Use of On-Farm Digital Technologies
This report presents the results of a project focused on assisting the United Soybean Board (USB) in determining means by which soybean farmers can better make decisions to adopt (or not) digital technology. Three key goals drive the project’s efforts:

1. Support communication and dissemination of findings from the 2018 project.
2. Create and deliver a framework to aid producers in evaluating opportunities to adopt digital technologies.
3. Evaluate the availability of mechanisms that will foster innovation and learning throughout the soybean farming community.

Primary data were collected through in-depth interviews with soybean farmers, representatives of agricultural technology providers, and industry influencers. The participating farmers were experienced in digital technology use. The project was conducted during the USB fiscal year, October 2018, to September 2019. However, because of the delayed planting event of 2019, the farmer interviews were primarily conducted during the summer of 2019.

This 2019 project builds upon a prior 2018 project conducted for USB. That effort identified a strategic gap. From an economic perspective, the systemic benefits and the whole farm effects of employing digital technologies tend not to be quantified even by lead users of the technology.
A primary focus of this study was understanding economic returns from technology utilization. Conventional wisdom is that technology adoption results in small, positive benefits. Analysis typically includes benchmarking on an application by application basis (e.g., Global Positioning System (GPS) guidance for tillage) within a single year.

**Conventional Wisdom**

Small, positive impacts on net returns and operating profits.

**Reality**

The cumulative benefit of applications working together over time.

<table>
<thead>
<tr>
<th>Year</th>
<th>Technology Stack</th>
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<tbody>
<tr>
<td>1</td>
<td>GPS guidance for tillage</td>
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<tr>
<td>2</td>
<td>GPS guidance for tillage, Variable Rate Technology (VRT), Automatic section control</td>
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<tr>
<td>3</td>
<td>GPS guidance for tillage, Variable Rate Technology (VRT), Automatic section control, Sensor to optimize seed placement and rate</td>
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| 4 or beyond | |}

**From the Literature**

2% impact on net returns.

$10 per acre benefit of precision agriculture is commonly cited.

Soil and yield maps, automated guidance systems, and variable-rate input applications have small, positive, impacts on net returns and operating profits.

**Farmer Estimated**

On average, farmer perceptions of net benefits (contribution to profits) were almost $90 per acre.

The associated benefit-cost ratio was 9.7 to 1.0.

Economies of scale are evident, but even small operations (500 acres) gain substantial benefits.
Novel applications of digital technology in the soybean sector continue at a seemingly accelerating pace. The confluence of basic technological capabilities is likely to continue that trend. However, the evaluation processes typically employed in the sector tend to emphasize direct impacts, with insufficient consideration of systemic and evolutionary effects.

During the course of the project, this observation and the study’s driving questions led to the identification of five key findings. The graphic below illustrates the further assessment that led to the formulation of four potential opportunities for USB leadership and action.
Catalytic Opportunities for USB Leadership

The following opportunities would enable USB to assist in advancing strategies that lead to improved profitability, sustainability, and consumer responsiveness for soybean farmers. As defined by the project scope, the findings of this study focused on productivity and economic performance.

However, it is important to realize that current and future technology advances will have critically important implications for the sustainability and social dimensions of soybean farming and sector performance.
Introduction

Digital agriculture has been developing at a rapid pace, as evidenced by the widespread adoption of precision agriculture over the past two decades. New companies, offering a variety of data services every year give rise to opportunities and challenges for farm decision-makers. Currently, the pressure to adopt digital technology on the farm emanating from end-use consumers also is mounting. One motivation for that pressure is the desire for more sustainable cropping systems. Documentation of best management practices and improved traceability from farm to fork contribute to these pressures.

USB, as part of its FY17–FY21 Strategic Plan, has committed to providing unbiased information that will allow farmers to make informed decisions regarding the adoption of digital technology services, including Big Data opportunities, to improve profitability. The analysis conducted within this project seeks to advance USB’s long-range strategic priorities by providing U.S. soybean farmers with information regarding the effective implementation of digital agriculture technologies and resulting economic benefits.

The advent and adoption of digital technologies offer profound potentials to enhance the effectiveness and profitability of soybean farming. Numerous agriculture technology companies have emerged over the past decade, offering products and data services purporting to achieve these goals. Many of those providers collect and utilize large amounts of environmental, production, and management data from farmer fields and analyze that data to provide a variety of recommendations or services. Determining the appropriate returns from information and information systems is particularly difficult in farming because of the many decisions made over the planting, growing, and harvest season. This is further compounded by the number of inputs and management practices that are employed. Finally, in addition to management and information-driven factors, weather and economic uncertainties materially affect outcomes.

Increasingly, farmers are being given the opportunity to respond to technology offerings that move beyond the application of a single technology (i.e., using yield monitors). Service providers offer the ability to combine multiple sources of information from an individual farmer’s operation with data from numerous farming operations with the goal of providing guidance that will better inform the individual decision-maker. However, methods to systematically assess the economic and non-economic benefits of employing that guidance are underdeveloped.

This report describes the project’s conduct and findings as well as identifying opportunities through which USB could significantly contribute to the process of soybean farmer decision making. The report’s content is organized into the following six sections:

1. Project purpose
2. Overview of the project activities
3. Strategic Perspectives
4. Key findings
5. Opportunities for USB leadership and action
6. Appendix. This section provides considerable detail regarding both the conduct of the project and the responses of the study participants, which form the basis for the project findings.
Project Purpose

The advent and application of digital technologies are driving transformative forces and results across the economy and throughout society. Agriculture is facing similar opportunities and challenges, although at a somewhat slower rate. This is partly because the evaluation and adoption of digital technologies are challenging for individual farmers and, therefore, implementation is proceeding in somewhat of a piecemeal fashion. This project’s purpose is to assist USB in determining means by which soybean farmers can better make decisions to adopt (or not) digital technology offerings both as existing technologies mature in the marketplace and as innovative applications continue to emerge. The following three topics framed the project’s efforts:

- Support communication and dissemination of findings from the 2018 project.
- Create and deliver a framework to aid producers in evaluating opportunities to adopt digital technologies.
- Assess the availability of mechanisms which will foster innovation and learning throughout the soybean farming community.

Overview of the Project Activities

The primary data collection vehicles for the study were in-depth interviews with soybean farmers and industry experts. Informed by a review of both academic and industry publications, these direct interactions assisted in identifying gaps as well as clarifying opportunities for further progress.

