



2021

# *ANNUAL REPORT*



## DIRECTOR'S LETTER

We entered the second year of the pandemic like everyone else, hoping that things would return to normal in 2021. Although the environment we live and work in did not return to pre-pandemic status this past year, conditions did improve and by summer the Center was again able to conduct in-person programs. By fall nearly all Purdue students were back on campus, Center faculty were back to teaching all classes in person and the Purdue campus was vibrant with record enrollment in West Lafayette.

The year began with a dramatic shift as, for the first time, the *Purdue Top Farmer Conference* was held in early January using a virtual format. Over 500 participants registered for the conference which featured presentations by Purdue's Jayson Lusk and Jason Henderson along with Iowa State's Wendong Zhang. Using Zoom to conduct the conference opened up attendance to participants from around the nation as well as several international attendees!

Continuing a shift that got underway in 2020, the Center emphasized online delivery of information in 2021. The Center provided 15 webinars during 2021 along with 38 episodes of the *Purdue Commercial AgCast* podcast. The Center's webinars during 2021 had over 10,000 registrants and *Purdue Commercial AgCast* had nearly 11,000 downloads.

The 2021 Purdue Farm Management Tour held in July was our first in-person program in over a year and Corn Belt producers were anxious to get back together. Over 250 producers and agribusiness personnel attended the Tour and Master Farmer reception held in southwest Indiana. Thanks to the Koester, Kron and Seib families for their willingness to open up their farming operations to visitors and to share their expertise on crop and dairy production, farm management strategies, succession planning and facility designs.

Making producers and agribusiness personnel aware of the information available from the Center is a challenge. The Center's monthly newsletter *Commercial AGNews* has proven to be a good way to provide an update regarding upcoming programming as well as what's new on the Center's website to over 11,000 subscribers. Social media is also an important way to get information in user's hands and during 2021 the

Center provided over 400 social media posts viewed by nearly 2,000 followers on Twitter and Facebook.

The *Purdue University-CME Group Ag Economy Barometer* is the nation's only monthly survey of commercial ag producers and provides insight into producer sentiment while also providing opportunities to learn more about producers' reactions to contemporaneous events. Each month the Center publishes a report summarizing survey results, posts a short YouTube summary video and provides an in-depth podcast interpretation of the current month's barometer survey, all accessible via the Center's website. The barometer is widely reported in both the ag and business press and is the subject of a large number of media interviews each month.

Thank you for your interest in and support of the Purdue Center for Commercial Agriculture. As always, if you have suggestions for future programs or research, or you just want to chat, we'd love to hear from you.

Sincerely,



James Mintert  
Director



## CENTER ACTIVITIES



# WEBINARS & VIDEOS

**Delivering key information to a broad audience on a variety of timely topics**

## WEBINARS

### Monthly Corn & Soybean Outlook Updates

Each month in 2021 the Center hosted a free webinar providing an update on the corn and soybean outlook following release of USDA's monthly Crop Production and World Agricultural Supply and Demand Estimates (WASDE) reports. Purdue ag economists Michael Langemeier, Nathanael Thompson and James Mintert reviewed the USDA reports and provided implications for the current and upcoming crop year during each monthly webinar. Corn and soybean exports, ethanol demand, corn and soybean basis, and farm income projections were regular topics.

December 15 -	YouTube views (first week): 127
	Live viewership: 50
	Registrations: 853
November 10 -	YouTube views (first week): 184
	Live viewership: 88
	Registrations: 860
October 13 -	YouTube views (first week): 168
	Live viewership: 85
	Registrations: 843
September 13 -	YouTube views (first week): 173
	Live viewership: 114
	Registrations: 865
August 13 -	YouTube views (first week): 188
	Live viewership: 99
	Registrations: 812
July 14 -	YouTube views (first week): 170
	Live viewership: 106
	Registrations: 731
June 14 -	YouTube views (first week): 159
	Live viewership: 96
	Registrations: 718
May 14 -	YouTube views (first week): 206
	Live viewership: 64
	Registrations: 654
April 12 -	YouTube views (first week): 123
	Live viewership: 151
	Registrations: 480
March 10 -	YouTube views (first week): 127
	Live viewership: 190
	Registrations: 631
February 10 -	YouTube views (first week): 155
	Live viewership: 253
	Registrations: 782
January 13 -	YouTube views (first week): 283
	Live viewership: 219
	Registrations: 589

# 11.5K

**VIEWS IN 2021**

The Center has delivered 140 webinars and recorded videos on farm and financial management, agricultural outlook and strategic topics, as well as on the Purdue/CME Ag Economy Barometer since 2014. During 2021, 15 webinars were broadcast live, with 2k live participants, and subsequently posted on the Center's YouTube channel, where an additional 9.5k viewed the videos.



## Indiana Farmland Values and Cash Rental Rates: 2021 Update

August 20, 2021

Purdue ag economists Todd Kuethe, James Mintert and Michael Langemeier discussed the 2021 Purdue Farmland Values Survey results and the USDA's Land Values report on August 20. The department of agricultural economics conducts the Purdue Farmland Values and Cash Rents Survey each June. The survey is produced through the cooperation of numerous professionals knowledgeable regarding Indiana's farmland market. The survey results suggest farmland prices across Indiana rose to all-time highs in June 2021. Statewide, 2021 cash rental rates increased across all land quality classes.

YouTube views (first week): 162

Live viewership: 134

Registrations: 377

## Carbon Markets For U.S. Row Crop Producers: Opportunities And Challenges

June 24, 2021

Questions about agriculture's potential role in carbon sequestration are on many ag producers' minds these days. Purdue ag economists Carson Reeling, Nathanael Thompson and James Mintert discussed the opportunities and challenges of the carbon markets in U.S. agriculture for row crop producers on Thursday, June 24.

YouTube views (first week): 376

Live viewership: 249

Registrations: 783

## 2021 Crop Insurance Decisions

March 1, 2021

Purdue ag economists Michael Langemeier and James Mintert provided insight into decision making on crop insurance on March 1. The webinar reviewed corn and soybean crop insurance choices and provided producers with considerations for their 2021 options. Crop insurance is an important aspect of nearly every corn and soybean farm's risk management program. There are some new choices to consider this year, including the Enhanced Coverage Option (ECO). This webinar recording is a great opportunity for producers to review their crop insurance alternatives as the Purdue team walked participants through considerations for their 2021 choices.

YouTube views (first week): 265

Live viewership: 178

Registrations: 661

# INFORMATIONAL VIDEOS

## Factors Impacting Feeding Cost Of Gain

Purdue ag economist Michael Langemeier discusses the key factors impacting feeding cost of gain in commercial feedlots. Though feeding cost of gain is influenced by many factors including type and quality of cattle fed, feeder weight, cattle performance, and feed prices; the vast majority of the variability in feeding cost of gain over time can be explained by feed conversion during the feeding period, and corn and alfalfa prices during the feeding period. The specific impact of each of these three factors is discussed in the video.

YouTube views (since posted on November 22, 2021): 46

## Commodity Classic 2021 Recordings

March 3, 2021

The 2021 Special Edition of Commodity Classic was delivered digitally March 2-5, 2021. Purdue University Center for Commercial Agriculture and the CME Group presented a Learning Center Session on Wednesday, March 3 entitled *Keys to Guiding Your Farm Through an Era of Tight Margins and Increased Risk*. In the session, the expert panel shared the key lessons from 2020 and helped producers plan for the financial and risk management realities of 2021. The discussion featured the latest data from the Purdue/CME Group Ag Economy Barometer, these results had specific focus on what farmers see happening with regard to their current financial situation, expected profitability in 2021, the desirability of making large investments in their farms, plans for expansion and their approach to risk management in these challenging times. Emphasis was placed on the role of technology adoption in improving farm profitability.

*Risk Management Tools for the 2021/22 New-Crop* - YouTube views (since posting): 34

*Growing Your Digital Ag Strategy* - YouTube views (since posting): 59

*Net Return Prospects and Breakevens for Corn & Soybeans* - YouTube views (since posting): 80

*The Economic Recovery's Impact on U.S. Agriculture* - YouTube views (since posting): 62

*Keys to Guiding Your Farm Through An Era of Tight Margins & Increased Risk* - YouTube views (since posting): 79

## CENTER ACTIVITIES

### Purdue/CME Group Ag Economy Barometer Breakdown Videos

The Center for Commercial Agriculture, in partnership with the CME Group, recorded monthly videos breaking down the survey insights from the Ag Economy Barometer. Each video included discussions about producer sentiment toward the agricultural economy and drivers of sentiment.

December 7 - YouTube views (since posting): 111

November 2 - YouTube views (since posting): 121

October 5 - YouTube views (since posting): 101

September 7 - YouTube views (since posting): 107

August 3 - YouTube views (since posting): 121

July 6 - YouTube views (since posting): 221

June 1 - YouTube views (since posting): 166

May 4 - YouTube views (since posting): 83

April 6 - YouTube views (since posting): 134

March 2 - YouTube views (since posting): 98

February 2 - YouTube views (since posting): 113

January 5 - YouTube views (since posting): 111



*The beauty of online content is the Center's faculty can broadcast these webinars live from the Purdue Video & Multimedia Production studio or any remote location to reach our audience. Registered participants can join via livestream or catch the recording on YouTube at their convenience.*

# PODCAST EPISODES

## Convenient with easy access on-the-go

Podcasts make it possible to connect with a broader audience in a more convenient way. The COVID-19 pandemic created a need for improved remote access to information and the Center responded by launching the Purdue Commercial AgCast podcast in late April 2020. Since launching the podcast, the center has delivered 73 episodes with over 17k downloads. Purdue ag economists Brady Brewer and James Mintert serve as the hosts of the podcast, geared towards covering farm management news and advice for top agricultural producers and agribusinesses, which covers a variety of topics from ag outlooks, farm succession-transition planning, and agribusiness/farm research, as well as insights from the Purdue/CME Group Ag Economy Barometer. The podcast episodes can be accessed directly from the Center's website or all major podcast apps including Apple Podcasts, iTunes, Stitcher, Spotify or Podbean.

# 17K

## DOWNLOADS IN 2021

*In 2021, the Center delivered 38 new episodes and listenership increased 260%. Apple Podcast is the favorite platform with over 52% of the downloads, followed by about 16% listening from a web browser via our website.*



## Monthly Corn & Soybean Outlook Update

The monthly outlook update webinar was also released as a podcast each month in 2021. Each episode provided an update on the corn and soybean outlook following release of USDA's monthly Crop Production and World Agricultural Supply and Demand Estimates (WASDE) reports. Purdue ag economists Michael Langemeier, Nathanael Thompson and James Mintert provided implications for the current and upcoming crop year, corn and soybean exports, ethanol demand, corn and soybean basis, and farm income projections.

*Episode 73, December 16 - Downloads (in first month): 292*  
*Episode 71, November 11 - Downloads (in first month): 304*  
*Episode 69, October 13 - Downloads (in first month): 313*  
*Episode 67, September 13 - Downloads (in first month): 293*  
*Episode 64, August 16 - Downloads (in first month): 220*  
*Episode 61, July 15 - Downloads (in first month): 241*  
*Episode 57, June 15 - Downloads (in first month): 237*  
*Episode 54, May 14 - Downloads (in first month): 211*  
*Episode 51, April 13 - Downloads (in first month): 245*  
*Episode 46, March 11 - Downloads (in first month): 207*  
*Episode 41, February 11 - Downloads (in first month): 190*  
*Episode 37, January 15 - Downloads (in first month): 196*

## Ag Barometer Insight

Purdue ag economists James Mintert and Michael Langemeier reviewed the *Purdue/CME Group Ag Economy Barometer* results and gave some insight into farmer sentiment each month in a podcast episode following the barometer release.

