POTENTIALS AND PROSPECTS OF PRECISION AGRICULTURE IN PAKISTAN - A REVIEW

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ABSTRACT:- Precision agriculture is to fine-tune the agricultural production system by emergence and convergence of several information-based technologies for enhancing profit and reducing environmental risks. These technologies have demonstrated to provide benefits to farmers as well as reduced environmental stresses in the developed world. Present paper provides an overview of precision agriculture and examines the potentials, prospects, implications, issues and relevance of precision agricultural applications in Pakistani agricultural system. There is a scope of many precision technologies to be implemented in the country. In this perspective, farmers and government authorities should look forward to adopt new and sustainable technologies to increase the efficiency of available resources and reduce the input costs. Before this, the effectiveness of precision technologies needs to be realised in Pakistan through field experiments and land management practices.

Key Words: Precision Agriculture; Modern Technologies; Adoption; Challenges; Potentials; Implications; Pakistan.

INTRODUCTION

Pakistan is a developing nation and an agricultural country of South Asia. Agricultural industry contributes 21 % to Pakistan's Gross Domestic Product (GDP) (GoP, 2012). Pakistani agriculture can be characterised by small farms with low productivity and inefficient use of crop inputs, although there are two categories of farmers: small to medium sized farmers and large established land managers. In recent years, the agricultural sector of the country has been facing serious problems, such as reduction in crop yield, increase in input prices, power shortage, water scarcity, and reduced acceptance of agricultural products in international markets (Amjad, 2012). Furthermore, lack of subsidies on agricultural necessities, uncontrolled prices of food items, unavailability of agricultural inputs, lack of information from consultant agencies, poor agricultural policies of government, decreased farmer's return and untimely availability of irrigation are some major factors which negatively affect agricultural sector and hence farming community (Amjad, 2012; Zaraimedia, 2013).

The conventional farm management systems are based on the use of generalised recommendations across

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the whole field or all the fields within a farm (Bakhsh, 2011). This increases the initial cost due to inefficient use of chemicals and raises environmental concerns, such as ground water quality (Corwin et al., 2003; McBratney et al., 2003). Before the revolution of agricultural mechanisation in the world, farmers used to vary treatments by making small sized fields. With intensive mechanisation, the fields were enlarged in the developed world and it was difficult to take into account within field variability without a revolutionary development in technologies (Stafford, 2000).

Precision agriculture is an information-and technology-based farm management system. This aims at the application of technologies and principles to identify, analyse and manage spatial and temporal variability associated with all aspects of agricultural production within fields for near-optimal profitability, sustainability, improving crop performance, protecting land resources and safeguarding the environment (McBratney et al., 2003; Pierce and Nowak, 1999; Shibusawa, 1998; Stafford, 2000; Zhang et al., 2002). From the definition it is clear that precision agriculture is a multidisciplinary approach that covers a broad array of topics, such as characterising variability in soil resources, soil tillage, irrigation, crop rotation, machinery performance, plant genetics and crop physical, chemical and biological inputs (Zhang et al., 2002). The development of new sensors, actuators, applicators, agricultural machinery and other apparatus owes to engineering discipline to a great extent. Precision agriculture also plays a role in determining engineering parameters related to soil and crops, such as predicting soil tillage and workability, determining irrigation requirement, soil strength and compaction and measuring draught force. In short, the concept of precision agriculture is to fine-tune the agricultural production system by emergence and convergence of several technologies for enhancing profit and reducing environmental risks (Whelan, 2007; Zhang et al., 2002).

Basic steps in precision agriculture are sensing variability, managing variability and evaluating the decisions based on the management of variability (Pierce and Nowak, 1999). Sensing variability is the most critical step in precision agriculture because proper management and better decision making cannot be done without proper knowledge (Minasny and McBratney, 2002; Mondal and Basu, 2009). After adequately assessing variability, it can potentially be managed by matching required inputs in spatial and temporal context. To account for within field variability, both proximal and remote sensing technologies have been developed and are being promoted in the developed world (Mahmood et al., 2012; Viscarra Rossel et al., 2011).

