PRECISION FARMING

Soil Fertility and Productivity Aspects

K. R. Krishna, PhD

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List of Abbreviations

AE_N	Agronomic efficiency of fertilizer-N
BMP	Best management practice
CEC	Cation exchange capacity
DGPS	Differential global positioning system
EONR	Economically optimum rates of N
EC	Electrical conductivity
EMI	Electromagnetic induction
FYM	Farmyard manure
GIS	Geographic information system
GPS	Global positioning systems
INM	Integrated nutrient management
LED	Light emitting diode
NIR	Near-infrared
NDVI	Normalized difference vegetative index
NMR	Nuclear magnetic resonance
PF	Precision farming
RVI	Reflectance vegetation index
SAR	State agency recommendation
SSNM	Site-specific nutrient management
SOC	Soil organic carbon
SOM	Soil organic matter
SPAD	Soil plant analysis development
STCR	Soil test crop response
VRT	Variable rate technology
WFM	Whole farm management

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Preface

Precision is an important concept that has induced, guided, and improved many aspects of human endeavor for ages. Historically, precision has been an important factor in agricultural evolution *per se*. Precision in planting dates and matching crops with seasons to derive maximum advantage from soils and precipitation patterns are perhaps the oldest aspects of agriculture. Farmers have been striving to achieve greater accuracy on these aspects of agricultural cropping since the Neolithic period. They continue to do so even today. There is no doubt that through the ages, precision as a concept has been imbibed into almost every technique and practice during crop production. Precision has been a key factor in selection of healthy seeds, seeding technique, fertile locations, types of manures, and moist zones. Precision has sometimes caused quantum changes in cropping pattern and productivity. Precision in matching soil fertility and its variations with crop species or its genotype with yield goals is a key aspect of agriculture in any part of the world. Precision is needed while selecting a crop genotype. The genotype should match the agro-environment, soils, season, grain yield goals, and profitability. Agricultural cropping trends and productivity, in particular, have depended on the extent of precision bestowed on farming procedures. For example, precise crop genotype, accurate supply of nutrients, and irrigation in time and space were major factors in improving crop productivity during first half of the 20th century. Today, precision techniques offer farmers the greatest opportunity to regulate soil nutrient dynamics, protect agro-environment and yet enhance crop productivity.

During recent years, a perceptibly greater degree of precision has been incorporated into almost all farming procedures. Soil fertility and manure supply trends, in particular, have received greater attention with regard to the extent of precision possible. The advent of computer models, simulations, and decision support systems have allowed us to direct exact quantities of seeds, fertilizers, water, and pesticides through the use of variable-rate technology. Actually, equipments such as computers, handheld sensors, and satellite-guided systems have remarkably enhanced precision during farming. Precision technique creates uniform soil fertility across a field. Grain/fruit and forage productivity too become uniform commensurately. Precision techniques often envisage use of slightly or markedly lower quantities of fertilizers and irrigation to achieve same levels of crop productivity. The reduction in fertilizer usage delays or totally avoids deterioration of soils, ground water, aquifers, and general agro-environment. Precision techniques also provide higher profits to farmers. Overall, reduction in use of natural resources, improved grain/forage yield, and extra profitability compared to farmer's traditional procedures hold the key to its rapid acceptance in most agricultural regions of the world.

During past decade, rapid improvements have occurred in precision techniques. Improvization of GPS-guided farm machinery, sensors, data capture, soil fertility mapping procedures, and GPS-guided variable-rate techniques have been marked.

The spread of precision techniques into different agricultural belts and evaluation of its advantages have received the greatest attention. Precision technique is most recent among the agronomic procedures exposed to farmers/researchers. Field evaluations across different continents suggest it could be a very popular and profitable technology in the near future.

This book, titled *Precision Farming*, is introductory. It begins with a discussion on historical aspects, provides brief descriptions on techniques, and enlists advantages as well as constraints that influence the adoption and spread of precision farming in different continents. Chapter 2 provides details on intricate instrumentation, their functioning, and advantages that accrue during precision farming. Chapter 3 forms the centerpiece of this book. It deals with the influence of precision farming approaches on soil fertility, nutrient dynamics, and productivity of various crops. The spread of precision farming methods into different geographic regions and profitability are discussed in detail in Chapter 4. A brief discussion about the future course of precision farming approaches appears in the last chapter.

This book on precision techniques is concise and provides valuable information on instrumentation and methodology. It encompasses lucid discussions about the impact of precision techniques on soil fertility, nutrient dynamics, and crop productivity. It is most useful to students, researchers, and professors involved in various aspects of agriculture.

— K. R. Krishna, PhD

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Dr. Eric Lund and others of Veris Technologies, Salina, Kansas, USA, provided pictures of sensors that estimate soil pH, electrical conductivity, and nutrients. Pictures on precision techniques such as management strips, strip tillage, variable-rate supply of fertilizer and seeds, GPS-guided seeder, fertilizer mixing trucks, and fertilizer application systems were obtained from Mr. David Nelson, Nelson Farms Inc, Fort Dodge, Iowa, USA. Pictures of hand-held portable instruments that estimate photosynthetic activity were obtained from Mr. Micheal Larman, CID-BIO Science, Camas, Washington, USA. Pictures of hand-held sensors that measure Leaf-N and chlorophyll content, help in gauging N status of a crop, and in forecasting yield were derived from Konica-Minolta Sensing Inc, New Jersey, USA.

I wish to thank my wife Dr. Uma Krishna and son Mr. Sharath Kowligi.

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1 Introduction

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1.1 HISTORICAL ASPECTS

Precision means exactness or accuracy in performance of a particular task. In the present context, it refers to accuracy of various agricultural practices and farming per square that are carried out by farmers. Precision is actually a concept that got imbibed into agricultural endeavor of human beings, since pre-historic times. Precision also induced evolution of agricultural techniques and farming. Earliest of the steps towards precision could be seen in preferential seeding of a particular crop species in the vicinity of prehistoric human dwelling sites of early to late Neolithic period. Neolithic farmers gained by seeding and growing a precise crop species in those backyards of their dwellings. It overcame difficulty in tedious collection of grains from swamps or plains that had admixtures of all kinds of plant species. In this case, precision in terms of crop species and domestication allowed farmer greater quantity of harvests. It is interesting to note that since these early stages of agricultural history, precision as a concept has been quietly imbibed and utilized too, mainly to make farming easier and enhance productivity of land. Farmers devised procedures and manufactured implements that enhanced accuracy. Precise soil management using plough meant better nutrient and water management. Farmers introduced ploughing and line sowing during ancient period. Ploughing and line sowing is indeed a conspicuous effort to add greater degree of precision into farming, in terms of planting geometry and density, efficient interception of light, as well as moisture and nutrient scavenging. It is a major event in the agricultural history that added precision to farms worldwide. Line sowing improved crop production compared to a field randomly broadcasted with seeds. Tillage and line sowing added precision to several other procedures like timing of interculture operations, top dressing, irrigation, pesticide application, and harvesting. During modern era (1820th century), precision got imbibed into agriculture through various improvements that farmers effected on to their implements, seeding procedures, irrigation devises, harvesting, and grain processing. During this period of history, farmers literally gained in efficiency and productivity by adding precision to farming procedures. Most glaring of the procedures introduced by farmers that added precision are precise planting dates to match with precipitation pattern and season. Even today, we strive hard to add precision into planting dates, seeding depth and plant population because it improves nutrient scavenging, moisture absorption and grain harvests significantly. Precise crop species and precise field to match fertility requirements of crops are other measures that improved productivity. Irrigation channels helped farmers in the supply of precise quantities of water at various stages of the crop development. During recent decades, there has been a steady improvement in precision aspects of implements, gadgets and procedures adopted in the field. Invention of fertilizer formulations improved accuracy further. Soil fertility could be mended accurately and sustained despite repeated cropping of the same field. Soil nutrients could be accurately replenished using various soil chemical analysis procedures and soil test crop response (STCR) studies. Automatic irrigation based on periodic soil moisture measurements and crops' need improved accuracy of crop production. Together, aspects like precise crop species/genotype, nutrient replenishment and irrigation were instrumental in enhancing crop yield. We should note that precise selection and genetic improvement of crop species has added to grain harvests significantly.

