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Potential Payoffs of Precision Agriculture



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Abstract

Precision agriculture or site-specific crop management attempts to observe, measure, and respond to inter- and intra-field variability. The goal of precision agriculture is to enhance yields, reduce cost, and/or mitigate environmental risks. This article discusses potential payoffs of precision agriculture from the producer, value chain, and environmental perspectives. Benefits of precision agriculture are discussed in the context of technology adoption and competitive advantage. Potential benefits associated with precision agriculture are manifold. In addition to potentially reducing cost and enhancing product value, precision agriculture has the potential to improve efficiency of machinery use, reduce risk, enhance property value, improve our ability to monitor food safety and enhance traceability, enhance our capability to execute and monitor

sustainable practices, reduce fertilizer and chemical leaching and runoff, and conserve irrigation water. The adoption of precision agricultural technologies will likely require a reexamination of a farm's workforce skills.

INTRODUCTION

The adoption of technology has been important to production agriculture for decades. Through the adoption of technology and improved managerial practices, aggregate farm output has expanded substantially faster than aggregate input. For example, aggregate U.S. farm output tripled from 1948 to 2017 with almost no corresponding increase in aggregate input (USDA ERS, 2021). For reasons explained below, the adoption of technology is expected to accelerate in the next decade.

Precision agriculture is having profound impacts on production agriculture, particularly crop production management. Crop management increasingly involves micromanagement of production activities by individual field or location within a field, driven by site-specific information about the environmental, biological, and economic factors that affect physical output, profitability, and soil and water quality. Precision production practices combine biological and nutritional technology; monitoring, measuring, and information technology; and process control technology. The critical linchpin among these “technology buckets” for successful execution is the data and information that can be continuously captured and utilized to manage the system and intervene in real time to control and enhance plant growth. The focus of biotechnology and nutritional technology is to manipulate the growth and attribute development of plants. Monitoring, measuring, and information technology helps trace plant development by measuring the impact of controllable and uncontrollable variables on plant growth. Yield monitors, global positioning systems (GPS), global information systems (GIS), satellite or aerial photography and imagery, weather monitoring and measuring systems, and plant and soil sensing systems are part of this technology. These systems

are increasingly being used to detect ways to improve plant growth performance, as well as to improve financial and physical performance accounting systems. Process control technology intervenes with the proper adjustments or controls to narrow the gap between actual performance and potential performance. Examples of this technology include irrigation systems tied to weather stations and soil sensors, variable rate application of fertilizer and chemicals with row shutoff technology, and precision planting technology that automatically adjusts seed placement and depth to changes in soil conditions.

Combining real-time monitoring and measuring technology with anytime intervention process control technology has the potential to generate significant benefits. Anytime intervention technology allows a producer to detect a problem when it occurs and in real time solve that problem rather than anticipate a possible problem and preemptively dispense control inputs that may be costly or unnecessary and possibly harmful to the environment. For example, anytime intervention technology allows the detection of corn borers and the treatment of those borers once they meet an economic threshold, rather than spending funds and using materials in anticipation that a corn borer infestation might occur. Similar approaches to fertility management facilitate lower levels of pre-season fertilizer applications by enabling additional applications during the growing season as real-time sensing technology and drop-down nozzle attachments for high clearance equipment enable split applications of fertilizer to be applied when needed.

This article discusses potential payoffs of precision agriculture from the producer, value chain, and environmental perspectives. Benefits of precision agriculture are discussed in the context of technology adoption and competitive advantage.

COMPETITIVE ADVANTAGE

As noted in the introduction, aggregate agricultural output has been expanding at a rapid rate due to technology adoption rather than increases in aggregate agricultural input. In other words, the production frontier has been shifting upward. Mugeru, Langemeier, and Ojede (2016) illustrate the large shift in the production frontier for a sample of farms. Farms that were not able to adopt technology as rapidly as their competitors saw a decline in their relative efficiency position over time. In addition to augmenting production, technological change also helps lower cost per unit of production.

