Precision Farming: Dreams and Realities for Indian Agriculture

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ABSTRACT

Human kind invented agriculture 10,000 years ago. After a long mile, nowhere in the world has agriculture made an impact as it has in India. The economy of the second most populous country in the world is inextricably linked to the pulse of its agricultural success or failure. The green revolution in the late 60's saw the country through a period of what could otherwise have been the worst famine in the world. Yet after nearly three and half decades into the post green revolution period, the country still faces crisis each year in trying to meet the burgeoning demand for food by its people. As the result of information technology application in agriculture, precision farming is a feasible approach for sustainable agriculture. Precision farming makes use of remote sensing to macro-control of GPS to locate precisely ground position and of GIS to store ground information. It precisely establishes various operations, such as the best tillage, application of fertilizer, sowing, irrigation, harvesting etc., and turns traditional extensive production to intensive production according to space variable data. Precision farming not only may utilize fully resources, reduce investment, decrease pollution of the of the environment and get the most of social and economic efficiency, but also makes farm products, the same as industry, become controllable, and be produced in standards and batches. However, precision farming has been confined to developed countries. Land tenure system, smaller farm size (<1ha) and crop diversity have limited the scope of precision farming in India. However, there is a wide scope for precision farming in irrigated/commercial/fruit and vegetable crops/high value crops. It is apparent that there is a tremendous scope for precision farming in India as well and it is necessary to develop database of agriculture resources, which will act as decision support system at the farm (<1 ha) level. This will be a stupendous task and a threatening challenge to space and agricultural scientists alike who are currently remotely placed from the ground truth of Indian farming. However, the speeds of these transformations depend very much on the level of commitment of politicians, scientists, bureaucrats and technocrats at whose mercy the farmer really is! The paper highlights the

precision technology transfer in agriculture sector, present status of precision farming in India, obstacle, prospects, scope and strategies for implementation to harvest the fruitful results.

Preamble

Ever since the man appeared on the earth, he has been harnessing the natural resources to meet his basic requirements. Reference to soil, water and air as basic resources, their management and means to keep them pure are mentioned in the Vedas, Upanishads and in ancient Hindu literature. The phenomenal increase in population of both man and animal in the last century and fast growing industrialization and urbanization in last few decades have overstrained the natural resource base, which are getting degraded much faster than ever before. Thus, the attention of whole world is focused on how to increase production to feed the burgeoning population and the question uppermost in every ones mind is "Can we produce enough food in a sustainable manner without damage to the natural resource base?"

Belying all predictions made to the contrary, India could achieve unprecedented increase in the food grain production as a result of expansion of irrigation and technological advancement in agriculture. While it has been a satisfying experience, Indian agriculture would need a new vision to make rapid progress in the ensuing millennium. To achieve the required growth will not be easy as some of the existing production systems are based on unsustainable use of the resources. The signs of fatigue in the natural resources have already appeared which is a cause for serious concern to the planners, decision-makers and researchers alike.

Precision Agriculture is the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for improving production and environmental quality. The success in precision agriculture depends on the accurate assessment of the variability, its management and evaluation in space-time continuum in crop production. The agronomic feasibility of precision agriculture has been intuitive, depending largely on the application of traditional arrangement recommendations at finer scales. The agronomic success of precision agriculture has been quite convincing in crops like sugar beet, sugarcane, tea and coffee. The potential for economic, environmental and social benefits of precision agriculture is largely unrealized because the space-time continuum of crop production has not been adequately addressed.

Successful implementation of precision agriculture depends on numerous factors, including the extent to which conditions within a field are known and manage, the adequacy of input recommendation and the degree of application control. The enabling technologies of precision agriculture can be grouped in to fine major categories: Computers, Global Positioning System (GPS), Geographic Information System (GIS), Remote Sensing (RS) and Application control.

Aspects of precision agriculture encompass a broad array of topics including variability of the soil resource base, weather, plant genetics, crop diversity, machinery performance and most physical, chemical and biological inputs used in crop production. Precision agriculture must fit the needs and capabilities of the farmer and must be profitable.

Content issues and the Gateway debate

Despite all the natural advantages, India's productivity of food grains per hectare is no more than three-fourths of the world average and less than half of that in agriculturally advanced countries, per capita food grain availability even after the Green Revolution, has been less than two thirds of the world average. Only five states in India, namely Himachal Pradesh, Punjab, Haryana, Uttar Pradesh and Madhya Pradesh – produce more grain than their populations can consume. The combined population of the five states is less than one-third of the total of the country. More than two thirds of the population lives in states that are still food-deficit. This requires transport of lakhs of tonnes of food grain, involving high costs and pilferage. Our effort should have been to make all the states self-sufficient with respect to food grains and if some disturbances occurred due to unnoticed natural calamities the nation must be in an ever ready position to mitigate such challenging tasks.

