[Webinar: Precision Agriculture in the Digital Era: Recent Adoption on U.S. Farms]

Good afternoon, everyone, On behalf of USDA's Economic Research Service, welcome to today's webinar on Precision Agriculture in the Digital Era: Recent Adoption on U.S. Farms. My name is Valerie Negron, your host for today. As a reminder, this webinar is being recorded and will be posted on the ERS website next week. If you have questions during the webinar, please enter them into the chat feature at the bottom, left-hand corner of the screen for our Questions & Answer session at the end of today's presentation. Today, our presenter is Jonathan McFadden, a research economist in our Resource and Rural Economics Division. As an applied microeconomist, his work centers on environmental economics and industrial organization as they relate to agriculture. At ERS, his research focuses on the development, commercialization, and adoption of technologies and management practices that increase the productivity and environmental performance of U.S. agriculture. Prior to ERS, Jonathan was an assistant professor in the Department of Economics at the University of Oklahoma. Thanks for joining us today, Jonathan. The floor is yours…

Thank you, Valerie. And thank you all for joining me today as a I present key findings from our recent ERS report, *Precision Agriculture in the Digital Era: Recent Adoption on U.S. Farms*. I should say at the outset that this research was done jointly with two co-authors: 1) Eric Njuki, a fellow economist at ERS who also works on issues related to agricultural structure, technology, and productivity, and who will be joining us in the Q&A session here today; as well as 2) Terry Griffin, an associate professor in the Department of Agricultural Economics at Kansas State University. Terry's expertise in the economics of precision agriculture, and particularly his expertise regarding how precision technologies are being used in U.S. field crop production, was a valuable asset to the research.

Over the past 1-2 decades, U.S. agriculture has faced substantial pressure from several important factors, including climate change, aging farmer populations, labor shortages, pesticide resistance, changes in international trade patterns, and dietary shifts. These have come at a time of domestic population growth, and, when coupled with the fact that the global population is projected to exceed 9.7 billion people by year 2050, places renewed emphasis on the importance of things like agricultural innovations needed to feed the world. To be sure, no single technology or set of technologies can fully address these challenges. For example, farmers' adjustments will entail new seed varieties, use of more sustainable production methods, changes to pest management practices, and, perhaps even more broadly, potential modifications to incentive structures and the overall mix of labor and capital used on farmers' fields. However, digitalization—an ongoing, major technological transformation of the modern economy—has become a focal point for agricultural policymakers seeking a multi-pronged, holistic solution to some of the challenges I outlined just a moment ago. Currently, at the core of digital agriculture is a set of several main precision agriculture (PA) technologies, which are the main focus of the research.

Today I will overview and summarize findings of the research we published just a little over two weeks ago. The report had two main goals. The first was to document trends in how farmers use precision agriculture technologies for six major field crops: corn, cotton, rice, sorghum, soybeans, and winter wheat. These trends are reported between years 1996, the first year for which data are available, and 2019, the last year for which data were available at the time of report writing. The second goal was to explore in some depth the various economic factors that contribute to farmers' use of these precision technologies.

So, just by way of previewing what's to come, I will briefly point out four of our principal findings. First, in U.S. corn and soybean production, farmers have been using yield maps, soil maps, and variable rate technologies, which I will call "VRT" for short, for 2-3 decades. Use of these technologies by now is far from minimal. On the other hand, these technologies have only been used on 5-25% of acres planted to winter wheat, cotton, sorghum, and rice in recent years. Second, automated guidance usage has gone from nearly zero in 2001 to well over 50% of planted acreage for each of the six crops in the most recent years. Third, there have been a number of factors driving farmers' adoption of precision agriculture, such as expected labor-saving benefits and productivity improvements, technology costs, farm size, and USDA programs. Fourth and finally, adoption rates differ substantially based on farm size. At least half of relatively large row crop farms rely on soil maps, yield maps, VRT, or guidance systems, while less than 25% of smaller farms use any of these four technologies.

Now, having previewed some of the key results, it would be helpful to take a step back and point out similarities, differences, and overlap between precision agriculture and digital agriculture. In the Venn diagram here, we see on the left side a number of traditional site-specific technologies with limited digital content. So, these would be things like manual soil testing, paper soil maps, and paper yield maps. By contrast, the right side of the diagram represents digital technologies that may or may not be designed for use on highly specific parts of farmers' fields. These kinds of digital technologies tend to incorporate predictive analytics, machine learning, automation, or perhaps even more broadly artificial intelligence. Examples include gene editing and cellular agriculture, distributed ledger technologies like blockchain, and fully autonomous tractors. Notice that there is not complete overlap: not all site-specific inputs are applied precisely, and not all digital technologies embed location-specific production aspects. The middle of the diagram represents conventional precision agriculture. These are technologies for site-specific production that are becoming increasingly digitalized.

