PRECISION FARMING

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Agricultural production system is an outcome of a complex interaction of seed, soil, water and agro-chemicals (including fertilizers). Therefore, judicious management of all the inputs is essential for the sustainability of such a complex system. The focus on enhancing the productivity during the Green Revolution coupled with total disregard of proper management of inputs and without considering the ecological impacts, has resulted into environmental degradation. The only alternative left to enhance productivity in a sustainable manner from the limited natural resources at the disposal, without any adverse consequences, is by maximizing the resource input use efficiency. It is also certain that even in developing countries, availability of labour for agricultural activities is going to be in short supply in future. The time has now arrived to exploit all the modern tools available by bringing information technology and agricultural science together for improved economic and environmentally sustainable crop production. Precision agriculture merges the new technologies borne of the information age with a mature agricultural industry. It is an integrated crop management system that attempts to match the kind and amount of inputs with the actual crop needs for small areas within a farm field. This goal is not new, but new technologies now available allow the concept of precision agriculture to be realized in a practical production setting.

Precision Farming is generally defined as an information and technology based farm management system to identify, analyze and manage variability within fields for optimum profitability, sustainability and protection of the land resource. In this mode of farming, new information technologies can be used to make better decisions about many aspects of crop production. Precision farming involves looking at the increased efficiencies that can be realized by understanding and dealing with the natural variability found within a field. The goal is not to obtain the same yield everywhere, but rather to manage and distribute inputs on a site specific basis to maximize long term cost/benefit. Applying the same inputs across the entire field may no longer be the best choice. Precision farming is helping many farmers worldwide to maximize the effectiveness of crop inputs. Precision agriculture often has been defined by the technologies that enable it and is often referred to as GPS (Global Positioning System) agriculture or variable-rate farming. As important as the devices are, it only takes a little reflection to realize that information is the key ingredient for precise farming. Farmers who effectively use information earn higher returns than those who don't. Precision farming distinguishes itself from traditional agriculture by its level of management wherein instead of managing whole fields as a single unit, management is customized for small areas *within* fields. This increased level of management emphasizes the need for sound agronomic practices. Before shifting to precision agriculture management, it is essential to have a good farm management system in place. Precision agriculture is a systems approach to farming. To be viable, both economic and environmental benefits must be considered, as well as the practical questions of field-level management and technologies needed (Figure 1). The issues related to precision agriculture include perceived benefits and also barriers to widespread adoption of precision agriculture management.

However, the conventional definition of precision farming is suitable when the land holdings are large and enough variability exists between the fields. In India, the average land holdings are very small even with large and progressive farmers. It is necessary to define revised definition of Precision Farming in the context of Indian farming while retaining the basic concept of Precision farming. The more suitable definition for Precision Farming in the context of Indian farming scenario could be: Precise application of agricultural inputs based on soil, weather and crop requirement to maximize sustainable productivity, quality and profitability. Today because of increasing input costs and decreasing commodity prices, the farmers are looking for new ways to increase efficiency and cut costs. Precision farming technology would be a viable alternate to improve profitability and productivity.