Adoption of precision agriculture is recognised as a new revolution in agricultural sector, especially in America, Australia and Europe, although the adoption is very slow (Mondal and Basu, 2009; Swinton and Lowenberg-DeBoer, 2001). A few years ago, the precision technologies were restricted to only some developed countries. Reports from the USA, Canada, Europe and Australia have shown that precision agricultural applications can result in reduction in input application rates without sacrificing crop yield (Bongiovanni and Lowenberg-DeBoer, 2004; Cook and Bramley, 1998; Gebbers and Adamchuk, 2010; McBratney et al., 2003). A widespread adoption of precision agricultural technologies may come from strict environment legislation, public concern over excessive use of agrochemicals and economic gain from reduced agricultural inputs and improved farm management efficiency (McBratney et al., 2003; Zhang et al., 2002). Adoption of precision agricultural technologies in the developed world has created a real challenge for the developing countries to include some suitable modern technologies in their farming systems to meet the food requirements of their growing population. Accepting this challenge, some developing countries, such as Argentina, Brazil, China, India and Malaysia have begun to adopt some components of precision agriculture, especially on research farms, but the adoption is still very limited (Aimrun et al., 2009; Baytas and Akbal, 2002; Fidêncio et al., 2002; Hamzah et al., 2008; Hendrickx et al., 1992; Mondal and Basu, 2009; Paixão et al., 2006; Srinivasan, 2001, 2006; Tiwari and Jaga, 2012; Zhang et al., 2002).

Currently in Pakistan, agricultural mechanisation is in its development phase, which was actively started two decades now. Before introduction of agricultural mechanisation, farm power was based on humans and animals. Although agricultural mechanisation helped to improve yield greatly, but had no effect on characterising within field variability in soil and crop attributes, such as soil texture, moisture content, soil nitrogen and other minerals, plant stress analysis and chlorophyll level (USAID, 2009). Precision technologies are able to predict within field variability which can be used for site-specific variable application of soil and plant inputs. As 93 % farmers of the country are small and marginal land holders (Ghafoor et al., 2010), therefore, to handle within field variability for maximising yield and profit has been a desire of the farmers.

There is a wide gap between the potential and the actual yield level in Pakistan (Bakhsh, 2011). This necessitates the promotion of precision agriculture to achieve the intended benefits. It has been postulated that despite small landholding and low income levels, precision technologies can make a significant difference in livelihoods of equipment operators and farmers (Mondal and Basu, 2009; Srinivasan, 2001). Since precision agriculture is a rather new for the farming community of the country, this paper describes the overview of precision agriculture and examines the potentials, prospects, implications, issues and relevance of precision agricultural applications in Pakistan.

MECHANISM FOR PRECISION AGRICULTURE

Precision agriculture has the potential and wisdom in utilising natural resources efficiently and protecting natural environment. There are four steps to implement precision agriculture: (a) characterising the extent and scale of variability in soil and crop attributes; (b) interpreting the significance and causes of variability; (c) managing variability on spatial and temporal basis and (d) monitoring the outcomes resulting from the variability management practices (Shanwad et al., 2004). The flow of information in precision agriculture for crop production is shown in Figure 1. The basic phases in precision agriculture include the accurate assessment of variation in soil and crop properties, management of spatial variation and evaluation in space and time. In the following lines, the three above mentioned steps for implemented precision are discussed.

Characterising Variability

Characterising variability is the most important step because other steps can be implemented successfully if variability is correctly known (Minasny and McBratney, 2002; Mondal and Basu, 2009).