The Indian green revolution is also associated with negative ecological / environmental consequences. The status of Indian environment shows that, in India, about 182 million ha of the country's total geographical area of 328.7 million ha is affected by land degradation of this 141.33 million ha are due to water erosion, 11.50 million ha due to wind erosion and 12.63 and 13.24 million ha due to water logging and chemical deterioration (salinization and loss of nutrients) respectively. On the other end, India shares 17 per cent of world's population with 2.5 per cent of geographical area, 1 per cent of gross world product, 4 per cent of world carbon emission and hardly 2 per cent of world forest area. The Indian status on environment is though not alarming when compared to developed countries, it gives an early warning to take appropriate precautionary measures.

The growth rate of grain production during the Ninth plan has been less than the population growth rate. The poor agricultural performance has not been because of the vagaries of monsoon. From 1997-98 to 2002-03, rainfall was between 92 and 106 per cent of the normal. Per capita availability of grain and per capita calorie intake, which were less than the minimum required for adequate nutrition, have further declined. According to Human Development Report 2003, the percentage of the undernourished in India, which was 21 a few years ago, has now reached 24.

The Government claims that India has emerged as the seventh largest exporter of food grains in the world. This is nothing to be proud of, if we take into account that the total Indian grain export in 2002-03 did not add up to even 4 per cent of the total world exports; and the value of our grain exports did not add up to even the value of our imports of vegetable oils and pulses. The more crucial question, however, is whether it is morally justifiable to export grain when 24 per cent of the population remains under-nourished.

The decline in agricultural growth and increase in rural poverty have been due to the long persisting government indifference towards the farm sector, which is evident from plan outlays on Agricultural and Allied activities, Rural Development and Irrigation, which added up to 37.1 per cent of the total during the first plan were brought down to only 19.4 per cent during the Ninth plan. However, the main reason, for poor performance of the farm sector has been the long persisting adverse terms of trade policies for agriculturists in addition to the mismanagement of natural resources leads to ever ending crisis.

The Need for Precision Farming

The 'Green revolution' of 1960's has made our country self sufficient in food production. In 1947, the country produced a little over six million tonnes of wheat, in 1999; our farmers harvested over 72 million tonnes, taking the country to the second position in wheat production in the world. The production of food grains in five decades, has increased more than three fold, the yield during this period has increased more than two folds. All this has been possible due to high input application, like increase in fertilization, irrigation, pesticides, higher use of HYV's, increase in cropping intensity and increase in mechanization of agriculture.

i) Fatigue of Green Revolution

Green revolution of course contributed a lot. However, even with the spectacular growth in the agriculture, the productivity levels of many major crops are for below than expectation. We have not achieved even the lowest level of potential productivity of Indian high yielding varieties, whereas the worlds highest productive country have crop yield levels significantly higher than the upper limit of the potential of Indian HYV's. Even the crop yields of India's agriculturally rich state like Punjab is far below than the average yield of many high productive countries (Ray *et al*., 2001).

ii) Natural Resource Degradation

The green revolution is also associated with negative ecological/environmental consequences. The status of Indian environment shows that, in India, about 182 million ha of the country's total geographical area of 328.7 million ha is affected by land degradation of this 141.33 million ha are due to water erosion, 11.50 million ha due to wind erosion and 12.63 and 13.24 million ha are due to water logging and chemical deterioration (salinisation and loss of nutrients) respectively. On the other end, India shares 17 per cent of world's population, 1 per cent of gross world product, 4 per cent of world carbon emission, 3.6 per cent of CO_2 emission intensity and 2 per cent of world forest area. One of the major reasons for this status of environment is the population growth of 2.2 per cent in 1970 – 2000. The Indian status on environment is, though not alarming when compared to developed countries, gives an early warning.

In this context, there is a need to convert this green revolution into an evergreen revolution, which will be triggered by farming systems approach that can help to produce more from the available land, water and labour resources, without either ecological or social harm (Swaminathan, 2002). Since precision farming, proposes to prescribe tailor made management practices, it can help to serve this purpose.

The Basic Components of Precision Farming

Precision farming basically depends on measurement and understanding of variability, the main components of precision farming system must address the variability. Precision farming technology enabled, information based and decision focused, the components include, (the enabling technologies) Remote Sensing (RS), Geographical Information System (GIS), Global Positioning System (GPS), Soil Testing, Yield Monitors and Variable Rate Technology.

Precision farming requires the requisition, management, analysis and output of large amount of spatial and temporal data. Mobile computing systems were needed to function on the go in farming operations because desktop systems in the farm office were not sufficient. Because precision farming is concerned with spatial and temporal variability and it is information based and decision focused. It is the spatial analysis capabilities of GIS that enable precision agriculture. GPS, DGPS has greatly enabled precision farming and of great importance to precision farming, particularly for guidance and digital evaluation modeling position accuracies at the centimeter level are possible in DGPS receivers. Accurate guidance and navigation systems will allow for farming operations at height and under unfavorable weather conditions even.