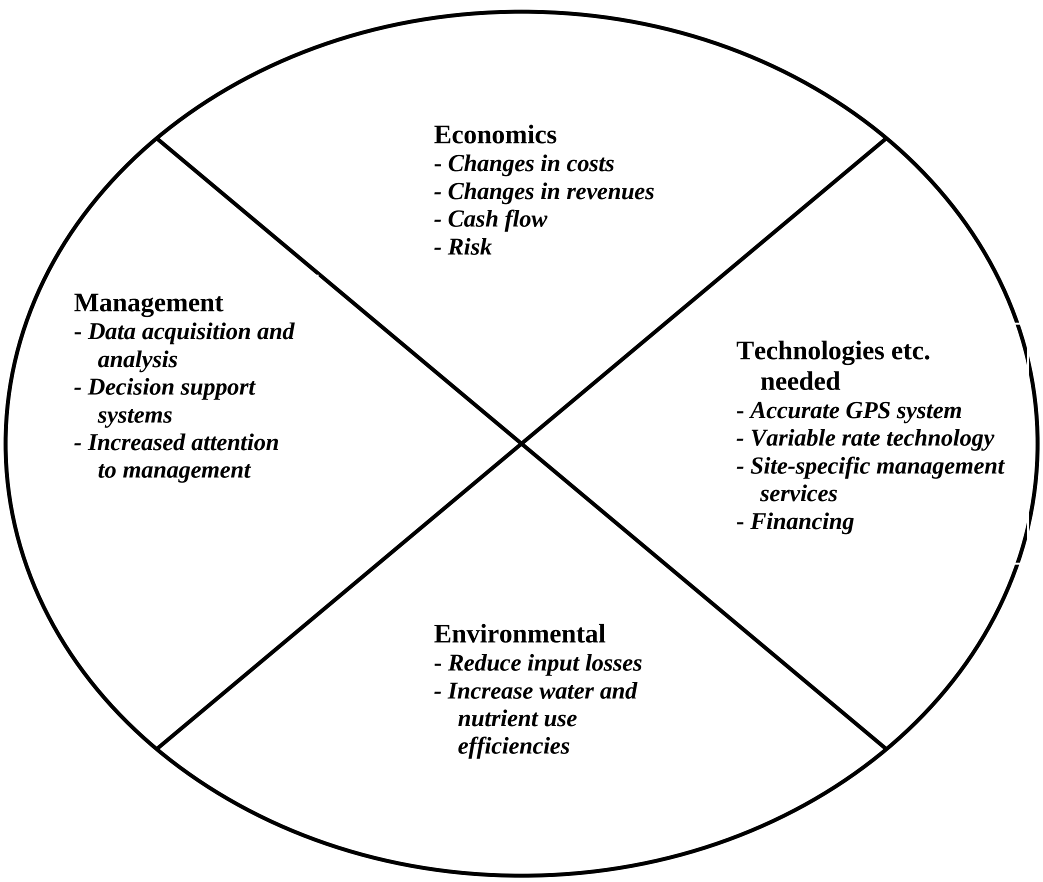

Figure 1: Important issues related to precision farming (adapted from Davis, 2004)

The Need for Precision Agriculture

The potential of precision farming for economical and environmental benefits could be visualized through reduced use of water, fertilizers, herbicides and pesticides besides the farm equipments. Instead of managing an entire field based upon some hypothetical average condition, which may not exist anywhere in the field, a precision farming approach recognizes site-specific differences within fields and adjusts management actions accordingly (Goovaerts, 2000). Farmers usually are aware that their fields have variable yields across the landscape. These variations can be traced to management practices, soil properties and/or environmental characteristics. Soil characteristics that affect yields include texture, structure, moisture, organic matter, nutrient status and landscape position. Environmental characteristics include weather, weeds, insects and diseases.

In some fields, within-field variability can be substantial. In one field, the best crop growth was observed near waterways and level areas of the field. Side slopes where erosion depleted topsoil showed moisture stress and reduced plant stands. In another farm in Missouri, it was observed that the variation in yield levels for corn and soybean was typically 2 to 1. Seeing this magnitude of variation prompts most farmers to ask how the problem that is causing the low yields can be fixed. There is no economically feasible method of "fixing" the depleted topsoil areas in this field, so the management challenge is to optimally manage the areas within the field that have different production capacities. This does not necessarily mean having the same yield level in all areas of the field. A farmer's mental information database about how to treat different areas in a field required years of observation and implementation through trial-and error. Today, that level of knowledge of field conditions is difficult to maintain because of the larger farm sizes and changes in areas farmed due to annual shifts in leasing arrangements. Precision agriculture offers the potential to automate and simplify the collection and analysis of information. It allows management decisions to be made and quickly implemented on small areas within larger fields.

