An Introduction to Precision Agriculture

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Chapter Purpose

Precision agriculture is a technology that can be used to improve profitability while reducing the impact of agriculture on the environment. The goal of this chapter is to summarize topics to be discussed in more detail in the following chapters. Precision agriculture is based on the use of information and science-based decision tools to improve productivity and profitability. Many farmers using precision farming rely on on-farm testing to fine tune recommendations.

Introduction

To some, precision agriculture is about grid sampling, yield maps, unmanned aerial vehicles, sensors, and applying variable rate treatments, whereas to others, it is about the decision-making process. No matter how you define it, precision agriculture is changing agriculture, and providing opportunities to reduce the impact of agriculture on the environment. Today, the impacts of precision agriculture can be seen around the globe. For some, precision agriculture uses technologies borne of the information age to create site-specific recommendations that account for natural and management-induced variation, whereas for others it accomplishes the same goals without information age technologies. However, both of these systems uses information in an attempt to optimize the goods and services produced by the land. It is important to point out that precision agriculture technologies do not replace the farmer’s essential role in the decision process. The core ideas behind precision agriculture consist of improved management decisions, higher yields, and reduced agricultural impacts.

Video 1.1. What is precision agriculture?

Precision agriculture is often defined by the technologies, such as GPS (Global Positioning System), GIS (Geographic Information Systems), autosteer, yield monitors, and variable-rate fertilizer. Each of these topics are discussed in detail in Chapters 3, 4, 5, and 11 (Brase, 2018; Fulton et al., 2018; Sharda et al., 2018; D.K. Shannon, University of Missouri Extension, Columbia, MO; D.E. Clay, South Dakota State University, Agronomy, Horticulture, and Plant Science, SAG214, Brookings, SD 57007; K.A. Sudduth, USDA-ARS, Washington, D.C. *Corresponding author (ShannonD@missouri.edu) doi:10.2134/precisionagbasics.2016.0084

As important as these technologies are, it takes reflection to realize that the human decision-making process is a key ingredient for precision farming success (Chapter 12, 15; Fulton and Port, 2018; Griffin et al., 2018). Precision farming distinguishes itself from traditional agriculture by managing portions of a field as opposed to the whole field, and ultimately the use of a systems-based approach that should optimize economic and environmental benefits (Chapters 14 and 15; Abit et al., 2018; Griffin et al., 2018). The use of precision agriculture has the potential to reduce costs, increase returns, and reduce environmental impacts. However, achieving these goals requires a substantial investment in technology and knowledge, which could produce adoption barriers (Fig. 1.1). Switching from conventional management to precision agriculture should only be conducted after careful reflection.

The Need for Precision Farming

The concept of treating small areas of a field as separate management units is not new, and has been used by farmers since the dawn of agriculture. Different strategies have been used by different people. In the United States, the soil land capability class system was developed to assess the risk of soil erosion. This classification approach implied that land use was dependant on the site characteristics. Others have used different techniques. For example, North America Native Americans reduced pest pressures and N stress by interseeding beans and squash between corn plants, whereas homesteaders used crop rotations to increase yields and provide feed for livestock (Clay et al., 2017b).

In the 20th century, many farms became mechanized, which provided an opportunity to increase the size of fields and farms. In many areas, the idea of managing smaller-than-field-size units was abandoned in order to take advantage of the speed of large tractors and implements. By treating large areas the same, the farmer spent less time in the field and covered more acres per day. The advantages of increased productivity were perceived to far outweigh any benefits from the labor intensive management of smaller, subfield units. Today, technology has reached a level that allows a farmer to measure, analyze, and deal with the in-field variability that was previously known to exist but was not manageable. Microprocessors,
sensors, and other electronic technologies are the tools available to help all farmers reach this goal. The description of these technologies and their implementation is the focus of this textbook.

The condition driving the adoption of precision farming is variability. Variability can be separated into spatial and temporal components. Spatial variability is the variation in crop, soil, and environmental characteristics over distance and depth. Temporal variability is the variation in crop, soil, and environmental characteristics over time. Variability can be seen in yield, soil fertility, moisture content, soil texture, topography, plant vigor, and pest populations. Both spatial and temporal variability are discussed in this manual.