In India, we have all these technologies available and they can be implemented through agricultural training centers by giving training to agriculture officers in these technologies.

Basic Steps in Precision Farming

The basic steps in precision farming are,

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

The available technologies enable us in understanding the variability and by giving site specific agronomic recommendations we can manage the variability that make precision agriculture viable. And finally evaluation must be an integral part of any precision farming system. The detailed steps involved in each process are clearly depicted in a diagramme.

i). Assessing variability

Assessing variability is the critical first step in precision farming. Since it is clear that one cannot manage what one does not know. Factors and the processes that regulate or control the crop performance in terms of yield vary in space and time. Quantifying the variability of these factors and processes and determining when and where different combinations are responsible for the spatial and temporal variation in crop yield is the challenge for precision agriculture.

Techniques for assessing spatial variability are readily available and have been applied extensively in precision agriculture. The major part of precision agriculture lies in assessing to spatial variability. Techniques for assessing temporal variability also exist but the simultaneous reporting a spatial and temporal variation is rare. We need both the spatial and temporal statistics. We can observe the variability in yield of a crop in space but we cannot predict the reasons for the variability. It needs the observations at crop growth and development over the growing season, which is nothing but the temporal variation. Hence, we need both the space and time statistics to apply the precision farming techniques. But this is not common to all the variability/factor that dictate crop yield. Some variables are more produced in space rather with time, making them more conducive to current forms of precision management.

ii). Managing variability

Once variation is adequately assessed, farmers must match agronomic inputs to known conditions employing management recommendations. Those are site specific and use accurate applications control equipment.

We can use the technology most effectively. In site-specific variability management. We can use GPS instrument, so that the site specificity is pronounced and management will be easy and economical. While taking the soil/plant samples, we have to note the sample site coordinates and further we can use the same for management. This results in effective use of inputs and avoids any wastage and this is what we are looking for.

The potential for improved precision in soil fertility management combined with increased precision in application control make precise soil fertility management as attractive, but largely unproven alternative to uniform field management. For successful implementation, the concept of precision soil fertility management requires that within-field variability exists and is accurately identified and reliably interpreted, that variability influences crop yield, crop quality and for the environment. There fore inputs can be applied accurately.

The higher the spatial dependence of a manageable soil property, the higher the potential for precision management and the greater its potential value. The degree of difficulty, however, increases as the temporal component of spatial variability increases. Applying this hypothesis to soil fertility would support that Phosphorus and Potassium fertility are very conducive to precision management because temporal variability is low. For N, the temporal component of variability can be larger than its spatial component, making precision N management much more difficult in some cases.

iii). Evaluation

There are three important issues regarding precision agriculture evaluation.

?? Economics
?? Environment and
?? Technology transfer

The most important fact regarding the analysis of profitability of precision agriculture is that the value comes from the application of the data and not from the use of the technology. Potential improvements in environmental quality are often cited as a reason for using precision agriculture. Reduced agrochemical use, higher nutrient use efficiencies, increased efficiency of managed inputs and increased production of soils from degradation are frequently cited as potential benefits to the environment. Enabling technologies can make precision agriculture feasible, agronomic principles and decision rules can make it applicable and enhanced production efficiency or other forms of value can make it profitable.

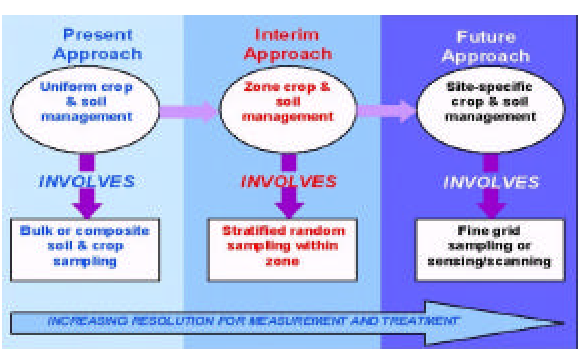
The term technology transfer could imply that precision agriculture occurs when individuals or firms simply acquire and use the enabling technologies. While precision agriculture does involve the application of enabling technologies and agronomic principles to manage spatial and temporal variability, the key term is manage. Much of the attention in what is called technology transfer has focused on how to communicate with the farmer. These issues associated with the managerial capability of the operator, the spatial distribution of infrastructure and the compatibility of technology to individual farms will change radically as precision agriculture continues to develop (Pierce and Peter, 1999).