The selected farmers were experienced in digital technology use. These producers could be characterized as belonging to the early majority of digital technology users. Interviews were conducted with 10 farmer participants from throughout soybean production regions (Appendix Page 17). The farmers interviewed tended to be mature, experienced decision-makers, although a younger cohort of producers were intentionally included. Overall, the study participants managed operations that ranged from 500 to over 13,000 acres in size.
Strategic Perspectives

The overarching purpose of this project (and its 2018 predecessor) is to assist USB in determining how to effectively support U.S. soybean farmers adapt to and exploit opportunities arising from the rapid growth in applications of digital technology. For innovations that directly enhance production, farmers have a history of readily adopting technological improvements. Indeed, the classic study of the technological innovation process was based upon the rapid adoption of hybrid corn in the Midwest United States. However, Information Technologies (IT) have characteristics in terms of their application, costs, and benefits, which differ from those of seed or equipment.

This brief discussion provides strategic perspectives that contrast digital technology adoption processes in soybean farming with predominant approaches elsewhere in the economy. This framework (along with the other findings of the report) can assist USB’s future efforts to support soybean farmers to navigate the challenges and opportunities that future technological advances will offer to society and to agriculture.

Insights from Other Sectors

The advance of digital technology over the last 40 years has impacted all sectors of the economy. However, those effects did not occur at the same pace or with the same impact. Agriculture has seen profound change, but still less than that experienced in the music or entertainment sectors, for example.

The issues and questions of managers throughout the economy have evolved markedly over that time period:

- The 1990s were defined by the term, the Knowledge Economy, to describe the revelation that a firm’s operating data could be employed in near real-time to advance decision making in the firm. However, realizing that goal required making what then seemed to be large investments for information technology capabilities. Senior managers scrutinized every IT expenditure to determine, “Exactly how much will this cost?” and “Will the investment pay for itself?”
- Moving into the 2000s, the growth and exploitation of communication capabilities led to the establishment of the Internet Economy. The ability to communicate at low cost, both internally and with external partners throughout the supply chain, offered unparalleled efficiency and effectiveness. However, massive investment for Information and Communication Technologies (ICT) was required. Senior managers demanded to know, “Will this investment exceed our hurdle rate for an ICT investment?” and “If so, how will it enhance our rate of return from the use of ICT?”

Today, managers are struggling to adapt to the current and future Digital Economy. Again, substantial investment is needed, but, in some cases, efforts to change “how the business operates” also may be needed. The questions of senior managers still include effects on costs and direct returns. However, the scope of concern has expanded. Now, the concerns include, “Will this capability increase our chances to survive?” and “Will this enable us to thrive?”

The Path in Agriculture

Interestingly, the adoption of digital technologies within soybean farming has followed a somewhat analogous path. The 1990s saw the emergence of what we now know as Precision Agriculture. After that came the advent of internet and communication capabilities, which included the massively important geospatial technologies to control and monitor field operations. Data-driven decision-making, from a mix of data sources, is now being added to the potential capability mix.

The questioning process for farmers, however, has not evolved along the same path as that experienced elsewhere:

- The initial focus for precision agriculture was understandably centered on the unparalleled capabilities of the technologies such as variable-rate input application and output measurement.
- Costs of adoption, primarily in comparison to the economic benefits of a specific application, were assessed, although sometimes informally.
- Findings from both this and the 2018 project, however, demonstrate that the practice of examining and understanding the broader contribution of digital technologies to the profitability of the soybean farming business is not routinely accomplished.
As documented elsewhere in this report, estimation of the systemic contributions of digital technologies to the profitability of soybean farming provides a much more complete assessment of their economic impacts. In contrast, considering only the economic effects of individual applications tends to underestimate the contribution to firm-level economic performance markedly. The lack of readily available tools and processes with which to easily conduct systemic analyses has constrained farmers’ ability to estimate the effect on overall performance.

**Tomorrow’s Opportunities and Questions**

Recognizing this gap is essential for soybean farmers as they evaluate current options to employ further (or not) digital technologies in their farming operation. This gap, however, may be even more of a detriment as additional technology applications become available to soybean farmers and to managers throughout the soybean value chain.

Decision-makers throughout the economy currently are striving to employ novel technology applications effectively. However, their strategic concerns are focused on unprecedented opportunities fostered by the continued evolution of technology. For soybean farmers, understanding the comprehensive role of technology in determining profitability will be essential to respond to and exploit future technology-inspired opportunities effectively.

Although at different rates of change, technology use has gone from being a curiosity to being essential in soybean farming as it has in the rest of the economy. Today many analysts are intrigued by the notion that the next “big thing” may not be one thing. Instead, strategic change is expected from the emerging confluence of four powerful technologies, as shown in the graphic. Individually, these technologies already are being employed throughout the economy and in the soybean sector. The increasingly routine availability of the individual technologies fosters innovation that can exploit powerful interactive effects as they are used in novel applications. The anticipated result of these developments is a digital transformation across society (Siebel, 2019). A transformation that is expected to shape how the economy operates and “how business is done” in industries and firms.

Without suggesting a precise prediction, it does seem highly likely that soybean farmers will be presented with new tools and opportunities based upon the interrelated application of two, three, or all of these technologies. As with all such choices, the expected economic impact will be critical in determining whether the tool is a good fit within each farming operation. In addition to the direct effect, it also will be necessary for farmers to be able to assess both the long-run and strategic impacts of implementation for the entire farm business. The methods and results presented in this report can provide guidance for the farm decision maker performing that assessment.

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Key Findings

Based upon the activities conducted within the project and on the extensive, long-term involvement of the project team with the adoption of digital technologies, five general findings of particular importance to USB and soybean farmers have been identified. These will be described in general terms in this section of the report. Detail supporting these findings can be found in the report’s Appendix.

**FINDING 1: Economic Benefits from Technology Adoption Surpass Conventional Wisdom**

Previous research has shown small, positive benefits from the use of precision technology (Appendix Page 6)

- Soil and yield maps, automated guidance systems, and variable-rate input applications have minor, positive, impacts on net returns and operating profits on the order of two percent positive, impacts on net returns and operating profits (Schimmelpfennig, D. 2018. “Crop Production Costs, Profits, and Ecosystem Stewardship with Precision Agriculture.” Journal of Agricultural and Applied Economics. 50(1):81-103.)
- Producer survey responses suggest benefits in the $10 to $20 per acre range. (USB funded “Digital Agriculture Tools to Support Soybean Production Final Report,” Fulton et al., 2017.)