So, this tends to straightaway invite the question: what are the precision agriculture technologies of interest? Here, I have a few photos of some, but not all technologies included in the research. The first image is that of a yield monitor, an in-cab device that displays crop yields and how those yields change over small areas. The second image depicts precision soil sampling, a process that involves taking cores of the soil profile based on a grid and then having them analyzed in labs to determine soil properties. The third image is an example of a soil map, a visual representation of a particular soil property—and its variation throughout the field—based on soil analysis. So, in this case, the map is showing a chemical property that relates to how well the soil can store plant nutrients. Image number 4 shows the in-cab computer screen that operators look at it in real time as inputs like seeds, fertilizer, or pesticides are applied at variable rates across the field. Image number 5 shows the in-cab computer screen that operators look at in real time as the tractor or harvester is automatically steered, part of what we call automated guidance systems. The sixth image shows a sprayer being used as part of controlled traffic farming, a practice which confines heavy equipment to specific lanes within and alongside fields. Notice the unplanted lanes the sprayer is situated on; confining traffic to these lanes can help reduce soil compaction and improve yields. The last image, number 7, shows an unmanned aerial vehicle, otherwise known as a drone. We see that the drone, in this case a "quadcopter" drone recognizable from its four rotors, is flying a foot or two above the landing pad. Not shown are automated section control, which is a particular kind of VRT, and telematics, which are systems that enable wireless data transfer.

So now that we've seen what the technologies look like, let's start reviewing national adoption status and trends, starting with yield monitors. Yield monitor use has been quite high for many years, and they are starting to be installed on new harvesters as standard equipment. Given that, our focus is on how farmers tend to use these monitors rather than overall adoption levels. In 2016 and 2017, on the fields managed with yield monitors, the main use of the technology was monitoring crop moisture content. This is indicated in the blue-shaded areas of the two left-hand bars. In 2016 corn production, yield monitors were also used substantially to add or improve tile drainage, which was also a common use on soybean fields in 2018. This is what the yellow bars are showing. However, in 2018 and 2019, yield monitors were most commonly used to help farmers determine their chemical input use, which is indicated in the light green areas on the right-hand side of the chart. Note that differences in use across years partly reflect the fact that the surveyed crops change over years, as well as the fact that the wording changed in 2018 for this particular question in the survey that provides the data points. That survey is the Agricultural Resource Management Survey (ARMS), or "ARMS" for short, which I'll overview and talk more about later in the webinar.

Information from yield monitors is the primary input needed to produce a yield map, which I turn to next. Because use of yield monitors has risen since the mid-1990s, we would expect to see similar increases in farmers' adoption of yield maps, which is what the data show. So, during 1996 and 1997, yield maps were used on 5% of soybean acres, 8% of corn acres, and only 1% of winter wheat acres. In the most recent years for which there are data, use of yield maps now occurs on 44% of corn acres indicated by the orange line, 43% of soybean acres indicated by the silver line and 21% of winter wheat acres, which is noted in silver…uh excuse me, I mean yellow. Similar increases have occurred for the three other crops. Based on current ARMS data, 15% of cotton acres in light blue, 17% of rice acres in green, and 23% of sorghum acres, which is the line in dark blue, are managed using yield maps.

Soil maps are a closely related technology. After rising sharply in the late 1990s, particularly for corn, soybeans, winter wheat, and cotton, soil map use has flattened or turned downward somewhat for these same four crops. Use in sorghum exhibits a similar, though shallower, trend as shown in the dark blue line. On the whole, planted acreage managed using soil maps is currently higher than that of the late 1990s and early 2000s, though it's below 25% for any of the crops. But to some extent though, we would not expect adoption rates for soil maps based on current precision soil sampling to be drastically higher. This is because crop farmers in the central part of the United States tend to only sample their soils every 3-4 years, and the data provide a snapshot in time for fields highly dispersed across the U.S. So, you know in other words, the data are capturing a large share of farmers who did not happen to sample their soils during the particular survey, and the data are also capturing fields located outside the central U.S., which could be managed on a different soil sampling schedule.

On the other hand, farmers' adoption of auto-steer and guidance systems has risen sharply over the past 20 years. In 2001 and 2002, guidance systems were used on only 5% of corn acres and 5% of soybean acres. In these early years, guidance systems took the form of technologies known as lightbars. These were narrow light-emitting strips that were attached in the cab directly in front of the operator. Using satellite signals, the lightbar would emit certain lights indicating if the tractor was moving off course, either to the left or to the right of a reference path. Since this time, these manual systems have been replaced with more sophisticated guidance technologies that automatically steer the equipment for the operator. Based on current ARMS data, over 50% of the planted acreage for the six commodities of interest is managed using guidance systems. Some of this adoption increase is due to the fact that guidance technologies have become easier to use and have also gotten more accurate with time.