Variability can be assessed in the following attributes:

Yield Variability

Yield variability of crop is determined using yield monitors fitted on combine harvesters with accurate

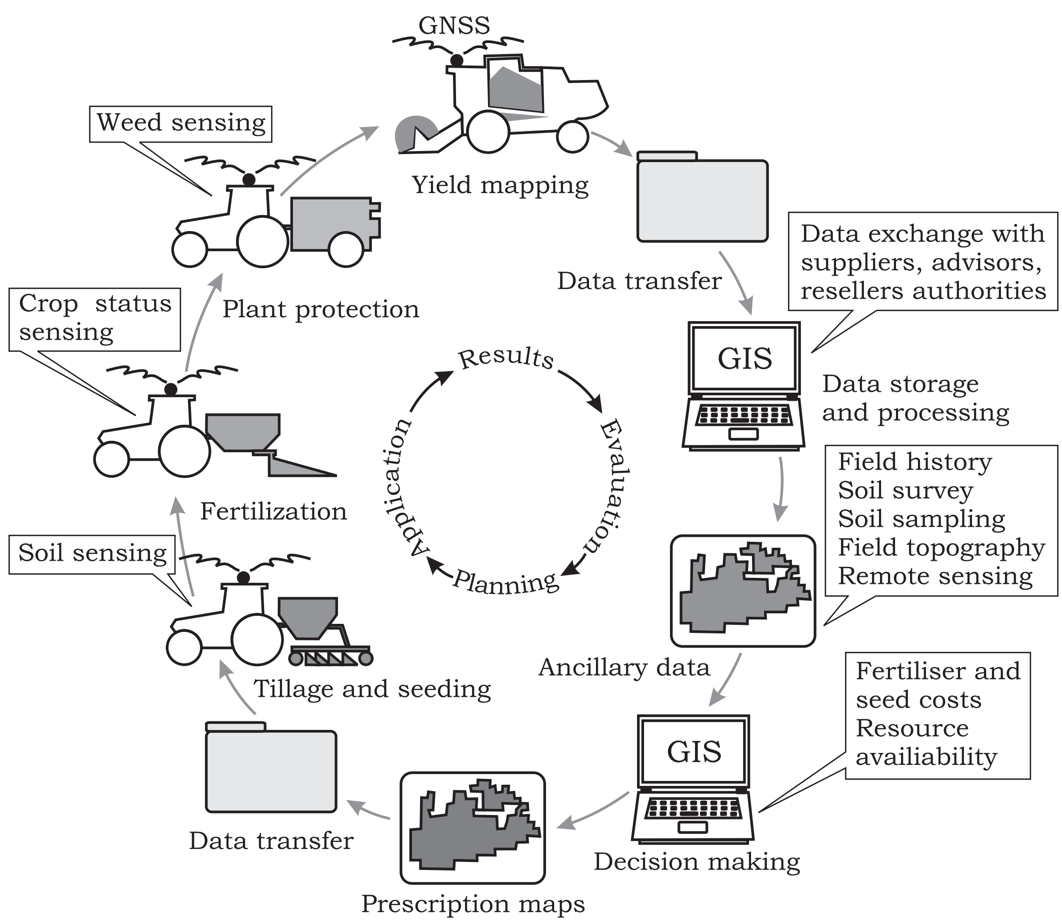

Figure 1. Precision agriculture information flow in crop production (Source: Gebbers and Adamchuk, 2010)

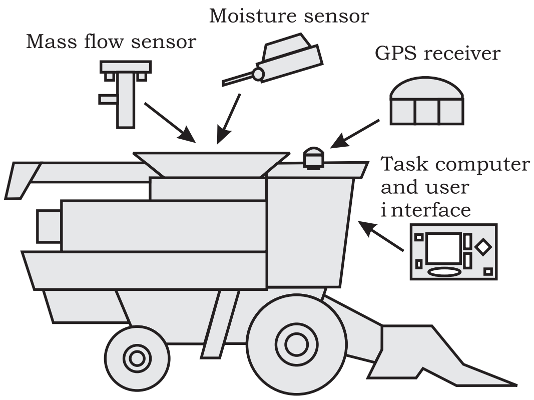

Figure 2. Components of a grain monitor (Robert, 2009)

spatial locations using an accurate differential global positioning system (DGPS) device. The leading manufacturers of yield monitors include: AgLeader Technology, Iowa, USA; PrecisionAg, Illinois, USA and TeeJet Midtech, Illinois, USA. After collection of data, yield maps are prepared. A grain monitor consists of a mass flow sensor, moisture sensor, a DGPS receiver, keypad and a display screen. A typical grain yield monitor fitted with a combine harvester is shown in Figure 2.

