SERIES

PRECISION AGRICULTURE AND TECHNOLOGY

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OVERVIEW

Precision agriculture utilizes biotechnology and nutritional technology; monitoring, measuring, and information technology; and process control technology to increase resource efficiency, reduce input cost, and/or improve product value. This series of articles will discuss precision agricultural technologies, potential payoffs of using these technologies, and the capabilities and skills that will be needed to manage these technologies.

Importance of New Technologies for Crop Farming

By Michael Boehlje and Michael Langemeier

Adoption of technology has been important to production agriculture for decades. Through the adoption of technology and improved managerial practices, aggregate agricultural U.S. farm output in the United States tripled from 1948 to 2017 with almost no corresponding increase in aggregate input (USDA-ERS, 2021). For reasons explained below, the adoption of technology in production agriculture is expected to accelerate in the next decade. This article discusses types of technology that are currently being adopted or that are likely to be adopted in the near future. Upcoming articles will discuss the critical role of information and precision agriculture technologies, possible payoffs of precision agriculture, automation and robotics, and gaps in skills pertaining to the adoption of new technologies.

CHANGES TO CROP AGRICULTURE

Crop farming around the world is undergoing a profound technological transition. The management of production is moving toward increased micro-management of production activities by individual field or location within a field driven by site-specific information about environmental, biological, and economic factors that affect physical output, profitability, and soil and water quality.

Increased use of monitoring technology will greatly expand the amount of information available regarding what affects plant growth and well-being. This will be made possible by innovations in sensors to use in monitoring and control systems, communication technologies, and data analytics. In addition, greater understanding of how various growth and environmental factors interact is forthcoming. This understanding will then be incorporated into management systems to determine optimum combinations of inputs at the field or within a field level. Precision farming in crop production includes the use of global positioning systems (GPS), yield monitors, and variable rate application technology to more precisely apply crop inputs to enhance growth, lower cost, and reduce environmental degradation.

Growing crops through precision production practices might be described as “biological manufacturing” which combines biotechnology and nutritional technology; monitoring, measuring, and information technology; and process control technology. The critical linchpin among these “technologies 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 the plant growth process. The transition of production agriculture from an industry that grows crops to one that biologically manufactures raw materials with specific attributes and characteristics for food and industrial use products is well underway. The discussion below will focus on three types of technology: biotechnology and nutritional technology; monitoring, measuring, and information technology; and process control technology.

BIOTECHNOLOGY AND NUTRITIONAL TECHNOLOGY

The focus of biotechnology and nutritional technology is to manipulate the growth, attribute development, and deterioration process in plant production. An improved scientific base impacts not only plant growth but attribute development and is providing additional capacity to manipulate and control processes. Also, biotechnology is advancing our capacity to control and manipulate plant growth and development including attribute composition (for example, starch or amino acid composition) through genetic manipulation. By combining nutritional and biotechnology concepts with mechanical and other technologies to control or adjust the growth environment (temperature, humidity and moisture, pest and disease infestation, etc.), the process control approach and thinking that is part of the assembly line used in mechanical manufacturing becomes closer to reality in biological manufacturing.

MONITORING, MEASURING, AND INFORMATION TECHNOLOGY

The focus of this technology is to trace the development and/or deterioration of attributes in the plant growth process, and to measure the impact of controllable and uncontrollable variables that are impacting that growth process. In crop production, 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. In future years, inplant sensors to detect growth rates and disease characteristics may be available. These systems will be tied to growth models to detect ways to improve plant growth performance, as well as to financial and physical performance accounting systems to monitor overall performance. The computer technology to manipulate the massive amounts of information is readily available; new monitoring and measuring technology including near-infrared (NIR) and electromagnetic scanning is now being developed to measure a broad spectrum of characteristics of the plant growth process.

PROCESS CONTROL TECHNOLOGY

The concept of process control technology is to intervene with the proper adjustments or controls that will close the gap any time actual performance of a process deviates from potential performance. Greenhouse production increasingly utilizes such technology to manipulate sunlight, humidity, temperature, and other characteristics of the plant growth environment. Irrigation systems are an example of this technology in field crop production; modern irrigation systems tied to weather stations and plant and soil sensors automatically turn irrigation systems on and off to ensure that moisture levels are adequate for optimum growth. Variable rate application of fertilizer and chemicals and row shut-off technology are current examples of process control technology in rain-fed crop production. Modern precision planter technology that automatically adjusts seed placement, depth, and soil coverage based on soil sensors is another example.

Combining real time monitoring and measuring technology with anytime intervention process control technology has the potential to generate significant benefits. Any-time intervention technology allows one 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 completely unnecessary (and thus costly) and possibly even harmful to the growth environment if that problem does not occur. 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

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infestation might occur which are unneeded if the infestation does not reach an economic threshold during the growing season. A similar approach might be used to control weeds. Similar approaches to fertility management may facilitate lower levels of pre-season fertilizer applications by enabling additional applications during the growth 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. If such technology is developed, it may be less essential to use biotechnology to control certain insects or larger than necessary fertilizer applications to insure the optimum yield.