*Episode 72, December 7 - Downloads (in first month): 280*  
*Episode 70, November 2 - Downloads (in first month): 278*  
*Episode 68, October 5 - Downloads (in first month): 235*  
*Episode 66, September 7 - Downloads (in first month): 209*  
*Episode 63, August 3 - Downloads (in first month): 239*  
*Episode 60, July 6 - Downloads (in first month): 248*  
*Episode 56, June 1 - Downloads (in first month): 232*  
*Episode 53, May 4 - Downloads (in first month): 212*  
*Episode 50, April 6 - Downloads (in first month): 209*  
*Episode 44, March 2 - Downloads (in first month): 134*  
*Episode 40, February 2 - Downloads (in first month): 201*  
*Episode 36, January 5 - Downloads (in first month): 172*

## Episode 65: Indiana Farmland Values & Cash Rental Rates: 2021 Update

*August 20, 2021*

Purdue ag economists Todd Kuethe, James Mintert and Michael Langemeier discussed the 2021 Purdue Farmland Values Survey results and the USDA's Land Values report. The department of agricultural economics conducts the Purdue Farmland Value and Cash Rent Survey each June. The survey is produced

through the cooperation of numerous professionals knowledgeable regarding Indiana's farmland market. The survey results suggest farmland prices across Indiana rose to all-time highs in June 2021. Statewide, 2021 cash rental rates increased across all land quality classes.

*Downloads (in first month): 271*

## Episode 62: Farm Succession: Non-Family Transfer

*July 28, 2021*

Many farms are not large enough or the next generation may not be interested in the farm business. Some farms may look outside their own family for non-related parties to bring into the farming operation. Purdue ag economists Brady Brewer discusses transferring the farm to a non relative with the Purdue Farm Transition team, Dr. Maria Marshall, Director of the Purdue Institute of Family Business and Renee Wiatt, Farm Business Management Specialist, and Dr. Julia Valliant of Indiana University, Research Scientist with the Ostrom Workshop. Finding a successor, determining a transition plan for the operational business and/or the land, and structuring the transfer process are discussed by the team on this episode.

*Downloads (in first month): 231*

## Episode 59: USDA Acreage Report & June 30th Outlook Update

*June 30, 2021*

According to today's (June 30) released numbers by USDA's National Agricultural Statistics Service (NASS), the acreage estimate came in on the low end of expectations. Purdue ag economists James Mintert, Nathanael Thompson, and Michael Langemeier provide a discussion of the implications for corn and soybean markets following USDA's release of the June Acreage report. The Acreage and Grain Stocks reports are available online at [www.nass.usda.gov](http://www.nass.usda.gov).

*Downloads (in first month): 213*

## Episode 58: Carbon Markets For U.S. Row Crop Producers: Opportunities And Challenges

*June 25, 2021*

Questions about agriculture's potential role in carbon sequestration are on many producers' minds these days. Purdue agricultural economists Carson Reeling, Nathanael Thompson and James Mintert discussed the opportunities and challenges of the carbon markets in U.S. agriculture for row crop producers.

*Downloads (in first month): 298*

## CENTER ACTIVITIES

### Episode 55: Farm Succession: Retirement Planning

May 20, 2021

Farm families face challenges with retirement planning and implementation similar to other small businesses but are unique as retirement can be implemented in various individualized situations for operations and management transitions. What activities will the retiring generation take part in? Will he/she remain involved in the labor, management, or ownership? Questions always arise on money for retirement living and similar to other businesses, a lawyer, a financial planner, an accountant, and other professionals may be of aid when retirement planning. Purdue ag economists Brady Brewer discusses retirement planning with the Purdue Farm Transition team, Kelly Heckaman, Jeff Pell and Denise Schroeder. *Downloads (in first month): 218*

### Episode 52: Farm Succession: Contingency Plan

April 26, 2021

A contingency plan is a set of procedures that defines how a business will operate in the event that some sort of disruption to the business occurs. Dr. Maria Marshall and Renee Wiatt join Dr. Brady Brewer to discuss what is in a contingency plan, risks that a contingency plan can cover, and why having one is needed for a successful farm transition. *Downloads (in first month): 195*

### Episode 49: Planting Intentions & March 31st Outlook Update

March 31, 2021

According to today's (March 31) estimates from USDA's National Agricultural Statistics Service (NASS), growers across the U.S. intend to plant 91.1 million acres of corn, up less than 1% from last year, and soybean producers intend to plant 87.6 million acres in 2021, up 5% from last year. Purdue ag economists James Mintert, Nathanael Thompson, and Michael Langemeier focus on the corn and soybean outlook in light of USDA's March Prospective Plantings and Grain Stocks reports. What does this mean for you? The Prospective Plantings and Grain Stocks reports are available online at [www.nass.usda.gov](http://www.nass.usda.gov). *Downloads (in first month): 176*

### Episode 48: The Value of Farm Data

March 24, 2021

Today we are talking about the value of your farm data. Purdue University agricultural economist Brady Brewer is joined by Purdue agricultural economist Nate Delay to discuss the types of farm data, the trust in sharing your data, and what price you'd put on that data. Farm data has come a long way and the value on it is a little unclear - a new Purdue study will help answer that question. *Downloads (in first month): 168*

### Episode 47: Farm Succession: Operating Agreements

March 17, 2021

Who can join the farm? And how? What terms are set on compensation if equity and contributions aren't equal? In this episode, our eighth in our Farm Transition Planning series, Purdue ag economists Brady Brewer and Michael Langemeier discuss agreements that are important in a farm business with Purdue Farm Transition team member Ed Farris. They spoke about operating agreements and common provisions, as well as buy/sell agreements. Find the rest of this series at <https://purdue.ag/3lnl6I0> and more information on farm succession planning on the Purdue Institute for Family Business' YouTube channel. *Downloads (in first month): 178*

### Episode 45: Making Your 2021 Crop Insurance Decisions

March 2, 2021

Crop insurance is an important aspect of nearly every corn and soybean farm's risk management program. There are some new choices to consider this year, including the Extended Coverage Option (ECO). This episode is a great opportunity for producers to review their crop insurance alternatives as Purdue University Center for Commercial Agriculture's ag economists Michael Langemeier and James Mintert walk participants through considerations for their 2021 choices. *Downloads (in first month): 224*

### Episode 43: Farm Succession: Business Entities

February 24, 2021

Choosing a business entity is a key aspect in liability, taxation, capitalization, decision making, agricultural government payments, and transfer options for all farm businesses. When it comes time to

transition your farm business to the next generation, whether your farm is set up as a sole proprietor, partnership, corporation, or LLC, how your business is structured will affect many aspects. Deciding on a business entity requires much thought and advice. In this episode, our seventh in our Farm Transition Planning series, Purdue ag economist Brady Brewer and members of the Purdue Farm Transition team Kelly Heckaman and Ed Farris discuss the impact of business structure in farm succession planning and give examples where it's important to have structures in place that fit for your business. Find the rest of this series at <http://purdue.ag/2OYomxd> and more information on farm succession planning on the Purdue Institute for Family Business' YouTube channel.

*Downloads (in first month): 181*

### Episode 42: Understanding the Five C's of Credit

*February 18, 2021*

Purdue University agricultural economist Brady Brewer is joined by Purdue agricultural economist Michael Langemeier to discuss credit underwriting and the criteria financial institutions use to determine eligibility of an applicant. Character, capital, capacity, collateral, and conditions are the five Cs of credit used in credit underwriting. These metrics are used for credit ratings to quantify and decide eligibility, interest rates and credit limits of borrowers. This episode focuses on what credit analysis means for farmers, how each of the 5 Cs are measured, and how farms can use this information for their gain and to manage risk.

*Downloads (in first month): 186*

### Episode 39: Farm Succession: Business Governance for Transition Planning

*January 26, 2021*

Adding on to our series about Farm Transition Planning, in this sixth episode, we focus on the importance of governance in a farm business. Having policies on who's in power, how decisions are made, and how to hold accountability among team members (especially when it comes to family) makes running a farm business easier. Purdue agricultural economists Brady Brewer and members of the Purdue Farm Transition team Renee Wiatt and Dr. Maria Marshall discuss the impact of governance in farm transition planning and give examples of decisions where it's important to have policies in place (in-laws, prenuptial, social media, employment and compensation). Find

the rest of the episodes in this series at <https://purdue.ag/3a5jXQb> and more information on farm succession planning on the Purdue Institute for Family Business' YouTube channel.

*Downloads (in first month): 156*

### Episode 38: 2021 Farm Bill Decisions for Crop Producers

*January 21, 2021*

Crop producers need to make their 2021 farm program choices at their local Farm Service Agency (FSA) office (or online) by March 15, 2021. Producers have the option of choosing either the Agriculture Risk Coverage (ARC) or the Price Loss Coverage (PLC) program. Purdue agricultural economists Michael Langemeier and James Mintert review how the most commonly chosen program options during the last sign-up period played out for the 2019 crop and are likely to play out for the 2020 crop. They conclude with a discussion about how to go about making your 2021 program elections. Find the accompanying pdf document of this discussion at <http://purdue.ag/2021farmbilldecisions>.

*Downloads (in first month): 509*



*Broadcasting to a wider audience on time sensitive material has been a benefit of the Center's response to COVID, especially evident in the 2021 Farm Bill Decision resources with over 680 total podcast downloads.*

## CENTER ACTIVITIES

# PROGRAMS & PUBLICATIONS

## Innovative farm management for producers

### Association of Agricultural Production Executives

The membership of the Association of Agricultural Production Executives (AAPEX), an organization that is now more than two decades old, is composed of many of the nation's leading agricultural producers. AAPEX is devoted to ongoing executive education for its members. Unfortunately, the 2021 AAPEX Annual Meeting was canceled as a result of the COVID pandemic. Plans were made to hold the 2022 conference in Ft. Worth, Texas.

### Purdue Top Farmer Conference

The Purdue Top Farmer Conference is one of the most successful and longest running management programs geared specifically for farmers. 2020 brought a year of challenges and uncertain economic conditions for the ag industry. The Center hosted the first-ever virtual Purdue Top Farmer Conference on January 8, 2021. Nearly 500 registered for this year's conference, which featured three of the nation's top experts on the agricultural economy and included thoughtful, innovative breakout discussions. Purdue's Jason Henderson discussed implications of the macroeconomic outlook for agriculture, Distinguished Purdue Professor Jayson Lusk outlined changing consumer behavior and what it means for U.S. agriculture, and Iowa State's Wendong Zhang provided an updated farmland outlook and future prospects for U.S.-China trade. During the discussion breakout, participants had a chance to interact with other attendees and consider strategic responses to the challenging economic environment.

### Purdue Farm Management Tour & Indiana Master Farmer Reception

The Purdue Farm Management Tour returned in grand form for 2021. Three outstanding farms hosted visitors wanting to learn about farm and crop management on July 8-9, 2021 in Posey and Vanderburgh counties in southwest Indiana. The Department of Agricultural Economics at Purdue University has organized an annual Indiana farm management tour every year since the early 1930s. Host farmers share keys to successful farm management and explain how the management of their operations is changing in response to the ever-changing agricultural economy and the evolving circumstances of their families. On this year's Tour, we had a chance to hear how working closely with a consultant over the course of a year helped the Seib family put in place their plan to transition their farm to the next generation. The risk management value of diversification along with the use of labor-saving robotic technology came through loud and clear on the Koester family's operation and the Kron family highlighted the importance of being involved in your community and your industry to make your voice heard. Of course, there are always opportunities on the Tour to pick up new technology and construction tips. Tour attendees got to see first-hand state-of-the-art farm shops, a new grain drying/handling system under construction and gained insight into how a NCGA corn yield contest winner uses precision technology to improve corn and soybean crop yields and profitability.