Variable rate technology (VRT) is another fundamental tool of precision agriculture. VRT allows for greater control of important variable inputs, possibly leading to more efficient input usage or lower production costs. VRT adoption has increased over time, though the upward trend is far less pronounced than that for guidance systems. In 1998, VRT adoption stood at 2% of winter wheat acres, 3% of cotton acres, 7% of soybean acres, and 8% of corn acres. Uptake was generally flat in the following years through the mid-2000s, with modest increases starting to take place in the late 2000s. The most recent years of ARMS data suggest that adoption rates range from a low of 14% of sorghum acres in 2019 indicated in the dark blue line near the bottom of the chart, to a high of 37% of corn acres in 2016 indicated by the orange line at the top of the chart. There are several factors that help to partly explain VRT adoption rates, and those include ease-of-use and degree of automation, reliance on related inputs like soil maps, and up-front fixed costs of purchasing or in some cases renting the equipment.

These national VRT adoption trends, however, mask underlying variability in how farmers are using the technology. In particular, VRT can be used to plant seeds or apply fertilizer or pesticides at different rates in real time within and across fields. We see from the most recent sets of ARMS data that these uses are quite varied, both within and across crops. VRT-applied fertilizers or lime was the most common use, with adoption rates ranging from 28% of corn acres in 2016 as shown by the dark beige line on the left most side of the chart to 8% of sorghum acres in 2019, which is the dark beige line on the right most part of the chart. Variable rate seeding is also widely used, with adoption rates ranging from 25% of corn acres in 2016 which is the blue bar on the left-hand side to 9% of sorghum acres in 2019, which is the blue bar on the right-hand side. By contrast, use of variable rate pesticide applications remains low, being used on only 7-10% of planted acreage depending on the particular crop. Among other things, differences among these three uses partly reflect the relative value that farmers get from applying inputs differentially across the field.

The last type of technology of interest to our research is imagery from drones, aircraft, and satellites. This kind of imagery tends to be used for things like crop mapping, livestock monitoring, land surveying, and crop spraying. Although imagery from airplanes and satellites has been available to farmers for decades, it was only in the mid-2000s that drones started to be used for agricultural purposes. Due to wording on the ARMS questionnaires, we are not able to report adoption rates for the three technologies individually, but we know that, collectively, adoption remains low. In 2019, only 3% of cotton acres were produced with imagery, while only roughly 10% of soybean acres in 2018 were produced with imagery. Although ARMS doesn't ask farmers about their adoption, technological complexity and the number of use cases are expected to influence farmers' use of these kinds of imagery.

So, one thing not readily apparent in the previous charts is the degree to which these technologies are used in combination with each other. Use of technology bundles occurs often in precision farm management because of the sequential nature of certain technologies. So, for example, VRT tends to rely on maps, which themselves rely on information from yield monitors or soil samples. Discounts in prices for adopting combinations of technologies may also play a role in determining use. Regardless of the specific cause, the most common precision technology bundle for corn production in 2016, adopted on 23% of corn acres, incorporated through technologies, maps, VRT, and guidance systems. That's the thing being circled in the left column of the table. Similarly, the most common combination in 2018 soybeans production included maps and guidance, being used on 15% of soybean acres. In certain instances, though, the most popular combinations actually just consist of one technology. So, for example, guidance systems only—and no other precision technology—were used on 39% of winter wheat acres in 2017 which is listing shown in the third column circled entry there and 36% of cotton acres in 2019, which is seen in the far right most column.

Apart from things related to technological complementarity and bundling of technologies, we know from standard economics that technological premium, fees and costs also drive demand for precision ag. The average cost of replacing a yield monitor for soybeans production in 2018 was $8,000 and over $13,000 for cotton in 2019, likely reflecting differences in harvest costs, which themselves relate to farm size differences. The average annual fee associated with yield monitors on cotton fields in 2019 was $1,700, which is higher than the annual fee associated with monitors on soybean fields in 2018. That most likely relates to differences in the number of harvesters on particular farms. Similarly, average guidance system replacement costs were $20,000 for soybeans in 2018 but $25,000 for cotton in 2019, likely indicative of cotton farmers' use of systems that require more expensive guidance sensors. The average annual fee associated with guidance systems in 2018 was $1,100. However, this number averages over fields that are relying on freely available, basic satellite signals, as well as expensive subscription-based correction services with high degrees of accuracy. Note that unfortunately data aren't available in 2019 for guidance-related annual fees or drone equipment replacement costs.