Historically, selection of genotypes that flowered and matured uniformly, produced non-dehiscent panicles/seeds of uniform traits have added to accuracy. Production of genotypes with uniform height and panicle development (semi-dwarfs) that aided efficient mechanical harvest is a glaring example that depicts gain in precision through crop breeding. Since mid 1900s, precision as a concept was imbibed as a matter of routine into almost all aspects of farming. Throughout past decades, almost every modification in traction machinery, types of coulters, their shape, size, seed drills, fertilizer drills, hoes, weeders, harvesters, right up to development of elaborate combine harvesters have all aimed at enhancing accuracy of specific tasks. Gadgets driven mechanically or through electrical power added further to precision of agricultural techniques. Electronic controls and timing too added precision to various farm operations.

Historically, most recent of the farming measures that seems to add precision into farming procedures, yet again and in significant amount, is the use of satellite-guided seeding, fertilizer application, irrigation, pesticide spray, harvesting, and yield monitoring. Satellite-guided procedures and computer-aided decision support systems are forecasted to revolutionize the way agricultural farms are managed. Such procedures are collectively termed Precision Farming (PF) because they add accuracy to soil fertility and moisture management, rather enormously. In summary, precision is a concept that has been imbibed into farming. It has helped farmers to carry out various tasks efficiently with due gains in input efficiency and grain/forage harvests. Right now, we have no idea regarding limit to precision or accuracy in farming procedures and the extent of benefits it may fetch. We ought to appreciate that evolution of agricultural operations and gain in precision has affected nutrient dynamics and productivity of the land, either directly or inadvertently. This aspect should be needs to understand in greater detail.

The PF as we know today currently involves, remote sensing, Global Positioning Systems (GPS) guided instrumentation, fertilizer supply based on Geographic Information System (GIS), computer models, and variable rate nutrient applicators. Historically, this aspect of farming is only one and a half decade old. Its development, refinement in technology, introduction and rapid spread into different cropping zones has occurred since mid 1990s. It is relatively a new scientific aspect with a short stretch of history. Some of the earliest references to within field variability pertaining to soil moisture, nutrients, and pH were made as early as 1986. Actually, precision agriculture as a concept that overcomes within field variability in soil fertility and one that provides better synchronization between nutrient need and supply was envisaged in 1986 (Fairchild, 1994). It received greater attention as a method that has impact on resource use efficiency, crop production, profitability, and environment during 1990s (Earl et al., 1996; Gerhards et al., 1996; Khakural et al., 1996).

Farmers situated in most regions of the world, including highly intensive crop production zones like Corn Belt of USA or Wheat expanses in Europe or rice cultivation areas in Southeast Asia or subsistence farming zones in semi-arid regions were ordinarily accustomed to simple and traditional techniques to estimate soil fertility. Then, they prescribed fertilizers/organic manure and recorded harvest derived from entire field. Identification of within field variations regarding soil physico-chemical properties, fertility trends and obtaining productivity maps was not practiced routinely. According to Berry et al. (2010), soil or yield maps played insignificant roles in crop production until mid 1990s. Soil and topographical maps were more generalized and directed towards demarcation of soil fertility regimes. Agricultural crop production was based mostly on whole field estimates of soil fertility. In fact, only broad averages were considered while taking nutrient management decisions. Soil sampling was superficial and done to know physico-chemical conditions and nutrient status at a broad field level. Grain elevators and combine harvesters recorded only final yield per field/farm allowing us to compute only average grain yield per hectare. Such data were used as efficiently and authentically to decide about cropping systems, soil fertility measures, planting densities, irrigation, and disease/pest control measures and harvest schedules. It is interesting to note that during past 15 years, geospatial technology as applied to agricultural crop production has improved enormously. This technology has expanded rapidly from a mere practice to operational reality in several million hectare all over the world (Berry et al., 2010). It is a fact that, at present, even least sophisticated tractors or harvesters bought come with ability to record and map grain yield. Most tractors with advanced instrumentation sense soil fertility variations. They are also equipped with variable rate technology (VRT). Lowenberg-DeBoer (2003a) has made an interesting comparison regarding adoption and spread of PF techniques. He states that initially, pattern of spread of precision techniques was slow and uneven. This seems more like the situation found with motorized mechanization of farm operation in the first half of 20th century or adoption of “No-tillage systems” during second half of 21st century. Hence, spread of precision techniques was not similar to rapid acceptance of say Hybrid Maize in 1930s or hybrids of other cereal species like Sorghum or Triticum. It has been argued that precision techniques are evolving and becoming more efficient with time rather slowly. It is not a finished product unlike a “Hybrid Corn”.

Adoption of PF has been relatively more widespread and rapid in developed nations. Farmers have moved from conventional mechanized farming to high technology PF that is guided by GPS, computer based decision support and electronically controlled variable rate applicators and other farm machinery. It is interesting to note that during past decade, sales, and use of equipments necessary for PF such as monitors and variable applicators have increased by 70% in USA and Canada (Tran and Nguyen, 2008). Large farms common to North American agricultural zones seems to induce adoption of PF. Whereas, in the Fareast, small farms seem to make its adoption slower. However, there are clear instances wherein farm size or geographic location does not seem to retard acceptance of PF. It is interesting to note that during initial years in 1990s, the PF techniques were adopted more by farmers situated in proximity to farm and fertilizer dealerships and stores. Farmers with fertile soils and those intending to obtain greater profits from nitrogen fertilizer adopted PF in greater number than, ones who were financially poor and possessed fields with low fertility soils (Kessler and Lowenberg-DeBoer, 1998). In the Mid-west region of USA, a few other surveys directed at assessing farmers adopting PF techniques indicated that in early 1990s, farmers who were young, less than 50 years old and educated up to collegiate level preferred newer techniques like VRT. Farmers previously exposed to computers and those already using electronic gadgets adopted PF despite its elaborate requirement of sampling, GIS, GPS, and VRT instrumentation (Khanna et al., 1999).

Dobermann et al. (2004) have pointed out that initial spurt in adoption of PF in North America and Europe was primarily driven by need to maximize profits, reduce fertilizer-N consumption and NO_3 leaching into ground water. However, adoption of PF was only patchy in North America, Europe, and Australia. Regarding initial use of yield monitors, Lowenberg-DeBoer (2003a) has stated that such instruments were first used in 1992 in USA. Since then its use has grown rapidly, especially in the Great Plains area. In 2003, 30% of tractors used in maize farms were fitted with yield monitors, 25% of soybean fields and 10% of wheat cultivating zones were being assessed using yield monitors. Currently, PF is a popular technology in the Corn Belt and entire Great Plains, where wheat and cotton cropping dominates. Further, it has been pointed out that, in 2004 A.D., about 30,000 yield monitors were in use in USA, 800 in Australia, 800 in Argentina, 1300–1500 in European cereal belt and a few on experimental basis in Asian cropping zones. This is indicative of popularity and usefulness of PF as perceived by farmers. Presently, European cropping zones that support cereal and forage production too use precision techniques more frequently. Dobermann et al. (2004) state that commercialization of soil and crop sensors began in 2000 A.D. It mainly involved estimation of pH, electrical conductivity, and soil nutrients. Whereas, crop sensors develop during this period, usually estimated leaf color, chlorophyll content, and moisture.