Benefits associated with technology adoption are often couched under the auspices of competitive advantage, which has been extensively explored in the business and farm management literature (Hunt, 2000; Besanko et al., 2010; Boehlje, 2013; Langemeier and Yeager, 2020). Competitive advantage is a circumstance that puts a business or farm in a favorable or superior business position. To obtain a competitive advantage, a firm either reduces per-unit cost while procuring average prices, receives higher prices with an average per-unit cost structure, or both. The strategy related to relatively higher prices is often referred to as a value-added strategy. Technological change impacts industry structure and can even lead to new industries. If a firm currently does not have a competitive advantage, early adoption of key technologies can create a competitive advantage. Technological change can lead to competitive advantage when it lowers per-unit cost or enhances product differentiation, results in first-mover advantages, or improves overall industry structure (Porter, 1985). In particular, technological leaders are often able to earn above-average profits until other firms in the industry “catch up.” Given the potential payoffs attributable to precision agriculture discussed below, firms that are late adopters may be leaving money on the table.

In addition to discussing traditional sources of competitive advantage, this paper explores the potential impact of precision agriculture on machinery use, risk, key relationships and alliances, land values, food safety, sustainability, and traceability. The adoption of precision agriculture technologies will also likely affect the environment. In recognition of this potential, the impact of precision agriculture on fertilizer and chemical treatments, nutrient management, and use of irrigation water will be discussed. When discussing potential payoffs below, we are referring to higher net returns, lower risk, or both.

POTENTIAL PAYOFFS

Potential payoffs of precision farming for producers and value chains (i.e., agribusinesses), as well as from an environmental perspective, are described below. The discussion of payoffs goes beyond the typical discussions involving just cost savings and enhanced production.

Potential Payoffs for the Producer

The improved measurement of soil characteristics and weather patterns that is part of precision farming

has the most direct and obvious payoff in terms of cost reductions and efficiency increases from more accurate use of inputs such as fertilizer, seed, chemicals, and other inputs and the systematic measurement of the impacts of these inputs on yield and profitability. Precision farming, combined with creative ways to schedule and sequence machinery use (including 24-hour-per-day operations, moving equipment among sites, and deployment based on weather patterns), has the potential to increase machinery utilization and decrease per-acre machinery and equipment costs.

Precision farming is also likely to impact value-added production or product differentiation. One dimension of that differentiation may be the production process itself. For some markets, such as the organic market, products cannot be produced using inorganic chemicals, and some processors and food companies want to trace the sourcing of crop products to specific locations or fields with detailed documentation of production processes. With more specificity required for raw materials to meet qualified supplier requirements, increased measurement and monitoring of both the growth process and the end product will be important for quality control and compliance. In fact, precision farming in its broader context of measuring, monitoring, and controlling the plant growth process is expected to have more payoff in differentiated product production than in commodity product production because it has the potential to not only lower cost but also simultaneously enhance revenue by producing a higher-value product; these dual outcomes have the potential to dramatically enhance a firm's competitive advantage.

A key concern in crop operations is the perceived and, in many cases, real limit on size of operation because of the difficulty of monitoring progress and performance on large geographically dispersed acreages. The fundamental argument is that if plant growth processes can only be monitored by people with unique skills and those individuals are costly or expensive to train, the monitoring process limits the span of control to what one individual (or at least a few individuals) can oversee personally. If electronic monitoring systems can be developed (whether it be machinery operations or the growth process of the crop or the level of infestation of insects or weeds), fewer human resources are needed for this task and larger scale is possible.