Technology Transition

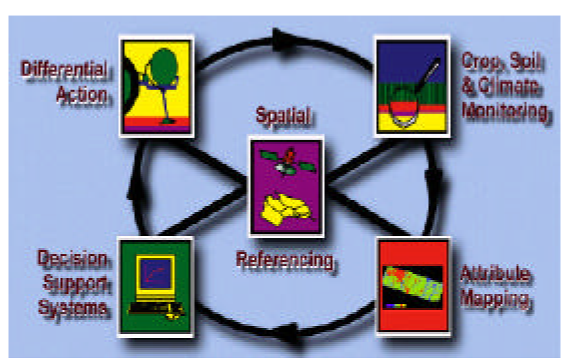
Precision agriculture is dependent on the existence of variability in either or both product quantity and quality. If this variability does not exist then a uniform management system is both the cheapest and most effective management strategy and precision farming is redundant. Thus, in precision farming, “Variability of production and quality equals opportunity”. Having said this, the nature of the variation is also important in determining the potential for PA in a system. For example the magnitude of the variability may be too small to be economically feasible to manage. Alternatively the variability may be highly randomized across the production system making it impossible to manage with current technology. Finally the variability may due to a constraint that is not manageable. Thus the implementation of precision farming is limited by the ability of current variable rate technology (VRT-machinery/technology that allows for differential management of a production system) to cope with the highly variable sites and the economic inability to produce returns from sites with low variability using precision farming (VRT).

Due to these constraints PA is at present operating on a zonal rather than a completely site-specific basis. As VRT improves and the capital cost of entering PA decreases, the minimum size of management zone needed to effectively implement PA will decrease till eventually a truly site-specific management regime is possible. Until this occurs there is need to be able to quantify both the variability of a production system and the size of the minimum manageable zone (MMZ). If the variability in the production system dictates management zones smaller than the MMZ than PA is not relevant to the system. At the present time (but may be in future). It will be interesting to see how the concept of the management zone develops and to see how it compares with the concept of terroir.

Precision Agriculture: Transition



Precision Agriculture: The Concept Wheel



Level of management, info content, environmental concern	Eventually can be applied to the entire spectrum of agricultural system for both quality & quantity control

Present Scenario

Though precision farming is very much talked about in developed countries, it is still at a very nascent stage in developing countries, including India. Space Application center, ISRO, in collaboration with Central Potato Research Institute, Shimla, has initiated a study on exploring the role remote sensing for precision farming.

The study on precision agriculture has already been initiated in India, in many research institutes. Space Application Center (ISRO), Ahmedabad has started experiment in the Central Potato Research Station farm at Jalahandhar, Punjab to study the role of remote sensing in mapping the variability with respect to space and time. M S Swaminathan Research Foundation, Chennai, in collaboration with NABARD, has adopted a village in Dindigul district of Tamil Nadu for variable rate input application. Indian Agricultural Research Institute has drawn up a plan to do precision farming experiments in the institutes' farm. Project Directorate for Cropping Systems Research (PDCSR), Modipuram and Meerut (UP) in collaboration with Central Institute of Agricultural Engineering (CIAE), Bhopal also initiated variable rate input application in different cropping systems. In coming few years precision farming may help the Indian farmers to harvest the fruits of frontier technologies without compromising the quality of land.

Prospects

Precision farming, though in many cases a proven technology is still mostly restricted to developed (American and European) countries. Except for a few (Wang, 2001), there is not much literature to show the scope of its implementation in India.

We feel that, one of the major problems is the small field size. In India more than 57.8 per cent of operational holdings have size less than 1 ha. However, in the major agricultural states of Punjab, Rajastan, Haryana and Gujarat there are more than 20 per cent of agricultural lands have operational holding size of more than 4 ha. These are individual field sizes. However, when we consider contiguous field with same crop (mostly under similar management practices) the field (rather simulated field) sizes are large. Using aerial data, has found that in Patiala district of Punjab, more than 50 per cent of contiguous field sizes are larger than 15 ha. These contiguous fields can be considered a single field for the purpose of implementation of precision farming.

There is a scope of implementing precision farming for major food-grain crops such as rice, wheat, especially in the states of Punjab and Haryana. However many horticultural crops in India, which are high profit making crops, offer wide scope for precision farming.

Misconceptions about Precision Agriculture

There are several mistaken preconceptions about precision agriculture.

a). Precision agriculture is a cropping rather than an agricultural concept

This is due to cropping systems, in particular broad-acre cropping, being the face and driving force of PA technology. However precision farming concepts are applicable to all agricultural sectors from animals to fisheries to forestry. In fact it might be argued that precision farming concepts are more advanced in the dairy industry where the "site" becomes an individual animal, which is recorded, traced and fed individually to optimize production. These industries are just as concerned with improved productivity and quality decreased environmental impact and better risk management as the cropping industry however precision farming concepts have yet to be applied on the same scale in these areas. For example a grazer's use of advance warning meteorological data and market predictions to estimate fodder reserves and plan livestock numbers is a form of precision farming.