Technologies for Precision Farming

In order to collect and utilize information effectively, it is important for anyone considering precision farming to be familiar with the modern technological tools available. The vast array of tools include hardware, software and the best management practices. These are described briefly in the following paragraphs.

Global Positioning System (GPS) receivers: Global Positioning System satellites broadcast signals that allow GPS receivers to compute their location. This information is provided in real time, meaning that continuous position information is provided while in motion. Having precise location information at any time allows soil and crop measurements to be mapped. GPS receivers, either carried to the field or mounted on implements allow users to return to specific locations to sample or treat those areas. Uncorrected GPS signals have an accuracy of about 300 feet. To be useful in agriculture, the uncorrected GPS signals must be compared to a land-based or satellite-based signal that provides a position correction called a *differential* correction. The corrected position accuracy is typically 63-10 feet. When purchasing a GPS receiver, the type of differential correction and its coverage relative to use area should be considered.

Yield monitoring and mapping: In highly mechanized systems, grain yield monitors continuously measure and record the flow of grain in the clean-grain elevator of a combine. When linked with a GPS receiver, yield monitors can provide data necessary for yield maps. Yield measurements are essential for making sound management decisions. However, soil, landscape and other environmental factors should also be weighed when interpreting a yield map. Used properly, yield information provides important feedback in determining the effects of managed inputs such as fertilizer amendments, seed, pesticides and cultural practices including tillage and irrigation. Since yield measurements from a single year may be heavily influenced by weather, it is always advisable to examine yield data of several years including data from extreme weather years that helps in pinpointing whether the observed yields are due to management or climate-induced.

Grid soil sampling and variable-rate fertilizer (VRT) application: Under normal conditions, the recommended soil sampling procedure is to take samples from portions of fields that are no more than 20 acres in area. Soil cores taken from random locations in the sampling area are combined and sent to a laboratory to be tested. Crop advisors make fertilizer application recommendations from the soil test information for the 20-acre area. Grid soil sampling uses the same principles of soil sampling but increases the intensity of sampling. For example, a 20-acre sampling area would have 10 samples using a 2-acre grid sampling system (samples are spaced 300 feet from each other) compared to one sample in the traditional recommendations. Soil samples collected in a systematic grid also have location information that allows the data to be mapped. The goal of grid soil sampling is to generate a map of nutrient requirement, called an application map. Grid soil samples are analyzed in the laboratory, and an interpretation of crop nutrient needs is made for each soil sample. Then the fertilizer application map is plotted using the entire set of soil samples. The application map is loaded into a computer mounted on a variable-rate fertilizer spreader. The computer uses the application map and a GPS receiver to direct a product-delivery controller that changes the amount and/or kind of fertilizer product, according to the application map.

Remote sensing: Remote sensing is collection of data from a distance. Data sensors can simply be hand-held devices, mounted on aircraft or satellite-based. Remotely-sensed data provide a tool for evaluating crop health. Plant stress related to moisture, nutrients, compaction, crop diseases and other plant health concerns are often easily detected in overhead images. Electronic cameras can also record near infrared images that are highly correlated with healthy plant tissue. New image sensors with high spectral resolution are increasing the information collected from satellites. Remote sensing can reveal in-season variability that affects crop yield, and can be timely enough to make management decisions that improve profitability for the current crop. Remotely-sensed images can help determine the location and extent of crop stress. Analysis of such images used in tandem with scouting can help determine the cause of certain components of crop stress. The images can then be used to develop and implement a spot treatment plan that optimizes the use of agricultural chemicals.

Crop scouting: In-season observations of crop conditions may include: Weed patches (weed type and intensity); Insect or fungal infestation (species and intensity); Crop tissue nutrient status; Flooded and eroded areas using a GPS receiver on an all-terrain vehicle or in a backpack, a location can be associated with observations, making it easier to return to the same location for treatment. These observations also can be helpful later when explaining variations in yield maps.