Field Variability

Field variability in topography, slope, elevation and field boundaries can be determined using proximal- and satellite-based remote sensors (McBratney and Pringle, 1997).

Soil Variability

It is the variability in soil physical (texture, organic matter, structure, and moisture), chemical (N, P, K, Fe and pH) and mechanical (compaction, bulk density and soil strength) properties. Proximal soil sensors in precision agriculture have capabilities to provide soil information with high spatial and temporal resolution and to explain variations in soil properties (Hendrickx et al., 1992; Hummel et al., 1996; Islam et al., 2003; Kuang et al., 2012; Mahmood et al., 2011; 2012; McBratney et al., 2005; Stenberg and Viscarra Rossel, 2010; Sudduth et al., 2010; Viscarra Rossel et al., 2011; Wong et al., 2010). Furthermore, proximal soil sensors are more accurate than the remote sensors and the depth of measurement can also be controlled. Using remote sensors, the depth of measurement cannot be controlled.

Crop Variability

It is the variability in different aspects of a crop, such as crop height, density, crop nutrient level, water stress, leaf area index and amount of biomass (Chapman and Barreto, 1997; Whaley et al., 2000; Wiegand et al., 1991; Wood et al., 2003).

Tillage Variability

For site-specific tillage operation, decision is made where tillage should be done based on soil strength and tillage related properties (Adamchuk et al., 2004b; Mouazen et al., 2003; Mouazen and Ramon, 2009; Vrindts et al., 2005).

Variability in Anomalous Factors

Variability in weed density (Tian et al., 1999; Wang et al., 2001), crop nitrogen level (Ahmad et al., 1999; Scharf and Lory, 2000), disease infestation (Riedell et al., 2000), leaf area index (Lee et al., 2010) and chlorophyll content (Ahmad et al., 1999; Hellebrand and Ehlert, 1996; Lee et al., 2010) is determined using remote as well as proximal sensors.

Managing Variability

Once variation is adequately assessed, it is managed by customising agricultural inputs such as tillage, irrigation, fertilisers and pesticides on a site-specific basis within fields. The management can either be done following a map-based approach or a reactive approach (Adamchuk et al., 2011; Mahmood et al., 2012). These two approaches are discussed under application control.

Evaluation

For precision agriculture it includes the assessment of economic gains, environmental benefits of these technologies and the value of technology transfer to the farming community. This requires a complete comparison of both conventional and precision agricultural approaches. Technology and knowledge transfer is the ability of a farmer or equipment operator to grasp the use of technology and the level of communication with other farmers.

COMPONENTS OF PRECISION AGRICULTURE

Precision agriculture depends on the measurement and understanding of variability, therefore, the main components of precision agriculture must address the variability (Plant, 2001). Precision agriculture comprises following components:

Differential Global Positioning Systems (DGPS)

A DGPS is a network of satellites, which is used to identify the location of data points of crop and soil attributes in latitude, longitude and elevation with high precision. Inputs can be customised to individual locations based on the precise DGPS information (ESRI, 2012; Mondal and Basu, 2009).

Geographic Information System (GIS)

This system integrates hardware, software and data for capturing, managing, analysing and displaying all forms of geographically referenced information (ESRI, 2012). A GIS is able to accept, organise, statistically analyse and display diverse types of spatial data that are digitally referred to a common coordinate system (Adamchuk et al., 2004a; ESRI, 2012). When these datasets are grouped and overlaid to combine new datasets, they can be used for further allocation decisions (Venkataratnam, 2001).