USDA programs, including conservation programs offered through USDA's Natural Resources Conservation Service (the NRCS), also play a role in farmers' adoption. In particular, the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP) are two major working-lands programs that provide farmers with financial and technical assistance for implementing certain conservation practices. Under EQIP, for each practice, NRCS defines a group of scenarios that are a set of activities that can be used to implement the practice. However, because cost data are no longer collected directly from EQIP participants, and certain scenario acreage was not available in recent years, our focus is on CSP. CSP offers assistance to farmers for improving their environmental performance to address resource concerns through activities called enhancements. Among CSP enhancements that aimed to improve cropland soil quality, the most popular practice related to precision agriculture in 2017 was use of precision pesticide applications to reduce risk of pesticides in surface water. Roughly 342,000 acres of cropland had a CSP contract for this practice in 2017. And that's what's being shown in one of the circled entries on the left part of the table. In 2020, this practice was again the most common, with contracted acreage at over 2.2 million acres as shown in the right most part of the table. Similarly, about 1.5 million acres of cropland in 2020 were contracted for use of precision ag technologies to reduce risk of nutrient losses to surface water.

But on a perhaps more fundamental level though, we observe major linkages between farm size and precision ag adoption. Now, some of this to some extent is mechanical: larger operations can be managed more easily or perhaps more efficiently with digital technologies. Beyond this, farms with a larger acreage base tend to have operators with reduced risk aversion, lower input costs on at least a per unit basis, greater soil variability – that's they manage greater quantities of land, uh, they tend to have access to favorable credit terms, and a larger number of managers. Regardless of one of these exact causes, we found that the largest farms across all commodities had adopted yield maps, soil maps, VRT, and automated guidance at higher rates than smaller farms. Of the farms growing corn in 2016, 73 percent of farms in the largest size category adopted guidance. This is the yellow bar on the right most part of the chart. The rates were similar for the group of largest farms growing other commodities in later years: 82 percent of the largest winter wheat farms in 2017 which is shown in dark beige, 68 percent of the largest soybean farms in 2018 shown in green, and 67 percent of the largest cotton farms in 2019, which is the silver bar on the right side. Conversely, among the smallest farms shown in the left most side of the chart, adoption of guidance systems was much lower: 10 percent of the smallest corn farms in 2016, 11 percent of the smallest soybean farms in 2018, and 7 percent of the smallest winter wheat farms in 2017. One exception is cotton, which starts at a relatively high rate of 50 percent for the smallest cotton farms in 2019 and then tends to go upward from there.

Along similar lines, farmers' perceptions of productivity impacts are closely related to farm size and its effects on adoption. A simple analysis of farmers' production outcomes shows that, in many instances, yields are statistically significantly higher for adopters of precision ag technologies than nonadopters. For example, ARMS data from 2016 indicated that the average corn yield on fields managed with yield maps was 183 bushels per acre, which an amount that is statistically significantly higher than the average corn yield of 139 bushels per acre on fields not managed with yield maps. So, this is what I'm showing with the circled entries in the upper left part of the table. Comparable trends hold for other technologies. So, the further example, adopters of variable rate seeding averaged 184 bushels per acre on corn fields in 2016, while nonadopters averaged 146 bushels per acre. And this trend holds for crops other than corn. As a final example, adopters of guidance systems on winter wheat fields in 2017 averaged 55 bushels per acre, which is significantly higher than the average of 43 bushels per acre among nonadopters. This is what's being shown in the circled entries in the lower right part of the table. It should be noted, though, that yield differences were not statistically significantly different across all technology types. So, for example, for winter wheat in 2017 we didn't observe significant differences in yields in adopters and nonadopters of variable rate seeding, variable rate pesticide operations, or imagery from drones, aircraft or satellites. And I should also point out that these estimates are, at best, interesting correlations because they don't control for other important factors that affect yields. So, in other words, these estimates shouldn't be interpreted as a causal effect of precision ag technologies on yields.

As precision technologies have become more complex over the previous two decades, the cost to farmers of learning about advanced machinery options has risen. For some farms, hiring consultant services could be a potential pathway for greater adoption if hiring the service increases operators' experience and trust with the technologies or reduces uncertainty about their return on equipment investment. Whatever the exact reason, there is a positive correlation between hiring consultant services and use of precision ag. Across all crops and for each type of site-specific advice service, greater shares of planted acreage were managed by adopters of any type of precision technology (maps, guidance, VRT, drones, aircraft, or satellites) than nonadopters. So, just as one example, nearly 7 percent of 2018 soybean acres were managed with at least one precision technology and employment of a consultant to develop or interpret a yield map or other remote sensing map. That's what's being shown in the first row under the circled area on the left. But this contrasts sharply with the fact that less than 1 percent of soybean acres are managed with a consultant to develop to interpret a yield map or remote sensing map, but without precision ag adoption. So that's what's being shown in the first row of the circled area on the right. Similar trends hold for the other five types of consultant services such as soil or tissue sample collecting, nutrient recommendations or management, pest scouting, pest control recommendations and management and irrigation management. We also observe these trends for the other two crops corn and winter wheat.