A critical determinant of productivity in crop production is timely operations: getting the planting completed in a timely fashion for optimal growth and harvest completed before harsh winter weather occurs. Delays

due to unanticipated breakdowns can be costly. Telematics that indicate the need for preventative maintenance can be very useful in reducing the prospects of a breakdown, and GPS guidance can extend the operating hours during the critical planting and harvesting seasons. Precision planting technology that enables more accurate seed placement at higher travel speeds increases the number of acres that can be planted per hour. In some cases, higher accomplishment rates and extended hours of operation per day can enable farmers to operate more acres with the same equipment or the same number of acres with a smaller machinery line.

No matter how skilled they are, people can and do make mistakes. Precision agriculture technology combined with automation reduces the chances of a mistake. GPS-based auto-guidance combined with row shutoff technology reduces overlap in chemical or seed application. Seed monitors reduce the chances of skips or other inaccuracies in seed placement. Yield monitors provide the data for more accurate selection of fertility and chemical programs, which combined with variable rate application technology reduces the risk of making an incorrect variety or weed-control selection in subsequent years. More timely planting and harvesting using precision farming technologies reduces the risk of yield reductions from unpredictable weather events. Precision farming could also provide tools for farms to manage regulatory risks such as nutrient and pesticide use.

One of the most important business relationships a farmer has is with the landowners who rent them the property. Keeping the landowner (or the management company that has been retained by the landowner to oversee this arrangement) informed of the farming activities that are occurring on their property, the progress of the growing crop, and the management and cultural practices that are being used by the operator to maintain or improve the productivity of the property strengthens and deepens this critical relationship. The data and information generated through use of precision farming tools and techniques enhance communication with the landowner/farm manager well beyond the pictures and phone calls typically used in the past. Communication with other suppliers such as lenders and agronomic input and farm equipment suppliers is also enhanced by the additional detail that can be provided to solve problems. In a similar vein, data and information useful to more effectively communicate with buyers concerning crop progress and/or production practices or problems can also enhance the "preferred supplier"

relationship that most farmers want to have with their product purchasers.

Finally, a longer-term payoff of adopting precision farming practices is improved productivity and soil health. Farm land values are heavily dependent on productivity, as reflected by yield. Precision farming will provide enhanced documentation that will help producers understand how more informed data-driven decisions pertaining to tillage, fertility, chemical use, seed selection, and planting and harvesting operations can enhance the natural productivity of the soil, thus creating additional value that can be captured not only by higher yields and profitability during the years the owner is farming the land, but also in the value of that land when it is eventually sold or a higher rental rate when rented to a tenant.

Potential Payoffs for the Value Chain

The current disruptions in the food production and distribution supply chain reinforce the challenges and opportunities of developing better linkages among participants in that chain. Better data/information on input and product characteristics and physical flows is a key part of the solution to these disruptions. For example, input suppliers are able to respond more accurately and timely to equipment repair and maintenance requests when telematics provides them data on engine or equipment wear and potential malfunction. Plant and animal growth progress data and planting and harvesting accomplishment information signals the need for more agronomic inputs for a specific tract of land or that harvest is being initiated at a specific location and will be delivered to the processor or storage facility at a specific time. The ability to share this and similar data/information from producers using precision agriculture tools and techniques across the stages of the supply chain reduces the chances of shortages (or excess inventories requiring storage) of critical raw materials and products and the prospects of supply chain disruptions, and it enhances the trust and deepens the relationships suppliers and buyers have with their partners in the supply chain. In other words, it improves the resiliency and the efficiency of the supply chain.

One of the most difficult risks to manage for a food processing firm is the potential contamination of raw materials. For a branded-product food company, a food safety scare can be disastrous. The improved measurement and monitoring of soil preparation, growth, harvesting, storage and handling, and processing processes that have the potential to be part of precision farming in the future will enable trace-back from end user through the production/distribution

chain, which is the only secure method of guaranteeing food safety. If food safety concerns continue to increase and consumers demand more documentation that food products are in fact safe, precision farming has the potential to become one of the most effective ways of providing that documentation and reducing the risk of food contamination.