b). Precision agriculture in cropping equals yield mapping

Yield mapping is a crucial step and the wealth of information farmers are able to obtain from a yield map makes them very valuable. However they are only a stepping-stone in a precision farming management system. The bigger agronomic hurdle lies in retrieving the information in the yield map and using it to improve the production system. The advance of PA adoption (usefulness) in this country is may soon be bottlenecked at this point due to the lack of decision support systems (DSS) to help agronomists and farmers understand their yield maps. Yield maps may not tell the whole story either with other data sources, e.g. crop quality and soil maps, economic indicators or weather predictions, proving further information necessary for correct agronomic interpretations.

c). Precision agriculture equals sustainable agriculture

Precision agriculture is a tool to make agriculture more sustainable however it is not the total answer. Precision farming aims at maximum production efficiency with minimum environmental impact. Currently it is the potential for improved productivity (and profitability) that is driving precision farming rather than the more serious issue of long-term sustainability. Precision farming will not fix problems such as erosion and salinity by itself although it will help to reduce the risk of these problems occurring. Sensible sustainable practices still need to be used in conjunction with precision farming.

Obstacles

There are many obstacles to adoption of precision farming in developing countries in general and India in particular. Some are common to those in other regions but the others are specific to Indian conditions are as follows.

- Culture and perceptions of the users
- 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

Opportunities

Despite the many obstacles listed earlier, business opportunities for precision farming technologies including GIS, GPS, RS and yield monitor systems are immense in many developing countries. The scope for funding new hardware, software and consulting industries related to precision agriculture is gradually widening. In Japan, the market in the next 5 years is estimated at about US $ 100 billion for GIS and about US $ 50 billion for GPS and RS (Srinivasan, 2001). Punjab and Haryana states in India, where farm mechanization is more common than in others, may be the first to adopt precision farming on a large scale.

Recently, the governments of certain Asian countries initiated special efforts to promote precision farming. In Japan, the Ministry of Agriculture has allocated special funds for research on remote sensing applications of precision farming. A quasi-governmental institute "Bio-oriented Technology Research Advancement Institute (BRAIN)" is also funding research on precision farming. In Malaysia, the Malaysian Agricultural Research and Development Institute (MARDI) is promoting research on precision farming of upland rice. In other countries, the private sector, which holds or leases a large acreage, is likely to adopt precision farming sooner than the small holders.

Precision farming is useful in many situations in developing countries. 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. 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. Researchers at Kyoto University recently developed a two-row rice harvester for determining yields on a micro plot basis (Iida *et al*., 1998).

Precision farming can bring several benefits to the sugar beet industry in Hokkaido, where the marketing system was changed in 1986 from a quantity (fresh weight) to quality (sugar yield) basis. Heavy N fertilization, a common practice here, results in excessive N levels and a decreased sugar concentration. It is now possible to estimate sugar and amide N concentration in leaves using reflectance in visible bands and root yield using reflectance in visible and infrared bands (Okano *et al*., 1997). Incorporation of such data into a GIS along with precise positioning of non-uniform areas using GPS can be used to vary fertilizer dose within a field, thereby improving productivity. Although weighing conveyor technology has been known for some time, effective yield measurement still remains the main problem in crops such as sugar beet, onion and potato. Further, the preparation of product quality maps for these crops is as important as yield maps. 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. In Sri Lanka, researchers at the Tea Research Institute are examining precision management of soil organic carbon.

In so far as dairy farming in Asia is concerned, precision farming techniques can help in improving efficiency of methods, timing and rate of application of animal wastes leading to high application efficiency and low environmental pollution. While considering soil and climatic conditions. For instance, factors determining the risk of NO_3 leaching, release of N_2O through denitrification and contamination of surface and ground water by runoff can be mapped and analysed. Likewise, poorly managed areas in grass lands can be identified and the optimum period for cutting on a plot basis determined.

Nutrient stress management is another area where precision farming can help Indian farmers. Most cultivated soils in India are acidic and spatial variation in pH is high. 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 sulphur. This in turn would increase fertilizer use efficiency and reduce nutrient losses. 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 temperature) can increase the effective use of applied water from 60 to 95 per cent there by, reducing runoff from 23 to 1 per cent and deep percolation from 18 to 4 per cent.

Pests and diseases cause huge losses to Indian 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. Like wise, 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. Perennial weeds, which are usually position-specific (Wilson and Scott, 1982) and grow in concentrated areas, are also a major problem in developing countries. Remote sensing combined with GIS and GPS can help in site-specific weed management.

Although through 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.

Strategies

Precision farming is still only a concept in many developing countries and strategic support from the public and private sectors is essential to promote its rapid adoption. Successful adoption, however, comprises at least three phases including exploration, analysis and execution. Data on crop yield, soil variables, weather and other characteristics are collected and mapped in the exploratory stage, which is important for increasing the awareness among farmers of long term benefits. The approaches to data collection and mapping must, therefore, reflect local needs and resources.