Remote and Proximal Sensors

Data from remote and proximal sensors have been used for many years to detect water, determine salinity and nutrients, to distinguish crop species, to monitor yield and to locate crop stress in fields (Adamchuk et al., 2004a; Gowrisankar and Adiga, 2001). Remote sensing applications are operated from a satellite or an airplane (Barnes et al., 2003; Ben-Dor et al., 2009; Bian et al., 2009; Mulder et al., 2011; Park et al., 2002), whereas proximal sensors are operated from a close distance from a measuring entity (Hossain et al., 2010; Jadoon et al., 2010; Kuang et al., 2012; Mahmood et al., 2011; Myers et al., 2008; Sudduth et al., 2010; Viscarra Rossel et al., 2011).

Application Control

Application can be controlled in two ways: map-based control (predictive approach) and real-time control (reactive approach) (Adamchuk et al., 2004a; 2011; Mahmood et al., 2009; 2012). Map-based applications are more common till today as they require less complicated apparatus and computing algorithms (Viscarra Rossel et al., 2011). In this method, sensors acquire the data and generate attribute maps off-site after data processing with location information from a DGPS. For the optimal use of agricultural inputs, decision-making is then followed. In reactive applications, sensors change the rate of application of inputs in response to local conditions at the time of application (Viscarra Rossel et al., 2011). These types of applications do not have widespread feasibility due to the complexity of sensor designs, which also need the most accurate GPS devices and GIS systems.

Variable Rate Technology

A soil nutrient map with GIS is stored in a computer mounted on a GPS guided tractor that senses the exact location of tractor within the field and sends signals to the computer. The decision support system decides the exact requirement of fertilisers and other inputs for each location in the field and commands the variable rate applicator to apply the exact dosage of input at each location (Maleki et al., 2007). This operation is done in real-time within seconds. Variable rate fertiliser applicators have been successfully used in the developed world. Other variable rate systems include sprayers, granular spreaders, tillage implements, hydrous ammonia spreaders, irrigation systems and herbicide applicators (Bennett and Brown, 1999; Swisher et al., 1999).

Yield Monitors

Yield Monitors are fitted to combine harvesters (Figure 2), which measure the yield and moisture content of grains real-time and yield maps are produced (Robert, 2009). The yield maps give the indication of poor and productive spots and then variable rate application of inputs are applied (Barnes et al., 2003). Yield monitors may be the point of entry to implement precision agricultural technologies for many farmers. Yield maps are an essential layer of data in a spatial database for management of land. Interpreting and using the yield maps is a key step in developing precision management skills (Adams et al., 2000; Barnes et al., 2003; Dobermann and Ping, 2004; Vitharana et al., 2008).

Computers and Electronics

Computers and electronics have made it easy to process and store a huge volume of data in the shortest possible time. Different types of information collected by static and mobile sensors in precision agricultural paradigm is stored in computers and used for further mapping and processing purposes. These technologies have made the processing of on-line data easy and very fast. Therefore, computers and related electronic components are very essential components of precision agriculture that have made a revolutionary progress.

PRESENT STATUS AND SCOPE OF PRECISION AGRICULTURE IN PAKISTAN

Some experts have stressed to initiate precision agriculture in the country for quite some time and have guided the farmers to use precision agriculture, such as tillage, water, agro-chemicals for increasing the benefits of the farming community

(Bakhsh, 2011), but a single report of the use of precision technology cannot be presented so far. The only precision technology that has been used in Pakistan successfully for a few years is the laser land levelling. This may also be termed as precision land levelling. This is a topographic modification, grading and smoothing of land to an even level with little or no slope, which improves irrigation application efficiency and increases the uniformity of water application with less chance of over and under irrigation (Kahlown et al., 2002). About 50% of total available water is lost in transit in tertiary level irrigation system and at the farm during application to crops (Gill, 1994). A significant amount of irrigation water is wasted due to undulated fields and due to field ditches (Kahlown et al., 2002). Precision land levelling increases crop yield about 26 % and reduces the mean time to irrigate an acre field from 2.12 h to 1.13 h (Johnson et al., 1977). Precision land levelling is a resource conservation technology to save irrigation and to gain more benefits. Despite useful benefits of precision levelling, there may be some environmental issues related with this technology, such as erosion and poor water holding capacity at filled spots (Kahlown et al., 2002). Other examples of precision technologies are not found in the country till now.