A growing number of food processors and retailers are responding to the “sustainability” concerns of their customers by requiring their suppliers to meet what they have specified as sustainability criteria and to document their sustainable practices. Some food retailers have or are considering adding a “sustainability” label to their food products much like the nutrition label that they currently carry. These “trust your food” initiatives are expected to expand. Precision farming provides the capability to execute and document the sustainability practices increasingly required to be a “qualified supplier” in a more demanding supply chain.

Not unrelated to the increasing concerns of food consumers about food safety and sustainability is the issue of traceability and the chain of custody. If there is a food safety issue or contamination of a food product, consumers as well as food companies and government officials are eager to quickly uncover the source and take mitigating action. Tracking and tracing at the farm gate level to uncover sources of contaminant are significantly enhanced with precision farming tools that have recorded the use of specific agronomic and production practices. Likewise, similar documentation can be used to verify that sustainability criteria have been met, or what adjustments might be needed to maintain “qualified supplier” status.

Potential Payoffs for the Environment

More precise applications of fertilizer and insect and weed control in terms of location, timing, and amount to better match plant needs should reduce leaching and runoff into ground and surface water and the resulting deterioration of water quality. Undoubtedly, this potential exists, but what if the precision farming recommendations are for the highest application rates on the soils closest to a stream or waterway or with a shallow water table and heavy rains occurring shortly after application. Precision farming has the potential to reduce environmental degradation of water sources, but we need to monitor and measure this phenomenon to be sure we are obtaining the expected results. It also would help farms and others document and manage pesticide drift for both row and specialty crops.

In many states and locales, concerns about soil and water degradation in rural areas has resulted in

pressures to regulate and restrict the application of inorganic and organic (manure and animal waste) fertilizer. Some states and locales are contemplating or requiring comprehensive nutrient management plans to reduce the environmental footprint of crop production. Precision farming tools and technologies can be very effective in developing and implementing those plans that in many cases will not only reduce the potential of environmental degradation, but also lower costs by more efficiently and effectively using fertilizer (including animal waste) inputs.

In some locations in the United States, particularly in the Plains and western states, the availability of water for irrigation purposes is declining because utilization and draw-downs exceed recharge rates for underground as well as surface water sources. Use of precision farming technology to manage irrigation systems by applying water at the needed amount at the right location and at the right time has been shown to significantly increase efficiency and effectiveness of irrigation, and thus conserve increasingly scarce water resources.

PREVIOUS RESEARCH ON PRECISION FARMING ADOPTION AND PAYOFFS

A 2019 survey of agricultural retailers provides a useful perspective of the current state of precision farming technology adoption (Erickson and Lowenberg-DeBoer, 2020). This periodic survey was initiated in 1997, so it provides an historical perspective of the development over time of precision farming technology as well as some evidence of future challenges and opportunities. A total of 165 dealers responded to the 2019 survey. Table 1 summarizes the dealer offerings of precision services in selected years. The information in the last column represents projections for 2022. Entries designated with N/A indicate that this information was not available in a given survey year, or that projections were not available for a particular service. In many cases for 1997 and 2008 a designation of N/A means that the service was not available because the technology was still being developed. The availability of service offerings has increased significantly over time. Services that were offered by more than two-thirds of the dealers in 2019 included field mapping with GIS, GPS-enabled sprayer boom, GPS guidance with auto control, grid or zone soil sampling, satellite and aerial imagery, variable rate technology (VRT) fertilizer application, and VRT lime application. Cost/profit mapping, guidance and autosteer sales and support, and drone imagery

adoption went from not being offered or surveyed in 2008 to 38% in 2019—and are projected to increase significantly by 2022.

Thompson et al. (2019) recently surveyed 837 commercial U.S. farms with at least 1,000 acres concerning their adoption of precision agriculture technologies. Results indicated that a large proportion of farmers with 1,000 or more operated acres use yield monitors (93%), autosteer (91%), and variable rate fertilizer application (73%). Moreover, 88% of the respondents indicated that precision farming technologies and services were an important contributor to farm profitability, and 80% indicated that these technologies have made them a better farm manager. Cost savings, yield improvement, and convenience were all found to be important reasons for adopting precision farming technologies.