So, before wrapping up today's talk, I'd like to say a brief word about the Agricultural Resource Management Survey (ARMS), which provided the vast majority of data used in this research.

Jointly administered by ERS and USDA’s National Agricultural Statistics Service (known as NASS), ARMS provides important field-level and farm-level information about the status of U.S. agriculture. At the field level, ARMS provides key information about farmers’ conservation practices, seed choices, fertilizer and chemical applications, equipment investment, and field operations. Target commodities, such as the six indicated in today’s research, are surveyed on a rotating basis every 4-6 years. At the farm level, ARMS gathers information about the financial health of farm businesses, including information about revenues, expenses, assets and debts, contracts, and inventories, as well as characteristics about the farm operators and farm households themselves. Aside from ARMS, we used data from NRCS on contracted acreage for the CSP, the Conservation Stewardship Program, which was freely available on the NRCS website through the RCA Data Viewer.

By way of a conclusion, I’d like to take a moment to summarize the main findings of our research. So, in U.S. corn and soybean production, farmers have been using yield maps, soil maps, and VRT for 2-3 decades. Use of these technologies has been substantial. On the other hand, these technologies have only been used on 5-25% of acres planted to winter wheat, cotton, sorghum, and rice in recent years. But in contrast, automated guidance usage has gone from nearly zero in 2001 to well over 50% of planted acreage for each of the six crops in the years for which the most recent data are available. This increased usage, and that for other technologies, has been driven by several factors, including expected productivity improvements and labor-saving benefits, technology costs, USDA programs, and farm size. The size of the farming operation is a particularly noticeable factor. At least half of relatively large row crop farms rely on soil maps, yield maps, VRT, or guidance systems, while less than 25% of smaller farms use any of these four technologies.

So, with that, I’ll go ahead and end my presentation. I’d like to thank you all for your participation, and I look forward to Eric’s assistance in answering your questions now during the Q&A.

Thanks, Jonathan. We’ll go ahead and open the floor for questions now. As a reminder, questions can be submitted through the chat feature located at the bottom left-hand corner of your screen. Before we begin, I’d like to introduce another panelist who will be helping us answer questions. Joining Jonathan, we have Agricultural Economist Eric Njuki, a research agricultural economist from our Resource and Rural Economics Division. Eric’s research focuses on productivity and efficiency analysis, including climate effects on productivity at the national, sub-national, and commodity levels. Prior to joining ERS, Eric was an Assistant Research Professor at the University of Connecticut. Thanks for joining us today Eric…. Now Jonathan, for our first question….

How does farmers adoption of things like yield monitors, VRT, and automated guidance vary with land characteristics like slope of the field?

Okay thank you Valerie. Interesting question…So generally speaking this is one thing that we looked at in the report although there wasn't just quite enough time to include in today's webinar, but one thing that we did find in the report is that generally speaking, adoption rates don't tend to differ considerably by field slope. So, adoption rates based on technology uh don't uh and the ARMS questionnaire, we ask information about uh whether the operator's field was essentially nearly flat, moderately sloped, or steeply sloped we're steeply sloped like having more than a 10 percent grade you know, and by and large we don't really observe you know major differences in adoption rates by field slope. But there is one exception and that is uh for guidance systems for soybean production in 2018. We did find for that in particular adoption was around 45 percent on nearly flat fields uh as opposed to say around 26 percent on steeply sloped fields. So, this is the trend for soybeans in 2018, but we see uh similar trends for corn, cotton and winter wheats for automated guidance. There's this tendency to use um guidance systems more on flat fields than on steeply sloped fields, which may be due to two facts that automated guidance in some instances might be more costly on those types of fields or perhaps more impractical.

Thanks Jonathan. For your next question, why were only six commodities covered in the report?

Thanks Valerie, another great question… I think I'll send that one over to Eric.

Thanks Jonathan, that's a good question. The reason why we only focused on the six row crops is because uh these six crops have been surveyed in the ARMS over multiple rounds across several years and thus, we are able to analyze precision technology adoption trends and patterns. That's the main reason why we focused on these six crops.

Thanks Eric… Jonathan, for your next… yep…

I was just going to say just to elaborate on Eric's uh answers to a small amount you know in the ARMS survey, we you know…how to target commodities that rotate every four to six years and so that's why we looked at say 2016 corn, 2010 corn, 2005 corn, uh 2018 soybeans, 2012 soybeans, uh and so on. And so, we're not able to get a clear snapshot of all commodities in all years, and we focused on these six because we have a fairly long uh time span going back in some cases all the way to ‘96 for these particular crops.

Thanks Jonathan, um for your next question…Why do larger farms adopt precision agriculture at greater rates than smaller farms?

