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Farm Types and Precision Agriculture Adoption: Crops, Regions, Soil Variability, and Farm Size

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Farm Types and Precision Agriculture Adoption: Crops, Regions, Soil Variability, and Farm Size

Abstract

In the United States average adoption rates have increased for precision agriculture (PA) technologies used to produce many field crops. PA makes use of information collected on the farm to target site-specific, intensive management of farm production. The United States Department of Agriculture (USDA) Agricultural Resource Management Survey (ARMS) allows close examination of regional patterns of adoption, and how crop types and region interact with differences in farm sizes and soil productivity variability to influence adoption rates. The most common PA technologies are guidance systems that use global positioning systems (GPS) to steer tractors and other farm equipment. Remote sensing, soil mapping, and yield mapping all use GPS to geolocate data and create maps used to guide farm management decision. Variable rate input-application technologies (VRT) make use of remote images, soil tests, yields maps and other sources of information to apply different, more precise levels of inputs in farmer's fields. GPS guided VRT fertilization was introduced in the early 1990s and increased slowly over the last three decades. The ARMS data for winter wheat (2017), corn (2016) and soybeans (2012) showed use of VRT seeding and pesticide applications growing rapidly. The data indicated that PA technology was being used on farms across all sizes and all regions, with adoption occurring more rapidly on larger farms. VRT use on soybean farms was highest in areas of higher soil variability.

Keywords: Global positioning system; yield maps, soil and aerial data, auto-steer, guidance, variable-rate

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Farm Types and Precision Agriculture Adoption: Crops, Regions, Soil Variability, and Farm Size

Introduction

This report shows how the use of precision agriculture (PA) mapping and field production technologies is changing in the United States (US). The implementation of these technologies differs across crops, regions, and farm sizes. Data shows that a higher percentage of large farms adopt these information-based crop production technologies, but smaller farms also use them. As farmers gain easier access to their farm's data, the effectiveness of crop production practices increases. The motivation behind farmers' increasing data collection, and use of tools to analyze and interpret data, is that with better information farmers can lower their costs and increase profits. Better data can help farmers reduce inputs when they are not needed, and increase inputs when yields can improve. Three types of PA technologies are used across a range of field crops, growing regions, and farm sizes: spatial information technology such as aerial and satellite remote sensing, and harvester yield-data and soil-test data mapped using Global Positioning Systems (GPS) co-ordinates to inform a wide-range of production management decisions; GPS guidance to help steer tractors and other farm machinery, and variable rate technology (VRT) seeding, fertilizer and pesticide applications which use GPS coordinates and input application prescriptions often based on remote sensing, yield maps and soil maps.

The overall objective of this study was to determine how farm characteristics influence precision agriculture adoption. The specific objectives were to: 1) compare PA adoption trends over time for major US field crops, 2) identify PA adoption patterns by farm size for winter wheat, corn and soybean, 3) show how soil variability affects PA adoption. The primary hypotheses were: 1) some technologies (such as guidance) are widely adopted by field crop producers, while others (such as VRT) have lagged, 2) larger farms are adopting PA more quickly, but smaller farms are also using the technology, and 3) greater soil variability is linked to a greater use of VRT.

Methods

The data used in this study comes from the Agricultural Resource Management Survey (ARMS) an annual survey of U.S. farms. In Phase II of ARMS, USDA selects nationally representative samples of producers of 1-2 target crops in each year, and then elicits information on input use (including the use of precision technologies), expenses, production practices, and production outcomes on a randomly selected field planted to a target crop. Winter wheat was a target crop in 2017, corn in 2016, rice in 2013, and soybeans in 2012. ARMS Phase II provides about 2,500 observations for soybean production in a nationally representative sample, and 2,200 observations for corn production, 500 for rice, and 1,020 for winter wheat. Further information on ARMS, including copies of Phase II questionnaires, is available on the USDA website: https://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/

Technology adoption for each crop was estimated using sample responses to individual technology use questions, expanded to the number of farms using sample weights, to estimate the share of soybean farms adopting a technology. The ARMS survey method means that each sample farm represents multiple farms from the same state and size class, and that the stratum weights are adjusted for nonresponse. Samples are expanded to population estimates with sample weights.

Because ARMS collects data for individual fields this study considered farm size, number of fields, and planted acreage for each crop. Each field's data represented per acre production expenses and output for that crop on the farm. Each farm's planted acreage on the tables came from several fields, with one field comprehensively surveyed. Farmers answered how many fields they have in soybean production and survey enumerators worked with the respondent to select a field at random.