Lowenberg-DeBoer and Erickson (2019) provide an excellent review of the research that has been done internationally on the adoption of precision agriculture technology. The authors noted that guidance systems, sprayer boom control, and planter row or section shutoffs are becoming standard practice in mechanized agriculture. VRT has been adopted at lower rates but is expected to grow with improvements in artificial intelligence (AI) and robotics.

What about the profitability of adopting precision agriculture technology? Schimmelpfennig (2016; 2018) found a small increase (1.1% to 2.8%) in operating profit for corn, and a small increase (1.1% to 1.8%) in operating profit for soybeans resulting from the adoption of soil and yield mapping, guidance systems, and VRT. A more recent exploratory study by Pope and Sonka (2020) pertaining to the use of digital technology in farming used a detailed interview survey of a sample of 10 farmers who are recognized as early adopters of precision agriculture technology to explore the benefits and costs associated with precision agriculture tools and practices, including yield monitors, autosteer, mapping, soil sampling, VRT, drones or aerial imagery, and management systems. The perceived benefits were almost \$90 per acre or a benefit cost ratio of 9.7. The relatively higher payoffs compared to previous studies were attributed to their examination of whole-farm system benefits of the interactions among individual technologies and management practices that compound or multiply the benefits of individual technologies and enable the implementation of a more systematic way of farming.

WHAT ABOUT THE FUTURE?

As noted in the discussion above, significant advancements in precision farming technology have been made in the past few years. Given the increased interest in and commitment by venture capitalists, innovators, and entrepreneurs to enhancing the “digitization of everything” in the food production and distribution industry, the development of new tools and technologies is likely to occur at an accelerated pace.

One of the more interesting and challenging areas of future innovation is automation and robotics. Autonomous grain carts and tractors have garnered considerable press. Autonomous grain carts enable an individual in the combine to locate the cart, tell the cart to follow and match speed with the combine, and unload on the go. Autonomous tractors use GPS and other wireless technologies to farm land without requiring a driver. These tractors are programmed to observe their position, determine speed, and avoid obstacles.

Another technology with a lot of promise in production agriculture, particularly for sensing and monitoring, is drones. As noted above, the adoption rate by retailers of drones reached 38% in 2019 and was expected to increase dramatically by 2022. Drones are used for crop and livestock monitoring; to plan and make land improvements; to make seed, fertilizer, and pesticide prescriptions; to help with replanting decisions; and to make grazing decisions. As technology continues to improve, farms will be able to use drones to enhance crop and animal health and to enhance the ability to assess the impact of seed, fertilizer, and pesticide applications. Also, drones will enhance a farm’s ability to assess the impact of adopting specific practices such as reduced tillage, use of cover crops, or rotational grazing.

The *Hands Free Hectare* project associated with Harper Adams University in the U.K. uses automated machines to grow crops remotely without drivers or agronomists in the field. The project utilizes autonomous navigation systems to plant, grow, and harvest an annual cereal crop. Individuals are not allowed to step on the field, so robots or drones are used to implement all in-field farming activities. Cost analysis on robotics by Lowenberg-DeBoer et al. (2019) based on data from this project suggests that automation has the potential of reducing the costs for smaller acreage farms more than larger acreage farms, but not entirely eliminating economies of size in farming.

3D printing could also contribute significantly to production agriculture. 3D printers will allow machinery

dealers and producers to manufacture spare parts on-site. This technology will likely change how we think about manufacturing batch size and inventories, and it will allow parts to be produced on-site and just-in-time, which could substantially reduce machine downtime. During peak workloads (e.g., planting and harvesting seasons), this reduction in downtime would be extremely valuable.