It would be unrealistic to expect these process control and sensing technologies and methods to be as successful as they have been in industrial manufacturing in reducing variability and systemizing the processes of producing manufactured goods such as automobiles, computers, or even chemical and industrial goods. However, it is also unrealistic to ignore the potential of these technologies in reducing variability and obtaining more control over biological growth processes so as to increase efficiency, reduce costs, improve quality, minimize environmental impacts and in general more systematically produce biological based attributes for food, feed, fuel, and fiber raw materials. In essence, this is what the concepts of biological manufacturing are all about, to use monitoring and measuring, biological and nutritional manipulation, and process control technologies to systematically manufacture food and industrial use products.

CONCLUDING COMMENTS

This article discusses types of technology that are currently being adopted or that are likely to be adopted in the near future. Specifically, technologies related to biotechnology and nutrition; technologies related to monitoring, measuring, and information; and technologies related to process control were briefly described. It is not an understatement to note that these technologies are going to result in profound changes to production agriculture operations. Upcoming articles will discuss the critical role of information technologies, possible payoffs of precision agriculture, automation and robotics, and gaps in skills pertaining to the adoption of new technologies in production agriculture.

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Information Technology and Value Creation

By Michael Langemeier and Michael Boehlje

A recent article discussed the importance of new technologies to crop agriculture. In this article, we continue this theme by discussing the value of information. Upcoming articles will discuss the critical role of information in today's uncertain business climate, possible payoffs of precision agriculture, automation and robotics, and gaps in skills pertaining to the adoption of new technologies.

The use of information technology systems or digital technology has evolved through a number of stages over the last two to three decades. During the 1990s, it was recognized that more accurate and timely data could be used to make better decisions. However, in the 1990s, in many cases, the information technology systems needed to collect and analyze data were perceived to be costlier and more difficult to implement than the data was worth for decision making. Improved communication and sensing technologies in the early 2000s allowed better data analysis and communication within the farm as well as with suppliers and buyers, but information and communication technologies (ICT) as well as limited connectivity in rural areas continued to present cost and implementation challenges. Today, the combination of cloud computing, artificial intelligence (AI), Big Data and the Internet of Things (IoT) technologies is breaking through the cost and effectiveness barriers to adoption. For this reason, experts believe we are in the early stages of a digital transformation in the farming sector.

THE VALUE OF INFORMATION

The concept of information means different things to different people. In this discussion, we will distinguish between three important concepts: 1) knowledge, 2) data, and 3) information.

Knowledge involves broad-based concepts, theories, principles, and models that are necessary to understand a particular phenomenon. Knowledge can be applied broadly across many sets of facts and circumstances or contexts. It is not data specific or unique, but helps one sort through the vast quantities of data available to determine what is relevant.

Data are more specific than knowledge, and can be quantitative or qualitative in nature. Data is distinguishable from knowledge in that data is specific while knowledge is general. Clearly this clean distinction becomes fuzzy at times.

Information is different from data or knowledge in two important dimensions: first, it is context specific, and second it is decision focused. In essence, if knowledge and data are combined and applied to a specific context (for example, a specific crop and parcel of land) and a specific decision (the proper level of fertilizer to apply to obtain a particular yield of a particular crop), they are transformed into valuable information. Data that is

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context specific and decision focused becomes information; information combined with knowledge results in improved decision making and better physical and financial performance.

Information has many attributes. It must be timely – appropriate to the decision context and not out-ofdate. It must be technically accurate and scientifically sound. It must be objective and unbiased, and/or value judgements must be explicitly identified. It must be complete (as opposed to partial) so as to be useful to decision making, or its partial or incomplete nature must be clearly specified. It must be understandable – communicated in such a way that the user can comprehend it. And finally, it must be convenient – available when and where and at what time the user needs or wants it. These attributes will determine the value of information.

ACCURACY AND RESOLUTION

As has been noted earlier, data becomes valuable as information as it becomes context specific and decision focused. In crop production, data are becoming more unit or activity specific. Geographic information and mapping systems combined with GPS guidance systems are being used to increase the resolution and accuracy in evaluating soil productivity characteristics and crop growing conditions by location in the field and make appropriate fertilizer, chemical, and other input adjustments to increase yield and/or reduce cost. This site specificity results in the potential for more precise crop farming.

At the same time as our measuring and monitoring systems have the potential to become more site or unit specific and real-time, the techniques for summarizing this data and converting it into decision focused information are becoming more common. Geo-referenced guidance linked to variable rate seed, fertilizer, and pest control application systems has the potential to generate not just yield maps, but profit or operating margin maps that enable us to assess which locales (acres, parcels, grids, etc.) generate the highest returns. And this data analysis system could even project or simulate during the growing season the profit potential of additional within season variable rate applications of fertilizer or insect and weed control informed by real-time sensing of the plant growth process.

Most standard farm accounting systems are driven by bottom-line, whole farm, or enterprise financial results with significant lags in measurement. With increased capacity to measure and monitor the process of crop growth combined with increased emphasis on process control to increase efficiency and improve quality, more of the record keeping activities must focus on process monitoring and measurement or activity accounting. This level of specificity and resolution is generally not yet part of standard accounting and data acquisition systems in agriculture, but changes are coming.