The Master Farmer program is a long-standing tradition in Indiana and honors individuals who



have contributed heavily to Indiana agriculture and demonstrated success in farming efficiency, stewardship of natural resources and community service. A reception with a panel discussion was held in conjunction with the tour to honor the 2021 Indiana Master Farmers on July 8, 2021. Attendance at the Master Farmer Reception and panel discussion was record high with nearly 250 attendees at the New Harmony Inn & Conference Center.

A special thanks to the Koester, Seib, and Kron families for sharing details about their farm operations, and to the Tour's local coordinator, Hans Schmitz, Purdue Extension's Posey County Educator as well as this year's Tour sponsors, Indiana Farm Bureau Insurance, Farm Credit Mid-America and Posey County Co-Op. We also want to thank Don and Joyce Villwock for their recent generous endowment to Purdue's College of Agriculture in support of the Purdue Farm Management Tour and Master Farmer Program! See more insights and photos from the Tour on Twitter #PFMT21.

### Commodity Classic

The 2021 Special Edition of Commodity Classic was delivered digitally March 2-5, 2021. Purdue University Center for Commercial Agriculture and the CME Group presented a Learning Center Session on Wednesday, March 3 entitled *Keys to Guiding Your Farm Through an Era of Tight Margins and Increased Risk*. In the session, the expert panel shared the key lessons from 2020 and helped producers plan for the financial and risk management realities of 2021. The discussion featured the latest data from the *Purdue/CME Group Ag Economy*



*Michael Langemeier, Aissa Good, James Mintert, Nathanael Thompson, Fred Seamon and Jason Henderson made a presentation during a digital Learning Center Session at the special edition 2021 Commodity Classic.*

*Barometer*, these results had specific focus on what farmers see happening with regard to their current financial situation, expected profitability in 2021, the desirability of making large investments in their farms, plans for expansion and their approach to risk management in these challenging times. Emphasis was placed on the role of technology adoption in improving farm profitability.

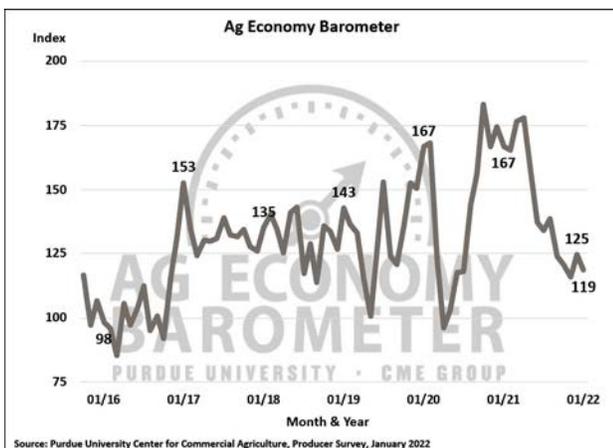


# AG ECONOMY BAROMETER

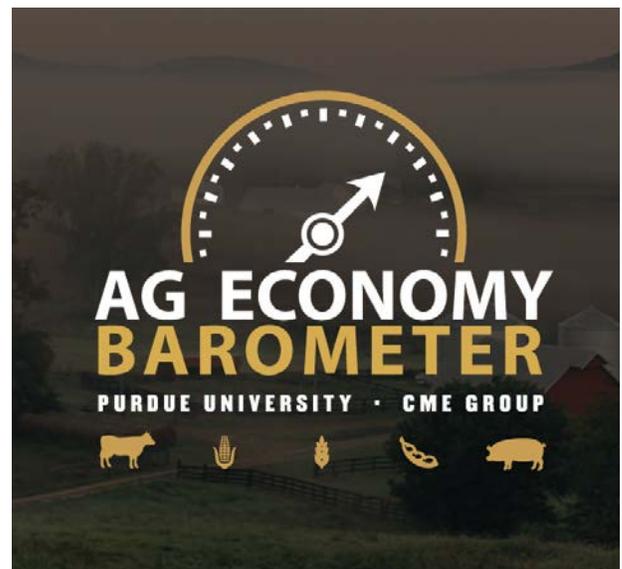
## Uncertainty Had a Big Impact on Producer Sentiment in 2021

James Mintert & Michael Langemeier

Ag producer sentiment shifted dramatically during 2021 and confirmed once again that changes in farmer sentiment are driven by more than just commodity price and income fluctuations. After peaking in fall 2020 just prior to the 2020 presidential election, the *Ag Economy Barometer* index began 2021 with a reading of 167, 9% lower than its fall 2020 peak. The barometer subsequently improved modestly into early spring but showed signs of weakening by mid-spring. Farmer sentiment continued to weaken throughout the remainder of the spring, summer and fall and at year's end the index stood at 125, 29% lower than one year earlier. Interestingly, weakness in farmer sentiment did not track farm income as net farm income for most commercial farm operations was up significantly in 2021 compared to the prior year.



*Purdue/CME Group Ag Economy Barometer, October 2015-January 2022.*



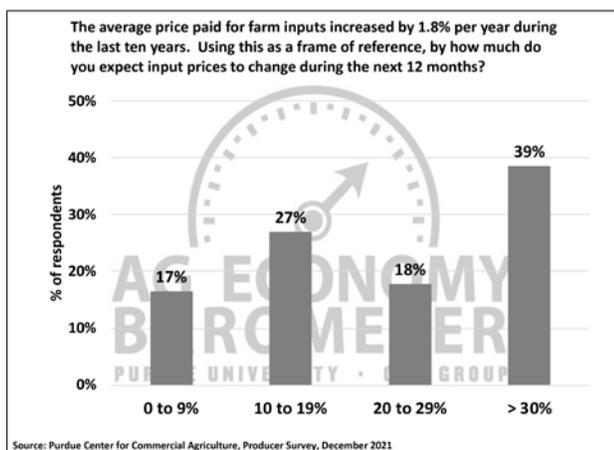
Over the course of the year, declining perceptions about both current economic conditions and expectations for the future were responsible for the decline in producer sentiment. Comparing December 2021 readings to December 2020, the *Index of Current Conditions* fell 28% and the *Index of Future Expectations* declined 29%. Why did farmer sentiment decline so sharply in a year when farm income was so strong?

It became increasingly clear as the year progressed that uncertainty was a major driver of weakening farmer sentiment. Changes in the *Farm Capital Investment Index* during 2021 provide some clarity regarding how uncertainty related to capital item availability amid supply chain disruptions was impacting farm operations around the nation. The *Farm Capital Investment Index*, with a reading of 93, was record high at the beginning of 2021 and remained very strong through early spring. But the investment index

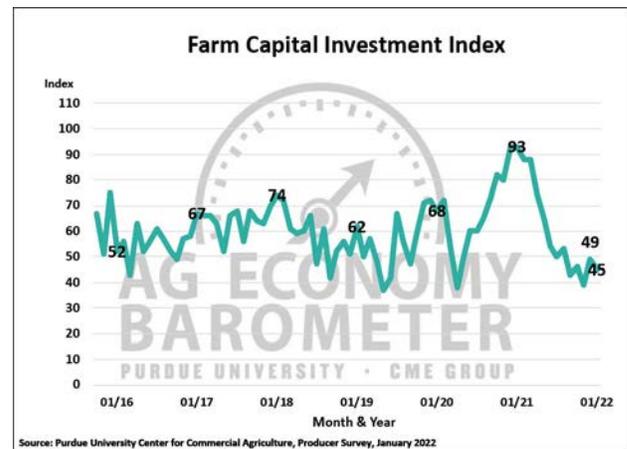
began to weaken in mid-spring and by early summer was 46% lower than at the start of the year, despite the fact that key crop prices had strengthened. The index weakened further in the fall and by November was 58% below its January reading. Supply chain issues were clearly weighing on producers' minds. For example, follow-up questions included on several barometer surveys revealed that over 40% of producers' farm machinery purchase plans were impacted by low farm machinery inventories.

Concerns and uncertainty about farm input prices also contributed to weakness in farmer sentiment. Starting in June barometer surveys asked respondents by how much they expected farm input prices to rise in the next 12 months. For reference, the question pointed out that in the prior 10 years the average rise was 1.8% per year. On the June 2021 survey, 44% of respondents said they expected input prices to rise less than 4% with 17% percent expecting prices to rise by 8% or more. By December conditions had changed dramatically with 83% of producers expecting input prices to rise by 10% or more and 38% saying they expect a price rise of 30% or more! Concerns extend beyond costs to input availability. In December nearly four out of ten corn and soybean producers said they experienced some difficulty in purchasing crop inputs for the 2022 crop season and the availability issues were widespread including fertilizer, herbicides, farm machinery parts and insecticides.

Despite the overriding decline in farmer sentiment that took place in 2021, producers remained relatively optimistic about farmland values. Comparing December 2021 to a year earlier, the *Short-Term Farmland Value Index* rose 12% while the *Long-Term Farmland Value Index* declined just 3%. Both indices were stronger than two years earlier with the short-



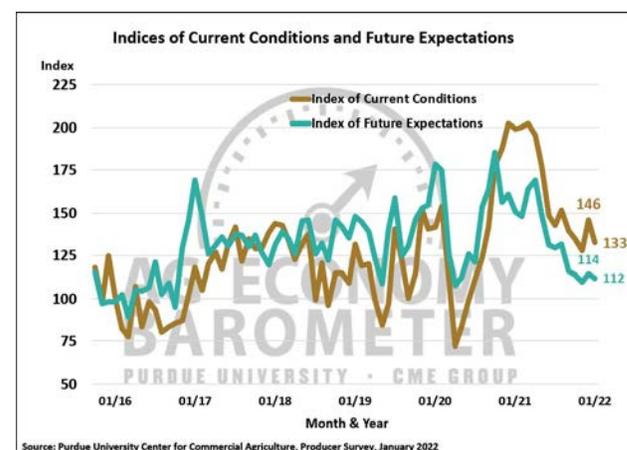
*How Much Do You Expect Farm Inputs Prices to Change During the Next Year?, December 2021.*



*Farm Capital Investment Index, October 2015-January 2022.*

term index rising 54% while the long-term index rose 6% over that two-year span. In a follow-up question on the December barometer survey, 61% of the respondents who expect farmland values to rise said the main reason they expect values to rise is non-farm investor demand for farmland.

Uncertainty will be an ongoing issue for U.S. ag producers in 2022. The December survey asked producers what their biggest concerns are for the upcoming year. The top three issues chosen by producers were higher input costs (47% of respondents), followed by lower crop/livestock prices (21% of respondents) and environmental policy (11% of respondents). To keep up with what farmers are thinking in 2022, stay tuned to upcoming monthly reports of the *Purdue University-CME Group Agricultural Economy Barometer*.