Our exploratory results show considerably larger net benefits to technology adoption, especially when considering the systemic benefits at the whole farm level. (Appendix Page 27)

- The average contribution to per acre profit was almost $90 per acre, with a benefit-cost ratio of 9.7 to 1.0.
- While economies of scale seem to exist, substantial economic benefits also were identified for smaller operations (500 acres).
- These findings were documented even though a conservative approach consistently was employed and quantification of less tangible benefits often not included.

**FINDING 2: Evaluating Operational Performance Using A Comprehensive Framework is A Novel Approach and Leads to Revelations of Systemic Whole Farm Benefits**

- At the time a new technology application is being considered, the potential economic benefit from the associated individual practice often is considered, although often informally.
- Whole farm systemic benefits that result from the integrated application of precision and digital agriculture tools utilized across the farm tend not to be quantified (a smaller machinery line over the same number of acres, less hired labor, more effective use of managerial time and attention, etc.).
- A capability justified for one task (autosteer to reduce tillage costs) can be instrumental in other applications providing multiplicative benefits.
- While adoption occurs at a point in time, technology application tends to foster learning, expanding the scope of the application over time.
- Although potentially significant, the amount of economic gain and recognition of the technology source of the benefit tends to go unrecognized.

**FINDING 3: Farmers Lack Methods and Tools to Quantify the Comprehensive Benefits**

- Because of the diversity of size and other characteristics of soybean farming, rigorous, detailed benchmarking is challenging and hasn’t been routinely conducted. Therefore, a managerial history of conducting internal farm evaluation, based upon data, has not developed.
- For many production inputs, the economic effect has been inferred from trials conducted by universities, cooperatives, and the private sector. For example, the recommended level of fertilizer was estimated for differing regions of the state.
• The economic effect of digital technologies tends to be uniquely tied to the choices of individual soybean farmers, making it difficult to create general recommendations. Further, digital technology applications tend to be integrated with the use of other inputs. For example, the outcomes associated with variable rate seed applications are integrally affected by the varieties planted.
• Recognizing these impediments, a novel approach was created, which facilitated the farmer in conducting an overall assessment of the effects of digital technology use on their specific farming operation.

**FINDING 4: Technology Is Enabling and Enhancing More On-Farm Experimentation**
• Farmer participants in this study identify the potential for analysis of the results of their farming operations:
  - “Technology enables more on-farm trials with less hassle—trials provide evidence for seed populations, fertilizer, and other inputs; trials can then drive the cost/return decision matrix.”
  - “With analytics, you can do whole field research instead of at the plot level.”
  - “Using geospatial technology, you can walk in a field throughout the growing season and in real-time, assess variety performance based on your location in that field.”
• However, they also recognize that there are key questions regarding the extent of variation and the potential managerial validity of the information that can be obtained at the individual farm level.

**FINDING 5: Organizational Efforts to Facilitate Experimentation and Collection of On-Farm Evidence Is Prevalent—But Application to Individual Farm Decision Making Exists Within A Continuum**
• Examination of offerings that currently exist to aid in the collection and analysis of on-farm operational data reveals that systems are currently in a state of flux with no one “perfect” model.
• Many Land Grant universities have extension services that provide supporting resources with an emphasis on research.
• Commodity organizations and cooperatives are engaged in efforts to facilitate on-farm research (Iowa Soybean Association, Illinois Soybean Association, AGTEGRA Cooperative, Growmark, etc.).
• Technology companies increasingly utilize farmers in beta testing technology to determine or demonstrate the benefits of technology adoption.
• Companies providing decision support technologies desire to provide data-based feedback, information, and guidance to their customers.
• Application to farm-specific decision making is not equal across organizational efforts. The applicability exists in a continuum: from traditional extension (here is a recommendation for the region you farm in—but not for your farm specifically) to farmer designed data/ICT-driven research trials.

**Opportunities for USB Leadership and Action**
This project’s primary objective is to assist USB in determining means by which soybean farmers can better make decisions to adopt (or not) digital technology offerings both as existing technologies mature in the marketplace and as innovative applications emerge. Within the project, three specific activities and areas of interest were explored:
• Support communication and dissemination of findings from the 2018 project. This information will assist farmers and agriculture technology providers in making informed decisions about adoption of digital agriculture technologies.
• Create and deliver a framework to aid producers in evaluating opportunities to adopt digital technologies. Here we are focused on developing a value proposition framework for farmers that provides evidence of the economic benefits of precision and digital technologies on their farms.
• Availability of mechanisms that will foster innovation and learning throughout the soybean farming community. Here we strive to identify the producer and organizational efforts in facilitating the collection of evidence from farm operations. A common umbrella term for this activity is “on-farm research.” Although the report also uses this term, it must be emphasized that the primary emphasis here is improved on-farm decision making.
Based on those parameters, four opportunities have been identified where USB leadership and action could aid farmer decision making with respect to the adoption of digital technologies. (These opportunities also were provided in the introductory section of the report.)

**OPPORTUNITY 1:**
*Communicate Economic Findings*

An important finding of this study is that the economic benefits of using digital technologies in soybean farming tend to be significantly understated. The nature of the adoption process for these technologies and the distinctive characteristics of soybean farming make this underestimation a “natural” result. However, soybean farmers will continue to need to assess technology-based opportunities. USB-based communication efforts can provide valuable information to soybean farmers regarding the nature and magnitude of the systemic benefits identified in this study. Such information will better enable soybean farmers to decide to invest (or not) in specific technology offerings.

**OPPORTUNITY 2:**
*Pursue Methods/Tools to Enable Digital Technology Assessment*

As detailed in this report, benchmarking to quantify the systemic benefits of digital technology use is not common among soybean farmers. Both the nature of soybean farming and digital technology applications contribute to the existence of this gap. This project’s exploratory work created a novel approach to quantify economic benefits but not unduly burden the individual respondent. A facilitated one-on-one process was necessary for this initial development phase. USB-supported research to further develop methods and tools could allow similar estimates to be quantified in a workshop and Internet-delivered formats. These developments could enhance the capabilities of soybean farmers to assess future technology offerings.