A point of caution concerning accuracy and resolution. Some decisions require further refinement of accuracy and increased resolution; this is particularly the case with tactical decisions in the production and marketing area where there will be an

increasing emphasis on process monitoring and control. Other decisions, particularly strategic decisions, may not require as much data specificity and resolution. One must be careful to not become immobilized in the decision-making process by too much data or too high a level of data specificity. Also, it is important to note that data gathering incurs a cost as well as a benefit. Thus, the level of data specificity must be matched to the decision that is being made, and the cost of gathering that data at an increased level of specificity or resolution must be compared to the benefits received.

COLLECTING DATA

Some argue that "I can't waste my time collecting data that I'm not sure will be useful in making decisions; and when they show me it is useful, I will start to collect it." That seems to be a reasonable argument, but it has a fatal flaw. Data that is available but not recorded is lost forever – for example it is virtually impossible to reconstruct yield data from different areas in a field if it is not collected and linked to specific location when the crop is harvested. Once we had the technology to make variable rate applications to more accurately apply seed and fertilizer to locations in the field where it could have the most potential to increase yield, we needed yield maps to inform the variable rate decisions. If we had not yet collected the data to generate a yield map, we could start to do so to enable us to make more informed decisions in future years. But given the complexity and the high level of variability in crop production, one or two (or even three or four) year's data observations doesn't provide very accurate information to make agronomic management decisions. Science based decision making indicates that multiple observations are required to have the accuracy needed given the complexity and high level of variability in rain-fed crop production. And with the annual production cycles for crops like corn and soybeans, the number of observations one can collect is severely constrained even over a farmer's lifetime. A missed observation lost forever is a high loss in long cycle-time crop production agriculture when data and information are an increasingly more important source of higher profitability and better financial success. Data must be collected and recorded when it is available – you can't wait until it is proven to be useful!

CONCLUDING COMMENTS

This article discussed the value of information. The accuracy and resolution of data has improved markedly in recent years. Even if the payoff of data is still marginal, collecting data in anticipation of technological improvements would be prudent. Remember the adage, you can't manage what you don't measure.

Upcoming articles will discuss the critical role of data in today's uncertain business climate, possible payoffs of precision agriculture, automation and robotics, and gaps in skills pertaining to the adoption of new technologies in production agriculture.

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The Role of Information in Today's Uncertain Business Climate

By Michael Langemeier and Michael Boehlje

Recent articles (March 5, 2021) and (March 12, 2021) discussed the importance of new technologies to crop agriculture and the value of information. In this article, we continue this theme by discussing the role of information in today's uncertain business climate. Future articles will discuss possible payoffs of precision agriculture, automation and robotics, and gaps in skills pertaining to the adoption of new technologies.

The business climate regularly presents challenges to the profitability and financial performance of even well managed crop farms. Given expectations that crop prices and farm incomes will periodically come under pressure, it will be critical for farmers to "double down" on implementing the management strategies and practices to maintain or enhance profitability and reduce the prospects of financial deterioration of their businesses. What are some of the strategies and practices, and where is data and information essential to be "best in class", irrespective of the business climate, to have the resiliency and agility to handle the kind of uncertainty farmers face?

1. IMPROVE EFFICIENCY AND PRODUCTIVITY

Without a doubt high efficiency and productivity are essential for success. Doing everything you can to choose the right seed, fertility, pest control, and other agronomic inputs and practices that will generate the best economic yield is essential. Remember that the highest physical yield is not the best if the cost to obtain additional bushels is higher than the value of those additional bushels. But given the uncertainty in weather and prices, it is difficult to be exactly correct in your agronomic decisions, so it is often better to over-apply than under-apply fertilizer in particular (but not too much!) to capture the yield potential that is available.

2. INTENSE COST CONTROL

In a commodity industry like crop farming, you have to be a low-cost producer to be successful in the long-run. So, cost control is absolutely essential. Determining cost per unit of production (i.e. bushel of corn or soybeans) and detailing those costs by major category (for example, seed, fertilizer, chemicals, etc.) is one way to know which costs are the most important to focus on and attempt to reduce. One of the biggest cost categories is land cost. Rental payments on cash rented land have not adjusted down as much as most other input costs, and it is a difficult but important discussion to talk to your land owners and negotiate a lower or adjustable rental rate. How long can you hold on to a rental property if you are losing money and expect to continue to do so? Maybe you could negotiate a flexible cash lease (a lower base payment per acre with an additional payment if prices or yields exceed a specified level), or a crop- share lease arrangement.

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3. IMPROVE EXECUTION

Get it done right and in a timely fashion. In manufacturing industries, this is known as “lean” production practices and procedures. Systemize the production processes by using check-lists and standard operating procedures (SOP’s) to make sure all the tasks necessary to produce a crop are done at the right time, in the right order and in the right way. Use the best data and information on field conditions and weather forecasts to schedule machine operations and sequencing of tillage, planting, and harvesting operations by field and location. Expand the number of hours in the field per day and/or increase your workforce to get the most work accomplished in the suitable field days during the growing season.
Maybe double or triple shift your field activities so you can operate as close as possible to 24 hours a day when field conditions allow you to do so. Use computer-based work flow scheduling procedures to plan your daily activities and have the capacity to quickly make the necessary adjustments when weather events or other interruptions such as equipment breakdowns disrupt your schedule.