*Indices of Current Conditions and Future Expectations, October 2015-January 2022.*

# OPPORTUNITIES & CHALLENGES ASSOCIATED WITH "CARBON FARMING" FOR U.S. ROW-CROP PRODUCERS

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## INTRODUCTION

Alternatives for addressing climate change are varied (McKinsey and Company, 2009). Here we specifically discuss one such alternative that is receiving increasing attention: sequestering carbon in agricultural soils. The soil carbon pool plays an important role in the global carbon cycle. However, the expansion of agriculture and modern agricultural practices have contributed to the release of soil carbon into the atmosphere. While it is estimated that much of these losses can be re-sequestered, carbon soil dynamics are complex and the amount of carbon that can actually be sequestered depends on the practices implemented, crop rotation, soil type, soil drainage, topography, and climate. Nonetheless, the potential to sequester carbon in agricultural soils has spurred a precipitous increase in public and private interest in markets that pay farmers to sequester carbon in their soils as a means for mitigating climate change. Proponents of these programs posit agricultural soil carbon sequestration as a win-win, serving as a climate solution and a supplemental source of revenue for farmers. However, this view is naïve to the significant challenges associated with successful implementation of a voluntary soil carbon market.

Soil scientists unanimously agree there are agronomic and environmental benefits associated with rebuilding soil organic carbon in agricultural soils (Bradford et al., 2019). Further, it has been well

demonstrated through scientific study that the impact of no-till and cover crops on soil organic carbon change can be detected after long-term management changes (> 10 years) (Poeplau and Don, 2015). However, there remains significant uncertainty regarding the ability to measure year-to-year changes in soil organic carbon—a necessity of a soil carbon market that makes annual payments (Amundson and Biardeau, 2019; Bradford et al., 2019;

Ogle et al., 2019). This has caused many in the soil science community to raise concerns regarding expectations of measurement of soil organic carbon in agricultural soils. Some go as far as to say that focusing on soils as a climate change solution could undermine broader efforts to restore agricultural soils (Bradford et al., 2019; Ogle et al., 2019; Ritter and Treakle, 2020). In addition to challenges associated with the physical science, social science challenges, including cultural, economic, and political constraints, are just as problematic and often overlooked (Lewandrowski et al., 2004; Smith et al., 2005; Amundson and Biardeau, 2019; Bradford et al., 2019; Pannell et al., 2020; Thamo and Pannell, 2016, Thamo et al. 2020).

Therefore, the objective of our discussion is to (i) provide much needed information about emerging opportunities for U.S. row-crop producers to receive payments for sequestering carbon in their soils, (ii) examine the carbon sequestration potential of common carbon sequestering practices on U.S.

cropland acres, and (iii) add transparency to current discussions by outlining some of the important challenges and questions that remain. In addressing these issues our goal is to equip farmers and policy makers with information necessary to make important decisions regarding the rapidly evolving agricultural soil carbon marketplace.

## SOIL CARBON SEQUESTRATION OPPORTUNITIES FOR FARMERS

A number of opportunities currently exist for farmers to receive payments for sequestering carbon in their soils. The crediting mechanism underlying these programs generally takes on one of two broad structures: offset or inset markets.

### 1. Offset markets

In offset markets, carbon offsets are generated by those who can reduce emissions or sequester carbon. These offsets are then verified and sold to emitters as a means of offsetting their carbon emissions. Offsets can be sold through voluntary offset programs (e.g., The Climate Trust or the United Nations Framework on Climate Change’s clean development mechanism markets) or to polluters regulated under carbon cap-and-trade programs. Briefly, these programs (i) cap the amount of emissions a regulated industry is allowed to generate; (ii) issue permits in accordance with this cap, where each permit allows the permit holder to emit one unit of pollution; then (iii) provides a forum for regulated polluters to trade permits according to their own costs and benefits such that they meet their abatement obligations in a cost-effective way. In

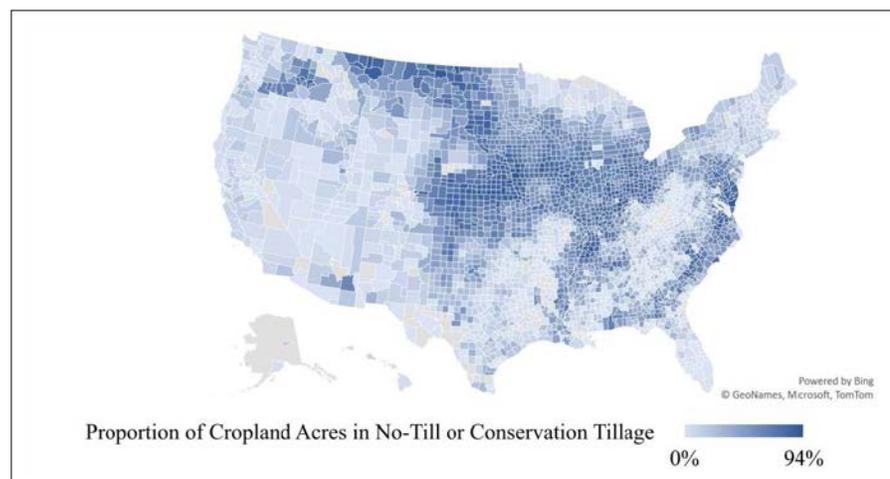
addition to purchasing permits, most permit markets also allow regulated firms to meet emissions caps through the purchase of offsets from unregulated sources outside the market. Indeed, all major cap-and-trade markets in the U.S.—including the Chicago Climate Exchange (which ceased trading in 2010 due to inactivity), the Regional Greenhouse Gas Initiative, and California’s cap-and-trade program—all allow regulated polluters to purchase offsets from outside sources. However, none of these programs allow row crop agriculture as a source of carbon offsets.

A number of emerging programs seek to enhance agriculture’s role in climate mitigation by supporting offset production from agricultural soil carbon sequestration, with the goal of selling these offsets in voluntary offset markets. Examples include Indigo Carbon (2021), Nori (2021), Truterra’s TruCarbon program (2021), Soil and Water Outcomes Fund (2021), and Ecosystem Services Market Consortium (2021). Although each program is unique, they generally work with farmers to implement practices that sequester carbon, provide measurement and verification of carbon offsets, and sell those offsets to buyers interested in offsetting carbon emissions.

### 2. Inset markets

Insetting represents an initiative taken by a company to combat emissions within its own supply chain. Internalizing these efforts ensures the entity seeking to reduce its emissions is actively engaged in collaboratively providing education, technical assistance, and in many cases financial assistance. There are currently several examples of carbon insetting where companies have directly targeted the agricultural segments of their supply chains for opportunities to sequester carbon through

*Figure 1. Proportion of Cropland Acres in No-Till or Conservation Tillage. Source: USDA National Agricultural Statistics Service, 2017 U.S. Census of Agriculture.*



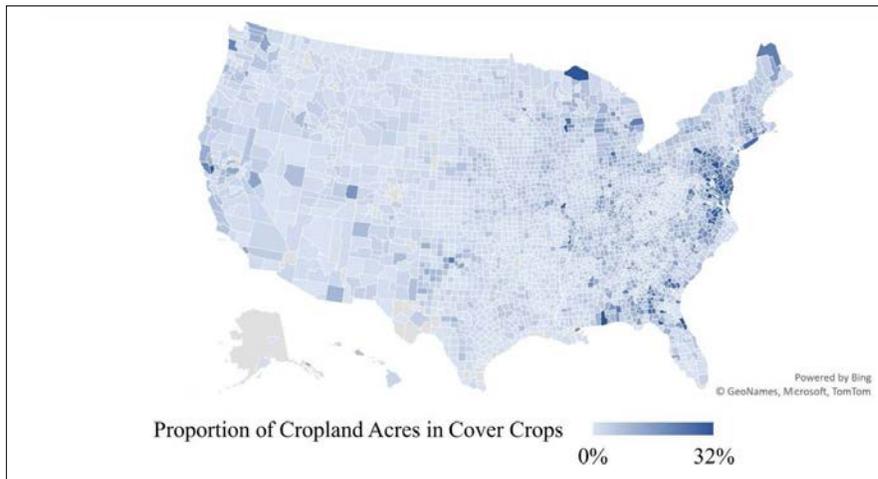


Figure 2. Proportion of Cropland Acres in Cover Crops. Source: USDA National Agricultural Statistics Service, 2017 U.S. Census of Agriculture.

implementation of regenerative practices. Examples of inset markets include initiatives by Nestlé (2021) and Bayer (2021) as well the efforts of the Field to Market Alliance (2021).

## PRACTICES THAT SEQUESTER CARBON

Eligibility for soil carbon programs requires the farmer to implement practices that sequester carbon. While there many practices available which can sequester carbon into soils (Thamo et al., 2020), here we provide a brief overview of the carbon sequestration potential of the two most frequently discussed practices for U.S. row-crop producers: no-till/conservation tillage and cover crops.

### 1. No-till and conservation tillage

Transitioning from conventional tillage to no-till reduces the loss of soil carbon by multiple mechanisms. Tillage enhances microbial activity due to aeration and mixes fresh residue from the surface into more favorable decomposition conditions, but also disrupts soil aggregates which protect soil organic carbon from decomposition. A meta-analysis on the efficacy of no-till farming for increasing soil carbon confirms that most corn-growing regions would be predicted to have an increase in soil organic carbon when switching from conventional tillage to no-till (Ogle et al., 2012).

Of the approximately 396 million cropland acres in the United States, the 2017 U.S. Census of Agriculture reported that over half are in no-till (104 million acres, 26%) or other conservation tillage practices (98 million acres, 25%) (USDA National Agricultural Statistics Service [NASS], 2021). Adoption varies geographically with the highest rates of adoption in the corn belt (Figure 1). Previous research has reported

carbon sequestration potential associated with no-till ranging from less than 0 to more than 0.4 MT/acre/year depending on climate and soil type (Ogle et al., 2019). The USDA Natural Resource Conservation Service (NRCS) COMET-Planner tool reports expected carbon sequestration of 0.31 MT/acre/year for no-till and 0.20 MT/acre/year for reduced tillage for most regions in the United States (USDA NRCS, 2021). Assuming this sequestration rate, current no-till and conservation tillage on U.S. cropland sequesters 52 million MT of carbon per year. This is equivalent to taking 11 million passenger vehicles (or 10% of all registered passenger vehicles in the United States) off the road each year. Putting all U.S. cropland acres into no-till would sequester a total of 123 million MT of carbon per year, or about 2% of all U.S. CO<sub>2</sub> emissions in 2019 (Environmental Protection Agency, 2021).

### 2. Cover crops

Cover crops increase soil organic carbon by adding biomass carbon input, improving protection for soil organic carbon in the form of soil aggregation, and decreasing carbon loss through soil erosion (Ruiz and Blanco-Canqui, 2017). Numerous studies have demonstrated cover crops' carbon sequestration effectiveness (e.g., Blanco-Canqui et al., 2015; Lal and Bruce, 1999).

Unlike conservation tillage practices, the 2017 U.S. Census of Agriculture reported that cover crops have only been adopted on about 4% (15 million acres) of U.S. cropland acres (USDA NASS, 2021), with the Chesapeake Bay area having the highest concentration of cover crop adoption (Figure 2). Previous research has shown cover crops to have carbon sequestration potential ranging from 0.04 to 0.4 MT/acre/year depending on biomass amount, years in cover crops, and initial soil carbon levels (Blanco-Canqui et al.,

2015). The USDA NRCS COMET-Planner tool reports expected carbon sequestration of 0.37 MT/acre/year for cover crops for most regions in the United States (USDA NRCS, 2021). Assuming this sequestration rate, current cover crop adoption sequesters 5.5 million MT of carbon per year. This is equivalent to taking 1.2 million passenger vehicles (or 1% of all registered passenger vehicles in the United States) off the road each year. Planting all U.S. cropland acres with cover crops would sequester a total of 147 million MT of carbon, or the equivalent of 3% of 2019 CO<sub>2</sub> emissions in the United States (Environmental Protection Agency, 2021).