Geographic information systems (GIS): Geographic information systems (GIS) are computer hardware and software that use feature attributes and location data to produce maps. An important function of an agricultural GIS is to store layers of information, such as yields, soil survey maps, remotely sensed data, crop scouting reports and soil nutrient levels. Geographically referenced data can be displayed in the GIS, adding a visual perspective for interpretation. In addition to data storage and display, the GIS can be used to evaluate present and alternative management by combining and manipulating data layers to produce an analysis of management scenarios.

Information management: The adoption of precision agriculture requires the joint development of management skills and pertinent information databases. Effectively using information requires a farmer to have a clear idea of the business' objectives and crucial information necessary to make decisions. Effective information management requires more than record-keeping analysis tools or a GIS. It requires an entrepreneurial attitude toward education and experimentation.

Identifying a precision agriculture service provider: It is also advisable for farmers to consider the availability of custom services when making decisions about adopting site-specific crop management. Agricultural service providers or properly trained extension workers may offer a variety of precision agriculture services to farmers. By distributing capital costs for specialized equipment over more land and by using the skills of precision agriculture specialists, custom services can decrease the cost and increase the efficiency of precision agriculture activities. The most common custom services that precision agriculture service providers offer are intensive soil sampling, mapping and variable rate applications of fertilizer and lime. Equipment required for these operations include a vehicle equipped with a GPS receiver and a field computer for soil sampling, a computer with mapping software and a variable rate applicator for fertilizers and lime. Purchasing this equipment and learning the necessary skills is a significant up-front cost that can be prohibitive for many farmers. Agricultural service providers must identify a group of committed customers (Self Help Groups or Co-operatives) to justify purchasing the equipment and allocating human resources to offer these services. Once a service provider is established, precision agriculture activities in that region tend to center around the service providers. For this reason, adopters of precision farming practices often are found in clusters surrounding the service provider.

Quantifying on Farm Variability

Every farm presents a unique management puzzle. Not all the tools described above will help determine the causes of variability in a field, and it would be cost-prohibitive to implement all of them immediately. An incremental approach is a wiser strategy, using one or two of the tools at a time and carefully evaluating the results. The examples shown here if of a farm in central Missouri in USA. The yields were adjusted to relative yields, that is, the actual yield was expressed as a fraction of the maximum yield within that year. The relative yield patterns for the three years changed from year to year, and between the different crops. The average yield map revealed two areas of high yield. One area was in the north-central part of the field, and the other extended from the western to eastern boundary in the southern one-third of the field. At this point, it is clear there is a persistent factor or factors affecting yield but more information is needed to determine those factors. In Figure 2 (Appendix), soil test phosphorus and potassium maps are shown alongside a soil pH map. Phosphorus and potassium maps are similar, with low soil test values in the northern one-third of the field. Soil pH values were higher (near neutral) in the southern one-third of the field and along the far southern edge of the field. The well-defined boundary of the high pH area and the fact that it appears to follow the direction of field management suggests this is a consequence of management rather than natural soil variability. Strong evidence that management resulted in the pH patterns is given in Figure 3 (Appendix) where a photograph taken in 1962 showed that the field, now managed as a single unit, was previously broken into three fields that were managed separately. Two farmsteads were located in the southwestern corner and south-central edge of the field (the high phosphorus concentration can be noticed in the areas near the previous farmsteads), and the southern part of the field was in pasture. The previous farmer confirmed that lime was applied to the three fields separately. A reasonable explanation for the high pH area is that more lime was applied on the field adjacent to the farmstead/pasture area than was applied to the fields farther north. The higher pH along the far southern edge was most likely caused by limestone dust blown from the gravel road that appears in the 1962 aerial photograph. An obvious corrective measure is to lime the other parts of the field to raise the pH of those areas. The higher grain yields that appear spatially related to the high pH area may be caused by favorable soil conditions related to pH. However, correlation between yield and a soil parameter is not certain proof that pH is the cause of higher yields. Past management of this portion of the field may have been the more important factor resulting in higher yields. Certainly, additional factors beside soil pH affected yield, because the area of high yield is substantially smaller than the area of high pH. The pH map does not spatially correspond to the area of high yield extending from the northwestern corner of the map to the north-central portion. Unlike the pH-affected area, this feature does appear to be a natural soil-related feature. It matches well with the drainage channel that is visible in the aerial photograph. Understanding this yield variability pattern requires some knowledge of this central Missouri farm soil. Soils in the area are classified generally as *claypan* soils. A claypan soil has an abrupt soil textural change (an increase in clay) between the surface soil and the claypan, a layer that restricts water movement and root growth. In years when water limits plant growth there is a close relationship between the depth of the topsoil overlaying the claypan and yields. The topsoil depth information was collected with a mobile sensing unit linked to a GPS receiver. The sensing unit actually measures the ability of the soil to conduct electricity, and clays conduct electricity better than soils that have less clay. So, claypan soils that have shallow topsoils conduct the electricity better than soils with deep topsoils. It was observed that the area of deepest topsoil is along the drainage channel and this area is clearly the high-yield portion of the field. Together the maps suggest that when the depth of topsoil is mapped, the soil's productive capacity related to soil water relationships can be predicted for different areas of the field. This has implications for nutrient application, especially nitrogen fertilizer. In Missouri, nitrogen is applied in accordance to predicted plant needs by estimating the *yield goal* for a field. Because yield goal (potential productivity) is closely related to topsoil depth, a map of topsoil depth can be used to guide the variable-rate application of nitrogen.