Historically, the VRT was among the earliest of site specific technologies adopted on farms. It was used first in 1992 in the "Corn Belt of Untied States of America". It was used to spread fertilizer evenly into farms/fields. Initially, VRT depended on accrued data or maps obtained from grid sampling. The VRT spread rapidly in the mid-west region of USA. In 1996, over 29% of cereal farms adopted VRT and the area improved to 50% in 2002 (Lowenberg-DeBoer, 2003a). Adoption of VRT was generally profitable to farmers in the Great Plains. High value crops responded better than low productivity cereal zones, whenever VRT was adopted to supply fertilizer. Currently, "on-the-go" soil analysis, decision support systems and rapid incorporation of fertilizers is practiced. However, overall goal of VRT is still the same even after 25 years. It aims at finding spatial variations and supplying nutrients/water appropriately at target spots (Sudduth, 2007).

The PF is an apt suggestion in countries that support large sized farms and expansive agriculture, for example in Argentina, Australia, United States of America, some regions in Western Europe, and Russia. PF could be a preferred technique in most of the large sized commercial farms situated anywhere on the globe. It is interesting to note that in USA, farms less than a square mile would become nonviable. Basically, these are large farms and a "field" would mean a vast area with wide fluctuations in soil fertility, especially nutrient and water distribution in the surface and subsurface of soil profile. Blanket application of fertilizer-based nutrient supply creates a mismatch. It results in unequal nutrient removals from patches of soil. Crops tend to be uneven with regard to productivity. Soil fertility continues to stay uneven in the entire farm. Therefore, precision approaches like, closely spaced grid sampling of soils and their analysis is a necessity. Demarcation of large field into "management zone" is a good alternative. Maps depicting soil fertility variations can be used to apply fertilizers accurately resulting in better economics, in addition to providing uniformity to soil fertility. According to Rickman et al. (2003), there are over 2 million farms in USA that are large and need to be managed using precision techniques. The situation is similar with large farms in other regions of the world. The PF allows us to impart uniformity in soil fertility and economize on use of fertilizers and water, especially in agricultural regions with large sized farms. During 2000–2010, extension programs in Ohio State of USA aimed at transmitting knowledge about PF from "early adopters" to those considering its adoption. The program aims at spreading information about usefulness of precision techniques to environmental quality, nutrient dynamics in the farm and grain yields. They mainly at aimed sharing details on yields monitors, variable rate applicators, and information gathering techniques (Batte and Arnholt, 2003).

Economic surveys conducted in the farming zones of South Central Plains, especially in Arkansas, indicated that about 35% rice farmers, 2% each of soybean, cotton, maize, and wheat cultivators had adopted PF in one form or other. Forecasts by Griffin et al. (2000) suggested that fraction of farmers shifting to precision techniques would increase rapidly by 10–20% in case of crops like rice, soybean, and wheat, say in 38 years time. Currently, farmers using VRT has crossed 20% in Arkansas, USA. Adoption of PF was induced through special incentives in several states of southern USA. Programs initiated in 2010 aimed at reduced fertilizer inputs, reduction in runoff and leaching of nutrients. It also aimed at improving water quality irrigation use efficiency.

Segarra (2001) states that PF was first tested in Northern Texas during mid 1990s. The PF was introduced as a method to economize on fertilizer based nutrient supply into fields that supported cotton, sorghum or corn. Farmers actually aimed at deriving greater profits by adopting "management zones" to place precise quantities of fertilizers and water. Surveys of cotton farms in Southern plains of United States of America showed that, PF was accepted by most farmers, mainly to lessen burden on fertilizer input, improve soil quality and most importantly gain extra cash benefits. The PF methods had spread into large portion of cotton belt by 2000 (Roberts et al., 2002).

Field experimentation with precision techniques began in early 1998 in New Mexico State. They used a series of techniques such as grid sampling, sensors to assess soil and crop nutrient status, variable rate applicators and so on. Farmers were also educated about usefulness of adopting PF. The PF was introduced in many locations within New Mexico, mainly to optimize fertilizer based nutrient supply, pesticide sprays and irrigation. Farmers in New Mexico could also obtain proper soil fertility and productivity data and revise their yield goals accordingly (Ball and Peterson, 1998).

Historically, soil sampling drew greater attention from farmers who intended intensive farming and those who wanted to replenish lost nutrients and reap uniform harvests. Soil sampling became more accurate when both surface and subsurface samples were drawn at close spacing. This provided better judgment regarding within field variations of soil fertility, especially major nutrient distribution. Intensive sampling of soil is a recent trend corresponding with adoption of PF approaches. In the North American farming zones, farmers adopting PF have consistently sampled soils using grid or management zones and analyzed them for nutrients and other traits since past 15–20 years (Ferguson and Hergert, 2009). Since 2000 A.D., remote sensed soil maps, yield maps, and maps depicting variations in soil fertility have been in vogue with farms practicing PF. During recent years, sampling densities and measurements have increased enormously. The main aim is to enhance accuracy of fertilizer supply across a field and remove unevenness in crop growth and grain harvests as effectively as possible.

According to Sparovek and Schnug (2001), historically the concept of PF emanated from North American fertilizer industry specialists, who aimed at improving soil fertility assessment and fertilizer efficiency. It was introduced into Brazilian cropping zones in South and Southeast during later part of 1990s. Argentineans have been using precision techniques, especially those related to soil maps and yield monitoring since past decade. Experimental evaluation and adoption of PF methods began in Argentina in 1996. Initially, it was tested on cereals and soybean grown in large expanses that are common to Pampas, more precisely in the Cardoba region of Argentina (Bongiovanni and Lowenberg-DeBoer, 2005). This program later expanded into other areas of the nation.

The PF techniques were in vogue in Chile by the turn of the century. Such techniques have been applied on major crops like wheat, oats, beet, and maize that are generally grown on Rhodoxeralfs (Alfisols). The PF that includes preparation of soil fertility maps; chlorophyll meter readings and variable rate N inputs have been practiced by Chilean farmers since 2000 A.D. (Claret, 2011; Molina and Ortega, 2006; Ortega et al., 2009; Villar and Ortega, 2003). Regulation of N dynamics in fields, mainly reduction in fertilizer-N supply and loss through leaching and emissions are major reasons for pursuing precision techniques.

Quest to standardize and adopt PF techniques began in many of the European nations during early part of 1990s. They adopted a range of techniques that suited different regions within Europe. Factors like topography, cropping systems, intensity of cropping, economic value of the crop, and advances in instrumentation affected the spread of PF. Sensor based technology was common in many farms that produced wheat. Fertilizer recommendations were guided by the computer based decision support and yield goals. In some regions, for example in the wheat growing regions of France, farmers started using digital imagery and remote sensing to regulate fertilizer and water supply to their fields. By the year 2002, farm cooperatives were supplied with remote sensed images and appropriate suggestions based on satellite pictures (SPOT) (Astrium, 2002).

In many parts of Southern Africa, PF is a modern technology that is fueled by recent advances in computer-based control of farm equipments and implements. Experimental evaluation and adoption of site-specific methods is more recent in South Africa. It began during early part of past decade. Much of the interest in PF in South Africa is focused around soil and fertilizer-based nutrients on crop productivity and farm profits (Maine et al., 2005). The PF techniques were also evaluated for use on horticultural and cash crops common to South Africa. Main goals were to assess its impact on soil and environment, crop productivity and economic advantages to farmers. Both short and long term benefits of PF were evaluated (Maine and Nell, 2005).

In South Africa, PF was initiated as part of a continuous 30 year steady modernization of machinery, implements and methods that improvise traction, seedings, interculture, harvest, and processing. Early efforts to introduce and standardize PF in South African farming zones occurred during mid 1990s (Rusch, 2001). Initially, techniques and instrumentation relevant to PF were derived from European nations.

Earliest of the reviews regarding adoption of PF during sugarcane production in Mauritius were made by Jhoty and Autrey (2000). They have made several suggestions regarding improvising sugarcane production through PF. They have argued that

PF approach that improves resource use efficiency (fertilizers, irrigation, and pesticides) and enhances profitability could make sugarcane production more competitive.