India has made significant advances in introducing precision agricultural technologies, such as micro-irrigation and protected cultivation during the last two decades (Tiwari and Jaga, 2012). This is attributed to the support of Indian government policies, which is encouraging farmers to adopt precision technologies. In Pakistan, there is also a need to support this information-based agriculture by the government agencies and the researchers should conduct research on farmers' fields to bring their attention towards this type of new agriculture. Unfortunately, Pakistan is far lagging behind in promoting this technology as this should be initiated with a comprehensive plan for increasing productivity. This is the fact that the initial uptake of new technologies is always slower due to costs and unknown benefits. It is also true that adoption of precision agriculture in the entire country is not possible as every farmer will not be ready to accept these sophisticated technologies, but there are some relatively developed areas, which can act as incubators for adoption of these technologies for emerging.

Precision agriculture is also feasible in small landholding where the contiguous fields with the same management can be considered a large field and map-based precision agricultural applications have a great scope (Mondal and Basu, 2009). For instance, about 1.5 mha of rice-wheat cropping system in the Punjab, where rice and wheat are grown in rotation, is the choice for precision technologies. Attractive site-specific decisions can be implemented in this area, such as soil characterisation, non-destructive monitoring of crop stress, crop nitrogen monitoring, weed infestation and determining crop biomass using remote sensing tools. Similarly, the progressive farmers of the country, with the help of government institutions and private agencies, can adopt some components of precision applications on a limited scale for demonstration to other farmers and stakeholders as the technology shows potential to increase yield and profit. The progressive farmers can buy or pay the cost of information used for precision agricultural applications. Initially the idea will progress from the progressive farmers not from a small farmer. Once this is introduced in the country then every farmer will be keen to follow. Effective coordination among the public sector, private sector and growers is very essential for achieving fruitful results of precision agricultural technologies. Successful examples of this coordination include United States Department of Agriculture (USDA) in the United States and Agricultural Development and Advisory Service (ADAS) in United Kingdom.

STRATEGIES FOR ADOPTION OF PRECISION AGRICULTURE IN PAKISTAN

Precision agricultural technologies can significantly reduce the inputs and environmental pollution. Precision technologies should be started for high value commercial crops that may bring more benefits to farmers. No technology proves economic benefits with their first use, but the long term adoption of a technology definitely brings these benefits. The initial goal should not be to get maximum yield, rather to optimise crop inputs and to prevent over- and under-application of agricultural inputs for reducing environmental risks. Furthermore, to get the farmers attention towards this type of agriculture should be the main focus of this strategy. Small farmers should start with a single precision application, whereas the progressive farmers should select more than one precision application on their farms because it will bring them more benefits. Small farmers can use low cost and small machine-based variable rate technology. Agencies in private sector can motivate the progressive farmers to use precision agriculture on their farms by providing them infrastructure support, operational support, coordination and control of farming activities and strategic support.

CHALLENGES, ISSUES AND IMPLICATIONS OF PRECISION AGRICULTURE IN PAKISTAN

Pakistan is an agricultural country, yet the agricultural sector is not able to produce the potential level of production from the existing resources. This is attributed to the lack of utilisation of modern technologies in agriculture, small landholding and high input costs. Lack of awareness is the first and foremost reason for this late start of precision agriculture in Pakistan. The farmers who have knowledge about these technologies, the exact reasons for their reluctance in implementation of precision agriculture in Pakistan include smaller farm size (< 1 ha), land tenure system, high-cost technology, unavailability of technology locally, heterogeneity of cropping systems or crop diversity and lack of technical expertise and knowledge. Perhaps the two major problems towards its implementation are small landholdings and high cost of this technology. Other challenges towards the adoption of precision agricultural technologies in agriculture are as follows:

- Introducing precision agricultural technologies in conventional agriculture requires modern technologies; such as smart computers, remote sensors, proximal sensors, yield monitors, actuators and variable rate applicators together with competence to use modern GIS software for incorporating GPS information in the outputs of precision agricultural technologies. Currently, there is no such facility in the country and therefore introduction of these technologies will take a longer period.