Variability of Soil Water Content and its Implications on Precision Water Management

It is well established fact that soil water content in a field varies over time and location and this temporal and spatial variability in soil water content patterns may have profound implications for precision agriculture in general, and water management in particular. Spatio-temporal variability in soil water was assessed by Starr (2005) over four fields in a two-year potato (*Solanum tuberosum* L.) and barley (*Hordeum vulgare* L.) rotation to determine the potato yield implications and the potential for precision water management based on a stable spatial pattern of soil water. A hammer-driven time domain reflectometry (TDR) probe was used to measure soil water content repeatedly along 10 transects. Irrigated, un-irrigated, and late irrigated treatments were employed. The temporally stable soil water pattern was mapped and compared with elevation and soil particle size classifications. A temporal stability model explained 47% of the observed variability in soil water content. An additional 20% of the variability was attributed to random measurement error. Calibrated in 2002, the model predicted water content (root mean square error of 0.05 m^3) along transects in 2003 from a single measurement at the field edge. Field-scale trends and extended (>100 m) wet and dry segments were observed along transects. Coarser particle size class soils were generally drier. Potato yield increased linearly with water content in un-irrigated areas. Yield was comparatively high in the drier areas for the irrigated treatment but was highly variable and frequently poor in the wetter areas. For the late-irrigated treatment, a strong yield response to added water was evident in the dry areas; however, the yield response was neutral to negative in the wetter areas. Knowledge of the underlying stable soil water distribution could provide a useful basis for precision water management and lead to savings in energy, water, equipment cost, labor, and improved production efficiency.

Spatial Variability of Hydraulic Conductivity and Bulk Density of an Experimental Farm at IARI

Identification and delineation of soil hard pan layers in agricultural fields is not only an essential prerequisite for reducing the cost of land preparation by limiting the operation of farm equipments to break the hard pans, but also for taking up precision farming activities. Such delineation can be achieved by measurement of bulk density of soil from different layers over the entire field and generation of an interpolated surface with varying bulk densities. The interpolation of the measured data can be carried out using deterministic and geostatistical approaches. In this study, geostatistical analysis were carried out on the bulk density and hydraulic conductivity values taken on a grid at 33.3 m x70 m interval covering