In the analysis stage, factors limiting the potential yield in various areas within a field and their interrelationships are examined using GIS-based statistical modeling. Sadler *et al*. (1998) showed that quantitatively important yield variation may occur over distances as short as 10m, however, only some factors such as soil structure, water status, pH, nutrient levels, weeds, pests and diseases can be controlled but not the others (soil texture, weather, topography). After determining the significance of each source of variability to profitability of a particular crop and relative importance of each controllable factor, management actions can be prioritized. It must be remembered that in some low yielding areas, the reason for poor yields may be the lack of sufficient soil nutrients in the first place. In such cases, application beyond just replenishment is necessary.

Lastly, execution phase includes variable application of inputs or cultural operations. In most developing countries of Asia. However, it is not always necessary and/or possible to use variable rate applicators. Efforts must, therefore, initially focus on limiting indiscriminate use of inputs in conventional methods. Once the economic and environmental benefits are known widely, variable rate technology would be rapidly implemented at least in high value crops.

To spur adoption of precision farming methods in developing countries, pilot demonstration projects must be conducted at various growers locations by involving farmers in all stages of the project. The pilot projects must attempt to answer the grower's needs and emphasize the operational implementation of technology and complete analysis of the costs and savings involved. Documentation of pilot projects would help in examining the operational weaknesses and identification of remedial measures. The projects can be used to train innovative farmers and early adopters, expose the neighboring nonparticipating farmers to the new technologies, and show the usefulness of the technology for short and long-term management.

The role of agricultural input suppliers, extension advisors and consultants in the spread of these technologies is vital. For instance, public agencies should consider supplying free data such as remotely sensed imagery to the universities and research institutes involved in precision farming research. Also, professional societies of agronomy, agricultural informatics, and engineering must provide training guidance in the use of technologies. The involvement of inter/disciplinary teams is essential in this. Small farm size will not be a major constraint, if the technologies are available through consulting, custom and rental services. 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, it is possible to fit these services within the structure of a progressive agricultural cooperative in each developing country.

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 later refer to taxes and financial incentives aimed at encouraging growers to efficiently use farm inputs. In most developing countries 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. Inputs such as water and fossil fuels are usually sold at prices that are well below the real resource cost of their use, which consists not only production costs but also includes scarcity value and costs of pollution. In such cases, the formulation of policies that reflect the real scarcity value of natural resources and penalize pollution and policies such as green payments for farmers adopting techniques that would lower environmental costs can promote the adoption of precision farming technologies (Branden *et al*., 1994).

In most developing countries, the pollution effects of agriculture have been largely ignored so far because of inability to effectively monitor such effects. The advent of precision farming, and the computerization of input and output flows, will now enable such monitoring. Higher taxes on pollution farms are often recommended, but there is strong opposition to the implementation of the polluter-pays-principle concept in most countries including India. At the same time, some consumers in India would like to see a drastic reduction in the use of pesticides and fertilizers, and are willing to pay as much as 4 to 6 times the normal price for produce such as organic vegetables, soybean and wheat. When the price elasticity of input use is low and the input costs are only a small part of the total production expenditure, as in the case of fertilizers and pesticides. Very high taxes are required to reduce their use adequately. Given the unfeasibility of such high taxes, a hybrid policy may be implemented for controlling pollution. A tax-free quota of N can be combined with taxes on additional N use.

At the research level, many issues remain to be resolved. Although some progress has been made at Space Application Center, Ahmedabad, yield monitors for small farm conditions are yet to be developed. The development of standards for the hardware and software (image transfer formats and GPS transfer formats, map projection formats) is another issue. Crop models and decision support systems must be improved by considering local resources. Data for calibration of models must be made available to increase their accuracy and/or predictability.

The ability to finance a creative information venture in agriculture will affect the speed of diffusion of precision farming technologies. Commercial banks, as well as other sources of funding, have to be educated regarding the potential of precision farming. In many developing countries, it may be worthwhile to develop programmes of subsidized credit to enable R&D activities on precision farming.

Conclusion

Precision farming in many developing countries including India is in its infancy but there are numerous opportunities for adoption. I believe that progressive Indian farmers, with guidance from the public and private sectors, and agricultural associations, will adopt it in a limited scale as the technology shows potential for raising yields and economic returns on fields with significant variability, and for minimizing environmental degradation. Although it is recognized that agriculture is a major polluter of the environment in many developing countries, farmers will not adopt precision farming unless it brings in more or at least similar profit as compared to traditional practice. The support from governments and the private sector during the initial stages of adoption is, therefore vital. It must be remembered that not all elements of precision farming are relevant for each and every farm. For instance, introduction of variable rate applicators is not always necessary or the most appropriate level of spatial management in Indian farms. Likewise, not all farms are suitable to implement precision farming. Some growers are likely to adopt it partially, adopting certain elements but not others. Precision farming cannot be convincing if only environmental benefits are emphasized. On the other hand, its adoption would be improved if it can be shown to reduce the risk. We must be cautious, however, is not overselling the technologies without providing adequate product support. The adoption of precision farming also depends on product reliability, the support provided by manufacturers and the ability to show the benefits. Effective coordination among the public and private sectors and growers is, therefore, essential for implementing new strategies to achieve fruitful success.