Based on their observation in several developing countries of Asia, Tran, and Nguyen (2008) state that PF system got initiated in early 1990s. It was practiced in various forms depending on knowledge base and available technologies. It is implementation depended on access to combination of advanced information technology and farm mechanization. Electronic methods of data collection and decision making played the key role in its adoption. The basic components of PF in any agro climatic region comprises remote sensing, GIS, GPS, soil testing, sensors, mapping of soil fertility variations, yield monitors, and VRT.

According to Indian Agricultural Research agencies, facilities for adoption of PF are available for use in many agro-ecoregions of India. The basic aspects involved are assessing soil variability, managing variation, and evaluation of impact of precision techniques. During recent years, PF has been evaluated in India, on crops like potato, rice, wheat, and cotton. It seems there are clear possibilities to economize on fertilizer-N supply and still improve crop productivity.

The PF that involves GPS, GIS, grids and soil fertility maps, sensors, VIT, and yield monitors was introduced in parts of Southern India, on an experimental basis in the dry regions of Dharmapuri in Tamil Nadu, during 2003–2004 kharif season. It included 5 crops that were managed using chisel ploughing, satellite based soil fertility maps, and fertilizer application using variable rate instruments and drip irrigation to regulate soil moisture uniformly. In three years between 2003 and 2006, number farmers adopting PF increased and the crops covered included many cereals, legumes, and vegetables. Farmers making profits from PF congregated to create “precision farming societies”. Such societies disseminated knowledge among others in the area (India Development Gate, 2010; Shanwad, 2010). Reports by Maheswari et al. (2008) clearly suggest that quite a large number of vegetable farmers situated in different districts of Tamil Nadu adopted PF. In Dharmapuri District of Tamil Nadu, which is situated in dry region, economic surveys indicated that PF was in vogue by 2005 and most farmers reaped better profits compared to conventional farming procedures. During past decade (2000–2010), several other agencies initiated long term evaluation of PF. For example, Indian Space Research Organization evaluated remote sensing and soil fertility maps derived from it for potato production at Jalandhar, in Punjab. Similarly, cropping systems project at Modipuram evaluated soil fertility mapping and variable rate inputs into several crop rotations followed in Gangetic plains.

Regarding practice of PF in the horticultural belts of South India, it is interesting to note that at present, several “Precision farming Development Centers” has been started. Such centers standardize precision techniques to suit to the cropping pattern adopted locally and test them commercially in the farmer’s fields (KSHMA, 2011). Most of the PF centers meant for horticultural crops are situated in the Agricultural universities and research institutes of Indian Council of Agricultural Research, New Delhi (Shanwad, 2010).

In China, effort to introduce PF was guided by the Chinese Academy of Agricultural Science, Beijing. They conducted a series of experimental evaluations in 1990s on crops like cotton, maize, and wheat in the provinces such as Hebei, Shanxi, and Shandong. Reports suggest that Chinese farmers used soil fertility maps, GIS, and GPS guided systems on maize grown in Shandong as early as 1998 (Jiyun and Cheng, 2011). State Agricultural Agencies and farmers were driven to adopt PF mainly to improve fertilizer efficiency and productivity of land per unit time.

Maize is an important cereal crop of China. It is often intercropped or rotated with soybean. Fertilizer supply and its efficient use are priority items within this cropping belt. Therefore, efforts to manage soil nutrients using PF during maize production were initiated during later half of 1990s and 2000 A.D. (Wang et al., 2006). Similarly, rice production zones are vast and intensive in many areas of China. The PF approaches were evaluated for their utility in rice production during the past decade (Wang et al., 2006; Xie et al., 2007; Zhang et al., 2006). Currently, many farmers in major cereal production zones are practicing PF.

In the Australian wheat belt, experimentation and use of PF got initiated during late 1990s. Initially, it was confined to preparing soil fertility maps and variable rate N application. At present, PF has been applied to several other aspects of wheat production (GRDC, 2010). Dobermann et al. (2004) opines that during mid 1990s, Australian farmers were enthusiastic about the newly developed yield monitors and GPS guided instrumentation. Yield monitors were introduced in the Australian wheat belt during 1993. Large farms in Western Australia used GPS guided machines for wheat production on duplex soils. However, farmers found cost of grid sampling and using yield maps prohibitive. Hence, they resorted to management zones and strip-based techniques to supply variable rates of fertilizers. During recent year that is since 2005, precision techniques based on "on-the-go" soil analysis, computer-based decision support systems and use of computer simulation/models are becoming popular.

The Australian rice belt is relatively very small, yet its productivity is high at 10 t grain ha^{-1}. The soil fertility variation that occurs during rice cultivation is being tackled using PF approaches, at least in some areas of New South Wales (Spackman et al., 2003). Precision techniques are being used to supply in season split dosages of fertilizer-N. They use both sensors placed close to crop canopy as well as multispectral remote sensing data to feed their variable rate fertilizer applicators. Reports by AGMARDT (2002) suggest that in New Zealand, precision techniques were adopted to assess soil fertility and moisture variation in fields in order to supply nutrients/irrigation using VIT on cereals and oilseeds grown as early as 1998.

1.1.1 Trends in Soil Fertility Management Practices

The PF is part of a series of soil fertility management methods that farmers and researchers have been devising and adopting since ages. Indeed several of them are still popular and useful to farmer's world over. Now, let us consider a chronology of farming techniques that were shrewdly devised to maintain soil fertility, crop productivity, and ecosystematic functions. Historically, farmers began adopting soil fertility restoration methods many centuries ago. These nutrient management techniques generally involved *in situ* measures like residue recycling, fallows, and refurbishment using animal or farmyard manures. Soil fertility was held at optimum level, to the extent possible, depending on the nutrient content of the organic manures. Variations in nutrient availability were removed only to a certain extent and it persisted. Repeated cropping and insufficient recycling meant lower grain/forage yield, occurrence of soil fertility variations within a field and in many cases nutrient deficiencies were conspicuous. As a consequence, potential grain/forage yield possible in a given location or environment was not possible. Progressively crop yield would decrease in a location.

Knowledge gained through mineral theory of crop growth, several other soil fertility concepts and fertilizer technology helped us to develop a series of different soil nutrient management procedures, all aimed at restoring soil nutrient status and maximizing crop yield. Earliest of the soil fertility management methods involved visual score of crop, identification of nutrient deficiencies and matching a supply of fertilizer-based nutrient. Although, nutrient deficiencies were overcome to a certain extent, it did not ensure optimum yield. The nutrient supply was not based on a yield goal. It only ensured removal of nutrient deficiencies transitorily. Further, nutrient ratios were also not at all maintained and this could have lead to nutrient imbalance. In many situations, it actually led to lack of yield response due to Liebig's Law of Minimum.

Later, a concept more generally applicable and based on previous evaluation of crop's response to different levels of fertilizer supply was adopted. It was called "Critical Nutrient level". Critical nutrient availability in soil is a level at which at least 95% of maximum grain/forage yield potential in the given location or environment could be produced. The critical nutrient level varies depending on several factors mostly related to soil, crop, environmental parameters, and yield goals. During past 23 decades, farmers cultivating perennial crops have been exposed to fertilizer recommendations based on plant tissue analyses. It involves elaborate sampling and analysis of all essential nutrients in leaf, leaf blade or petiole or any other portion of a plant. It is more commonly known as DRIS. Since the method utilizes only a small portion of plant tissue and just a few samples, it is non-destructive, if we consider the entire crop. Fertilizer recommendations could be altered periodically as the crop grows or seasons progress, based on nutrient status of the crop.

Next, a concept called "STCR" was envisaged. It involved series of field trials that evaluated crop's response to different levels of fertilizers. Aspects like fertilizer formulations, nutrient ratios, methods of fertilizer placement, crop genotype, and yield goals could all be standardized and recommended to farmers on a blanket basis, as suitable for a given agro-ecoregion.