22ha of research farm at Indian Agricultural Research Institute using geo statistical module of ArcGIS 9.1 . The exploratory data analysis revealed the absence of any global outlier and presence of a couple of local outliers in the data. The local outliers identified thorough Voroni mapping were removed and the data normality was ensured using logarithmic transformations before feeding the data for semi-variogram model development. The empirical semi-variogram models were fitted with the data and it was observed that the spherical semi-variogram model fitted well ($0.003<RMSE<0.006$ and $0.81<R^2< 0.87$) for the data of 0-15, 15-30 and 30-45 cm soil layers. The generated spatial variability map (Figure 4, Appendix) revealed the presence of compact zones in the soil layers of 15-30cm in which the spatial extent of zones with bulk density > 1.6 Mgm^{-3} and hydraulic conductivity < 6 cm day^{-1} were more. Further, the geo-processing operation of the delineated spatial variability maps of these layers resulted in identification of effective operational area and depth of ploughing to break the compact zones for optimal land preparation leading to better crop production.

Conclusions

Precision agriculture gives farmers the ability to use crop inputs more effectively including fertilizers, pesticides, tillage and irrigation water. More effective use of inputs means greater crop yield and/or quality, without polluting the environment. However, it has proven difficult to determine the cost benefits of precision agriculture management. At present, many of the technologies used are in their infancy, and pricing of equipment and services is hard to pin down. This can make our current economic statements about a particular technology dated. Precision agriculture *can* address both economic and environmental issues that surround production agriculture today. Questions remain about cost-effectiveness and the most effective ways to use the technological tools we now have, but the concept of “doing the right thing in the right place at the right time” has a strong intuitive appeal. Ultimately, the success of precision agriculture depends largely on how well and how quickly the knowledge needed to guide the new technologies can be found.

The approach required to be adopted by the policy makers to promote Precision farming at farm level:

- Promote the precision farming technology for the specific progressive farmers who have sufficient risk bearing capacity as this technology may require capital investment.
- Identification of niche areas for the promotion of crop specific organic farming.
- Encourage the farmers to adopt water accounting protocols at farm level.
- Promote use of micro level irrigation systems and water saving techniques.
- Encourage study of spatial and temporal variability of the input parameters using primary data at field level.
- Evolve a policy for efficient transfer of technology to the farmers.
- Provide complete technical backup support to the farmers to develop pilots or models, which can be replicated on a large scale.
- Policy support on procurement prices, in formulation of cooperative groups or self help groups
- Designation of export promotion zones with necessary infrastructure such as cold storage, processing and grading facilities.

Appendix

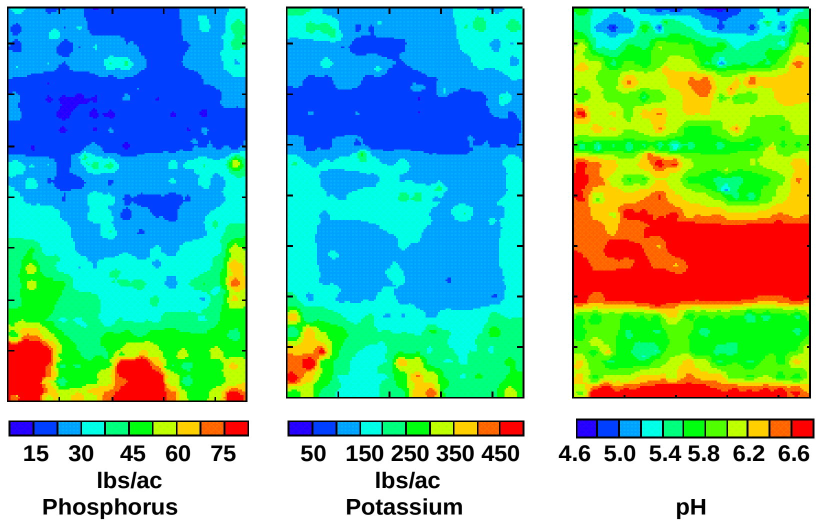

Figure 2: Soil test phosphorus, potassium and pH for a central Missouri farm.