References

Ahuja, S.S., 2000, Tea-production constraints stay. *In the Hindu-survey of Indian Agriculture*, 2000 pp. 105-108.

Branden, Bagemen, J. and Agkiosobud, C.F., 1994, Incentive-based non-point source pollution abatement in a re-authored clean water act. *Water Resource*. Japan Agricultural Software Association, 1996. Agriculture-related Software Book (In Japanese). Rakuyu Shobo, Tokyo.

Iida, M., Umeda, M., Kaho, T., Lee, C.K. and Suguri, M., 1998, Measurement of Annual Crops. International Conference on Precision Agriculture, St. Paul. MN. 19-22, July 1998, ASA, CSSA, and SSSA, Madison, WI.

Okano, C., Nishimune, A., Fukuhara, M., Okamoto, K. and Hayasaka, M., 1997, Sugar beet nutritional diagnosis using remote sensing. P. 381-382. In T. Ando *et al*., (ed) Plant nutrition for sustainable food production and environment. Kluwer Acad. Publi., Tokyo.

Pierce, J.F. and Peter Nowak, 1999, Aspects of precision Agriculture. *Advances in Agronomy*, **67**: 1-85.

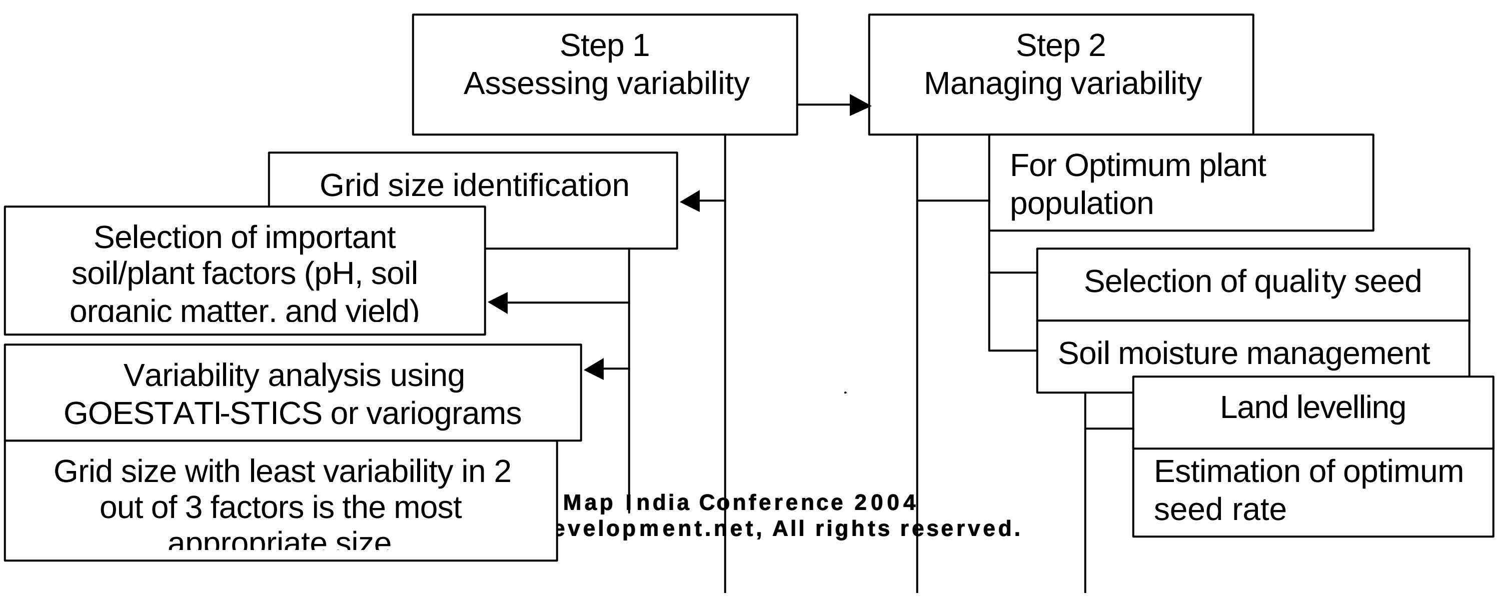
Ray, S.S., Panigrahy, P. and Parihar, J.S., 2001, Role of Remote Sensing for precision farming – with special Reference to Indian Situation *Scientific Note SAC/RESA/ARG/AMD/SN/01/2001*, Space Applications Center (ISRO), Ahmedabad, pp: 1-21.