Thanks Valerie, another great question. You know there are many different reasons uh as pointed out in the in the slides, things like um larger farms can have reduced risk aversion. They tend to have a larger number of managers who might be able to specialize uh in certain tasks such as becoming uh familiar and gaining experience with precision ag technologies. And then there are a few other reasons I'll let Eric elaborate on this uh somewhat.

Thanks Jonathan again um there are a variety of reasons in addition to what Jonathan just mentioned. We think that the primary reason, not only think, but we highlighted this in the report, but one of the primary reasons is due to economic scales and uh return to technology adoption are potentially greater for larger farms and this is because adoption can be spread over a larger outlay compared to smaller farms.

Thanks Eric, um for your next question…. Is there any correlation between younger generations of farmers and the use of digital or precision ag practices?

Thanks Valerie, yeah that's another great question. Uh…So I will say that in this particular report, we do not look at that specifically. Although I'll point out that there is one benefit to the ARMS questionnaires, and that is we are you know, if we, if um, if that had been a particular focus of the research, we could have. Uh, we do have information as I pointed out here just a few moments ago, we do have information about uh things like age of the operator and so we could have we could have looked into that. One mechanical reason why we didn't though is that we get data on uh things like operator characteristics in the farm households from a different uh phase or different module of the of the survey if you will. And so, when we try to you know, when we link those answers uh from that phase with the information from the field level, we tend to lose some observations or sample size becomes lower. And so, we really wanted to focus on just the field level information here as much as possible uh to get the, to get the largest sample size possible.

Thanks Jonathan, um you pointed out a few times that precision agriculture can help farmers save labor. How does that work and what are the estimated benefits?

Okay, thanks Valerie…um yeah, so you know in practice these types of technologies can save labor uh in a number of different ways. So, you know one…you know one thing that's fairly common is when farmers are using uh their tractors that are…that have automated guidance systems for example…. uh we know that the, you know the tractor is being automatically steered uh throughout. There are some cases when a farmer does actually have to manually steer even with uh completely automated steering, but by and large those are minimal and so that really greatly frees up the farmer's time in the cab. And so, then what can happen is in cab the farmer can then reallocate the time to other things. So, things like you know checking a smartphone, checking on the weather or checking on some other aspects of the farm business sending emails to say input providers or other managers on the farm or to other workers, or even you know engaging in leisure activities, so you know uh watching Netflix or something like that. Um and so it can free up labor like that in some instances, it can also reduce the demand for labor you know more broadly on the, on the farm operations. So, you know that's how…that's what it looks like uh or that's how it works I should say. In this particular report, we didn't we didn't quantify…we didn't attempt to estimate the labor-saving benefits, but I will point out some other ERS research. So, uh in 2016 ERS published a report on profitability of precision agriculture. And so, in that report using the same data set for corn fields uh from the 2010 ARMS, uh that report found that the total labor hours per bushel of corn for adopters of maps was about 35 percent lower relative to non-adopters. And the report also found that um labor hours for per bushel of corn uh were 28 percent lower for VRT adopters as compared to non-adopters. And so, you know those were some findings from that particular report. Eric and I have done related research that finds uh, that defines similar results. In particular we find uh using a similar sample from ARMS focused on Midwest corn production adopters of guidance systems uh worked 49 fewer hours per acre than non-adopters and adopters of the RT uh worked 41 percent less per acre than VRT adopters. So again, not quantified in this report, but past ERS research has looked at it.

Thanks Jonathan. What's the adoption rate for use of drones for position application of pesticides as opposed to data collection?

Alright interesting…Thank you, thank you Valerie. Right, interesting question…So um, so if we go back to the figures on adoption of drones, you know unfortunately we're not able to quantify specifically uh drones versus aircraft versus satellites. The way the survey question is worded it combines all three of those technologies, and so unfortunately, we don't really know exactly uh you know what percent uh is just…is just drones. And even you know within that um we don't know exactly how the…how the drains are being used. But I'll turn it over to Eric for his thoughts. He might have done a little bit more work than myself on use of drones and specifically uh how they're being managed.

Thanks Jonathan, uh just like you mentioned I don't think the ARMS provide us with a breakdown of the different types of man aerial vehicles such as drones or whether you're looking at aircrafts or satellite imageries and how they're taken. So, I don't think uh it's possible to do a breakdown and in the manner that's being asked by one of the attendees.

Thanks Eric. For your next question, our presentation goes into a lot of depth about use of these technologies on crop fields. But what do we know about precision agriculture use on farms more broadly?