**OPPORTUNITY 3:**
*Communicate Untapped Potential*

Throughout the economy, the ability to capture, learn from, and adapt based on real-time information from internal processes has led to unprecedented productivity gains. Digital technologies, like those becoming available in soybean farming, provided the necessary, low-cost capabilities to fuel continued performance improvement. Although an intriguing analogy, soybean farms produce one crop per year, which limits the pace of learning within the individual operation. Considerable potential exists for the development of protocols that could foster learning from operations on the individual farm and from collaborative efforts that rigorously combine observations from numerous farms. While several organizational approaches currently exist, USB-based communication efforts could markedly raise the strategic profile of these capabilities and their potential to enhance future performance in the sector.

**OPPORTUNITY 4:**
*Foster Improved Public/Private Sector Collaboration*

Beginning with the Land Grant/Extension system, U.S. agriculture has benefitted from effective support systems, which fueled the adoption of new technologies and production practices. The increasing application of digital technologies is providing unprecedented means to capture information on soybean operations as they happen and as the crop evolves in the field. This report documents the range of organizational activities to support data-based learning, which is currently being explored both in the public and private sectors. Soybean farmers have an interest in the rapid and effective (from the farmer perspective) development and implementation of these capabilities. With the farmer perspective, USB could foster collaborative interactions among the entities working in this domain to improve and accelerate innovation.
Objectives and Key Goals

Objectives

Assist USB in determining means by which soybean farmers can better make decisions to adopt (or not) digital technology offerings both as existing technologies mature in the marketplace and as innovative applications emerge.

Key Goals

1. **Support communication and dissemination of findings from the 2018 project.**  
   This information will assist farmers and agriculture technology providers in making informed decisions about the adoption of digital agriculture technologies.

2. **Create and deliver a framework to aid producers in evaluating opportunities to adopt digital technologies.**  
   Here we are focused on developing a value proposition framework for farmers that provides evidence of the economic benefits of precision and digital technologies on their farms.

3. **Availability of mechanisms that will foster innovation and learning throughout the soybean farming community.**  
   Here we strive to identify the producer and organizational efforts in facilitating the collection of evidence from farm operations (on-farm research).

Timeline

- Met with USB staff
- Prioritized interests and actions
- Developed work plans for identified priorities
- Supported communication and dissemination of findings from the 2018 project

- Conducted literature review
- Developed a catalog of producer and organizational efforts in innovation/experimentation
- Developed a prototype framework to evaluate benefits of technology adoption

- A finalized prototype tool for evaluating economic benefits
- Began farmer interviews

- Completed farmer interviews
- Completed a report of findings
- Prepared recommendations of high priority USB actions
KPIs

Communication and outreach efforts demonstrate USB interest and engagement to assist soybean farmers evaluate and effectively implement digital technologies in their farming operations.

The pilot peer group initiative provides valuable information and insights to guide USB leadership in assessing the strategic benefits of peer groups as a high-value tool for soybean farmers.

A majority of those farmers defined as being in the “moveable middle” will adopt digital technologies as a result of these efforts by 2021.

Milestones

1 Podcast
3 Article Summaries

Comprehensive Interviews with:

10 Producers

Majority of “moveable middle” farmers employ technologies.
Industry Best Practices for Information System Adoption
Literature Review

Adoption and implementation of precision and digital technologies to support management decision making is increasing, but at a slower pace than expected. Furthermore, the costs and benefits of adoption are not well understood. A targeted literature review was conducted to gain the maximum level of insights available. The following includes a summary of the literature review, which summarizes key findings on trends in adoption and the value of adopting precision agriculture technology.

The following pages provide:

- A list of study results illustrating the conventional, perceived value of precision agriculture and digital technologies (Page 6).
- Descriptive findings from the Purdue/CropLife Precision Agriculture Dealer Survey (Page 7-9).
- Descriptive findings of technology use among a progressive group of Brazilian farmers (Page 10).
## Literature Review on Technology Adoption and Economic Benefits

<table>
<thead>
<tr>
<th>Technology Adoption and Economic Benefits</th>
<th>Source</th>
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<tbody>
<tr>
<td>Precision agriculture and information technologies (soil and yield maps, automated guidance systems, and variable rate input applications) allow farmers to optimize their production practices.</td>
<td>Schimmelpfennig, D., 2016, October. “Farm Profits and the Adoption of Precision Agriculture.” USDA-ERS, Economic Research Report, Number 217.</td>
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<tr>
<td>Soil and yield maps, automated guidance systems, and variable-rate input applications have small, positive impacts on net returns and operating profits. Precision agriculture technologies can also promote stewardship or best management practices.</td>
<td>Schimmelpfennig, D., 2018. “Crop Production Costs, Profits, and Ecosystem Stewardship with Precision Agriculture.” Journal of Agricultural and Applied Economics. 50(1):81-103.</td>
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<td>Retail manager survey respondents indicate value gains from precision practices through decreases in input use (10-30% input reduction) and yield gains (10-30% yield increase). Respondents also noted that farmers lack of understanding of benefits is a major constraint to technology adoption.</td>
<td>Schrimpf, Paul. 2018. “Taking Measure of the Precision Agriculture Program: 6 Key Observations.” Internet site: <a href="https://www.precisionag.com/market-watch/taking-measure-of-the-precision-agriculture-program-6-key-observations/">https://www.precisionag.com/market-watch/taking-measure-of-the-precision-agriculture-program-6-key-observations/</a>.</td>
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<td>Eighty-eight percent of surveyed farmers agreed that precision farming technologies and services are important contributors to their farm’s current financial profitability. Eighty percent agreed that using precision farming technologies made them a better farm manager. The most compelling reasons for adopting precision technology were cost savings and yield improvements.</td>
<td>Thompson, N.M., C. Bir, D.A. Widmar, and J.R. Mintert. 2019. “Farmer Perceptions of Precision Agriculture Technology Benefits.” Journal of Agricultural and Applied Economics 51:142–163.</td>
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<tr>
<td>Underlying benefits from precision agriculture technologies are heterogeneous, and to understand a farmer’s decision to adopt or not, you must first understand their perceptions of the benefits the technology provides.</td>
<td>Thompson, N.M., C. Bir, D.A. Widmar, and J.R. Mintert. 2019. “Farmer Perceptions of Precision Agriculture Technology Benefits.” Journal of Agricultural and Applied Economics 51:142–163.</td>
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Purdue/CropLife Precision Agriculture Dealer Survey

Farmer use of precision technologies, estimated by retailers

The graphs reflect changes over time in the percent of the market area (percent of acres in the retailer’s market area) for various precision ag technologies used by farmers. The graph on the left summarizes the Purdue Crop Life survey results from 2017, the graph on the right is the 2019 updated survey results.