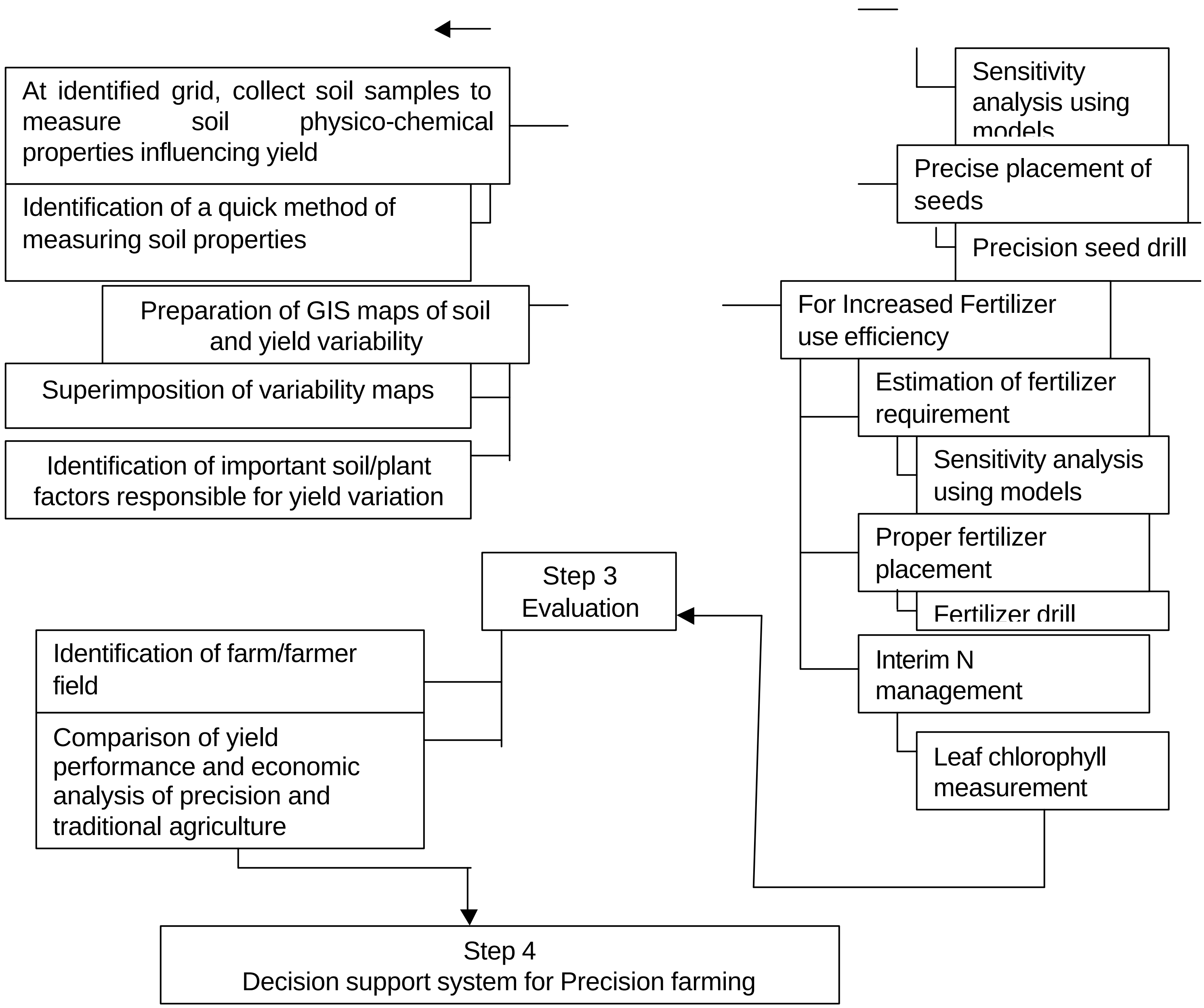
Sadler, E.J., Busscher, W.J., Bauer, P.J. and Karlen, D.J., 1998, spatial scale requirements for precision farming: A case study in the southeastern USA. *Agronomy Journal,* **90**: 191-197.

Srinivasan, 2001, Precision farming in Asia: Progress and prospects, Geospatial Analysis Center, Regional Science Institute, Hokkaido, Japan.

Wilson and Scot 1982, Concepts of variable rate technology with considerations for fertilizer application. *Journal of Production Agriculture*, **7**(2): 195-201.

Precision Farming at a Glance- Steps Involved




At identified grid, collect soil samples to measure soil physico-chemical properties influencing yield
Identification of a quick method of measuring soil properties
Preparation of GIS maps of soil and yield variability
Superimposition of variability maps
Identification of important soil/plant factors responsible for yield variation
Sensitivity analysis using models
Precise placement of seeds
Precision seed drill
For Increased Fertilizer use efficiency
Estimation of fertilizer requirement
Sensitivity analysis using models
Proper fertilizer placement
Fertilizer drill
Interim N management
Leaf chlorophyll measurement
Step 3
Evaluation
Identification of farm/farmer field
Comparison of yield performance and economic analysis of precision and traditional agriculture
Step 4
Decision support system for Precision farming