Um thanks Valerie. That's a great, that's a great question. And so, I sort of answer that in sort of one of two ways, and so you know one thing that we looked at you know in the report was some information from uh the farm level version of our survey and so uh particularly in 2013 and 2019 uh, we do have a little bit of information about uh the share of farms and acreage. They're making use of GPS for on-farm production activities. So, in particular um about 12 percent of all U.S farms in 2013 and 2019 were using you know GPS for on-farm production. That 12 percent of farms represents about uh 37 percent of total farm and ranch acreage in 2013 and about 40 percent of total farm and ranch acreage uh in 2019. That's sort of what it looks like nationally. You do see some variability across crops, states…Generally speaking, you know well over uh half the farm and ranch acres were managed with GPS. In the corn belt, uh while adoption of some GPS was less than 10 percent of farm and ranch acres for certain eastern states. Um, so that's sort of one way to think about it. And I think another way to think about it too is to sort of think about, you know, what do we know about uh precision agriculture used for things like livestock? And so, you know in this particular report, we didn't analyze specifically how precision ag is being used on livestock farms. Um but we do know that it is being used, and we know that from other versions of the ARMS questionnaire. And so specifically, we also survey dairy farms and hog operations, and we know that there's a…it's playing a prominent role there. So, for example, we know from say the 2016 and 2021 ARMS data that the U.S dairy producers have been using robotic milking equipment for several years now. We know that they're using uh computerized feeding systems as well as computerized milking systems that gather data each time the cows are milked. And so, right the research here for the most part focused on…focused on fields, but we do have through the ARMS data a window into use more broadly across the farm.

Thanks Jonathan. Um next question…. Does precision agriculture and digital agriculture go hand in hand? Does one require the other or are they independent?

Great thank you Valerie. Another great question. Yeah, so how you sort of think about this and just put in the context of our of our research in the report here is that, you know, I tend to think of site-specific production technologies that are analog. And so those might be things like you know, a yield map or a soil map or other types of input maps that are, that are printed out on paper. Um or say soil sampling that doesn't really happen on a grid – it isn't particularly digital or linked to a digital map uh as one thing. And sort of at the other end of the continuum, I think of you know uh fully digital spatial technologies. So those would be things like uh gene editing and cellular agriculture. Those would be things like blockchain. You know, these are things that can be used on the farm to enhance, you know, agricultural uh performance um… and environmental performance, but they aren't really tied into a particular site. And so, I sort of view those as being sort of the opposite ends of a continuum. And then in the middle, we have what we would refer to as conventional precision technology. So, we would have things like, you know, digital uh…digital uh soil maps, electronics-based yield maps, VRT guidance telematics, you know, automated texture control and things like that. And so those technologies are becoming increasingly digitalized. So those technologies, you know, many of those uh were around, um you know, in the in the mid to late 90s early 2000s uh when digitalization certainly really hadn't happened yet. And so, I wouldn't say necessarily that…that you know one requires the other, or that they're fully independent. I would say that, you know, at least how we're thinking about them, conventional precision technologies sort of embed uh site-specific production, but they're being increasingly digitalized. And so, you'd have to sort of really go in more depth about the particular technologies to sort of say whether or not you know this one depends on uh on digitalization, or this one does not. Um so it tends to be more context specific, I think. So broadly, there is…there is overlap.

Great answer Jonathan. For our next question, um did the report discuss why variable rate technology adoption is lower for pesticides than other uses?

Yeah, that is uh…that is a great question. The report uh did document trends in usage, you know, of course we documented the usage for a variable of pesticide applications just lower um you know as part of the report, we analyzed and took into account a lot of past research and a lot of past literature. Um and so, you know, one thing that we're not doing in the…in the report because it's not being done in the ARMS data is asking farmers, you know, why they adopted or why they didn't adopt specifically. Um, so we don't know that from ARMS data, but we do know from past work on this that, you know, it can be difficult for farmers to know exactly where pest infestations are. You know, are they, you know, in this part of the field or are they on that part of the field at what time are they occurring and so on. And so, um there's a connection there with just information requirements and so the farmer might not have the information required to make the best use of VR pesticides. Um that's one…that's one thing that we found uh you know while conducting the research for this report. Um there are other…there are other reasons, but I'll you know, I'll leave it at that. And I'll uh, I'll turn this one over to Eric to see if you might have more insights on that.

Jonathan, I think you're absolutely right with the uh questions that we capture in the ARMS survey, I don't think it's possible, you know, to tell, you know, one of the reasons why VR pesticides are low compared to uh variable rate technologies. For example, seeds, fertilizers in line, and you know, as we continue to get more information from the ARMS going forward, that is something that we will definitely be interested in looking at. For now, we just have to leave it at that, and, you know, just follow the patterns and trends that we capture with the information that we have.

Thank you, Eric. For your next question Jonathan, have you or others at ERS found differences in adoption by age, region of the U.S. or other demographic categories?