## SOIL CARBON SEQUESTRATION QUESTIONS AND CHALLENGES

Despite increasing opportunities for agricultural producers to receive payments for sequestering carbon in their soils, a number of questions and challenges remain. We seek to address some common questions raised by farmers about soil carbon markets. To inform this discussion a random sample of 1,201 U.S. commercial scale agricultural producers were asked about their awareness of and participation in soil carbon markets as part of the Purdue University-CME Group Ag Economy Barometer's February, March, and April 2021 surveys (Figure 3). In the March and April 2021 surveys and additional question was posed to survey respondents, asking them about the factors inhibiting their participation in soil carbon markets (Figure 4). For details on the survey methodology, see Purdue University-CME Group Ag Economy Barometer (2021).

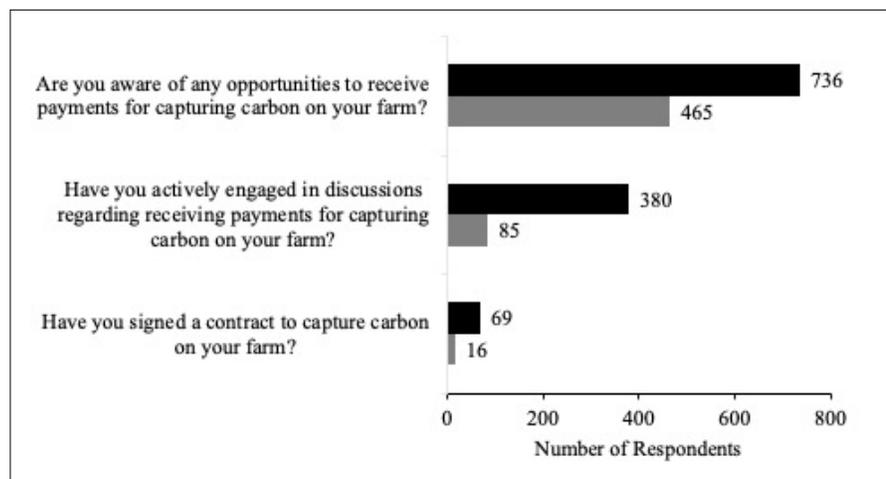
### w1. How much will I get paid?

As with any market, the price of offsets from carbon sequestration will ultimately be determined by supply and demand. In general, supply is lagging demand in these markets. While thirty-nine percent of producers in our survey were aware of opportunities to receive payments for storing carbon on their farms, only 7% have actively engaged in discussions about storing carbon and just 1% have actually entered into a contract to store carbon (Figure 3).

Demand for carbon offsets is more developed, with companies lining up to make carbon-neutrality pledges (e.g., Amazon, Uber, Microsoft, and IBM [The Climate Pledge, 2021]). However, it is important to note that these pledges are voluntary, leaving firms with wide latitude in deciding how to meet them and uncertainty as to their longevity. As a result, demand is uncertain and may vary with the quality of carbon offsets generated by a given program. Factors that affect offset quality include the degree of additionality (i.e., whether offsets represent carbon reductions that would not have occurred in the absence of payment) and permanence (i.e., the risk that sequestered carbon will be released when offset projects end). Without these features, buyers are likely limited in what they will pay for soil carbon offsets, potentially stagnating supply.

So, what does that mean for the price of carbon sequestered? Much of the current discussion seems to indicate prices available to producers are currently \$10-\$20/MT of carbon sequestered, although this price seems to be quite arbitrary given (i) there is no actual scarcity of carbon offsets (these are 100% voluntary markets) and (ii) different offsets represent different commodities (e.g., different programs pay for carbon

*Figure 3. Farmer Awareness, Engagement, and Participation in Carbon Contracts (n = 1,201). Source: Purdue University-CME Group Ag Economy Barometer February, March, and April 2021.*



sequestered at different depths and some programs pay directly for practices implemented).

Current prices are likely too low to provide incentives for widespread participation. Indeed, producers most frequently identified the payment level offered as the reason they are not participating in soil carbon markets (Figure 4). For perspective, a study by Gramig and Widmar (2018) found that Indiana farmers would have to receive an additional \$40/acre in net revenues to switch from conventional tillage to no-till. At an assumed carbon storage rate of 0.31 MT/acre (USDA NRCS, 2021), that would require a carbon price of \$129/MT of carbon, plus the amount that compensates for increased production costs and potential yield drag in a no-till system. Further, estimates of the social cost of carbon—or the present value of avoided marginal damages from carbon abatement—are currently around \$50/MT (IGW, 2021). Therefore, the price farmers are currently being offered to sequester carbon is well below both the minimum needed to induce widespread adoption as well as the benefit that the carbon sequestration provides to society.

Further complicating the discussion of price is the fact that there is currently very little price transparency in these markets. That is, how does a farmer know he or she is getting the best price for their carbon sequestration? How easy is it for a farmer to back out of a contract to take advantage of higher prices in other programs? These are important questions that need to be addressed.

## 2. What are my contractual obligations as a producer to continue the practice?

The second most frequently identified impediment to participation in carbon markets among the farmers in our survey was the legal liability associated with contract noncompliance (Figure 4). One of the uniquely challenging aspects of soil carbon sequestration is that it is extremely impermanent (Thamo and Pannell, 2016; Ritter and Treakle, 2020). Carbon may be released from soils if the practice used to sequester carbon is discontinued (e.g., a return to conventional tillage following no-till). This impermanence poses risks to producers who are contractually obligated to sequester carbon.

Take, for example, an Eastern Corn Belt producer who faced wet field conditions during planting and harvest of 2019. For some, the optimal decision was to get into the field under less than ideal conditions resulting in field ruts given the cost associated with waiting and not making the ruts (i.e., yield losses). In the absence of a carbon contract, a producer who chose to create the ruts would get into the field in the spring to do some tillage. However, under the conditions of a soil carbon contract, this may violate a carbon sequestration agreement by re-releasing soil carbon back into the atmosphere. The question is, what is the legal liability in this case? It seems that most programs would deal with this by “pausing” future payments until the farm can re-sequester the carbon released due to the one-time event (Bruner and Brokish, 2021). If the farm is unwilling to continue the practices to re-sequester released carbon in the absence of payments, it is unclear what the legal liability would be. At the

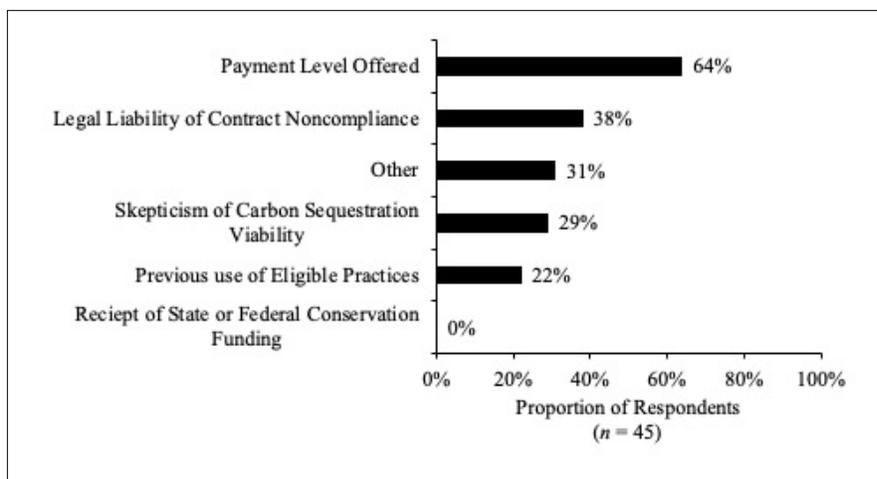


Figure 4. Reasons Preventing Producers from Enrolling in a Program to Capture Carbon on Their Farm (n = 45). Source: Purdue University-CME Group Ag Economy Barometer March and April 2021.

very least it would likely require the producer to repurchase carbon offsets it had previously sold at the prevailing market price. Bound by contract, the producer may also choose not to make the rust in the first place, but this also comes at a cost.

The discussion of permanence raises another important question: what is the duration of currently available soil carbon sequestration contracts? In the United States, the major programs enrolling farmers in soil carbon sequestration programs are currently using 1- to 20-year contracts (Bayer, 2021; Bruner and Brokish, 2021; Truterra, 2021). What happens after the contract ends? Is the farmer obligated to maintain the practice or are they free to revert to previous practices without legal liability for re-releasing stored carbon? The answer to this question is not clear, but it is important—both for the producer and the offset purchaser. If there is no legal liability to maintain sequestered carbon beyond the contract term, it is hard to see how these programs could possibly be helping mitigate the effects of climate change—and helping offset purchasers meet their sustainability goals—given the lack of permanence.

For perspective, consider that programs abroad, such as Australia's Emissions Reduction Fund initiative, started out with requirements to maintain sequestered carbon for 100 years (Thamo and Pannell, 2016). A 25-year contract was later added at a discounted payment level (Thamo and Pannell, 2016). While a 100-year contract still does not ensure permanence, it is a commendable attempt at ensuring stored carbon is maintained relative to currently popular programs in the United States. So, how do we reconcile permanence with current short-run contracts? First, additional clarity on the farmers legal liability beyond the contract is needed. Second, if there is truly no legal liability to maintain carbon after the contract period, this raises serious concerns over the quality of the offsets and, hence, whether demand for these offsets will be sustainable.

### 3. Do I qualify if I am already using eligible practices or if I already receive state or federal conservation funding for those practices?

An important aspect of emerging markets for carbon sequestration in agricultural soils is the focus on additionality. At present, nearly all of these programs seek to enroll producers who were not previously using eligible practices in an effort to sequester “new” carbon. This generally means that producers who have been previously implementing

practices such as no-till and cover crops are ineligible to receive payments for carbon sequestration on land where those practices have been in place. Only adoption of new practices or implementing practices on new acres qualify for carbon sequestration programs. While some currently available programs have short lookback periods that allow producers to receive back payments on previously implemented practices, these only go back five years or less (Bruner and Brokish, 2021; Truterra, 2021).

The focus on additionality is intended to incentivize sequestration of carbon that would not be captured sans the incentive. However, for farms that have been implementing these practices for years, this can be a major point of contention. Among the farmers in our survey who said they engaged in discussions regarding sequestration program participation, twenty-two percent of them indicated that their previous use of eligible practices disqualified them from participating in a carbon market (Figure 4). While many are looking for ways to reward producers who have long made investments in regenerative practices, to our knowledge no clear solutions currently exist. Ultimately, the demand for “vintage” offsets—offsets for carbon stored in the past—is low.

When combined with the physical aspects of soil carbon sequestration—soil carbon sequestration increases at a decreasing rate and carbon storage potential is finite and can only be exploited once (Thamo and Pannell, 2016)—additionality requirements also raise concerns about adverse selection and moral hazard (Varian, 2006). In addition, the rhetoric of an ever-impending increase in the price of carbon may be adversely impacting farmers' incentive to participate given the option value of waiting (Dixit and Pindyck, 1994). In other words, why would a farmer start selling his or her finite ability to sequester carbon today for \$15/MT when they could wait and possibly sell that same sequestration for \$30/MT or more three to five years from now?