Some soil-related characteristics, like soil texture, are very stable, changing very little over time (Fig. 1.2 for example). Other characteristics, such as nitrate levels, soil moisture content and soil organic matter content can contain substantial amounts of spatial and temporal variability. In Fig. 1.2, light colored soils have low organic matter contents and dark colored soils have high organic matter contents. Precision farming involves collecting soil and crop samples to gain information about this variability. Variability influences many decisions, including what, how, and when to sample. Sampling methods differ in terms of the expense in collecting samples and in sample analysis. Sampling frequency requirements can affect the way in which the farmer manages money, labor, and time. Some crop production inputs can be varied based on maps generated from sampling data collected months, or even years prior to application. Limestone applied to address soil pH variability is one example of such an input. However, other inputs such as N fertilization are a function of N mineralization that are dependent on soil temperatures and moisture contents that vary rapidly. If a characteristic changes rapidly, it is logical to use equipment that senses and responds to this variability in “real-time.”

Whole-field management approaches ignore variability in soil-related characteristics and seek to make applications of crop production inputs in a uniform manner. In fact, not too long ago, farmers viewed application controllers that allowed them to maintain constant application rates across the field as “state of the art”. Constant-rate applications were often based on whole field information. For example, a single composite soil sample is collected from a field, from which the whole field fertilizer recommendations are developed. However, by using whole-field single rate fertilizer recommendations there are large areas where fertilizer is under-applied and large areas where it is over-applied. With today’s technologies, farmers can do a better job of managing inputs (which can make a large difference in the profitability of the crop).

Economics is among the most important factors affecting the transition from whole-field to site-specific crop management. Precision farming can affect both input costs and crop production revenue by:

- Increasing yields with the same level of inputs, simply redistributed
- Targeting inputs to where they are needed
- Improving crop quality

Achieving these goals, requires that the farmer identify appropriate goals and strategies. Serious questions that farmers should answer before adopting precision farming include:
• How do crop, soil, and environmental characteristics vary spatially and temporally?
• Does this variation affect crop yield and/or crop quality?
• Can this variability be managed profitably?
• What are the short- and long-term goals?
• Do I have the resources to implement precision agriculture?

Agronomic Inputs

Fertilizers

Each year the world’s farmers apply over 185 million tons of nitrogen (N), phosphorous (P), and potassium (K) fertilizers to their fields. In the United States, 97 percent of all acres planted to corn receive nitrogen fertilizer. For a typical Midwestern corn grower, fertilizer accounts for about one third of total cash production expenses. Therefore, the ability to better manage input costs can have a significant impact on profitability. It is well known that nutrient deficiencies can reduce crop growth and lower crop quality. However, the overapplication of fertilizers can also reduce wheat yields and sucrose content in sugar beets (Lamb et al., 2001).

It is desirable to apply the right source of fertilizer in the right place at the right application rate and at the right time, as determined through agronomic analysis. This is known as the 4Rs approach to nutrient management. To date, the majority of variable-rate application adoption has taken place in the area of fertilizer application. Applicators on the market today can apply a variety of different combinations of fertilizer products across the field. Combinations can be changed “on-the-go” as the applicator travels across the field (Fig. 1.3). The machine operator simply maintains a travel speed and drives an appropriate pattern through the field. The applicator prompts the operator to change speed if necessary and can have a guidance system which prompts the driver to the right or to the left. Some guidance systems, even control vehicle steering. With guidance systems, it is possible to maintain accurate swaths as the unit moves through the field at speeds of 15 miles per hour or more.

Pesticides

Each year in the United States, farmers spend over $12 billion on the purchase and application of agricultural chemicals, herbicides, insecticides, and fungicides. Ninety-eight percent of all acres planted to corn and soybeans receive herbicide applications. Improper application of pesticides can have negative effects during the crop growing season and well beyond. If application rates are too low, pest control is poor. If application rates are too high, pesticides can be toxic to the crop, can carry over to future growing seasons, and can end up in ground or surface water. Variable-rate application of pesticides is relatively new, and may save significant sums of money and reduce the potential for crop and environmental damage. There have been reports of variable-rate technologies reducing application rates by 50 percent and more. One can easily imagine if a pesticide is sprayed only on weed targets in a field instead of being broadcast on all plants and between rows of plants, a significant amount of pesticide can be saved.

Seeds

The great increases in crop production in the United States during the 20th century can be attributed, at least in part, to the development and widespread use of high-yielding cultivars. In the 1900s, one United States farm worker produced enough food and fiber for eight people. Along with the use of chemical fertilizers, pesticides, and improved field machinery, ever-improving crop varieties now enable a single American farmer to provide food and fiber for well over 140 people. Genetic improvements have been linked to improved water use efficiency, development of transgenic crops, and the creation plant cultivars that allows fertilizer rates to be increased (Clay et al., 2014; Lee et al., 2014). The technology now exists to accurately place seeds and to vary the cultivar and seeding rates to match the pests and yield potential.