4. MANAGE MARGINS

Projecting profit margins is not easy when you don’t know what prices and/or yields will be, but it is still useful to estimate your profit margin, and even more valuable to estimate it for different levels of prices and yields to determine the sensitivity of profit and cash flows to weather and market conditions. Determining potential margins per bushel of production requires estimates of costs per bushel which can also be useful in making marketing decisions. If product prices are above costs, maybe you should capture or lock in that margin/profit on some of your potential sales just in case market prices deteriorate in the future. And if you are projecting a negative margin and expect to lose money, it is important to know the size of the potential loss and develop a plan to make sure you can cover your financial commitments and not impede the survivability of the business.

5. BUY RIGHT

Some businessmen say that the first and most important “marketing” decision they make is what inputs or raw materials they purchase and what they pay for them because that sets their cost structure. This is why most industrial manufacturing businesses have someone responsible for procurement (i.e., buying right). And certainly, particularly in farming, you have more control over costs than you do over market prices, so time spent on making the best decision on “buying right” is critical to financial performance. Comparing potential suppliers’ offers just like one compares the prices offered by different product buyers is an important task in buying right. One common practice in the business world is to use a “spec sheet” to systemize and document those offers (Boehlje and Downey, 2015). This spec sheet should include not just prices, but other features such as services included, performance guarantees or warranties, discounts if available, delivery conditions, information sources, contacts for complaint resolution, financing terms, etc.

6. MANAGE OPERATING RISK

Operating or business risk is the variability in the income generation and financial performance of the farm resulting from the variability in the prices, yield, and costs that the farm business faces. Managing this risk can almost be a full-time job. It involves choosing the right technology

to reduce yield loss from weed and insect pests, from nutrient/fertility inadequacy or losses, seed that is not disease or weather resistant, equipment that is not reliable and subject to frequent breakdowns, etc. Operating risk can also result from marketing decisions that don't recognize product price and basis volatility and input price increases. Choice of the government farm program options and the most appropriate crop insurance alternatives are important management strategies to manage operating risk, along with having the appropriate casualty and liability insurance program.

7. DEBT AND CAPITAL MANAGEMENT

The capital structure of the business (the proportion of the assets financed with borrowed or lease funds compared to owner's equity funds) is a critical source of financial risk. Common sense says a business has increased financial vulnerability as it relies on increased amounts of debt (and thus has a higher debt to asset ratio) to finance its activities. But there is more to it. Using short-term credit (an operating loan for example) to fund the purchase of a capital asset such as machinery or land can be a disaster if the operating line is reduced or not renewed in subsequent years. Loan repayment terms must be "matched" to the useful life of the asset so that earnings from using those assets can be used to service the debt. Lenders are interested not just in the total debt of a business, but the structure and repayment terms of that debt. And a premium is placed on the "liquidity" of the business as indicated by the amount of cash that will be generated during the normal business cycle from sales of products and inventories which will be available to make principle and interest payments on the debt. Lenders want a cushion or reserve in this "working capital" position so the scheduled payments can be made even if lower prices/yields or other factors reduce incomes or cash flows. Making the right choice to lengthen loan repayment terms, reduce capital expenditures, sell some underutilized assets to generate cash, use excess cash or negotiate a cash infusion from outside the business, or use some other strategy to respond if debt repayment problems are encountered is a difficult decision that is best avoided if possible by well-developed debt/capital management plans.

8. SIMPLIFICATION/AUTOMATION

One way to improve the operations/execution process and the accuracy of getting everything "done right" is to simplify the processes as much as possible. Complexity creates confusion and results in mistakes. This doesn't mean taking "short-cuts" and not doing the critical tasks correctly. Rather, it means dropping the steps/activities that aren't essential and making sure everyone is not just familiar with the SOP's, but is actually using them to get the work done. And better yet, new precision farming technology (autonomous self-driving tractors, irrigation control systems, automated calibration of yield monitors, automated combine header and threshing controls, etc.) is increasingly making it possible to automate more and more farming activities.

9. DO FEWER THINGS BETTER

Unfortunately, many farmers suffer from the "jack of all trades, master of none" phenomena. They do not have the time/energy to be "best in class" in everything they do, so aren't as successful as they might be. A standard question asked by consultants who specialize in business management is what do you do better than anyone else. In other words, what is your core competency? Figure out what you are really good at and then focus on continually getting better at it over time. But what about those activities that need to get done but you don't have the time/energy to do them? Hire or retain someone who specializes in that activity, a standard

practice for legal or accounting work. Maybe you need to do more “outsourcing” of other activities such as retaining a crop consultant or a market advisory service, hiring someone to custom spray your crops, or transporting the crop to the elevator. Focus on doing fewer things better.