- As 93 % of farmers have smallholding (Ghafoor et al., 2010) and application of these technologies may not provide comparable benefits, such as variable rate application of inputs real-time. However, the management of zones can be successfully delineated by using remote and proximal sensors to characterise soil and crop attributes.
- Heterogeneity of cropping systems is also a challenge in the adoption of precision agriculture in the country.
- The lack of legislation from the government towards using environmental friendly production practices in agriculture is a big hurdle in this regard. Organic farming and controlled use of farm inputs are the key approaches in this respect, which can attain sustainability in agriculture, improve human health and significantly reduce the environmental contamination, such as ground water and soil contamination with excessive chemicals and fertilizers. The government should take initiative to address these issues to bring sustainability in agriculture.
- In developed countries, there are skilled organisations and agencies in private sector that provide consultancy services to farmers to use precision technologies and obtain potential benefits. Unfortunately in Pakistan, there are no such agencies in private sector that can provide such consultancy services to farmers. If there is any agency/organisation, it does not possess such skill to convince farmers.
- Agricultural machinery manufacturers are not so skilled and aware about these technologies yet. They should be supported to introduce the modernisation in agricultural sector with the help of research and educational institutions.
- The low export volume of agricultural products is also a reason of unawareness of these modern technologies in agriculture. In modern world, people are demanding safer foods, which contain very low or minimum amount of chemicals. The competition in the international market will drive local farmers to use these modern technologies for producing safer foods.
- Cheap and vast land can be grown with conventional type of agriculture, but precision technologies may fit better in the country because of small landholding and high prices of land to get maximum benefit from the limited land resources.

POTENTIALS AND PROSPECTS OF PRECISION AGRICULTURE IN PAKISTAN

Most farmers in the country have small landholding. It is true that most precision applications are not applicable in the small-scale farming culture and searching for suitable technologies matching these conditions of the developing countries is a real challenge. However, some precision technologies can be used in small-scale farming system as discussed by Cook et al. (2003). For example, application of GIS to small farms has been very successful in some developing countries, such as Korea, Japan and China (Mondal and Basu, 2009). In rice-wheat belt of the Punjab, combine harvesters are used for harvesting rice and wheat. Yield monitors can be successfully used on those combines for site-specific yield monitoring. This information can be linked with the determination of soil characteristics based on the yield of different locations in the field and for making soil maps. Currently, not a single combine is equipped with a yield monitor in the country (Personal Communication, 2012). Similarly, fertiliser applicators/spreaders can also be used in small-scale farming system if soil variability maps are available. For in situ measurement of crop nitrogen status, portable chlorophyll meters are excellent diagnostic tools (Mondal and Basu, 2009). Potable pH meters can be used on-the-go for determining soil pH and making map. Map-based precision agriculture has more applicability in the country than the reactive systems, which are more complicated and need large fields. Excessive use of pesticides can be reduced by adding the precision gadgets to spraying machines. If the benefits of new technologies are advocated to farmers in Pakistan and these technologies are offered to them at reasonable prices, they will embrace them happily. But, a prerequisite is that technologies are reliable and do not increase the risks (in terms of food availability or finances). If this can be achieved, then we can suggest that adopting modern tools in our agriculture that have innovation and sustainability may help avoid the potential food, environmental and social disasters.

CONCLUSION

There is a need to drive precision agricultural technologies in Pakistan. It is suggested that despite small landholding and low income levels, precision technologies can make a significant difference in the livelihoods of equipment operators and farmers. There is a good scope of many precision technologies to be implemented in the country. In this perspective, farmers and government authorities should look forward to adopt new and sustainable technologies to increase the efficiency of available resources and reducing the inputs costs. Before a widespread implementation of precision agriculture in the country, its effectiveness needs to be realised on experimental farms for different possible precision applications.

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