Farmer's traditional practices were also in vogue in many agricultural belts. Farmers adopt several practices that maintain soil fertility and maximize crop yield. Such agronomic measures were standardized through the ages drawing knowledge from folklore and based on recent experiences. Collectively, these approaches are called

"Farmer's Traditional Practices". Farmers may apply soil test values before prescribing fertilizers. Farmer's practices envisage supply of nutrients through both inorganic and organic sources. The quantity of fertilizers supplied is guided by the soil type, crop genotype, and season. Nutrients supplied may not suffice to achieve maximum possible yield. Also, fertilizer dosages may not be the best in terms of economic advantages. Nutrient ratios in soil may or may not get satisfied. Usually application of organic manures removes dearth for micronutrients. Currently, farmer's practice in a moderately fertile belt involves inorganic fertilizers, Farmyard manure (FYM), biofertilizer and amendments to correct soil pH, if required.

State agency recommendation (SAR) was formulated to guide farmers in an agricultural belt or large cropping expanse. Fertilizer recommendation is primarily guided by State Agricultural Programs related to land management, cropping systems, intensity, and annual yield goal. Fertilizer supply rates are stipulated for a soil type, crop, region or yield goal. The SAR do not consider within field variations. Therefore, nutrient supply could often be higher than required or sometimes insufficient depending on variations in soil fertility. Nutrient dynamics in a large area is optimized through state agency stipulations.

Best management practice (BMP) is a term more commonly used to denote a collection of soil fertility management methods that result in high grain/forage yield and offers best economic advantages in a given location. Fertilizer supply is held at high levels so that deficiencies are not expressed. Grain yield is generally high. Soil fertility is held optimum using inorganic and organic sources. Bio-fertilizers are also used.

Maximum Yield Technology is a concept that envisages fertilizer supply so that grain/forage productivity is highest in a given locality. Yield maximization involves application of high rates of inorganic fertilizers and FYM. Basically, aspects like fertilizer quantities, their timing, ratios, and formulations are all aimed at maximizing biomass production. It does not consider soil fertility variations within a single field. Often, a certain quantity is held in subsurface layers of soil as residual nutrients.

Integrated nutrient management (INM) envisages supply of nutrients based on soil tests, crop's demand for nutrients, and yield goals. Most importantly, it considers environmental issues like soil deterioration, exhaustion of nutrients, and recycling and soil quality. Therefore, under INM, farmers are asked to supply nutrients using as many different sources. Both, organic and inorganic sources of nutrients are utilized at different ratios. In addition, bio-fertilizers are also used. Crop yields are generally optimum but not the best or maximum in a given locality. Again, INM does not consider soil fertility variations that may occur within a field. Nutrient accumulation or depletion in soil based on a given locality and cropping pattern is a clear possibility.

Site-specific nutrient management (SSNM) or PF is perhaps the most recent technique among the series of nutrient management methods that is known to farmers situated worldwide. It considers relatively minute variations in soil even within a small field. Often, it involves use of detailed grid sampling, soil nutrient estimations; preparation of soil maps, GIS, computer models and GPS guided soil fertility distribution using variable applicators. Of course, SSNM is also amenable manually. The PF is a relatively new procedure. Basically, it considers soil fertility and crop's demand for nutrients as accurately as possible in time and space. Since nutrient supplies are exact, undue accumulation in the soil profile is avoided. It also avoids soil and ground water deterioration. Crop yield is optimum and economic benefits are generally slightly more than that achieved using other procedures. Ecosystematic functions are not altered or affected to any great extent.

1.2 DEFINITIONS FOR PRECISION FARMING

According to Khosla (2011), PF has indeed experienced unprecedented expansion and popularity in some parts of the world, especially where intensive farming practices are in vogue and productivity is relatively high. The PF as a concept has been understood and utilized in different ways by the farmers and researchers. There are of course several different explanations about what is PF or not. Khosla (2011) says PF connotes several "Rs". They are right input, right timing, right amount, right place, right methods, right manner, right machinery, right crop, right fertilizers and other inputs and so on. However, he also cautions that PF is often misinterpreted as complex technological invention of the recent times, meant to be used mostly by the rich farmers and large farms. The PF is said to be costly because it involves large machinery, high electronic and mechanical sophistication, and costly labor. It is not so. The PF is amenable to both, highly mechanized farms that are controlled electronically and small farms that depend on manual distribution of seeds, farm inputs and regulation of irrigation.

The PF has been defined and explained in variety of ways depending on context, purpose or end use, relevant agricultural operations and inputs such as fertilizers, water, pesticide, methods employed and so on. Most of these definitions or explanations deal with utility of PF in managing soil fertility that is obtaining uniform and accurate distribution of soil nutrients and/or water. Following is a list of definitions and brief explanations provided by various researchers.

One of the definitions arrived at the Second International Conference on Site-specific Management for Agricultural Systems, held at Minneapolis in 1994 states that, PF or site-specific crop management is an information and technology based agricultural management system to identify, analyze and manage site-soil spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment.

One of the most common definitions for PF states that it begins with an accurate assessment of soil fertility through GPS mapping, soil sampling, and testing. It aims to achieve maximum efficiency with regard to nutrient and water supply, and maximize profits. According to National Agricultural Research Council of United States of America, PF that is also frequently termed as "site-specific crop management" refers to developing agricultural management system that promotes variable management practices within a field. It is dependent on site's soil fertility conditions (NARC, 1997).

Berry et al. (2010) consider a wider horizon for PF. They define it as a system that focuses on sound crop production, applying geotechnology to effectively understand and manage the dynamic flows and cycles of nutrients within a field or agroecosystem.

Rickman et al. (2003) have suggested that a mismatch between uniformity of crop treatments, nutrient supply and distribution necessitates adoption of PF. The PF actually integrates a suite of technologies that retain benefits of large-scale mechanization. Yet, it recognizes local variations and aims to correct them. Satellite-based data accrual regarding soil fertility variations and crop development allows farmers to fine tune seeding, fertilizer, and water supply. It generally lowers cost of production.

Blackmore (2003) states that PF strives to improve yield goal and efficiency in agricultural practices. It involves developing techniques and procedures that help agricultural managers to enhance production efficiency. It integrates computing, electronic gadgetry, and satellite based-techniques.

Hernandez and Mulla (2008) have opined that PF is a holistic, new and developing agricultural system. It is adoption could progressively change crop production practices and trends in United States of America and other parts of the world. The PF is already influencing the agricultural crop production through adoption new GPS-based techniques. Precise spatial and temporal information regarding soil fertility and moisture can increase input efficiency, farm productivity, and profitability. At the same time, it imparts a certain influence on environmental quality of farm.

Karlen et al. (1998) have defined that precision agriculture, at the minimum, requires three elements, namely:

(a) Positioning capabilities (GPS) to know where certain equipment is located;
(b) Real-time mechanisms for controlling nutrient and water related inputs; and
(c) Databases or sensors that provide information needed to develop input schedule to suit the site-specific conditions.

Ess and Vyn (2010) define PF as an old idea provided with new life by the advent of technologies based on GPS. These GPS-based techniques are used to tailor soil and crop management in order to match conditions at every location in the field.

Precision agriculture usually includes the management of within field variability using information technology (GIS) and geopositioning methods. In addition, such new techniques help the farmer in meticulous documentation of field data related to soil fertility, water, labor inputs, and crop productivity (Vrindts et al., 2003).

Goddard (1997) had suggested that PF should not be construed as a simple yield mapping and variable rate fertilizer distribution method. Instead, it also includes production aspects like extension, management and economic advantages.