Finally, there are also questions about whether producers who receive federal or state funding for conservation practice adoption (e.g., Natural Resource Conservation Service Environmental Quality Incentives Program [EQIP] payments) are eligible to also receive payments for carbon sequestration, or vice versa. Ultimately, the answer is that it depends. There are some programs that allow and encourage this sort of program “stacking” and there are others that strictly prohibit it (Bruner and Brokish, 2021). It is not our goal to speak to the efficiency of program stacking here; prior work finds stacking can be consistent

with efficiency in some cases (Horan et al., 2004; Woodward, 2011; Reeling et al., 2018) but not others (Lentz et al. 2014). Note that none of the farmers in our survey identified restrictions on program stacking as an impediment to their participation in soil carbon markets (Figure 4). However, producers seeking a contract to sequester carbon should clearly ask about opportunities or limitations on receiving additional funding for the practices implemented.

#### 4. Who pays for verification and am I actually paid for carbon stored on my farm?

The technical challenges associated with measuring and verifying soil carbon are well documented (Amundson and Biardeau, 2019; Bradford et al., 2019). The purpose of this article is not to rehash these issues, but instead to examine the pragmatic questions that these difficulties create for implementing a soil carbon market. First, it is important to understand who bears measurement or verification costs. Currently available soil carbon programs almost unanimously bear the costs of testing, meaning the farmer does not have to worry about paying for soil carbon verification (Bruner and Brokish, 2021).

Still, most farmers will likely want to understand the process for how carbon will be measured on their farms. After all, unlike yield, which farmers can easily measure, carbon stored in the soil is intangible. Current soil carbon programs all rely on a combination of in-field soil sampling and modeling to measure carbon sequestration (Bruner and Brokish, 2021). That is, given high transactions cost, it is infeasible to sample every field in the program for actual soil carbon sequestration. For this reason, verifiers rely heavily on biogeochemical modeling to predict soil carbon sequestration. Although the science behind these models is continuously improving, it is important for farmers to understand they are not necessarily getting paid for actual carbon sequestration measured on their farm. Instead, they are likely being paid for predicted carbon sequestration from a model. Companies should be transparent about this and should work on messaging to earn the trust of the farms they work with. Furthermore, both parties should contemplate how future improvements in biogeochemical prediction and soil carbon measurement will be factored into contract payments.

There have also been questions about the government's role in legitimizing and bringing oversight to soil carbon markets—most notably, recent U.S. Senate Bill S.1251, “Growing Climate Solutions Act

of 2021” (Braun et al., 2021). This bill seeks to provide a framework that assists farmers participating in carbon markets by providing reliable information and establishing a series of standards for certification for carbon offsets. The USDA would be the major driving force behind this program by setting necessary guidelines for carbon offset certification by third party verifiers. While this could certainly help to bring standardization to the soil carbon marketplace, the parameters of this bill, or government involvement more generally, do not unilaterally resolve the other challenges associated soil carbon markets.

## CONCLUSIONS

Increasing opportunities for farmers to receive payments for sequestering carbon in their soils are receiving much attention. While implementing practices that sequester carbon can help in the fight against climate change and serve as a source of supplemental revenue for farmers, it is not a panacea. Examining the carbon sequestration potential of common carbon sequestering practices (no-till and cover crops) indicates that even if these practices were purely additive and implemented on 100% of U.S. cropland acres, they would only sequester about 5% of total 2019 U.S. emissions. Therefore, while discussions of agriculture as part of the climate solution are a positive development, it is important to be realistic about the potential of U.S. cropland to sequester carbon. We also attempt to address several of the most common questions/challenges associated with soil carbon markets. Our goal is not to solve these issues, but instead to provide transparency to current discussions regarding these aspects of soil carbon markets. For soil carbon markets to be successful in attracting widespread participation by U.S. row-crop producers, the challenges we have identified here will need to be addressed.

# RECENT TRENDS IN PA TECHNOLOGY ADOPTION AND BUNDLING IN CORN PRODUCTION: IMPLICATIONS FOR FARM CONSOLIDATION

Nathan Delay & Haden Comstock

*This article has been adapted from its original version published in the Western Economic Forum, Volume 19, Issue 2 found here: [https://waeaonline.org/forum\\_archives/2021/](https://waeaonline.org/forum_archives/2021/).*

## INTRODUCTION

Precision agriculture (PA) technologies allow producers to manage crops more accurately by exploiting within-field variability in soils and topography. By optimizing input applications, PA promises to reduce operating costs without sacrificing output. Adoption of PA has risen steadily among Corn Belt farms since the commercialization of the yield monitor in the early 1990s. While individual PA technologies address specific management decisions, the impact of PA adoption is likely cumulative, meaning the benefits are realized when complementary tools are integrated to form an overall precision farming strategy. Despite significant growth in the breadth and depth of precision farming tools, take-up has somewhat lagged expectations. Economies of scale in PA may be a contributing factor, as adoption rates are shown to vary significantly by farm size.

The primary motivation behind farmers' adoption of PA technology and data collection is to reduce costs, improve management decisions, and increase

profitability. Profitable implementation of PA also depends on the quality of information and data that informs its use. Beyond profitability, some PA technologies are perceived to increase the convenience of farming by automating certain tasks.

Bundling is an important aspect in PA adoption. Tools such as grid soil sampling and variable rate technology (VRT) can be combined to form complementary technology packages, which can either work directly together or be used individually. While PA may be most impactful when technologies are used in concert, new technologies are often adopted in sequential order. Farms first adopt elemental bundles, and then layer in more advanced technologies as time goes on.

While a number of farm and operator characteristics influence new technology adoption patterns (e.g. uncertainty, risk preferences, credit constraints), farm size is often cited as a potential barrier to PA adoption. PA technologies—particularly equipment like variable rate applicators—involve large up-front investments. This will naturally deter small operations who cannot spread the fixed costs over a large number of acres or output. The effects of PA on farm profitability appear small, but may become meaningful when aggregated over a large scale. This aggregation effect will be even greater in the presence

of high fixed costs. Large farms are also more likely to have the degree of variability in soils and topography to warrant the use of site-specific crop management. Lastly, successful implementation of PA requires knowledge of the spatial differences in yield response within the field. The capacity for this kind of on-farm research may again privilege large farms.

In this paper, we investigate how the adoption of PA has changed over time using the most recent available data from the U.S. Department of Agriculture (USDA) Agricultural Resource Management Survey (ARMS) of corn producers. By comparing the adoption trends for specific technologies and technology bundles by farm and by acreage, we can better understand the importance of scale economies within PA. Results have implications for consolidation within U.S. corn production.

## DATA AND METHODS

We use data from the last three available ARMS for corn operations: 2005, 2010, and 2016. Farm respondents are expanded to construct nationally representative PA adoption estimates for all corn producers in the U.S. We also look at adoption rates for PA in terms of the number of acres on which various technologies and technology bundles were used to raise corn. Additional information about the ARMS and how it is administered can be found here: <https://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/documentation/>

## PRECISION AGRICULTURE ADOPTION TRENDS

Table 1 summarizes trends in adoption rates for individual PA technologies across U.S. corn farms for 2005, 2010, and 2016. Figures 1 and 2 depict trends in adoption rates for key technologies. Below we examine these trends by technology type.

### Yield Monitoring and Yield Mapping

Yield monitors remain the most commonly used type of PA technology both in terms of farms and acres. As of 2016, over half of all corn farms had a yield monitor and were used on nearly 70% of all corn acres. However, adoption grew more rapidly between 2005 and 2010 than between 2010 and 2016, particularly in terms of planted acreage. Farm-level adoption of yield monitors rose by 15 percentage points from 2005 to 2010 and by 10 percentage points between 2010 and 2016. By contrast, the proportion of planted corn acres using a yield monitor rose by 20 percentage points from '05 to '10 and only seven percentage points from '10 to '16.

Yield monitoring technology has been commercially available since 1992 and is widely considered an “entry-level” PA technology that integrates with more advanced packages. Yield monitoring technology often comes standard with new combine harvesters, meaning part of these adoption trends are likely explained by capital replacement and the factors that influence it. The relatively high changes in yield monitoring among corn farmers

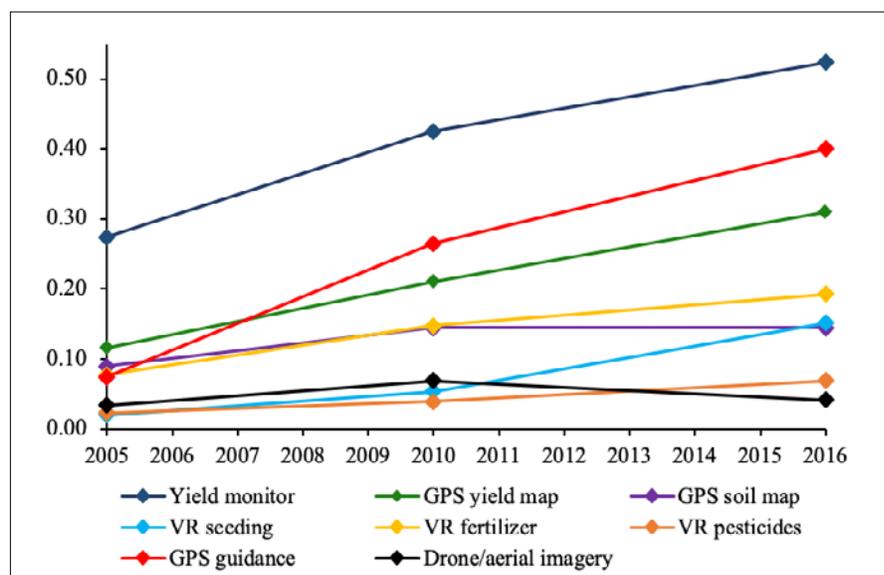


Figure 1. Precision Agriculture Adoption Trends by Corn Farms, 2005-2016

**Table 1. Precision Agriculture Technology Adoption (2005-2016)**

VARIABLE	2005 (n=2,145)		2010 (n=2,633)		2016 (n=1,819)	
	% of corn farms 2005	% of corn acres 2005	% of corn farms 2010	% of corn acres 2010	% of corn farms 2016	% of corn acres 2016
Yield monitor	0.27	0.42	0.43	0.61	0.52	0.68
GPS yield map	0.12	0.19	0.21	0.34	0.31	0.45
Yield monitor - grain drying	0.24	0.36	0.35	0.52	0.43	0.57
Yield monitor - tile drainage	0.05	0.08	0.08	0.16	0.1	0.17
Yield monitor - negotiate lease	0.01	0.02	0.03	0.05	0.05	0.1
GPS soil map <sup>a</sup>	0.09	0.15	0.14	0.22	0.14	0.22
VRT any	0.09	0.12	0.17	0.22	0.25	0.38
VR seeding <sup>b</sup>	0.02	0.03	0.05	0.07	0.15	0.25
VR fertilizer	0.08	0.1	0.15	0.19	0.19	0.29
VR pesticides	0.02	0.02	0.04	0.05	0.07	0.08
GPS guidance <sup>c</sup>	0.07	0.15	0.26	0.45	0.4	0.61
Drone/aerial imagery <sup>a</sup>	0.03	0.06	0.07	0.08	0.04	0.07

*Notes:* Source: USDA ARMS Phase II for corn 2005, 2010, 2016. Summary statistics represent all corn fields in their respective years using expansion weights provided by USDA NASS. <sup>a</sup> Question changed between 2010 and 2016 surveys. <sup>b</sup> Planters bought between 2010 and 2016 were more likely to come w/ VR seeding capability. <sup>c</sup> GPS guidance systems include both autosteer and light bar technology.