Notable changes over the two year survey period are the increase in grid or zone soil mapping (up to 91% by 2022) and the increase in the use of satellite/aerial imagery (up to 80% by 2022). The use of guidance/autosteer is not shown in the 2019 survey results.

Source: 2017 and 2019 Precision Agriculture Dealership Surveys, Departments of Agricultural Economics and Agronomy, Purdue University.
Purdue/CropLife Precision Agriculture Dealer Survey

Farmer use of variable rate precision technologies (VRT), estimated by retailers

The graphs reflect changes over time in the percent of the market area (percent of acres in the retailers) for various precision agriculture technologies used by farmers.

All practices show steady growth, except for VRT pesticide applications, which fell in 2017.

Over the two year survey period, variable rate technology usage dramatically increased in all categories. Notable changes include the increase in VRT fertilizer application (up to 91% by 2022).

Source: 2017 and 2019 Precision Agriculture Dealership Surveys, Departments of Agricultural Economics and Agronomy, Purdue University.
As reported by dealers, over the two year survey period, decision making is increasingly being influenced using pooled customer data. Among the categories listed in the survey, fertilizer, lime, and seed hybrid decisions are the most likely to be influenced by pooled customer data.

Source: 2017 and 2019 Precision Agriculture Dealership Surveys, Departments of Agricultural Economics and Agronomy, Purdue University.
Digital Technology Adoption in Competing Countries

Use of Precision Agriculture Technologies in Brazil

These charts show feedback from 19 large commercial agriculture producers in Brazil. The results indicated a reasonable level of digital technology being applied by the group. Big data analytics (pooled data) was reasonably spread across the group.
Benefits Framework: Prototype Tool/Questionnaire
In prior work with experienced users of precision agriculture, an interesting and important strategic gap was identified. When asked about economic returns arising from the use of precision ag technologies, the following uniform two-part response was received:

1. “Although I feel that I’m effectively employing these technologies, I really don’t know what the economic return is.”

2. “You know, that’s a really interesting question, and I wish I knew the answer!”

Further discussion revealed that although farmers carefully consider the returns when adopting a particular technology or practice, once adopted; they don't attempt to quantify resulting benefits. While understandable, a result is that the benefits and costs of their entire set of precision agriculture technologies are not evaluated. The lack of implementable methods and tools is an important reason for this information gap.

To fill this gap, a framework as a component of this analysis was developed to help farmers quantify the economic benefits of adopting technologies on their farms. Standard survey techniques have been used in previous studies to gauge producer’s perceptions about the benefits and costs of precision technology adoption.

The approach developed here is novel in that a comprehensive operational review was conducted with producers, capturing costs and benefits after careful thought and reflection by participants. A prototype tool was developed to collect cost and benefit information and then estimate the economic returns from a farmers use of precision agriculture and digital technologies on their own farming operations.
Prototype Tool/Questionnaire

The framework created in this project for evaluating a producer’s perceptions of the costs and benefits of technology adoption is a novel approach compared to what has been done previously. The process involved the following:

- Understanding the producer’s current precision technology applications
- Discussing with producers their operations and technologies utilized
- Capturing costs and benefits at the practice level (estimates based on user experience and knowledge). Costs and benefits were viewed as an incremental dollar per acre estimates (those incurred or achieved with the use of precision agriculture technology compared to those incurred or achieved without the use of precision agriculture technology.)

After framework development, a complementary tool was developed and utilized to guide the producer through the individual practices they routinely perform. This tool effectively captures information on farmer perceptions of cost and benefits on a per-acre basis. Source costs and benefits by practice within each category were provided as a baseline where appropriate. Data collected from producers included the following:

- Operation characteristics (acres and average yield)
- Costs and benefit estimates per acre by category
  - Legacy Control Systems
  - Mapping
  - Agronomic/Fertility Systems
  - Monitoring Systems
  - Decision Support Technologies

The results that were generated included total and per-acre costs, benefits, and net benefits. Results should be interpreted as the contribution to current operating profit margins. It must be emphasized that even though the contribution amounts noted in this analysis may be large and positive, that doesn’t necessarily mean that overall farm profits are positive.

The following two slides list first the cost categories employed in the tool, followed by an analogous listing of benefit categories.
## Prototype Tool/Questionnaire—Cost Categories

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<tr>
<th><strong>“Legacy” Control Systems</strong></th>
<th><strong>Monitoring Systems</strong></th>
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<tr>
<td>Yield Monitor</td>
<td>UAV or Drone Imagery</td>
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<td>Autosteer</td>
<td>Satellite or Aerial Imagery</td>
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<th><strong>Mapping</strong></th>
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<td>Soil</td>
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<td>Application</td>
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<th><strong>Agronomic/Fertility Systems</strong></th>
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<td>Grid/Zone Soil Mapping</td>
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<td>VRT(^1) Fertilizer Application (Corn)</td>
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<td>Nitrogen</td>
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<td>Granular (Management System)</td>
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<td>Agrible (Supply Chain)</td>
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\(^1\) Variable Rate Technology (VRT)
Prototype Tool/Questionnaire—Benefits Categories

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<thead>
<tr>
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<tr>
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<td>UAV or Drone Imagery</td>
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<td>Satellite or Aerial Imagery</td>
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<td>Chemical</td>
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<td><strong>Agronomic/Fertility Systems</strong></td>
<td><strong>Decision Support Technologies</strong></td>
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<td>VRT¹ Fertilizer Savings (Corn)</td>
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<td>Variable Hybrid Placements</td>
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<td>Crop Sensing Systems</td>
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**Less Tangible Benefits**
- ex. Software time savings (Paper filing to digital)
- ex. Autosteer (Less fatigue/stress)
- ex. Labor efficiencies
- ex. 10% cost savings using platforms for price comparisons
- ex. Experiment with practices (On-farm research)
- ex. Facilitation of contract growing/traceability

¹ Variable Rate Technology (VRT)
Exploratory Analysis
Interviews were conducted with a pilot group of soybean farmers. Because of the unprecedented delays in the 2019 planting season, the timeline for interviews was extended into late summer. Ten farmers from three states and farming from 500 to 13,000 acres participated in the pilot interviews. The selected farmers were experienced in digital technology use and can be characterized as belonging to the early majority of digital technology users. The interviews lasted from 45 to 90 minutes. These were in-depth conversations that focused on identifying the practices used on each farm. Then individual practices were evaluated to capture costs and benefits on a per acres basis. Upon completion of the interview, an initial estimate of net benefits (or contribution to profit) was shared with the participant.