Dobermann et al. (2004) have provided a definition that considers PF as a more holistic approach with far fetching influence on agriculture. They state that, although PF started as a technology-led development, it is not just synonymous with yield mapping and VRT, for managing spatial variability within a field. Instead, PF should be considered as a systems approach to crop production, in which the goal is to reduce decision uncertainty through better understanding and management of uncontrolled variation. Expertise from many disciplines is utilized, including information technology to bring data from multiple sources and scales to bear on decisions associated with crop production.

While dealing with Malaysian rice growing areas, Gholizadeh et al. (2009) have stated that PF is a conceptualized "systems approach". It considers crop production as a total system that aims at sustainable low inputs and high efficiency. It is practically a site-specific strategy to manage production inputs and outputs.

While discussing the economic aspects, Batte and Arnholt (2003) have stated that PF has the potential to help farmers with appropriate input allocation within each field, thereby lowering quantity of fertilizers/water to be applied. In other words, it reduces on production cost and improves profitability. Batte and Van Buren (1999) suggest that precision faming or site-specific crop management is actually a combination of technologies or methods and their integration permits the following: namely:

(a) Collection of data on an appropriate scale at a suitable time;
(b) Integration and analysis of data to support a range of management options; and
(c) Implementation of a management response on an appropriate scale and at a suitable time.

Sparovek and Schnug (2001) describe PF as an umbrella terminology that encompasses knowledge (agronomic practices), and its practical expression (machines, computers, software, treatments, and procedures) in order to solve problems related to soil fertility variations.

Bramely (2006) states that precision agriculture seeks to exert greater control over a crop production system by recognizing variation and managing different areas of land differently, according to a range of economic and environmental goals.

The PF technologies are used to identify and measure within field variability and its causes. It prescribes site-specific inputs (fertilizers and/or water) that differ with crop and soil type. Reduction in input (fertilizers and/or water) levels, increased efficiency, uniformity in soil fertility or moisture, and proper timing are known to enhance cotton crop yield and cost benefit ratios (Banerjee and Martin, 2007).

Basic mapping and field level record keeping is one of the first practices under PF. The benefits of implementing PF include increased profits through increased efficiency, reduced agronomic inputs, improved production, and reduced environmental impact (Koostra et al., 2003).

The zonation within a field is an important aspect of PF. According to Aimrun et al. (2011), identification and management of spatially coherent regions (zones) is a crucial aspect under site-specific management or PF. In order to obtain maximum efficiency of inputs (fertilizers), it is said that management zones should be homogeneous combination of potential yield limiting factors.

Regarding PF practices in vogue with cotton farmers of Northern Texas; Yu et al. (2001) explain that it is a set of site-specific methods involving advanced information-based agricultural management system. It has been designed to identify, analyze, and manage spatial and temporal variability of soil effectively and obtain maximum profitability. It also aims at preserving physico-chemical characteristics and quality of soil.

The PF in European farming zone integrates GPS and GIS technologies into daily routines of farms. The PF is said to be an old traditional farming in the modern way. It involves optimizing agricultural production through improving the precision of agronomic procedures by implementing them at subfield scale.

With regard to paddy farming, Norasma et al. (2010) state that PF involves satellites, sensors, and field or thematic maps. It is a fairly comprehensive approach designed to optimize crop production by tailoring soil and crop management procedures to fit each and every field separately.

Jhoty and Autrey (2000) explain that PF is a concept based on fact that soil fertility and moisture distribution are site/location specific. Soils are feebly or immensely variable with regard to nutrient and moisture distribution, microclimate, weed species and so on. We should note that crop productivity is directly influenced by site-specific variations (Khakural et al., 1996).

According to Mishra et al. (2003), PF is a buzzword that is based on the philosophy of soil heterogeneity and homogeneity. It requires precise information on the degree of variability for fertility/water management within a field.

The PF or Precision Agriculture is a concept that involves use of new techniques, field information, adopting right agronomic practice, applying right amounts of nutrients/water, and at right time. Most importantly, information collected about specific field is utilized to evaluate and decide on optimum planting density, estimate fertilizer requirements accurately at various stages of the crop, and predict grain/forage yield (India Development Gateway, 2010). The PF avoids unnecessary or excessive use of inputs.

The PF is defined as application of principles and technologies that allow us to manage spatial and temporal variability associated with various soil fertility factors. It is relatively a comprehensive approach that optimizes crop production by utilizing data accrued *via* several sources including satellite-based information (Shylla et al., 2006).

Patil and Shanwad (2010) have defined PF keeping in view the large expanse of cereals and legumes in the Vertisol belt of South India. They state that PF aims at optimizing profitability and protecting environment through efficient use of inputs, based on temporal and spatial variability of soils and crops.

Regarding precision agriculture in the West African Sahel Florax et al. (2005) state that identification of local soil variability caused by within field differences in macronutrient availability and relevant ecological features is important, for effectiveness of PF methods. Several spatial statistical, economic, soil and crop related analyses are utilized to arrive at appropriate input levels.

In South Africa, PF is also called as Computer-aided Farming systems. It is defined as a process whereby, a large field is divided into finite number of subfields, allowing variation of inputs in accordance with the data gathered. It results in maximization of profits, minimizes risks like nutrient accumulation and reduces ill effects on agro-environment (Rusch, 2001). Godwin et al. (2001; 2003) described PF as a name given to a method of crop management that entails management of areas within a crop field that require different levels of input.

The PF or “Prescription farming” or “Site-specific Crop Management” involves collection of site-specific data in order to make appropriate decisions, regarding nutrients, and water supply to discrete areas within a field. The PF utilizes GPS, GIS, and VRT (Ball and Peterson, 1998).

Roberts et al. (2002) state that, PF of cotton in Tennessee involves use of set of technologies to identify and measure within field variability and its causes. It then prescribes site-specific inputs (fertilizer, water) that match varying crop and soil needs during a crop season.

Regarding fertilizer-N inputs to cotton crop cultivated in Tennessee, Torbet et al. (2008) state that PF improves accuracy of fertilizer-N supply by using data and information drawn through various GIS and GPS methods. Geospatial mapping, crop development, and yield sensing help in improving fertilizer-N efficiency.

Definitions that relate to role of PF in improving management of within field soil N and moisture variations are available in plenty. According to Shaver et al. (2010), one of the primary goals of PF is to regulate on-farm inputs such as fertilizer-N by determining in-field variability that directly affects crop growth and development. Data derived from several methods could be used to decide most appropriate quantity, timing and distribution methods.

Al-Kufaishi (2005) explains that with regard to irrigation, primary goal of PF is to supply the growing crop with right amount of water at the right time and in the right place, avoiding any surplus that could lead to the leaching of water and nutrients that limits plant growth and reduce yield.

1.3 MAJOR COMPONENTS OF PRECISION FARMING OR SITE-SPECIFIC FARMING

The PF or site-specific farming is a set of geospatial technologies and accurate procedures that actually link mapped locations in a field with most appropriate decisions regarding seeding, fertilizer inputs, irrigation, plant protection chemicals, and yield recording (Berry et al., 2010; Davis et al., 1998). The PF in any agricultural zone has following components at the least. They are:

(a) GPS,
(b) Remote Sensing Imagery or Sensor data regarding soil fertility variations and crop productivity,
(c) GIS software, and
(d) Variable Rate Applicators (VRT with robotics that are guided by computer models dealing with soil fertility status and crop response data.