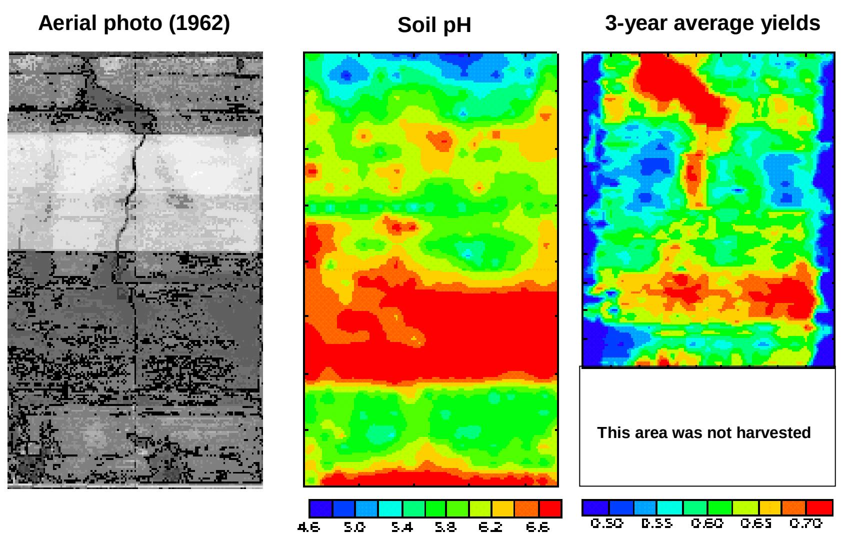

Figure 3. Aerial photograph, soil pH and 3-year average grain yields for central Missouri farm.

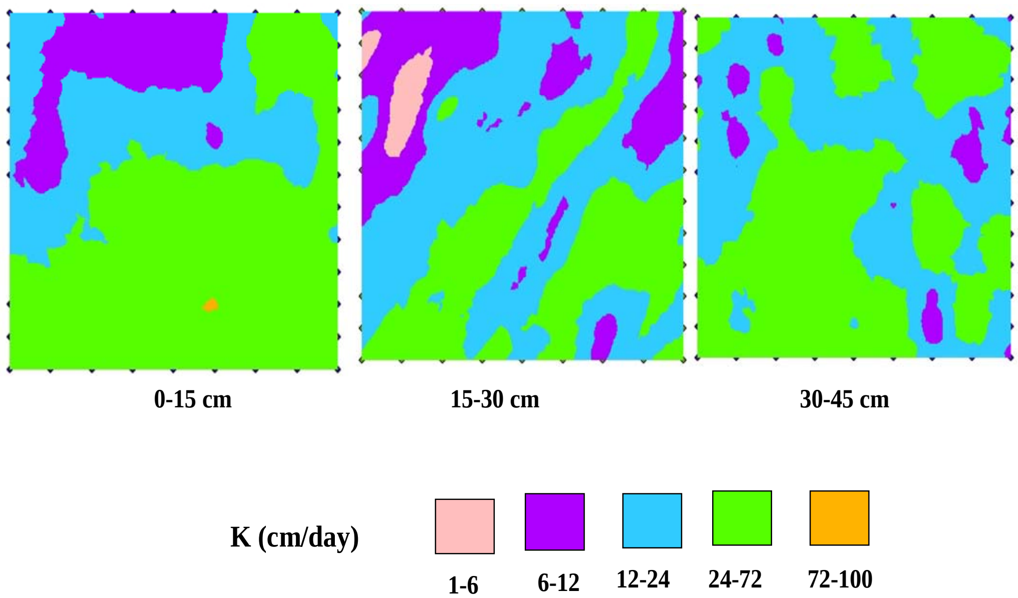

Figure 4: Spatial Variability of Hydraulic Conductivity for different depths at IARI farm: Identification of zones essential for Deep Chiselling