It is important to emphasize that the values incorporated in this analysis reflect the perceptions of the farmer participants. These perceptions are consistent with the decision processes that these farmers have and will employ in considering technology adoption and implementation.

The following seven pages summarize results by cost and benefit categories. Then the next four pages present overall results generated from the farmer participants in this exploratory analysis.
Prototype Tool/Questionnaire—Cost Categories

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The following summarizes the cost results by category.
“Legacy” Control Systems and Mapping Costs

“Legacy” control systems include applications such as yield monitors and autosteer. All participants noted that they consider yield monitors as an integral component of equipment costs, similar in nature to the cost of tires on the machine. Comments include, “you need to have tires on the machine – do you pay extra for those?” Therefore farmer respondents chose to not assign annual costs for the utilization of yield monitors.

Two costs were commonly attributed to utilizing autosteer capabilities: the system or receiver cost (with an average useful life of 3 to 4 years) and the annual signal cost. System or receiver costs ranged from $0.46 per acre to $16.00 per acre, with an average of $2.82 per acre. The maximum of $16.00 per acre is directly attributable to the size of the farm. Signal costs were between $0.29 per acre and $3.10 per acre, with an average of $0.86 per acre.

Mapping has become a product of other service offerings, either through technology utilized for another capability or through decision support technologies. While every participant utilizes mapping as a tool, none attributed any annual costs to these practices. However, soil mapping in this context does not include grid or zone soil mapping, which is necessary for variable rate applications. Grid or zone soil mapping costs are included in the agronomic/fertility cost category.
Annual costs associated with Agronomic or Fertility costs included the following common practices: grid or zone soil mapping, application of variable rate technology (both on inputs and seeding), and automatic shutoffs.

Other technology utilized, but less often, included variable down pressure, variable hybrid placements, and crop sensing systems such as Greenseeker and Smart Firmers.

The costs for variable-rate practices include both the application costs and the cost of prescriptions. These vary by the participant, due to the fact that some wrote their own prescriptions and did not attribute a cost for their time.

Per acre costs for variable down pressure, variable hybrid placements, Greenseeker and Smart Firmers were based on per row or per system investment costs, amortized over the participants perception of economic life.
Monitoring Systems and Decision Support Technology Costs

Monitoring systems include the use of UAVs (Drones), satellite, or other aerial imagery. While a few participants purchased drones (with an average cost of $950), most participants utilize resources provided with other decision support technologies for satellite or aerial imagery information.

Costs for the use of decision support technologies depend on the specific application. Most participants utilize free or basic level offerings. Costs included annual subscription costs and also per acre cost, if the technology was used to access recommendations on variable rate prescriptions.

Gross and Net Benefits

The categorization of benefits follows closely the delineations for costs – which were just described. These categories are presented and results discussed in the following three slides.

Then perceived yield increases and associated economic benefits are presented.
## Prototype Tool/Questionnaire—Benefit Categories

### “Legacy” Control Systems
- Autosteer
- Overlap Input Savings
  - Seed
  - Fertilizer
- Chemical
- Fuel

### Agronomic/Fertility Systems
- VRT Fertilizer Savings (Corn)
  - Nitrogen
  - Phosphorus
  - Potassium
  - Lime
- VRT Fertilizer Savings (Soybeans)
  - Nitrogen
  - Phosphorus
  - Potassium
  - Lime
- VRT Seeding (Corn)
- VRT Seeding (Soybeans)
- Automatic shutoffs (Swath control)
- Variable down pressure on planter
- Variable Hybrid Placements
- Crop Sensing Systems

### Monitoring Systems
- UAV or Drone Imagery
- Satellite or Aerial Imagery

### Decision Support Technologies
- Encirca (Analytics)
- FBN (Analytics)
- Fieldview (Climate – Management System)
- Farmlogs (Management System)
- Granular (Management System)
- Agrible (Supply Chain)

### Less Tangible Benefits
- ex. Software time savings (Paper filing to digital)
- ex. Autosteer (Less fatigue/stress)
- ex. Labor efficiencies
- ex. 10% cost savings using platforms for price comparisons
- ex. Experiment with practices (On-farm research)
- ex. Facilitation of contract growing/traceability

The following summarizes the benefit results by category.
Overlap savings from the use of guidance systems have consistently been touted as the first real payback seen from precision agriculture adoption. Input overlap savings from the use of guidance systems ranged from four to ten percent savings on inputs.

- Seed savings averaged $9.82 per acre and ranged from $2.80 to $16.00 per acre.
- Fertilizer savings averaged $8.93 per acre and ranged from $3.40 to $18.50 per acre.
- Chemical savings averaged $9.21 per acre and ranged from $2.50 to $27.30 per acre.
- Depending on the amount of tillage performed, fuel cost savings ranged from $0.50 per acre to $1.00 per acre.

It should be noted that there is a sustainability benefit from not over-applying inputs. This sustainability benefit was not quantified or captured in these estimates.
Fertilizer savings occur when precision technology utilization reduces fertilizer applications.

Use of variable rate technology (VRT) for nitrogen applications depended on the variability of soils. More than half of participants do not use variable rate nitrogen as they indicated that they didn’t think it had a payback. For those that do variable rate nitrogen, they did not believe they capture savings from less nitrogen application. They are likely applying the same amount of nitrogen, but precision technology allows them to target applications to where it most needs to be applied.

Use of variable rate technology for phosphorus resulted in average savings of $3.81 per acre for corn (with a range of $1.13 to $6.50 per acre) and $6.50 per acre for soybeans. Note that only one participant provided estimates for variable rate phosphorus for soybeans, so no minimum and maximum ranges are provided in the chart.