Precision Farming Tools

In order to gather and use information effectively, it is important for anyone considering precision farming to be familiar with the technological tools available. These tools include hardware, software and recommended practices. The summaries of these topics are provided below.

Global Navigation Satellite Systems (GNSS)/Global Positioning System (GPS)

Today, Global Navigation Satellite Systems satellites broadcast signals allowing GNSS receivers to calculate their position on the earth. Prior to
2010, positioning information relied only on the United States GPS satellites (Chapter 3; Stombaugh, 2018). Today, GNSS includes GPS and the Russian GLONASS satellites. The GNSS information is provided in real time, meaning that continuous position information is provided while in motion. Having precise location information at any time, allows soil and crop measurements to be mapped. GNSS receivers, either carried to the field or mounted on implements, allow users to return to specific locations to sample or treat those areas. Global Navigation Satellite System satellites provide information that allows for the precise application of pesticides, lime and fertilizers to problem areas.

Accuracy is an important consideration when purchasing and utilizing GNSS. The Global Navigation Satellite System by itself provides a horizontal (XY) accuracy of about 30 feet. However, this accuracy level is generally not acceptable for many precision agriculture applications. Accuracy can be improved with differential correction. In the United States, WAAS (Wide-Area Augmentation System) provides free differential correction information that improves accuracy to approximately 3 ft. Similar systems are available in other areas of the world. Higher levels of accuracy can be achieved by using real-time kinematic (RTK) correction. High accuracy is critical for auto-guidance systems and topographic surveying. When purchasing a GNSS receiver or guidance system, the type of differential correction and availability relative to the intended area of use should be considered.

**Yield Monitoring and Mapping**

Grain yield monitors continuously measure and record the flow of grain in the clean-grain elevator of a combine (Fig. 1.4, Chapter 5; Fulton et al., 2018). When linked with a GPS receiver, yield monitors provide the data necessary for producing yield maps. Yield measurements are essential for making sound management decisions. However, soil, landscape and other environmental factors also need to be considered when interpreting these maps. Examining yield maps from several years and including data from extreme weather years helps to determine if the observed yield level is due

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**Video 1.4.** International precision agriculture: from oxen to precision leveling.

**Fig. 1.4.** GPS-equipped yield mapping combine. Courtesy of Kurt Lawton, Content Director, Corn and Soybean Digest. http://www.cornandsoybeandigest.com/node/12922/gallery?slide=19
to management or climate. When used properly, yield information provides important feedback in determining the effects of fertilizer, lime, seed, pesticides and cultural practices including drainage, irrigation, and tillage.

**Soil Sampling and Variable-Rate Fertilizer Application**

In the U.S. Midwest, the recommended soil sampling procedure is to randomly collect 15 to 20 soil samples from portions of fields that are no more than 20 acres in size (Chapter 6; Franzen, 2018). The resulting composite soil sample is subsequently sent to a laboratory to be tested (Clay et al., 2017a). Crop advisors make fertilizer application recommendations from the soil test information for the 10- to 20-acre area (Chang et al., 2017). Grid soil sampling uses the same principles of soil sampling, but may increase the number of samples collected from 1 to 10 (Chapter 6; Franzen, 2018). Based on the soil test results, an application map is created (Fig. 1.5), which subsequently is loaded into a computer mounted in a variable-rate fertilizer spreader (Ferguson et al., 2017).

**Remote Sensing**

Remote sensing is collection of data from a distance. Data sensors can be hand-held or mounted on a satellite or manned or unmanned aircraft (Ferguson et al., 2017). Plant stress related to moisture, nutrients, and compaction, crop diseases, and other plant health concerns are often easily detected in remotely sensed images. Images provide in-season information that can be used to improve crop profitability. This topic is discussed in Chapters 8 and 9 (Ferguson and Rundquist, 2018; Adamchuk et al., 2018). It is important to remember that remote sensing should be validated with crop scouting reports.

**Geographic Information Systems**

Geographic information systems (GIS) are computer hardware and software systems, that use feature attributes and location data to produce maps (Brase, 2018). An important function of an agricultural GIS is to store layers of information, such as yields, soil survey maps, remotely sensed data, crop scouting reports and soil nutrient levels (Fulton and Port, 2018). Georeferenced data can be displayed in the GIS, adding a visual perspective for interpretation. In addition to data storage and display, the GIS can be used to evaluate present and alternative management practices by combining and manipulating data layers to produce an analysis of management scenarios.
Data Management

The adoption of precision agriculture requires the joint development of management skills and pertinent information databases (Fulton and Port, 2018). Effectively using data requires that the appropriate information was collected and that the manager has clear business objectives. Effective data management requires an entrepreneurial attitude toward education, experimentation, and data interpretation.

