results can be translated into spatial coverage based on geostatistical interpolation[5], which gives chemical properties of the soil, nutrient status, organic matter, salinity, moisture content, etc. This information on spatial variability can be used with other geo-references to identify both seasonally stable and variable units, based on which management strategies can be developed. Space technology combined with satellite RS and communication provides valuable, accurate and timely information like early warning, occurrence, progressive dangers, damage assessment, quick dissemination of information regarding disaster and decision support to mitigate it[11].

### *Geographic Information System*

Recently, use of GIS in agriculture has increased because of misuse of resources like land, water, etc. GIS is the principal technology used to integrate spatial data coming from various sources in a computer[9]. GIS techniques deal with the management of spatial information of soil properties, cropping systems, pest infestations and weather conditions. This is primarily an intermediate step because it combines the data collected at different times based on sampling regimes, to develop the subsequent decision technologies such as process models, expert systems, etc.

The manipulation of spatial information had begun in the 1960s, but has grown rapidly with the development of computer-aided techniques. In the new millennium, GIS-aided techniques are indeed needed for sustainable food production and resource utilization, without further depletion of the environment. GIS technology will help the farmers and scientists in decision making, as precise information on field will be readily available. GIS techniques make weed control, pest control and fertilizer application site-specific, precise and effective; it would also be very useful for drought monitoring, yield estimation, pest infestation monitoring and forecasting[11,13,14]. GIS coupled with GPS, microcomputers, RS and sensors is used for soil mapping, crop stress, yield mapping, estimation of soil organic matter[14] and available nutrients. In combination these technologies have brought out rapid changes in data collection, storing, processing, analysis and developing models for input parameters[13].

### *Manual mapping during field operations*

Measurements may also be taken during field operations by the farmers. The most common measurements during field operation are yield recording and soil properties during tillage. Manual measurement has also been done for soil sample, pest infestation and other crop problems[15]. These measurements are performed at a specific time and usually provide the most accurate and useful information.

Whatever may be the mapping technique followed, the crucial element always seems to be the measurement of the quantity to be mapped[10]. Accurate and reliable sensors are needed for the conversion of physical and biological quantities into electronic value. Mapping also requires an accurate locator to establish the geographical location of the quantities measured, for which differential GPS (DGPS)[10] is very useful in PF.

## Control strategies

The documented spatial variability in maps is used to control the variability of soils, crops or pests through field operations. The common response to soil variability within fields is the control of fertilizer application in a spatially variable manner. In the same way, soil moisture map is used to control irrigation[16]. The crop yield and pest infestation maps are also used to control the application of irrigation, fertilizer and patch spray of pesticides[17]. Field operations in a spatially variable manner will need the following equipments[10]:

(i) A control computer to co-ordinate field operations based on the maps on computer memory; (ii) A locator to determine the current location of the equipment; (iii) An actuator to receive the command from the control computer.

The important aspect for these equipments is the dynamic response; otherwise the action will be performed after it was desired. The instruments SOILECTION[10] and FALCON[18], developed by AgChem, USA are used for application of fertilizer and pesticides in a spatially variable manner, according to digital maps. Combine-mounted crop yield monitor is one of the most popular instruments for PF, with a large number being used in North America[9]. Yield monitors are also currently available for corn, soybeans, wheat, potatoes and peanuts. Variable-rate technology (VRT) is another instrument, which uses the variability information and applies the inputs according to the requirement of the site, which includes fertilizer, pesticides and micronutrient application, liming, seed rate, irrigation and drainage[8,10,19,20]. VRT and yield monitors are an essential component of PF, which has mostly relied on the integration of GIS and GPS technologies, plus the implementation of VRT farm equipment. The success of PF depends mainly on the communication links and it enables a continuous electronic conversation among the workers, to interpret the information for better decision making.