A good example of the use of automation in the livestock industry is the spread of robotic milkers. This technology has been adopted for a number of reasons including labor cost savings, lack of availability of labor to milk cows, and improved milk production per cow. Robotic milkers adapt milking frequency to individual cows and by lactation stage. Also, just as precision agriculture adoption for crops results in more timely data collection and improved decision making, a robotic milking system creates a wealth of data that can be used to make decisions (e.g., optimal dairy cow replacement). Use of cameras and heat sensors to monitor movements and temperatures to detect lameness and animal behavior, including feed consumption and waste, and possibly diseases and health issues, are other examples.

The adoption of precision farming technologies will require an enhanced “mental model” of the farm manager and workforce. Choosing and using precision farming tools and technologies requires an enhanced appreciation and understanding of science and fact-based decision making. This includes a more advanced understanding of the biological and physical sciences to frame these decisions, as well as the ability to use data analytics and quantitative analysis tools such as statistical analysis and optimization models to make these decisions. It is thus essential to bring new capabilities and skills into the farm of the future.

The emergence of precision farming and in particular automation technologies is rapidly changing the nature of work for all businesses, including farms and ranches. To maintain a competitive advantage, farm operators will need to take a more active role in identifying the capabilities and skills needed by the business and to develop mechanisms to recruit, train, and retain employees. As part of a skill assessment, it is important to identify gaps in capabilities and skills and to determine how the business will address these gaps.

As noted by Manyika, Chui, and Miremadi (2017) and Willcocks (2020), automation could perform certain tasks at medium to high performance. For example, general equipment and navigation, inspecting and monitoring, basic data input and processing, and basis

communication could be performed relatively well with automation technologies. However, capabilities pertaining to creativity, leadership, complex information processing and interpretation, and advanced IT skills and programming would be difficult to emulate with automation technologies. In particular, tacit knowing or the fact that humans know more than they can describe is problematic to automation (Polanyi, 2009). Obviously, tacit knowledge makes it difficult to write code for machine learning.

Table 2 compares current capabilities and skills with potential future skills needed in production agriculture. This table was adapted from Willcocks (2020). To summarize the table, skills related to those that are difficult for machines to emulate (e.g., creativity, leadership, strategic positioning, and interpretation of data and information from precision agriculture technologies) will be critical to the farms of the future. Individual farms need to assess whether they have someone on board who has these capabilities and skills. If they don't, would it be possible to contract for these skills? More options related to developing the workforce of the future are discussed below. From a management time standpoint, one of the upsides of current trends in automation is that it may free up employees to spend more time on their distinctive human capabilities and skills (e.g., interpretation of data and information from precision agriculture technologies) rather than on predictable physical work, potentially augmenting labor productivity.

In addition to discussing changes in skills needed in the workforce as businesses adopt automation technologies, Bughin et al. (2018) describe potential changes in the business workforce environment and options for companies to build the workforce of the future. Though the authors focus their discussion on businesses with numerous employees, many of the concepts discussed also apply to small businesses. In terms of the workforce environment, developing a mindset of life-long learning, stressing collaboration, and making sure that we have personnel who are responsible for leadership tasks, for supervising and training employees, and for developing a strategy to purchase and fully utilize precision agriculture technologies is important. Options for building the workforce of the future include retraining current employees, redeploying employees so that they can focus on future skills needed, hiring individuals with specific automation or other skills, contracting with outside parties for a portion of the skills needed, and removing skills that are not as pertinent as they have been historically. Even with a small workforce, farms will likely use a combination of these options rather than just one of the options.

We would be remiss if we did not indicate that there is going to be substantial competition for individuals with distinctive human capabilities and skills. Having these individuals in place or making sure that one of the operators or employees has the necessary skill set is likely to be critical to a farm's competitive advantage. Thus, creating a plan to develop or obtain these skills from an outside party is very important.