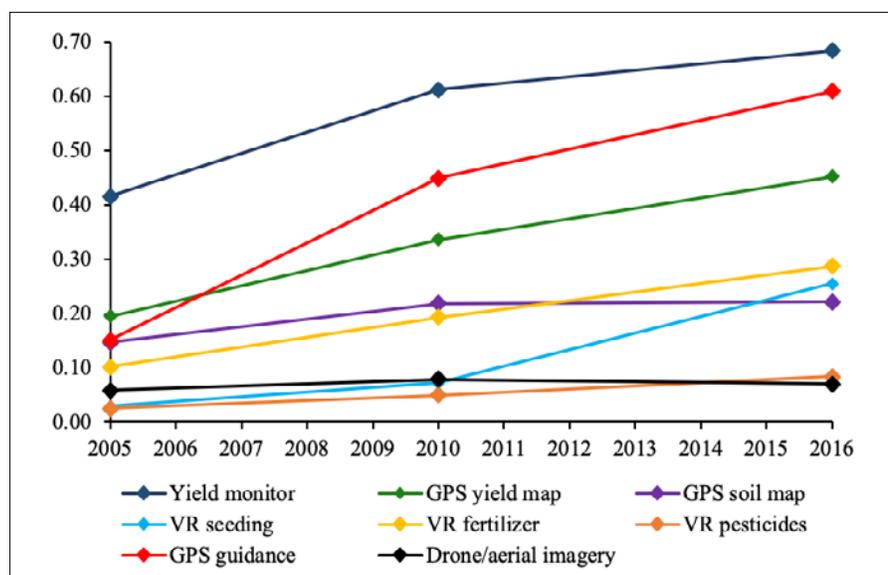
Table 1. Precision Agriculture Technology Adoption (2005-2016)

vs. corn acreage implies that, at least for the time period examined here, yield monitoring became more popular among smaller, late adopting corn farms.

A standard measure of yield monitor usage is the proportion of users that use the data to generate GPS yield maps of their fields. Historically, less than half of yield monitor adopters produce such maps, suggesting site-specific yield data collected at harvest does not often inform input management decisions made the

following year. However, the practice has become more popular in recent years, rising to 31% of farms and 45% of acres by 2016. In percentage terms, yield mapping rates grew faster as a share of corn farms than it did as a share of corn acres—a sign that existing yield monitor adopters are becoming more active in their use of the technology over time. The share of yield monitor owners that generate yield maps is also increasing. About 42% of yield monitor users created yield maps in

Figure 2. Precision Agriculture Adoption Trends by Planted Corn Acreage, 2005-2016



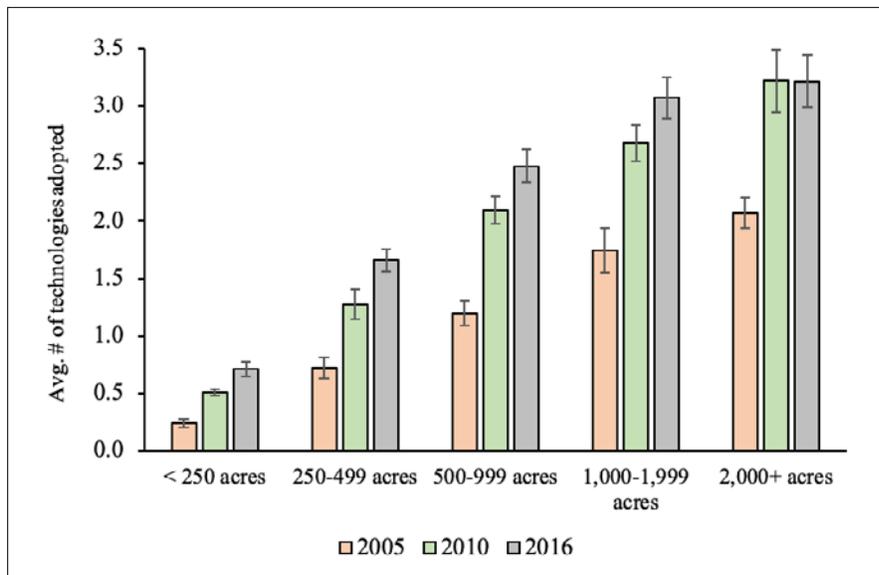


Figure 3. Mean Number of PA Technologies Adopted by Farm Size, 2005-2016

2005 vs 59% in 2016, a 40% increase.

While GPS yield mapping rates provide a good measure of yield monitor usage for precision application decisions, yield monitors inform other relevant management decisions. Yield monitor can estimate moisture content at harvest, allowing farmers to determine whether their grain meets elevator standards or if drying is necessary. Forty-three percent of farms used a yield monitor to inform grain drying decisions in 2016, or 82% of yield monitor users, by far the most common usage of yield monitor data. Trends in the use of yield monitors for grain drying decisions reflect the growth in on- and off-farm grain storage capacity since the early 2000s.

Managers can also use yield monitor information to identify areas within a field that are prone to excess moisture accumulation. Almost one fifth of yield monitor adopters used the technology to inform tile drainage additions or improvements in 2016, a 40% increase from 2005. Large operations are significantly more likely to use yield monitor data for this purpose.

Finally, producers can leverage yield monitor information to renegotiate cropland lease agreements. Data on historic yields, soil moisture retention, and grain moisture content all enhance the information available for the operator to calculate the true value of rented farmland. Yet less than 10% of operations with yield monitor technology reported using this information in farm lease negotiations in 2016. Given that less than half of corn operations rented fields in 2016, the share in Table 1 is misleading. Among yield monitor adopters and cropland renters, use of yield monitor information to renegotiate leases grew ten-fold, from less than four percent in 2005 to over 14%

in 2016. With a per-acre adoption rate twice the size of the per-farm adoption rate, using yield monitor data in lease negotiations is the most heavily skewed toward large operations. The acceleration in this practice implies a growing awareness of precision agriculture applications for farmland rental markets, at least among commercial operators who are the most likely to lease farmland. In the future, sharing yield maps, satellite imagery, and other PA data could become a normal part of farmland lease arrangements.

Yield mapping is the most common yardstick for measuring successful implementation of yield monitor technology. However, these results indicate that operators are more likely to use yield monitor data to inform storage, marketing, and investment decisions—discrete changes that can have large impacts on profitability—than fine-scale input decisions, where the effects of those decisions are less discernable. As grain storage, tile drainage, and farm data sharing become more common across the Corn Belt, yield monitor data will grow in importance.

### Guidance Systems

GPS guidance system adoption has risen from seven percent of corn farms (15% of planted acres) in 2005 and to 40% of farms (61% of acres) in 2016. While GPS guidance adoption remain skewed toward large operations, guidance technology saw the largest decline in the ratio of acre-level adoption to farm-level adoption. In 2005, the percentage of corn acres using guidance was twice that of corn operations. By 2016, this ratio had fallen to 1.5, suggesting the technology is increasingly within reach for smaller operations. Guidance systems confer multiple benefits to producers that may

Bundle	2005 (n=2,149)		2010 (n=2,654)		2016 (n=1,819)	
	% of corn farms 2005	% of corn acres 2005	% of corn farms 2010	% of corn acres 2010	% of corn farms 2016	% of corn acres 2016
Yield monitor (YM) only	0.12	0.14	0.12	0.12	0.11	0.07
YM + Yield mapping (Ymap)	0.12	0.19	0.21	0.34	0.31	0.45
YM + GPS guidance (GPS)	0.05	0.11	0.2	0.37	0.36	0.56
YM + variable rate technology (VRT)	0.05	0.08	0.12	0.18	0.23	0.36
YM + GPS + VRT	0.01	0.03	0.08	0.13	0.21	0.33
YM + Ymap + GPS	0.03	0.05	0.13	0.24	0.26	0.41
YM + Ymap + VRT	0.04	0.06	0.08	0.13	0.18	0.29
YM + Ymap + GPS + VRT	0.01	0.02	0.06	0.11	0.17	0.27
Mean PA technologies adopted (std. error)	0.68	-0.04	1.29	-0.05	1.67	-0.06

*Notes:* Source: USDA ARMS Phase II for corn 2005, 2010, 2016. Summary statistics represent all corn fields in their respective years using expansion weights provided by USDA NASS. Bundles represent technology packages that include at least the individual technologies. As such, bundles are not mutually exclusive.

Table 2. Precision Agriculture Technology Adoption Bundles (2005-2016)

be scale neutral—creating value for small farms. One is the ability to more efficiently harvest and apply inputs by reducing overlap, potentially cutting costs on a per-acre basis. Another is convenience—a feature that may not directly affect profitability but that nonetheless increases producer utility.

### Soil Mapping

The practice of creating GPS soil maps grew modestly from 2005 to 2010, but was flat between 2010 and 2016.<sup>1</sup> Unlike other PA practices, soil mapping acts as an intermediate input for precision applications. It is often coupled with other PA practices, mainly yield monitoring, yield mapping, and variable rate technology (VRT) to relate yield outcomes to soil properties and inform seed or chemical applications. Performing GPS soil mapping in isolation has not been linked to cost savings.

### Variable Rate Technology

Overall, use of VRT in corn production remains modest at 25% of corn farms and 38% of corn acreage, though adoption rates and trends differ considerably across application types. Of the three types of VRT, variable rate (VR) seeding has experienced the most rapid growth in adoption. Close to 60% of farmers who reported using any VRT used the technology for seeding purposes in 2016, up from 23% in 2005. As shown in Figures 1 and 2, most of the rise in popularity of VR for seeding corn took place between 2010 and 2016, when adoption rates tripled. Relative to VR

fertilization, VR seeding is a more recent phenomenon, which may explain its high growth relative to other forms of VRT in recent years. Planters bought between 2010 and 2016 were more likely to come with VR seeding capability and digital tools that generate plant population recommendations.

Though growing less rapidly, VR fertilizer application remains the most common form of VRT. As of 2016, 19% of all corn producers (29% of corn acres) used VRT for nutrient application. Though the effects of VR nutrient management on profitability are mixed, the practice has been shown to reduce variable costs and enhance nitrogen productivity when combined with detailed soil information. The lack of consensus on VR fertilizer's impact may be a limiting factor in its growth.

VR pesticide applications is both the newest and least common form of VRT at less than 10% of corn farms and acres in 2016. Interestingly, VRT for pesticides has the lowest ratio of acre-level adoption to farm-level adoption. Novel technologies are typically adopted first by large operations, which would cause the percent of acres using VRT pesticides to be significantly higher than the percent of farms.

### Drone, Satellite, and Aerial Imagery

As of 2016, drone or aerial (including satellite) imagery is the least adopted practice among the examined PA technologies, both in terms of corn farms (four percent) and planted acreage (seven percent). Imagery is also the only technology to show a decline from 2010 to 2016 despite significant advancements in

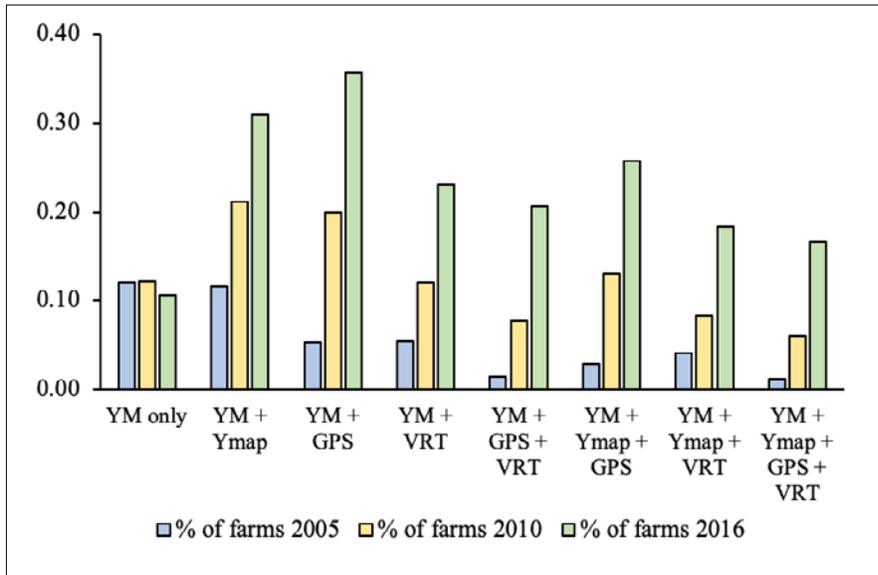


Figure 4: Adoption of PA Bundles by Corn Farms, 2005-2016

drone and satellite technology during this time period. Note that the 2016 ARMS changed the questions related to drone and aerial imagery to more directly measure use of these tools for data collection and mapping. Raising the standard of what is considered use of the technology may partially explain the drop in adoption. Nevertheless, the 2016 survey does not indicate widespread active use of these technologies. However, since the 2016 survey, satellite imagery resolution has improved and costs have fallen.