10. DATA MANAGEMENT

Just think about what your grandfather would say if he had all of the data and information that is now available to you to make farming decisions. Certainly, he would be concerned about “data overload” just like you are today, but the tools and techniques are increasingly available to sort through that data/information and make more informed and better decisions. No doubt you will need assistance in collecting the data and carefully analyzing it to sort-out false signals or noise from facts and true insight. But as we will discuss in an upcoming article, the payoff is there for time/energy/money spent on data management. The lynch-pin and common denominator of all these strategies and practices is to have the most accurate data and information as well as the appropriate analytics and decision processes to make the right choices and implement the best strategies. Digitization of agriculture and the significant advances in the development of precision agriculture tools and techniques have enhanced our capacity to adopt strategies that will improve resiliency and agility to respond in these increasingly uncertain times.

CONCLUDING COMMENTS

The increasing role that knowledge and information play in obtaining control of resources, increasing profits, and reducing risk in farming is occurring for two fundamental reasons. The first reason is the dramatic growth in knowledge and information of the chemical, biological, and physical processes involved in agricultural production. This vast expansion in knowledge and understanding means that those who can sort through that knowledge and information and put it to work in a practical context have a better chance of success. Second, the “food business” has become an increasingly sophisticated and complex business in contrast to producing commodities as in the past. This increased complexity means that those with more knowledge and information about the detailed processes as well as how to combine those processes in a total system (i.e. a food chain approach) will have a comparative advantage. Whereas the physical resources of land, labor, and capital were the key determinants of financial success in the past, the role of knowledge and information will become more important in the future. Superior knowledge and information will enable producers to more successfully obtain the physical resources of land, labor, and capital and combine them in an efficient manner. Thus, the role of knowledge and information to success in the farming sector and agricultural industry is more important today than ever before.

This article discussed the role of information in today’s uncertain business climate. Upcoming articles will discuss possible payoffs of precision agriculture, automation and robotics, and gaps in skills pertaining to the adoption of new technologies in production agriculture.

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Adoption Of Precision Agriculture Technologies

By Michael Langemeier and Michael Boehlje

Recent (March 18, 2021, March 12, 2021, March 5, 2021) articles discussed the importance of new technologies to crop agriculture, and the value and role of information in the adoption of these technologies. In this article, we continue this theme by discussing the adoption of precision agriculture technologies. Upcoming articles will discuss the potential payoffs from the adoption of precision agriculture technologies, automation and robotics, and knowledge gaps on farms.

CURRENT STATUS AND AVAILABILITY OF PRECISION AGRICULTURE TECHNOLOGY

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 survey was initiated in 1997, so it provides a historical perspective of the development over time of precision farming technology adoption 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 increased dramatically from 2008 to 2019. 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, VRT fertilizer application, and VRT lime application. Interestingly, cost/profit mapping, guidance and autosteer sales and support, and UAV or drone imagery went from not being offered or surveyed in 2008 to 38% in 2019, and are projected to increase significantly by 2022.

A 2019 survey of 800 commercial farmers (1000 acres or larger in size) by Purdue's Center for Commercial Agriculture (Thompson et al, 2019) provides further insight on issues of precision agriculture technology adoption, and data analysis and utilization. Results indicate that a large proportion of farmers with 2000 or more operated acres collect yield monitor (approximately 75%), soil sample (approximately 85%), and imagery (close to 90%) data. This data has the highest influence on fertilizer decisions, seeding rate decisions, and drainage decisions. Survey respondents appeared to be very satisfied with the results: 72% report a positive yield impact from data-driven seeding rate decisions; 81% from fertilizer decisions, and 85% from drainage decisions. Collecting data from all three sources results in even more satisfaction with the results than if only one data stream is collected. As to data management practices, 47% of the farms collecting data use one or more data software products/services; 63% of farmers with 5000 acres or more use at least one data software product/service. In terms of data sharing, over 70% share their farm data with at least one service provider. Farmers who subscribe to a data software platform or share their data with an outside service provider are more "highly influenced" by the data in their seeding and fertility decisions than those who collect data but do not use a platform or share their data.

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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%
Satelite 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: 2019 Precision Agriculture Dealership Survey.

Table 1. Dealer Offering of Precision Services in Selected Years

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, and have been adopted in some cases as

rapidly as GM seed. However, the adoption of VRT has be slower, suggesting that it is more difficult to access the benefit/cost relationship for these technologies. The authors noted that adoption of VRT technologies are likely to expand with robotics and AI.

What about the profitability of adopting precision agriculture technology? Schimmelpfenning (2016) found a small increase (1.1% to 2.8%) in operating profit for corn, and Schimmelpfenning (2018) found a small increase (1.1% to 1.8%) in operating profit for soybeans resulting from the adoption of GPS soil and yield mapping, guidance systems, or 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 small sample (10) of farmers who are recognized as early adopters of precision farming technology to obtain their estimates of the costs and benefits of approximately 25 individual precision farming tools or practices. Categories of tools and practices included:

- "Legacy Control Systems" (e.g., yield monitors and auto steer)
- "Mapping"
- "Agronomic/Fertility Systems" (e.g., gird/zone soil mapping, variable rate technology, sensors)
- "Monitoring Systems" (e.g., drones or aerial imagery)
- "Decision Support Technologies" (e.g., analytics, management systems)

The perceived average net benefit was almost $90 per acre, and the benefit cost ratio averaged 9.7 to 1. These results suggest a much higher payoff of precision farming than previous studies. This higher payoff is a result of the whole-farm system benefits of the interactions among individual tools and technologies which result in a new way of farming.