## Issues

PF is a new development of present-day space, electronics and information technology, which has the great potentiality in resource utilization and to increase agricultural production. There are certain issues which need further attention, research and development to deliver the best in field. The issues are as follows:

### *Area coverage and data management*

Area coverage, collection of data, their calibration, correction, documentation and their integration for management approach by the provider and user, need clear distinction. As the soil and crop parameters are dynamic with time, so repetitive coverage with RS platforms are essential for correct information and these can be used in conjugation with management units to evaluate the problems and to provide best effective management solution. Algorithmic analysis has to be done for geometric calibration, correction and registration of various RS data products[5].

### *Scale bias*

This is a major concern in PF. The larger farms are able to adopt it and reap more gains. Therefore, comparative technological advantage and limitations of PF over small and large holding has to be experimented, to have a clear understanding of the bias.

### *Infrastructure*

Not only will the technical developments help the farmers, but also supporting infrastructure is essential to facilitate data processing, its storage, accessibility and timely product delivery at the user and provider levels. It needs huge investment for the development of access and monitoring system. Information technology such as network, has to be developed extensively for subsequent distribution to the end-user[5]. There is a great need to participate on impact assessment for both long-term and short-term planning, in order to continue development of this technology.

### *Ownership and privacy*

These issues are compounded as the data are combined with other entities, transformed, interpreted and processed. IPR issues are not unique as these are new to the farming system and add to the confusion over ownership and other related problems. Solutions have to be found out to these inherent issues and how to protect ownership and privacy of data.

## Commercialization of PF

Any technological development does not provide a total solution for the user until and unless it is commercialized for extensive use as a service mode. The interest in PF and its introduction has resulted in a gap between the technological capabilities and scientific understanding of the relationship between the input supplies and output products. Development of PF has been largely market-driven, but its future growth needs collaboration between private and public sectors. The private sector has to take up the responsibility of market development, product credibility and customer satisfaction. Whereas, the public sector needs to coordinate the activities involved in developing and implementing PF, by providing support programmes to achieve the objectives[5]. Linkages between government, university and corporate sectors are essential to facilitate the transfer and acceptance of technology by end-users. The potential of this technology has already been demonstrated, but in practice, meaningful delivery is difficult as it needs large-scale commercial application to realize the benefits.

## Indian perspective

The green revolution has not only increased productivity, but it has also several negative ecological consequences such as depletion of lands, decline in soil fertility, soil salinization, soil erosion, deterioration of environment, health hazards, poor sustainability of agricultural lands and degradation of biodiversity. Indiscriminate use of pesticides, irrigation and imbalanced fertilization has threatened sustainability[1,2]. On the other hand, issues like declining use efficiency of inputs and dwindling output–input ratio have rendered crop production less remunerative. According to CGIAR, 'Sustainable agriculture is the successful management of resources to satisfy the changing human needs, while maintaining or enhancing the quality of environmental and conserving natural resources'.

Nehru said, 'everything can wait but not the agriculture'. Therefore, agricultural research seeks the generation of new technologies to reorient the current and future needs and constraints. The new technology should be highly productive, cost-effective and ecologically sustainable. In the present context, maintenance of ecological balances through precise and site-specific management is most desirable. Planners have long recognized that an accurate and timely crop production forecasting system is essential for strengthening the food security[11]. The concept of PF may be appropriate to solve these problems, though it looks unsuitable to Indian conditions; but it is not impossible to adopt. Research efforts are needed to find out its applicability in the Indian agricultural scenario. The M. S. Swaminathan Research Foundation, Chennai, India has joined hands with Israel to initiate PF on an experimental basis, including conducting training programmes[21].