Use of variable rate technology for lime application resulted in savings on average of $3.75 per acre for corn and soybeans (with a range of $2.50 to $5.00 per acre).
Yield Increase, Bushels per Acre

In contrast to overlap and input savings, the farmer respondents found it difficult to assign per acre benefits to individual technologies. Instead, a yield benefit was attributed to the entire suite of precision agriculture tools used on the farm. As many technologies are complementary and enable additional capabilities, a systemic benefit was captured through the estimated yield increase.

Perceptions of the yield impact from adopting precision technologies ranged from five to ten percent improvement.

For corn, the average per acre benefit was 13.98 bushels per acre, with a range of 7.75 to 23.50 bushels per acre.

Average soybean yield increases were 3.84 bushels, with a range from 2.25 to 8.00 bushels per acre.
**Costs and Gross Benefits, Dollars per Acre by Acres Farmed**

Results are summarized by three size (in acres) categories: less than 1,000 acres, 1,000 to 5,000 acres, and greater than 5,000 acres.

Across the size categories, average cost per acre was $10.76, and ranged from $2.99 to $24.10 per acre. On average, the lowest costs were achieved by the middle size category (1,000 to 5,000 acre).

Across the size categories, the average gross benefit per acre was $100.31, and ranged from $28.94 to $167.83 per acre.
Across the size categories, the average net benefit (or contribution to profit) was $89.55 and ranged from $25.95 to $156.33 per acre. The greatest benefits were achieved within the largest size category (greater than 5,000 acres), indicating that there are economies of size to technology application.

In corresponding fashion, the average benefit-cost ratio across the size categories was 9.7 to 1.0.

It should be noted that these results are intentionally conservative. Elements relating to the value of information from technology use are difficult to quantify and therefore were not included. Further, when respondents expressed uncertainty relative to a parameter, no value or the lower edge of a range were employed.
A sensitivity analysis was conducted to identify the yield increase that would be needed to cover the incremental costs of technology use.

For corn, an average yield increase of 1.7 bushels per acre was needed to cover costs (compared to the average per acre benefit of 13.98 bushels per acre noted earlier on page 25).

For soybeans, an average yield increase of 0.5 bushels per acre was needed to cover costs (compared to the average per acre benefit of 3.84 bushels per acre noted earlier on page 25).
What We Learned—Perspectives

- **Precision Agriculture** is the way we farm today.
- It’s not just one thing—**the systemic whole-farm benefits of technology** are key.
- One or two more people would be needed in labor if we didn’t have the technology.
- Technology provides better records, better insights, and less mistakes.
- The technology is here, you either use it or don’t use it.
Producer Insights

The following insights were captured during the interviews with producers:

1. **Precision Agriculture is the way we farm today**

2. **Economic benefits of technology adoption are achieved through cost savings and efficiency gains**

3. **Technology enables on-farm research**

4. **Technology enables documentation**

5. **Technology improves management**
Key Insights

1. **Precision agriculture is the way we farm today**
   - Precision Agriculture has made farming easier today.
   - There are a lot of ways farmers can be successful, and precision agriculture is just one of them.
   - Some people just don’t want to use precision agriculture and find it to be a big hassle.
   - Technology is here; you either use it or don’t use it.
   - If you buy new equipment today, it will have many precision components embedded already; the question is – do you add more?
   - If you are using the monitor only in the combine, you aren’t covering it’s potential. You have GPS and the monitoring equipment. If you use them for planting, spraying, and tillage, you can create layers of data and record what you are doing.
   - Systemic whole-farm benefits are the key.

2. **Economic benefits of technology adoption are achieved through cost savings and efficiency gains**
   - Autosteer leads to savings on machinery. This occurs from covering more acres using the same equipment or covering the same acres with less equipment.
   - Without autosteer, you may need more iron – I could get by with one size less in equipment, and that means less fuel, less seed, and less fertilizer.
   - Autosteer adds one extra hour of fieldwork in the day, enables “rolling office time,” and allows you to harvest at night.
   - Autosteer provides consistent performance.
   - Using less experienced labor in the tractor because the tractor is “driving itself.”
   - One or two more people are needed in labor if we didn't have the technology. You can have a less experienced person in the field setting up track lines. Reduced compaction and fuel savings are key.
   - Controlling the grain cart from the combine allows more efficient operations.
   - Farmer to farmer networks are leveling the playing field in terms of input costs and seed selection.
   - Technology provides better records, better insights, and less mistakes.
Key Insights

3 Technology enables on-farm research
- Technology enables more on-farm trials with less hassle. These trials provide evidence for seed populations, fertilizer, and other inputs that ultimately drive the cost/return decision matrix.
- With analytics, you can do more whole field research instead of only at the plot level.
- Technology can be used to facilitate on-farm research – for example, testing varieties in real-time while planting.

4 Technology enables documentation
- Accurate record keeping.
- Reporting for landlords (current and potential).
- Spraying documentation provides savings in insurance and for use as evidence in potential lawsuits.
- Documentation for crop insurance claims.
- Providing a complete set of documents for the lender that proves yields, production practices, and management ability. This can result in a lower interest rate on operating loans.

5 Technology improves management
- Communication is so much easier when you don't have to keep your eye on the marker.
- Understanding rainfall events, knowing when to or when not to go to the field.
- Knowing what is going on with different hybrids within the field. Poor performance can justify “culling” the bad hybrids.
- Quantifying the water damage by drawing polygons of what is happening in the field in real-time.
- More and more information is available. If you can get 2 to 3 years of good information, then you can decide to “cull” fields (from land that is cash rented).
On-Farm Research: Evidence from On-Farm Operations
On-Farm Research Continuum

Organizational efforts in facilitating experimentation and collection of on-farm evidence is prevalent, but the application to individual farm decision making exists within a continuum. This continuum ranges from traditional extension (e.g., less direct application to farm-specific decision making) to farmer designed data/ICT-driven research trials (real-time trials).
Traditional Extension (University Research Focus)

Traditional Extension includes research that is more focused on researcher questions and less on individual farm operation specificity.

- Conducting research on university-owned farm plots.
- Some trials conducted on farmer-participant plot.
- Trials designed by university researchers.
- Trial specifications may be more or less relevant to actual farmer operations.
- Most land grant universities have traditional extension programs.

University Research

County Educators

Farmers/Local Interest Groups

“Boots on the ground” professionals translating research to target audiences.