As reflected by the specific interview responses of the participants in this study, the payoff of adopting precision farming technologies is well beyond the cost savings and efficiency gains of specific farming practices. It is the "system" benefits of a new way of farming – the interactions among the practices that compound or multiply the benefits of individual practices or technologies and enable the implementation of a more systematic way of farming. These systemic whole-farm benefits are reflected in some of the insights from the farmer interviews reported in that study:

- Understanding rainfall events – knowing when to go to the field
- Knowing what is going on with different hybrids within the field
- Deciding when to cull cash rented fields
- Documentation for crop insurance claims, lenders, landlords, and buyers Facilitates on-farm research
- Leads to savings in machinery investment and costs Provides data for benchmarking with other farmers\
- Enables savings in labor costs
- Has made farming easier and less stressful
- Understanding rainfall events – knowing when to go to the field
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- Enables savings in labor costs
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NEW PRECISION AGRICULTURE DEVELOPMENTS

As noted in the discussion above, significant advancements in precision farming technology have been made in the last 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 should continue at an accelerated pace. What should we be watching to monitor the new advances in precision farming? Here is a partial list:

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

CONCLUDING COMMENTS

This article discussed the adoption of precision agriculture technologies. Adoption rates have been very high during the last ten years, and given the increased venture capital devoted to developing these technologies is likely to continue at an accelerated pace. The next article on this topic will discuss possible payoffs for the agricultural producer, for the value chain, and for the environment associated with the further adoption of precision agriculture tools and technologies. As we expand the toolkit for precision farming and digitization systems and platforms to enhance farmer's profit margins as well as create value for the value chain and society as a whole, the farming sector will be increasingly transformed from "growing stuff" to biological manufacturing.

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Potential Payoffs of Precision Farming

By Michael Boehlje and Michael Langemeier

Recent articles discussed the importance of new technologies to crop agriculture (March 5, 2021), the value and role of information in the adoption of these technologies (March 12, 2021) and (March 18, 2021), and the adoption of precision agriculture technologies (March 26, 2021). In this article, we continue this theme by discussing potential payoffs of precision farming from the producer, value chain, and environmental perspectives. Upcoming articles will discuss automation and robotics, and gaps in the skills pertaining to the adoption of new technologies in production agriculture.

POTENTIAL PAYOFFS FOR THE PRODUCER

COST REDUCTION/EFFICIENCY IMPROVEMENT INCREASES

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. In essence, precision farming is one step closer to the manufacturing mentality of production agriculture. 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 lower per acre machinery and equipment costs as well.

VALUE ENHANCED DIFFERENTIATED PRODUCTS

Part of production agriculture is expected to move from commodity to differentiated product production. One dimension of that differentiation may be the production process itself. For example, the use of chemicals during only certain stages of the plant growth process. For some markets such as organic, 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 in the raw material 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 to simultaneously enhance revenue by producing a higher valued product.

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SPAN OF CONTROL

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 generally larger scale is possible. An analogy is the transformation from the labor-intensive corn processing or feed milling plants of the past to the electronically controlled and monitored plants and mills of today with computer-based monitoring and control systems and fewer employees producing significantly more output. Crop production can and will move more and more in that direction with improved electronic monitoring and control systems, which expands the span of control.

REDUCED DOWNTIME AND BETTER CAPACITY UTILIZATION

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 very costly. Telematics that inform preventative maintenance can be very useful in reducing the prospects of a breakdown and GPS guidance can extend the hours of operating during the critical planting and harvesting seasons. Precision planting technology which 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.

RISK REDUCTION

No matter how good 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 shut-off 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, reduce the risk of making an incorrect variety or weed control selection in subsequent years. And more timely planting and harvesting using precision farming technologies reduces the risk of yield reductions from unpredictable weather events.

LANDLORD/SUPPLIER AND BUYER RELATIONSHIPS

One of the most important business relationships a farmer has is with the land owners who rent him/her their property. Keeping the land owner (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 enhances communication with the land owner/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/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.

ENHANCED PROPERTY VALUE

Finally, a longer-term payoff of adopting precision farming practices is improved productivity and soil health, and thus value of the land. Farm land values are heavily dependent on productivity as reflected by yield, and in today's and tomorrow's agriculture yield is more and more impacted by data driven investments in land improvements. In the past these improvements have been primarily in the form of investments in drainage, land clearing, terraces and contour tillage, waterways, etc., but in recent years they have included the adoption of management practices that improve fundamental characteristics of the soil such as microbial activity, water-holding capacity, acidity, organic matter, compaction, soil tilth, etc. The use of management practices informed by improved sensing technology and data analytics that document the long-term yield response of 4R (right source, right rate, right time, right place) applications of agronomic inputs, soil conserving tillage techniques, cover crops, lime application, etc., have demonstrated the productivity benefits of improved soil health. Just to illustrate, one of the most common and well-recognized data driven precision agriculture soil health investments is variable rate lime applications to increase soil pH which enhances root growth and nutrient uptake.