1.3.1 Precision Farming: A Map and/or Sensor based Technology

Morgan (1997) has suggested that at least two sets of methodologies could be used during PF. One of them is termed map-based and the other sensor-based. Map-based methods involve grid sampling, laboratory analysis of soil samples at least at two depths, generating soil fertility and nutrient distribution maps or maps that depict soil physico-chemical characteristics like pH, cation exchange capacity (CEC), electrical conductivity, and so on. The map generated using soil data is then used to guide a variable applicator. During both soil sampling and variable rate inputs, we need a positioning system—Differential Global Positioning System (DGPS) to identify each location. The second method, usually called Sensor-based PF involves extensive use of real-time sensors and feedback control system to measure soil properties rapidly “on-the-go”. Then, immediately use these signals to direct a variable rate applicator appropriately. Often tractors are fitted with sensor in the front or on a separate vehicle that leads the tractor fitted with variable applicator. This allows sufficient time for data accrual *via* sensors, then to process it using computer models and direct variable applicators. The sensor-based technique does not need a GPS system, if treatments are made immediately. However, traction equipment fitted with GPS can be loaded and data preserved for posterity. Let us consider an example. “Soil DoctorR” produced and marketed by Crop Technology Inc, Houston, Texas, USA, is an example that examines, soil type, organic matter content, CEC, soil moisture, and NO_3-N using a rolling electrode as the tractor moves through the field. The need for GPS is eliminated. Yet another example is a Sensor-based technology developed by researchers at Purdue University, Indiana, USA. It is a sensor (photodiode) surrounded with Light Emitting Diode (LED). The reflected light is measured to estimate soil organic matter. Soil moisture can also be estimated. Examples pertaining to real time sensors that estimate soil texture, pH, NO_3-N, K, and P are available in literature.

1.3.2 Global Information Systems (GIS)

In general, GIS enhances our ability with regard to decision support system and planning of fertilizer, water and pesticide distribution. It is actually organized collection of computers that help in data capture, storage, retrieval, update, manipulation, and analysis. It also helps us in integrating geographical data with various aspects like field history, soil fertility, crop husbandry, and crop production projections. It allows us to simulate fertilizer supply and crop response in a location, so that appropriate decisions could be made. The GIS relevant to crop production allows us to analyze data collected through a period of time at a given location. GIS allows us to study spatial effects of soil management and agronomic factors on crop productivity. For example, effects of soil type, its texture or fertility status, pH, organic matter or moisture on grain/forage yield could be ascertained using spatial data. Actually, regression analysis of data regarding influence of major nutrients (N, P, and K) from entire field could be stored and used to derive appropriate decisions in the following season. Soil nutrient maps, maps that depict spatial variations pertaining to several other relevant soil characters like texture, pH, electrical conductivity, and so on could be effectively used. GIS helps in preparing prescription maps for each field or smaller management zones based on spatial data and crop production trends (Berry et al., 2010).

In addition to information on soil fertility and nutrient distribution within specific fields, GIS records for larger cropping zones and stretches that encompass a state or a small nation are also available. They help us in channeling fertilizers and prescribing cropping patterns more accurately in a given cropping belt. For example, such detailed information on soil nutrient status and pH variations in different states and sub-regions are available in USA and many European nations. Fertilizer recommendations that are arrived after considering a range of natural factors, crop production systems, yield goals, and most importantly the economic advantages are also available to be retrieved and consulted quickly using GIS (Bundy et al., 2005; Laboski and Bundy, 2005). A recent report suggests that NLEAPGIS are a tool that helps farmers with US soil database and climatic parameters. It aids in soil N management and risk assessment (Delgado, 2011). This facility covers entire USA. Similarly, soil nutrient distribution and productivity data for countries in Latin America, Africa and Asia are available for retrieval through computers.

Web-based GIS Decision support systems are also available in certain regions. Its functions are comparable to other computer-aided services like e-commerce, information sharing and disseminating web sites. It is an open source technology that allows free access anywhere in the world. For example, researchers at Universiti Putra, in Malaysia have explored the use of Minnesota open map server, hypertext preprocessor, Apache Web server and MySQL database to study the soil fertility variations in paddy growing regions (Norasma et al., 2010). It actually allows the farmers to access webs that carry information on rice cultivation procedures and economic advantages due to them.

Historical data on paddy planting dates, fertilizer input schedules, agronomic practices, growth and yield pattern, and yield response data could be retrieved or used directly to arrive at computer-aided decisions. This system also allows integration with soil fertility maps and variable rate inputs of fertilizers-N, P, and K. Farmers may of course print soil maps or carry digital information separately and feed it to their vehicles carrying variable rate applicators. It is believed that such web-based decision support will become fairly common across farming zones in all continents. It is adoption involves least cost to the farmers. Yet, it allows farmers with large and wide array of information on which they could base their agronomic procedures. It also allows rapid sharing of information. It should be a helpful tool to policy makers involved in deciding cropping pattern, input supply, and yield goals.

1.3.3 Global Position Systems (GPS)

The GPS are techniques that provide farmers with unequalled accuracy, flexibility in positioning farmer’s vehicles (tractors), navigation, and data capture about a particular spot, a field or farm. The spatial variations are easily deciphered and stored through GPS satellites. The GPS technology is known to use a set of 2431 satellites, situated in high altitude orbit above earth. They are focused to survey earths’ surface soil, water, and crops. These satellites transmit signals continuously that are picked up by special receivers. The GPS is divided into three aspects:

(a) A space segment that includes 21 operational satellites that orbit the earth at 20,000 km,

(b) A control system in Colorado, in central USA and linked stations, and

(c) A user segment that consists of receivers which help in positioning, velocity and time information to the user. A GPS receiver, it is said requires at the least contact with four satellites to set its coordinates and location on earth. The GPS signals have to be sharp and accurate. Raw and hazy signals are not useful to determine a position in a field. The GPS referenced signals are often used to plant seeds prepare soil fertility maps, yield variations, soil moisture distribution and so on (Plate 1).

PLATE 1 Planting Maize in Iowa, USA.
Source: Mr David Nelson, Nelson Farms Inc, Fort Dodge, USA
Note: Planting Maize and Soybean using GPS guided seeders is common in the Northern plains.

A medium range GPS receiver can establish positions within a field with an accuracy of 1.0 m between two spots (Berry et al., 2010). Such receivers allow us to stamp data pertaining to soil nutrient status, moisture or pH and so on with accurate geographic coordinates to locate them at any time. Currently, combination of two or more constellations of satellites, like US GPS system and Russian GLONASS has improved accuracies to 2 cm. The GPS aided field boundaries and management zone demarcation are becoming common. In areas prone to soil maladies like salinity, GPS can be coupled with salinity meter sledge and towed on a pick up van, all along the field. Salinity mapping is an important procedure in the areas afflicted with high salts. The GPS receivers are also used to map weed intensity and spread in a field. It helps while accurately distributing herbicides in a field. The DGPS uses two GPS receivers– a base station that is stationary and located at a referenced point and the other is mobile fitted on the vehicle. The DGPS helps in overcoming problems related to resolution.

Incidentally, Franzen et al. (2008) have cautioned about use of the word “GPS” in place of PF. The GPS actually makes use of a series of military satellites to determine a precise geographic location. Deciphering exact location of farm vehicles or a point in a field accurately has its advantages. The GPS helps in geographic identification of soil properties. The GPS helps in distributing fertilizers accurately at each point based on soil maps. The GPS helps in accurately mapping crop growth productivity through yield monitors. The GPS helps in identifying areas that support low or high yield.

A satellite system equivalent to GPS is available to farmers in Europe. It was developed by former Soviet Union and is called GLONASS. It is controlled by CIS space command. It is a satellite system that has about 24 satellites (Blackmore, 2003).

Variable Rate Technology

The VIT involves application of seeds, fertilizers, and irrigation or pesticides in quantities that is specific to each spot and variable (Plate 1). Inputs are decided by field map and a decision support system. For example, in case of soil fertility, a computer-based decision support considers soil fertility maps, nutrient availability pattern, crop species/genotype, yield goals, and profitability. The quantity of input such as fertilizers or water channeled at each spot depends on directions received from decision support systems by a GPS guided vehicle. Variable rate fertilizer supply provides uniformity with regard to soil fertility in an individual field. Similarly, variable rate irrigation based on soil moisture map creates uniform availability of soil moisture to the crop. Details on VIT and instrumentation involved are made available in Chapter 2.