Thanks Valerie that's a great question. So, it sort of goes back to a question that we had a moment ago. In this particular research, we didn't look at, you know, we didn't look at differences in adoption rates by age. That's just mainly due to you know wanting to have the largest possible sample to be able to say uh the most with the survey data that we have. In this particular report though, we did look at differences by region. So specifically, we would use of farmers use of GPS for on-farm production activities, and we, you know, we have one figure in the report where we show a sharp of state level adoption uh by lower 48 states. And so, you know, if we if we look at sort of regional differences there, again we saw that you know well over half of the farm ranch acres uh in the corn belts were managed with GPS – so a substantial amount of GPS use in places like Illinois, Indiana, Iowa, Kansas, Minnesota and the Dakotas. But we found that adoption was less than 10 percent of farm and ranch acres and certainly eastern states like Massachusetts, New Hampshire, and West Virginia. And so, you know for the most part the report was focused on national adoption status and national adoption trends we do have that. I will say the ERS has conducted research that was put out uh several years ago. I would refer you to the 2016 reports uh that may be able to further break that down, but certainly uh the 2011 report does. And so ERS published a report in 2011 um on the doorstep of the information age was that all over the report I looked at uh national adoption trends, but it did actually break down uh differences in adoption by uh different regions of the country. So, things like the corn belts, the South, uh and things of that nature.

Thanks Jonathan. It looks like we're getting close to time, so we have um some time for two to three more questions. For your next question Jonathan, do we have data on yield result by state for adopters versus non-adopters?

Okay, thanks Valerie. That's a great question, uh you know I think the answer to that really just depends. So, the field level information from ARMS is designed to be, you know, nationally representative of uh you know acreage of the particular commodity in a particular year. Generally speaking, uh for some things we're able to make meaningful statements about say state level planted acreages for commodities and in some cases we're able to make you know meaningful statements about adoptions of technologies, you know, by state but that's really heavily dependent on, you know, quality of the data and availability of the data – so things like sample size for example. Um so I haven't, I haven't checked on this…So and that's certainly something that we didn't, we didn't do in the report uh, but it's something that could be looked into given the AMRS data that we have.

Great Jonathan, um let's see for your next question, has there been any research looking at how these technologies may have changed the knowledge, skills and abilities needed to do farm work?

Okay thanks Valerie, that's a great question. Um knowledge skills and abilities needed to do farm work. You know, so that wasn't…that particular uh question wasn't addressed uh by our particular report. So, our report can't really weigh in on that particular matter, but researchers are beginning uh to look at that question. I know in particular our co-author uh Terry Griffin at Kansas State does have a few publications along those lines and so uh unfortunately Terry is not with us for the Q&A, um but I would refer you to some of his…some of his work, which you can find on his website uh to sort of see how economists are looking into that.

Perfect, looks like we may have one more question here…time for one more question. Given that there are linkages between precision ag use and employing technical or consultant services, are there any relationships between precision ag adoption and farmers' use of public data or crop management recommendations?

Great, thank you Valerie. Yeah, another great question. So, you know, this is something that we did look at in the report. So, you know, we're able to sort of look at adoption of public data downloads and adoption of things like crop management recommendations based on uh the extent to which farmers are adopting, you know, these precision ag technologies or not. And so, you know, uh it appears to be the case from the data um farmers are intending to use data more in the form of crop management recommendations rather than directly downloading it themselves. So, for example uh we know that 63 percent of the corn acreage managed with CRT had operators who use crop management recommendations based on data from their fields. So that's a fairly large number - 63 percent - and that's in sharp contrast to uh the non-adopters, which was something uh on the order of 10 to 20 percent. Adoption rates were relatively lower for soybeans in 2018 and cotton in 2019, but the basic trend that we see from the data, that we documented in the report, is that you know adopters of precision ag technologies are much more likely to make use of data-based management recommendations than non-adopters. They're more likely to make use of uh downloading public data than non-adopters as well, although uh it's just that the overall level of adoption of public data downloads is fairly low regardless of use of precision ag. A great, great question.

Great Jonathan. um alright, that's all the time we have for today. Jonathan, Eric thank you both for presenting this new research on precision agriculture in the digital age. And thank you to our listeners for taking time out of your day to join us. Before closing, we’d like to invite you to our upcoming Data Training Webinar, March 28th at 1 P.M, E.T. In this webinar, ERS Economists Matthew MacLachlan and Megan Sweitzer will provide an overview of the data and analysis available from the Food Price Outlook data product, highlight its uses, and demonstrate how to find the data on the ERS website. You can register and learn more by visiting the link shown on your screen. Lastly, I’d like to give a quick shoutout to the ERS Charts of Note mobile app. With this app – available free of charge on Apple and Android devices – you can receive digital snapshots of ERS research delivered straight to your mobile device. Along with our website and charts of note mobile app, you can also find more about ERS on social media where you can connect with us on Twitter and LinkedIn. Again, thank you for joining us today. This concludes our webinar.