SUMMARY OF PAYOFFS TO PRODUCERS

So how specifically does this show up in a direct payoff to farmers? One way to think about and actually document the payoff is to measure the additional value of farmland that results from using precision agriculture tools and techniques. A common way of measuring farmland productivity in the Midwest is the CSR (Corn Suitability Rating), a soil productivity index driven primarily by fundamental soil characteristics (texture, tilth, water-holding capacity, etc.) or soil types, and less so by current and past farming practices. Precision agriculture documentation can help us understand how more

informed data driven decisions on tillage, fertility, chemical use, seed selection, and planting and harvesting operations can enhance the natural productivity of the soil (compared to properties with the same CSR rating where these practices are not used), 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. In essence, land farmed with precision farming practices has the potential to be more productive over a lifetime and consequently has higher value (i.e., it is worth more to the property owner as well as to society).

POTENTIAL PAYOFFS FOR THE VALUE CHAIN

FOOD SAFETY

One of the most difficult risks for a food processing firm to manage is the potential of contamination of raw materials. And 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 traceback 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.

SUSTAINABILITY

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 document their sustainability 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.

TRACEABILITY

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 is 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

REDUCED FERTILIZER AND CHEMICAL LEACHING AND RUNOFF

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 occur 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.

CONSERVING IRRIGATION WATER

In some locations in the U.S., particularly in the Southern Plains, 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.

COMPREHENSIVE NUTRIENT MANAGEMENT

In many states and locales, concerns about soil and water (or even air) 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/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.

CONCLUDING COMMENTS

This article discussed the possible payoffs for the agricultural producer, for the value chain, and for the environment associated with the further adoption of precision agriculture. As we develop technologies and tools to expand the toolkit for precision farming and digitization systems and platforms to enhance farmer’s profit margins as well as create value for the value chain and society as a whole, the farming sector will be increasingly transformed from “growing stuff” to biological manufacturing. Readers are encouraged to check out the Lowenberg-DeBoer and Erickson (2019) and Thompson et

al. (2019) articles for more details pertaining to the benefits accruing to agricultural producers from the adoption of precision agriculture technologies.

Upcoming articles will discuss automation and robotics, and gaps in skills pertaining to the adoption of new technologies in production agriculture. The automation and robotics article will discuss how agriculture fits into general trends in adoption and will provide examples of technologies that are either starting to be adopted or that are expected to be adopted in the near future. Adopting precision agriculture technologies and robotics will require additional management skills. The article pertaining to the gap in skills will address these potential skill gaps and indicate whether it would be better to internalize the skills or contract for these skills.

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Automation and Robotics in Production Agriculture

By Michael Boehlje and Michael Langemeier

Recent articles have discussed the importance of new technologies to crop agriculture (March 5, 2021), the value and role of information in the adoption of technologies (March 12, 2021 and March 18, 2021), and possible payoffs for precision farming (March 26, 2021 and April 2, 2021). This article explores trends in automation and robotics in the general economy, and provides examples of the use of these technologies in production agriculture.

TRENDS IN AUTOMATION AND ROBOTICS

Before discussing the expected adoption of automation and robotics in production agriculture, we will discuss trends in automation technologies that are important to most, if not all, industries. Willcocks (2020) discusses the importance of three primary automation technology types: physical robots, robotic process automation, and cognitive automation. Physical robots will perform industrial tasks that were previously more labor intensive. Robotic process automation uses software to automate tasks that were previously performed by humans. Cognitive automation uses sophisticated software to automate tasks or improve task precision. Machine learning, visual processing of data, and the use of large data sets to improve decisions are components of cognitive automation.

Turning to the adoption of these technologies, Chui et al. (2016) note that automation will not necessarily eliminate entire occupations. However, automation is likely to affect portions o almost all jobs. The authors identify three groups of occupational activities: 1) those that are highly susceptible to automation, 2) less susceptible to automation, and 3) least susceptible to automation. Least susceptible tasks include personnel management and decision-making, planning, and creative tasks. Less susceptible tasks include stakeholder interactions and unpredictable physical work. Examples of unpredictable physical work provided by the authors included construction, forestry, and raising animals. Highly susceptible tasks include data processing and predictable physical work. Examples of predictable physical work provided by the authors included welding and soldering on an assembly line, food preparation, and packaging.

It is important to note that a portion of most industries have data processing and predictable physical work activities that are susceptible to automation. Chui et al. (2016) estimated that approximately 20 percent of the time spent in U.S. workplaces involved performing physical activities or operating machinery in a predictable environment. The authors listed the service sector, manufacturing, and the retail sector as the most susceptible to automation. Activities and sectors classified in the middle range for automation included financial services and insurance, construction, and agriculture. As the authors noted, unpredictable physical work conducted in unpredictable environments, which is prevalent in agriculture and construction, make it more challenging, but not impossible, to automate tasks.

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The most difficult activities to automate are those that involve managing and supervising people, and activities that apply expertise to decision-making, planning, and creative work. Computers do a good job with well-defined tasks. However, as noted by both Chui et al. (2016) and Willcocks (2020), it is difficult to codify and improve machine learning techniques to mimic human skills and capabilities such as leadership, creativity, intuition, judgement, tacit knowing, social interaction, peer judgement, motivation, and many other tasks. 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.