1.4 ADVANTAGES THAT ACCRUE DUE TO PRECISION FARMING

The PF offers a wide range of advantages to farmers. The extent of advantages derived is based on geographic location and farming enterprise in question. Yet, we can generalize and group the advantages. For example, Tran and Nguyen (2008) have suggested that extent and range of benefits accrued due to adoption of PF may differ between developing and developed nations. Obviously, low or moderate supply of fertilizer-based nutrients, water and other farm amendments may offer commensurate gains in developing nations. Whereas, high input trends in agriculturally developed regions may allow us proportionately higher advantages in terms of soil quality, its productivity, economic gains, and environment related advantages.

With regard to rice farming in South Asia and Fareast, Segarra (2002) have grouped the advantages from PF as follows:

- *Overall Grain/Forage Yield*: Aspects like, precise genotype, exact fertilizer input in as many splits as possible, proper nutrient ratios, appropriate irrigation schedules and timely monitoring of growth/maturation results in greater grain/forage yield, compared with similar levels of uniform or blanket application of fertilizers and irrigation.
- *Improved Efficiency of Inputs*: Aspects like, use of advanced electronically controlled machinery, geospatial techniques of identification of soil fertility/moisture variations, advanced computer-based growth and grain yield models that allow us to distribute variable and exact quantities of nutrients/water in space and time, contribute to enhanced efficiency of inputs.
- *Reduced Production Costs*: For a similar grain/forage yield level, fertilizer-based nutrient supply and irrigation required is usually marginally or conspicuously smaller. It results in lessening of input costs to farmers. Generally cost per unit grain/forage yield is lower in farms maintained using precision techniques.
- *Better Decision Making*: Agricultural machinery, satellite guided geospatial techniques and computer models allow us to accrue data and therefore helps farmers in taking decisions regarding farm operations especially nutrients and water supply.
- *Reduced Environmental Impact and Risks*: Placement of nutrients and water in accurate quantities at appropriate timings during crop growth results in rapid removal of nutrients. It reduces undue accumulation of fertilizer-based nutrients in the soil profile or ground water. Loss of nutrients like N to ambient atmosphere is lessened.
- *Accrual of Accurate and Easily Retrievable Data about a Farm or Region*: Actually almost all farm operations; their intensity and timing are recorded. Data on exact quantities of nutrients supplied to each fertility zone is available, since soil fertility maps and variable applicators are computer controlled with data retrieval facility. It definitely allows management of farm operations as we move from one season or crop to next in sequence in the same field.

We should note that advantages that accrue from PF are also specific to geographic area, soil, cropping pattern, agronomic requirements of the crop, and economic value of the produce.

For example, in the European Plains, Cragg (2004) suggests that major advantages are as follows:

(a) Precision technique saves on costs. It allows us to apply fertilizer-P and K at rate to match crop's need.

(b) The PF improves efficiency of seeding and fertilizer supply to fields.

(c) The PF improves the accuracy of crop husbandry by providing soil map, yield maps, and accurate placement of nutrients.

(d) The PF offers environmental benefits by reducing on fertilizer and chemical supply to fields.

1.5 CONSTRAINTS TO ADOPTION OF PRECISION FARMING

Precision techniques are not easily amenable to all agricultural conditions. Farmer's stipulations and desires in each continent and its sub-region too vary enormously. Constraints faced during adoption and standardization of precision techniques is indeed many.

Bongiovanni and Lowenberg-DeBoer (2005) have stated that major constraints to adoption of PF in Argentina and other Latin American countries are high initial investments on equipments and management time (labor), lack of significant variations in the soil fertility, tendency to use low amounts or no fertilizers during cereal production, risk in grain pricing, and profits from precision technology. Above all, in several cases, precision techniques fetch only small increases in returns due to low value of the product.

Cragg (2004) opines that following are the major constraints to adoption of PF in the European farming regions.

They are:

(a) Procedures to be adopted and instrumentation are too elaborate and time consuming. At times procedures get complicated.

(b) The PF needs initial investment that could be prohibitive.

(c) Interpretation of data drawn from digital imagery and other procedures could involve specific skills and may add up to already high costs.

(d) Precision involves data collection that could be costly. The remote sensing and digital imagery of fields showing variations in organic matter, nutrients and water are generally costly.

(e) The PF may not turn out to be immediately profitable. Sometimes its benefits are perceived, only if adopted on a long run for example environmental benefits. Also, often the reduction in fertilizer supply that occurs due to PF may be marginal, not perceived significantly, if the farm is small and value of the crop is low.

According to Srinivasan (2010) constraints to adoption and popularization of PF in the Asian cropping zones are as follows:

(a) High cost of obtaining site-specific data;

(b) Lack of willingness to share spatial data among various organizations;

(c) Complexity of tools and techniques that require new skills;

(d) Culture, attitude and perceptions of farmers including resistance to adoption of new techniques and lack of awareness of agro-environmental problems;

(e) Small farms, heterogeneity of cropping systems, and land tenure/ownership restrictions;

(f) Infrastructure and institutional constraints including market imperfections;

(g) Lack of success stories about adoption of PF and lack of demonstrated impacts on yields;

(h) Lack of local technical expertise;
(i) Uncertainty on returns from investments to be made on new equipment and information management systems;
(j) Inadequate understanding of agronomic factors and their interaction;
(k) Lack of understanding of the geostatistics necessary for displaying spatial variability of crops and soils using current mapping software; and
(l) Limited ability to integrate information from diverse sources with varying resolutions and intensities.

In general, researchers have consistently strived to remove lacunae and improvise precision techniques, so that it matches farmer's economic requirements and at same time answers environmental concerns.

KEYWORDS

- **Geographic information system**
- **Global positioning systems**
- **Precision farming**
- **Soil fertility**
- **Variable rate technology**

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5 5. Precision Farming: Summary and Future Course

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Ess, D. R. Precision and Profits: Producers heed bottom line when considering high technology farming methods. Resource Engineering and Technology, pp. 1–3 (2002), Retrieved from http://www.highbeam.com/doc/IGI-83374244.html. PRECISION FARMING Soil Fertility and Productivity Aspects K. R. Krishna, PhD P R E C I S I O N F A R M I N G S o i l F e r t i l i t y a n d P r o d u c t i v i t y A s p e c t s K r i s h n a PRECISION FARMING Soil Fertility and Productivity Aspects Precision farming is the latest trend with sophisticated and large farms all over the world. Precision farming involves soil fertility and crop growth monitoring, electronic equipment, remote sensing, global information systems, global positioning systems, computer models, decision support systems, variablerate technology, and accurate recordkeeping. It potentially leads us to “Push Button Agriculture”. This book on precision techniques is concise and provides valuable information on instrumentation and methodology. It encompasses lucid discussions on the impact of precision techniques on soil fertility, nutrient dynamics and crop productivity. This book highlights the application and impact of GPS techniques to regulate fertilizer supply based on soil nutrient distribution and yield goals set by farmers. It considers advances and examples from different agroecosystems from all continents. It will be highly useful to advanced-level students, professors, farmers, and those involved in agro-industries. About the Author K. R. Krishna received his PhD in agriculture from the University of Agricultural Sciences in Bangalore. He has been a cereals scientist in India and a visiting professor and research scholar at the Soil and Water Science Department at the University of Florida, Gainesville, USA. Dr. Krishna is a member of several professional organizations, including the International Society for Precision Agriculture, the American Society of Agronomony, the Soil Science Society of America, the Ecological Society of America, and the Indian Society of Agronomy. www.appleacademicpress.com Apple Academic Press 9 781926 895444 00009 ISBN 978-1-926895-44-4 Apple Academic Press PRECISION FARMING Soil Fertility and Productivity Aspects K. R. Krishna, PhD P R E C I S I O N F A R M I N G S o i l

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