Identifying a Precision Agriculture Service Provider

Farmers should consider the availability of custom services when making decisions about adopting precision agriculture technologies. Agricultural service providers offer a variety of precision agriculture services. By distributing capital costs for specialized equipment, farmers can increase the efficiency of precision agriculture activities.

Common services provided by service providers include intensive soil sampling, mapping, and variable rate applications of fertilizer and lime. Equipment required for these operations includes a vehicle equipped with a GPS receiver and a field computer for soil sampling, a computer with an agricultural GIS and a variable-rate applicator for fertilizers and lime. Purchasing this equipment and learning the necessary skills is a significant up-front cost that can be prohibitive for many farmers.

Agricultural service providers must identify a group of committed customers to justify purchasing the equipment and allocating human resources to offer these services. Once a service provider is established, precision agriculture activities tend to center around the service providers. For this reason, adopters of precision farming practices often are found in clusters surrounding the service provider.

Additional Precision Farming Tools

Precision farming technologies can be used in all aspects of the crop production cycle. Technology is available to improve soil property sampling, tillage, planting, fertilizing, spraying, crop scouting, harvesting, and even basic machine functions.

Fig. 1.6. Illustration of automatic section control technology. Courtesy of Raven Industries, Inc. http://ravenprecision.com/assets/users/photo-gallery/15_accuboom-illustration.png


Fig. 1.7. Grain yields for five years (left, top to bottom: 1, 2, 3, 4, 5). Higher yielding areas are indicated by the color blue and lower yield areas are indicated by the color red. Courtesy of USDA-ARS Cropping Systems and Water Quality Research, Columbia, MO.
such as guidance. In addition, to improving the effectiveness of crop production operations, it is now possible to use precision farming technologies to accurately document field operations.

**Equipment Guidance and Control**

Global Positioning System–based guidance systems are used in many agricultural operations. These systems are particularly useful in applying pesticides, lime, and fertilizers and in tracking wide planters and/or drills or large grain-harvesting platforms. These guidance tools can replace foam for sprayers and planter and/or drill-disk markers for making parallel swaths across a field. GPS-based guidance helps reduce skips and overlaps. In addition, this technology has the potential to safeguard water quality and implement controlled traffic. Applying variable rate treatments is also based on automatic section control technology (Fig. 1.6), that turns application equipment OFF in areas not requiring treatment and ON in areas that require treatment.

**Documenting Field Operations**

GPS receivers provide accurate position and time information on a continuous basis during crop production operations. This information can be collected and combined with planter and applicator sensor data to produce site- and time-specific record of input applications. This data can then be used to create an as-applied map for any and all crop production inputs. The same type of record
can record field operations such as tillage. Such records can assist farmers in documenting compliance with environmental regulations and the location of crop chemical and/or manure applications. The information can also be used in human and equipment resource assessment.

Wireless devices now permit field operation information to be viewed beyond the field boundary. Machines equipped with GPS and cellular communication hardware can communicate their status to owners or managers who might be miles away. Such information can be used to monitor machine condition and diagnose any mechanical problems so that repairs can be made quickly. Wireless technologies also allow for transfer of a variety of data back to the office or service provider.

**Precision Farming Management Examples**

Every farm presents a unique management puzzle that may require on-farm research to help create a profitable precision management program. Because, only some of the tools described above will be useful for a given problem, we recommend that an incremental approach be considered. For

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**Fig. 1.10.** Aerial photograph, soil pH, and 5-year average grain yields for central Missouri farm. Courtesy of USDA-ARS Cropping Systems and Water Quality Research, Columbia, MO.

**Fig. 1.11.** Depth of topsoil in inches and five-year normalized yield for a central Missouri Farm (Courtesy of USDA-ARS Cropping Systems and Water Quality Research, Columbia, MO).
example, if the goal is to implement precision herbicide applications, grid sampling the field for soil nutrient levels may not be needed.

The following example, highlights information that can be collected if the purpose is to identify the yield limiting factor. This field is located in central Missouri. Yield monitor data was collected from this field for 5 years (Fig. 1.7). In Years 1, 3, and 5 corn was grown and in Years 2 and 4 soybeans were grown. For all field, the yields were standardized so that they ranged from 0 to 100% (Fig 1.8). Sample calculations for this process are available in Clay et al. (2017c).

When inspecting these maps, notice the relative yield patterns for the five years changed from year to year. However the standardized yield map reveals two areas of high yield. One area was in the north-central part of the field, and the other extended from the western to eastern boundary in the southern one-third of the field.