EXAMPLES FROM PRODUCTION AGRICULTURE

Rather than provide a comprehensive list of automation technologies that are either being developed or that are already being used, we will briefly describe some noteworthy examples. 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 the speed of 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. Erickson and Lowenberg-DeBoer (2020) indicate that the adoption rate by retailers of drones reached 42% in 2020. Moreover, 46% of the retailers indicated that they currently offer drone imagery. This percentage is expected to increase 19% in the next three years. Drones are used for crop or 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 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, the use of cover crops, or rotational grazing.

The Hands Free Hectare project associated with Harper Adams University in the UK 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 drones are used to take soil and crop samples, and to monitor the growing crop. 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, thus reducing, but not entirely eliminating, economies of size in crop farming.

3-D printing could also contribute significantly to production agriculture. 3-D 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 will allow parts to be produced on site and justin-time, which could substantially reduce machine downtime. During peak work-loads (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 to improve 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.

CONCLUDING COMMENTS

This article discussed trends in automation and robotics in the general economy, and provided examples of using these technologies in production agriculture. Possible benefits of the adoption of automation and robotics will include reductions in costs, improvements in productivity, increases in the production of value-added products, reduced downtime and improved capacity utilization, and reductions in operating risk. Due to synergies associated with the adoption of multiple technologies, the economic evaluation of automation and robotics will require a whole farm system approach rather than employing a partial budgeting approach, which just examines the adoption of one specific technology at a time. Many of the technologies that are currently being developed for other industries can or will be readily adopted in production agriculture. As technology continues to develop, robotics and machine learning will at least partially replace physical activities. However, it is important to note that additional expertise and skills will be needed to implement these new technologies. An upcoming article will describe the gap in skills related to the further adoption of automation and robotics, as well as other precision agriculture technologies, in production agriculture.

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What Will Be the Capabilities and Skills Needed to Manage the Farm of the Future?

By Michael Langemeier and Michael Boehlje

A recent article discussed a number of automation and precision agriculture technologies that will be increasingly used in production agriculture. The adoption and use of these technologies will require additional expertise and skills of managers and the workforce on the farm in the future. This article explores the capabilities and skills that may be needed to manage automation and precision agriculture technologies, and provides a list of options for farms to build the workforce of the future.

STAFFING AND MANAGING THE WORKFORCE

Even though the quantity of labor used in production agriculture has been declining for decades, improving labor efficiency and finding the "right people" for the "right jobs" remains imperative to the success of farms and ranches. In general, labor efficiency can be improved by investing in more capital per worker and/or the adoption of less labor-intensive technologies. As a farm increases capital per worker, particularly in today's environment where many of the new technologies utilize automation, it is important to assess whether the farm's employees have the prerequisite capabilities and skills to fully take advantage of new technologies. As noted by Langemeier and Boehlje (2017), technology is a key driver influencing both financial performance and consolidation in production agriculture.

Precision farming will require a different (or at least enhanced) "mental model" of the farm manager and farm 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, and 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.

SKILL ASSESSMENT

One of the ways to get a handle on the farm's ability and proficiency with regard to a skill set such as working with new technologies is to perform a skill assessment, which simply stated is an evaluation of each individual's ability to perform a specific skill or set of skills. A skill assessment measures what employees can do, and does not distinguish whether those skills were obtained through education or experience. Skill assessments are often used when recruiting, for career

development, and when rapidly adopting new technologies which require new skills, reskilling, or upskilling.

A couple of previous articles discussed production skills and management practice skills. Langemeier (2018) noted the importance of using a suite of technologies that provides the most efficient use of inputs; employing consultants to assist with difficult or complex production problems; and identifying, monitoring, and benchmarking key production efficiency measures. Langemeier (2019) discussed the importance of developing a strategic plan that identifies "strategic issues". One of the components of a strategic plan is a regular assessment of technology needs for the business and a financial plan that examines how the business is going to pay for new technologies.

SKILL GAPS

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 is going to address these gaps. The discussion below will first discuss potential gaps in capabilities and skills and then pose some potential responses to these gaps.

As noted by Manyika et al. (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 basic 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 1. Changes in Capabilities and Skills Needed in Agriculture[/caption]

Table 1 illustrates 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 in the future. Individual farms need to assess whether they have someone on board that 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 time management 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.

Table 1. Changes in Capabilities and Skills Needed in 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).

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 that 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 skills, contracting with outside parties for a portion of the automation 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 skills set is likely to be critical to a farm's competitive advantage. Thus, developing a plan to develop or obtain these skills from an outside party is very important.

CONCLUDING COMMENTS

This article discussed the capabilities and skills that will be needed to manage the farm of the future. As we have noted, production agriculture is changing very rapidly. Adopting precision farming and automation technologies (e.g., robotics, drones, autonomous machines) will be critical to a farm's competitive advantage. Each farm needs to evaluate whether it has the workforce in place to take full advantage of precision agriculture and automation technologies, or develop a plan to access these capabilities and skills from an outside party.

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