## Conclusion

During the last century, numerous changes have taken place in the major components of agriculture, both in the positive as well as in negative direction. Over last few decades, the impact of science and technology on society and ecosystem has intensified the deterioration of the ecosystem, leading to depletion of biological resources. The agriculture of the forties, which was eco-friendly, has now become fully chemicalized with new farming technologies and commercialization of agriculture. In future, agriculture will face formidable challenges to provide adequate nutrition for people. Therefore, it is the right time to take decisions, how to increase agricultural productivity, as the developing countries have the lowest productivity for most of the food crops. It is obvious that unless the latest tools of science and technology are applied for sustainable and equitable distribution of natural resources of our country, poverty and hunger will persist. The new technology may be able to harness several newer possibilities in managing the farm sector precisely. These vignettes are not science fiction, but real, and developed countries reaped benefits from it. These technologies should be used to complement the traditional methods for enhancing productivity and quality, rather than to replace conventional methods. In the light of today's urgent need, there should be an all out effort to use new technological inputs for the development of our society, as well as to make the 'Green Revolution' an 'Evergreen Revolution'. Now what we require is the development of a symbiotic relationship between man and nature to harmonize the ecological balance.


1. Ghosh, S. K., Murthy, K. M. D., Ramesh, G. and Palaniappan, S. P., *Employment News*, 1999, **222**, 1–2.
2. Singh, K. K., Khan, M. and Shekhawat, M. S., *Yojana*, June 2000, pp. 26–28.
3. Cassman, K. G. and Plant, R. E., *Fert. Res.*, 1992, **31**, 151–163.
4. Dawson, C. J., in *Precision Agriculture* (ed. Stafford, J. V.), BIOS Scientific Publishers Ltd, 1997, vol. 1, pp. 45–58.
5. Brisco, B., Brown, R. J., Hirose, T., McNairn, H. and Staenz, K., *Can. J. Remote Sensing*, 1998, **24**, 315–327.
6. Palmer, R. J., in Proc. Site-Specific Management for Agric. Syst., Minneapolis, MN, ASA-CSSA-SSSA, Madison, WI, 27–30 March, 1996, pp. 613–618.
7. Carr, P. M., Carlson, G. R., Jacobsen, J. S., Nielsen, G. A. and Skogley, E. O., *J. Prod. Agric.*, 1991, **4**, 57–61.
8. Schueller, J. K., *Fert. Res.*, 1992, **33**, 1–34.
9. Heimlich, Ralph, *Agric. Outlook*, April 1998, 19–23.
10. Schueller, J. K., in *Precision Agriculture* (ed. Stafford, J. V.), BIOS Scientific Publishers Ltd, 1997, vol. 1, pp. 33–44.
11. Singh, K. K. and Shekhawat, M. S., *Farmer and Parliament*, 2000, 10–13.
12. Moran, M. S., Vidal, A., Troufleau, D., Inoue, Y. and Mitchell, T., *Remote Sensing Environ.*, 1997, **61**, 96–109.
13. Reddy, G. P. and Anand, P. S. B., *Yojana*, June 2000, 35–36.
14. Biswas, C. and Subba Rao, A. V. M., *Yojana*, June 2000, 24–25.
15. Stafford, J. V., Lebars, J. M. and Ambler, B., *Comput. Electron. Agric.*, 1996, **14**, 234–247.
16. Wall, R. W., King, B. A. and McCann, I. R., Proceedings of the Third International Conference on Precision Agriculture (eds Robert, P. C., Rust, R. H. and Larson, W. E.), Minneapolis, 23–26 June 1996, pp. 757–766.
17. Stafford, J. V. and Miller, P. C. H., in Proceedings of the Third International Conference on Precision Agriculture (eds Robert, P. C., Rust, R. H. and Larson, W. E.), Minneapolis, June 23–26, 1996, pp. 757–766.
18. Ortlip, E. W., USA Patent 4630774, 23 December 1986.
19. Searcy, S. W., in Proc. Site-Specific Management for Agric. Syst., Minneapolis, MN, ASA-CSSA-SSSA, Madison, WI, 27–30 March 1995, pp. 603–608.
20. Fleischer, S. J., Weisz, R., Smilowitz, Z. and Midgarden, D., in *The States of Site-Specific Agriculture* (eds Pierce, F. J., Robert, P. R., Sadler, J. and Searcy, S.), Soil Science Society of America, 1996, pp. 213–218.
21. Narayan, L. R. A., *The Hindu Survey of Indian Agriculture*, 2000, 193–195.



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