Turning to possible new precision farming advances, what should we be watching for? Here is a partial list:

- Better understanding of the fundamental drivers/determinants/constraints of plant growth and the specific structure and parameters of the underlying growth process.
- Improved technologies to more accurately measure/sense/monitor the plant growth process in real time.
- Better understanding of how frequently and at what level of granularity (by acre, field, parcel, etc.) to monitor and manage production processes.
- Improvement in the accuracy of measuring outputs (yield, production) and inputs (seed, nutrition, chemicals, tillage, etc.) of crop production processes.
- Further advances in the application and process control technologies that can be used in real time to manage and intervene in order to enhance plant and animal growth.
- A better understanding and control of the accuracy of "application" technology (e.g., seed and fertilizer placement, spray patterns and dosage, tank or batch composition and concentration, etc.).
- A better understanding of the challenges and opportunities of data aggregation and sharing needed to obtain essential insights in crop and livestock production.
- Increased availability of broadband connectivity in rural areas to enable faster and more accurate data transmission and communication.
- Advances in data security systems and resolution of issues concerning privacy and data sharing between farmers and their business partners in the value chain.
- Further advances in cloud computing, AI, Big Data, and the Internet of Things (IoT) technologies that will accelerate the digital transformation of the farming sector.

CONCLUSIONS

This article discussed the potential payoffs of precision farming and the adoption of precision agriculture technologies, as well as provided thoughts on future developments. The technological transformation of production agriculture using precision farming systems and processes is well underway. Adoption rates have been very rapid during the past 10 years. Given the potential benefits and increased venture capital devoted to developing these technologies, adoption rates are likely to accelerate. Potential payoffs for producers include efficiency improvements, enhanced ability to produce value-added products, risk reduction, and enhanced land values. Precision agriculture is also expected to generate payoffs for the value chain and the environment. Specifically, the ability to more efficiently utilize seed, fertilizer, and pesticides as well as improved traceability will be extremely beneficial.

In summary, the adoption of precision agriculture technologies will lead to a competitive advantage for some farms. Another way of stating the same thing is that farms that do not adopt these technologies will face a competitive disadvantage. Having said that, it is important to note that the adoption of precision agriculture technologies will likely change the required capabilities and skills used by the production agriculture workforce. Farms will thus need to assess whether they have gaps in the skills needed to successfully adopt and manage these new technologies.

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Table 1. Dealer Offering of Precision Services in Selected Years

Service	1997	2008	2019	P 2022
Cost/Profit Mapping	N/A	N/A	38%	55%
Field Mapping with GIS	29%	47%	85%	90%
GPS Enabled Sprayer Boom	N/A	N/A	75%	N/A
GPS for Logistics	4%	8%	38%	N/A
GPS Guidance with Auto Control	N/A	37%	90%	N/A
GPS Guidance with Manual Control	24%	73%	59%	N/A
Grid or Zone Soil Sampling	33%	53%	90%	91%
Guidance and Autosteer Sales and Support	N/A	N/A	38%	46%
Precision Planter Equipment Sales	N/A	N/A	28%	34%
Satellite and Aerial Imagery	N/A	26%	70%	80%
Telematics Equipment Sales	N/A	N/A	20%	22%
UAV or Drone Imagery	N/A	N/A	38%	60%
VRT Fertilizer Application	20%	56%	88%	91%
VRT Lime Application	N/A	44%	70%	74%
VRT Pesticide Application	N/A	23%	20%	50%
VRT Seeding Prescriptions	3%	15%	59%	70%
Yield Monitor Sales and Support	15%	26%	40%	46%
Yield Monitor with Other Data Analysis	24%	34%	63%	70%

Source: Erickson and Lowenberg-DeBoer, 2020.

Table 2. Changes in Capabilities and Skills Needed in Production Agriculture

Current	Future
Physical	Digital
Non-Technical	Technical
Non-Cognitive	Cognitive
Basic Human	Distinctive Human
Repetitive	Non-Repetitive
Low Skills	Medium to High Skills

Source: Adapted from Willcocks, 2020.