Strength

Weakness

Top-down research directives, typically regionally-based recommendations – applicability to specific farm problems or conditions makes information less actionable to farmer decision making; financial pressures have reduced local presence. Mostly use of university plots for trials, some local engagement through the use of farmer plots.
Digital Extension (More Farmer Input/Engagement)

Digital Extension improves farmer input and engagement through the use of digital platforms that enable individual farmer input and analysis or provide protocols for farmer directed research trials.

- More geographic dispersion of trial plots.
- Trials are conducted on farmer-participant plots.
- Universities design and provide trial protocols, and farmers implement the study.
- Data is collected and analyzed by the university. Universities provide individual feedback and create an aggregate group or geographical-level study reports.
- Farmers may be able to choose a specific research trial in which to participate.

Examples: Ohio State University eFields On-Farm Trials, University of Nebraska Lincoln On-Farm Research Network

Strength

Provides farmers with direct access to university research and researchers through digital platforms for farmer tailored input and analysis or farmer directed research trials (protocols/guidelines for implementing on-farm trials).

Weakness

Still typically driven by university research questions. More use of farmers and farm plots to implement trials leads to more granularity of data collection, but still less precision in terms of specific on-farm application.
Farmer Focused (Localized Testing and Results)

Farmer focused on-farm research is tied directly to farmer interests and questions, is facilitated by organizations that provide resources for implementation, and enables localized testing for peer to peer comparisons.

- Guided implementation of on-farm trials.
- Research questions developed with farmer groups and tailored to the specific needs of the operation.
- Trial data is further analyzed across multiple locations.
- Producers engage in a peer-to-peer group discussion with local participants to compare local aggregated data.
- Producers within peer groups compare and implement management practices to optimize inputs and improve profits.
- The organization facilitates on-farm research by providing educational workshops to teach techniques and analysis methods.
- Organizations may even provide funding for on-farm research through research grants.

*Examples: Iowa Soybean Association, INFIELD ADVANTAGE, Kansas State University (KARTA)*

**Strength**

Connecting local peer groups around common interests and questions. Organizations provide resources for implementation (protocols, analytics, meetings).

**Weakness**

“Peer” groups need to be dispersed across a few county radius to avoid competition between neighbors.
Data-Driven (Data Analytics)

Data-driven efforts are focused on analytics of data collected on the farm more than traditional on-farm research.

- Providing data management services for farmers.
- Analytics of farmer data in addition to consultations with specialists.
- Assessments of best management practices, performance on crop productivity, soil health, and farm profitability.
- Assistance with enrollment in conservation programs.

Examples: Precision Conservation Management

Strength

Collecting and analyzing data from producers based on current practices. Uses data to assess best management practices.

Weakness

Not focused on traditional research, therefore, protocols may not allow for scientific replication or collecting data for statistical significance.
Farmer Designed (Real-time trials)

Farmer designed research includes real-time trials that utilize site-specific data to address an individual farmer’s research questions.

- Organizing and processing data directly from farmer's equipment.
- Allows farmers to conduct their own field experiments on their farms.
- Uses collected site-specific information to make optimal management decisions.

*Examples: Data-Intensive Farm Management – Pilot program at the University of Illinois*

**Strength**

Driven by farmer specific questions and applicable to individual farmer fields. Real-time trials that use information and communications technology (ICT) to direct recommendations.

**Weakness**

In a pilot stage, so not yet proven to be successful in providing data that leads to farmer decision making.
The following table summarizes a sampling of organizational efforts currently underway to facilitate on-farm research.

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<thead>
<tr>
<th>Organization</th>
<th>Resource</th>
<th>Links</th>
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Opportunities for USB Leadership and Action
Catalytic Opportunities for USB Leadership

The following opportunities would enable USB to assist in advancing strategies that lead to improved profitability, sustainability, and consumer responsiveness for soybean farmers. As defined by the project scope, the findings of this study focused on productivity and economic performance. However, it is important to realize that current and future technology advances will have critically important implications for the sustainability and social dimensions of soybean farming and sector performance.

**Opportunity 1: Communicate Economic Findings**

An important finding of this study is that the economic benefits of using digital technologies in soybean farming tend to be significantly understated. The nature of the adoption process for these technologies and the distinctive characteristics of soybean farming make this underestimation a “natural” result. However, soybean farmers will continue to need to assess technology-based opportunities. USB-based communication efforts can provide valuable information to soybean farmers regarding the nature and magnitude of the systemic benefits identified in this study. Such information will better enable soybean farmers to decide to invest (or not) in specific technology offerings.

**Opportunity 2: Pursue Methods/Tools to Enable Digital Technology Assessment**

As detailed in this report, benchmarking to quantify the systemic benefits of digital technology use is not common among soybean farmers. Both the nature of soybean farming and of digital technology application contribute to the existence of this gap. This project’s exploratory work created a novel approach to quantify economic benefits but not unduly burden the individual respondent. A facilitated one-on-one process was necessary in this initial development phase. USB-supported research to further develop methods and tools could allow similar estimates to be quantified in workshop and internet-delivered formats. These developments could enhance the capabilities of soybean farmers to assess future technology offerings.

**Opportunity 3: Communicate Untapped Potential**

Throughout the economy, the ability to capture, learn from, and adapt based on real-time information from internal processes has led to unprecedented productivity gains. Digital technologies, like those becoming available in soybean farming, provided the necessary, low-cost capabilities to fuel continued performance improvement. Although an intriguing analogy, soybean farms produce one crop per year, which limits the pace of learning within the individual operation. Considerable potential exists for the development of protocols that could foster learning from operations on the individual farm and from collaborative efforts that rigorously combine observations from numerous farms. While several organizational approaches currently exist, USB-based communication efforts could markedly raise the strategic profile of these capabilities and their potential to enhance future performance in the sector.

**Opportunity 4: Foster Improved Public/Private Sector Collaboration**

Beginning with the Land Grant/Extension system, U.S. agriculture has benefitted from effective support systems, which fueled the adoption of new technologies and production practices. The increasing application of digital technologies is providing unprecedented means to capture information on soybean operations as they happen and as the crop evolves in the field. This report documents the range of organizational activities to support data-based learning, which currently is being explored both in the public and private sectors. Soybean farmers have an interest in the rapid and effective (from the farmer perspective) development and implementation of these capabilities. With that farmer perspective, USB could foster collaborative interactions among the entities working in this domain to improve and accelerate innovation.