## TRENDS IN PRECISION AGRICULTURE TECHNOLOGY BUNDLES

PA implementation may be best measured by the extent to which farms layers multiple complementary technologies to create a systems approach to site-specific management.<sup>2</sup> Bundling of PA technologies can lead to positive outcomes, but benefits vary by adoption pattern and performance metric. Studies show that the timing and intensity of technology bundle adoption varies with farm size. According to ARMS, the mean number of PA technologies adopted by corn farms has increased from 0.68 in 2005, to 1.67 in 2016, though most of this increase occurred prior to 2010. Figure 3 shows the trends in average technologies adopted by farm size category. Even by 2016, farms with under 250 acres of corn adopted less

than one PA technology type, indicating a low capacity for technology bundling among small operations. Interestingly, it is the mid-sized farms (those between 500 and 2,000 acres of planted corn), not the largest farms (those with 2,000 acres or more) that exhibit the most dramatic increase in the number of technologies adopted between 2005 and 2016. Large farms actually show no change in their intensity of adoption from 2010 to 2016—at least for the standard PA technologies included here (see footnote 2). Another notable feature is the mean number of technologies appears to be bounded from above at three technologies, suggesting that there is limited capacity for multiple technologies, even among the largest operations.

To explore this more deeply, we select seven commonly used PA bundles and analyze their adoption trends over time. Table 2 reports the share of corn farms adopting each package and the share of corn acreage using each package by year. For comparison, we include the exclusive adoption of a yield monitor as the “base-level” package. The adoption of “higher order” PA bundles grew in every case from 2005 to 2016, though there are some differences in the pattern and intensity of growth across bundles. Figures 4 and 5 illustrate these trends by corn farms and corn acres, respectively. In 2005, the most commonly adopted bundle by corn farms was a yield monitor only with just over 12% of farms, while in 2010 and 2016, the most common packages were yield monitors with yield mapping (YM + Ymap) and yield monitoring with GPS guidance (YM + GPS).

GPS guidance enabled bundles experienced the most rapid growth over the 2005-2016 period. This makes sense given that GPS guidance enhances, and in

some cases is required by, other PA technologies (e.g., mapping technologies and variable rate applicators). Notably, three and four technology packages have become more common in recent years. For example, using yield monitors, yield mapping, and GPS guidance (YM + Ymap + GPS) grew from three percent of corn farms and five percent of corn acreage to become the third most common PA bundle at over one-fourth of farms and 41% of planted acres.

To measure the importance of scale in PA bundling, we look at changes in acre-level adoption rates relative to changes in farm-level adoption rates between 2005 and 2016. Differences in adoption rates and ratios of relative changes are displayed in Figure 6. A ratio above one indicates that larger farms (those responsible for a larger share of U.S. corn production) were more likely to adopt the technology bundle during the 2005-2016 period. A clear pattern emerges from Figure 6; bundles with more technologies grew more as a percentage of corn acres than they did as a percentage of corn operations. Bundles of three or more PA technologies grew about 60% faster on an acreage basis than they did on a farm basis. The bundle of YM + VRT was the only two-technology bundle with a ratio that high. Adoption of the most basic PA bundle YM + Ymap had the most balanced adoption path, with a ratio of 1.33.

## CONCLUSION

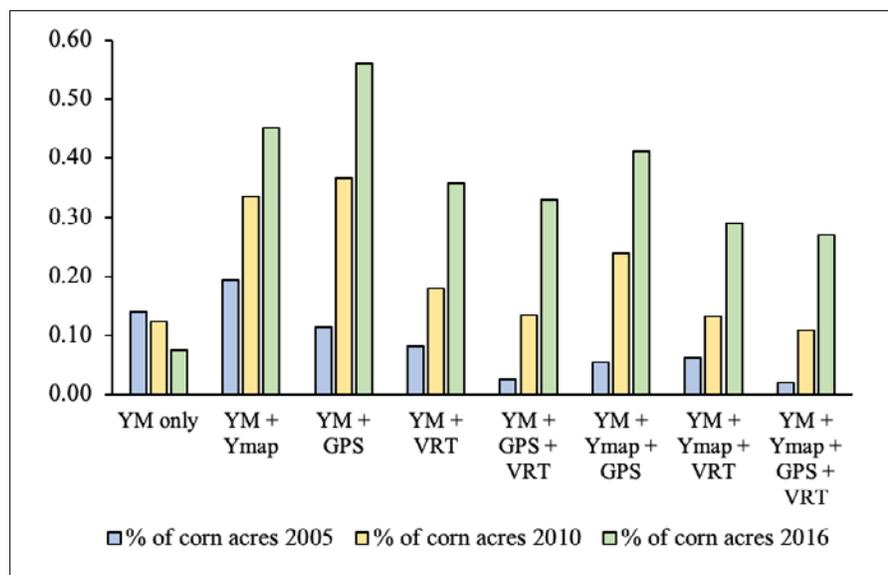
We analyze recent trends in precision agriculture technology adoption by U.S. corn producers using data from the USDA Agricultural and Resource Management Survey (ARMS). Consistent with previous

findings, we find overall usage of PA expanded between 2005 and 2016, but trends in adoption differed by time period. Though most PA technologies grew in popularity, the pace of adoption appears to have slowed somewhat in recent years. This may indicate a degree of saturation for the standard PA technologies (yield monitoring, yield mapping, soil mapping, guidance systems, variable rate technology (VRT), and aerial imagery).

Trends also varied by technology type and technology bundle. GPS guidance and guidance enabled technology packages have seen rapid take-up by corn growers, while novel tools such as unmanned aerial vehicles (UAVs) and satellite imagery have lagged. In all cases, the proportion of acres using a given technology or technology package exceeds the proportion of farm operations using the technology. Additionally, the rate of growth in acre-level adoption greatly exceeds the rate of growth in farm-level adoption for most technology packages. This pattern is especially true for bundles of three or more technologies (e.g., using a yield monitor, GPS guidance, and VRT). Relative adoption trends show that large farms are consistently more likely to adopt PA technologies, particularly technology packages consisting of multiple tools and practices.

Adoption patterns found here are generally consistent with the sequential adoption models in PA, where farms first adopt a “base level” technology, then stack more advanced technologies in piecewise fashion. This path dependence means that as more farms adopt upstream PA bundles (e.g., yield monitoring and GPS yield mapping), VRT and other

Figure 5: Adoption of PA Bundles by Corn Acreage, 2005-2016



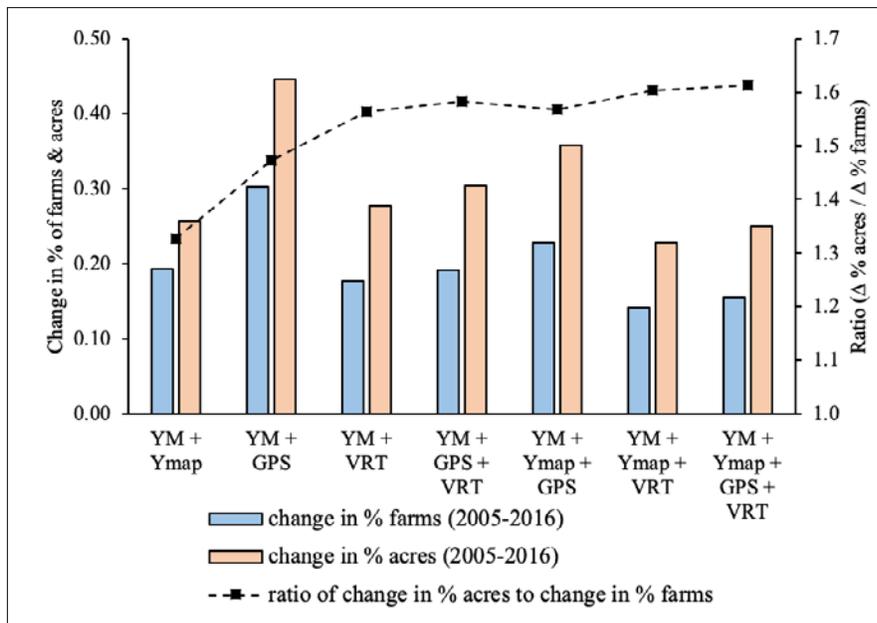


Figure 6: Changes in Adoption Rates of PA Bundles, 2005-2016

advanced practices will become more common. Results of this analysis suggest two things. One, use of PA in U.S. corn production will likely continue, but the overall pace may slow for certain technology types as they face saturation by innovators and early adopters. And two, growth—particularly for advanced PA bundles—will be skewed toward large operations that are better equipped to offset the fixed investment costs and aggregate the incremental benefits of managing crops on a granular scale. If these small benefits add up to meaningful production advantages at scale, PA could be a driver of future farm consolidation. Though not addressed in this paper, there are meaningful differences in PA adoption across corn producing regions. Corn Belt farms are significantly more likely to adopt most PA technologies than corn farms in other regions. They also contribute close to half of all U.S. corn acreage. To the extent to which PA contributes to farm consolidation, the effects will be most concentrated in the Midwestern corn producing states.

The findings of this paper can inform various policy discussions. Public-private investment in rural broadband could increase usage of precision farming technologies, which may favor large farms disproportionately. Alternatively, small farms could become more competitive by adopting certain PA technologies (e.g. by enhancing their efficiency or lowering their input costs), but are unlikely to do so due to the high investment costs and uncertain benefits. Policymakers looking to incentivize technology adoption should consider these possibilities.

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1 The soil mapping question was revised in the 2016 survey making the question more specific. The flat change in adoption between 2010 and 2016 may be partially the result of this change.

2 Note that the 2016 ARMS broadened the PA questions to include new technologies (e.g. crop and soil sensors and data analysis tool). For comparability, we calculate the number of PA technologies adopted based on a common set of technologies that are typically analyzed in the literature: yield monitors, yield mapping, guidance systems, soil mapping, VRT, and aerial imagery.

# WHAT WILL BE THE CAPABILITIES & SKILLS NEEDED TO MANAGE THE FARM OF THE FUTURE?

Michael Langemeier and Michael Boehlje

A recent article (April 9, 2021) 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 & 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

**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).

Table 1. Changes in Capabilities and Skills Needed in Agriculture

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 *farmdoc* 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 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.

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.

## CONCLUSION

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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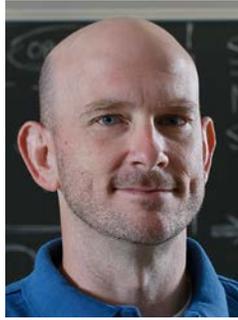
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