In many fields, soil nutrients and yields may follow different patterns. In this field, there are relatively low soil test values in the northern portion of the field (Fig. 1.9). In addition, soil pH values were higher (near neutral) in south central and along the southern edge of the field. The well-defined boundary of the high pH area and the observation that they appear to follow the direction of field management suggests that this is a consequence of management rather than natural soil variability.

Strong evidence for management causing the pH patterns is shown in Fig. 1.10 where a photograph taken in 1962 showed that the field, now managed as a single unit, was previously broken into smaller fields. Two farmsteads were located in the southwestern corner and south-central edge of the field, and the southern part of the field was a pasture. The rest of the area was divided into three fields that were managed separately. The previous landowner confirmed that lime was applied to the three fields separately. A reasonable explanation for the high pH area is that more lime was applied on the field adjacent to the farmstead and/or pasture area than was applied to the fields farther north. The higher pH along the far southern edge was likely caused by limestone dust blown from the gravel road that appears in the 1962 aerial photograph. An obvious corrective measure is to lime the other parts of the field to raise the pH of those areas.

However, correlation between yield and a soil parameter is not certain proof of causation, so pH may not be the cause of higher yields. Certainly, additional factors besides soil pH affected yield. The soil pH map does not spatially correspond to the area of high yield extending from the northwestern corner of the map to the north-central portion. Unlike the pH-affected area, this feature does appear to be a natural soil-related feature. It corresponds with the drainage channel that is visible in the aerial photograph.

In most situations, understanding yield variability requires some local knowledge about the soils. In the example highlighted in Figs. 1.8, 1.9, and 1.10, the soils are generally classified as claypan soils, which have an abrupt increase in clay between the surface soil and the claypan. This claypan layer restricts water movement and root growth. In years when water limits plant growth there is a close relationship between the depth of the topsoil overlaying the claypan and yield. In Fig. 1.11, a map of topsoil depth is shown alongside the five-year standardized yield map. The topsoil depth information was collected with a soil electrical conductivity (EC) sensing instrument. The sensing unit actually measures the ability of the soil to conduct electricity, where clays conduct electricity better than soils comprised of less clay. Electrical conductivity sensors are also sensitive to changes on soil water content and salt concentrations. For this claypan soil, EC was used to identify areas with shallow topsoil.

Figure 1.11 shows the area of deepest topsoil is along the drainage channel and this area also includes some of the higher-yielding portions of the field. When all of the maps are combined, it become apparent that the topsoil depth was a major factor limiting yield. Once the critical factors limiting yield are understood, management practices designed to optimize the resources used to produce the crop can be designed. For an example in Missouri, nitrogen is applied in accordance to predicted plant needs by estimating the yield goal for a field. Because yield goal (potential productivity) is closely related to topsoil depth, a map of topsoil depth can be used to manage variable-rate application of nitrogen.

**Summary**

Precision agriculture provides the opportunity to more effectively use fertilizers, pesticides, tillage, and irrigation water, which can lead to greater crop yield and (or) quality and reduced impacts on the
environment. However, achieving these goals is the product of hard work and often requires the use of on-farm research (Chapter 13, Kyveryga et al., 2018) and analysis to create appropriate solutions (Chapter 13, Kyveryga et al., 2018). When using precision farming, it is important to determine the positive and negative aspects of what you want to accomplish. It is easier to be successful when the goals are well defined. For example, I want to reduce the over-application of herbicides to headlands.

Precision agriculture can address both economic and environmental issues that surrounds production agriculture today. It is clear, that many farmers are at a point where they could benefit from precision management. Methodologies continue to be developed regarding the cost-effectiveness and the most effective ways to use today’s technological tools, but the concept of “doing the right thing in the right place at the right time” has a strong intuitive appeal. Ultimately, the success of precision agriculture depends largely on how well and how quickly the knowledge needed to guide the new technologies can be realized.

The remaining chapters of this book provide an introduction and discussion of the major technologies and techniques used in precision farming.

Additional information on precision agriculture is available in this and an associated text book (Clay et al., 2017b), as well as Davis et al. (1998), Ess and Morgan (2003), Grisso et al. (2009), Rains and Thomas (2009), and Stombaugh et al. (2001).

**Questions**

1. In this chapter, it was discussed that precision agriculture has the potential to affect crop production input costs and revenues.

2. What are two site-specific management strategies that can be implemented with the goal of increasing profit?

3. What are the three questions a farmer must answer before adopting precision farming?

4. Define spatial variability.

5. Define temporal variability.

6. Develop a strategy to determine the yield limiting factor.

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**REFERENCES AND ADDITIONAL INFORMATION**