Description of Precision Agricultural Technologies

PA refers to several information-based production technologies used by farmers around the world. The formal definition of PA by the International Society of Precision Agriculture (ISPA) focuses on the spatial and temporal management of agricultural production (https://www.ispag.org/about/definition). Adoption of many PA technologies was pioneered by U.S. field crop farmers (Lowenberg-DeBoer and Erickson, 2019) and PA adoption patterns in the US have been a useful precursor to how the technology will be adopted elsewhere in the world. For this study it was useful to consider these technologies in three groups that have distinct functions. Spatial information technology that uses GPS to organize yield, soil and remote sensing data collected in the field, GPS guidance steers machinery, and variable rate technologies (VRT) apply inputs where they are needed in the amounts required by the crop. In this report the term "GPS guidance" included both auto-steer which completely takes over steering of the equipment and lightbars which assist a human driver.

Spatial information technology provides images and maps help to inform production management decisions. Yield-by-location data from harvesters with yield-monitoring sensors requires GPS latitude/longitude coordinates to create a yield map. Usually several years of yield data are used to discern consistent yield patterns. Soil tests at sample sites are used to create a map of soil properties using GPS to organize the data spatially and geostatistics is used to interpolate between sample locations. Soil testing often uses soil core samples, but in some cases data is collected with proximal soil sensors. Soil test maps for most soil characteristics have the benefit of less year-to-year variation than yield maps. Remote sensing images show growing conditions using data collected from satellites, light aircraft mounted with sensors, and unmanned aerial vehicles (UAVs) commonly referred to as drones. These UAVs may be quadcopters with four sets of propellers or civilian versions of the fixed wing drones used in some military applications. Use of satellites images and aerial photography for agricultural management predate GPS, but current practice uses GPS coordinates to link data from remote sensing, yield monitors, soil testing and other sources for a given location in the field.

Producers can use GPS guidance systems that steer tractors and other self-propelled farm equipment using GPS boundaries of their fields available with GPS maps. Guidance has the benefit of requiring less external data than GPS mapping and less human input in the decision making. With auto-steer the computer takes over routine driving and the human operator's role is to deal with the unexpected. In case studies, guidance systems have helped farmers reduce input costs by increasing the accuracy of planter row shut-offs and reducing overlapping or missed fertilizer and pesticide applications. More accurate input application can increase yields by ensuring that inputs are applied where intended. GPS guidance can also reduce operator fatigue and give farmers more flexibility in choosing drivers.

VRT uses spatial information to program machinery controllers to apply different levels of inputs, including seed, at different rates within a field. Machinery with these controllers are more expensive to purchase and time-consuming to maintain than other PA options. Information from maps and remote images helps fine-tune production management decisions on input applications, but also by helps identify conditions when <u>not</u> to implement VRT. Uniform application of fertilizers and pesticides may be almost-as-good as VRT when conditions are nearly consistent across a field. This can avoid the time and costs of installing, operating, and maintaining specialized PA machinery. Maps can still help the farmer set appropriate uniform rates. VRT users can benefit from guidance systems, in addition to GPS maps, because guidance can free-up the operator to monitor variable input systems that control input flow rates and application cut-off points.

Adoption of PA Technologies

Adoption of each of the PA technologies has increased, but the patterns varied for each of the major US field crops: corn, cotton, rice, soybeans, and winter wheat. As far back as 2001 to 2005, GPS yield maps and guidance systems were already increasing in popularity, while the most common VRT application, VRT fertilization, remained in the range of 5-10 percent (Figs. 1, 4 and 6; see Schimmelpfennig and Ebel, 2011 for discussion of early adoption rates). Over the data period considered, GPS yield maps (Figure 1, 0-50 percent adoption rates on axis) were the most common maps for corn and soybeans by acres planted, and GPS soil maps were used on between 15-25 percent of corn, soybean, peanut and rice acres (Figure 2, 0-30 percent adoption rates on axis). Yield maps were made on less than 10 percent of planted acres for cotton, peanuts and rice. Yield monitoring devices for cotton have been widely available since 2000 utilizing real-time optical sensing technology.

Adoption of soil maps grew in rice production at about the same rate as for soybeans, and the fastest in corn and peanut production. The growth in soil map use for corn production roughly coincided with perceived difficulties corn farmers have had understanding year-to-year variations in their yield maps. In the data period soil map adoption for cotton and wheat was below 10 percent, matching low adoption rates for VRT fertilizer for cotton and wheat. Soil maps help manage fertility requirements for some crops, but were not popular yet for cotton or wheat when the data was collected.

During the data period remote sensing stagnated below 10 percent of acres for all these crops, with cotton and winter wheat dropping below 2 percent of all U.S. planted acres. The technology was more common with cotton and rice farmers in the past than more recently (Figure 3, 0-16 percent adoption rates on axis). This study investigated if remote sensing was more often used on larger farms with more planted acres, farms with larger fields, or in some regions of the U.S. for certain crops. The low and for some crops declining percentages of planted acres covered by remote sensing probably indicated that the technology had substantial room for increased adoption.

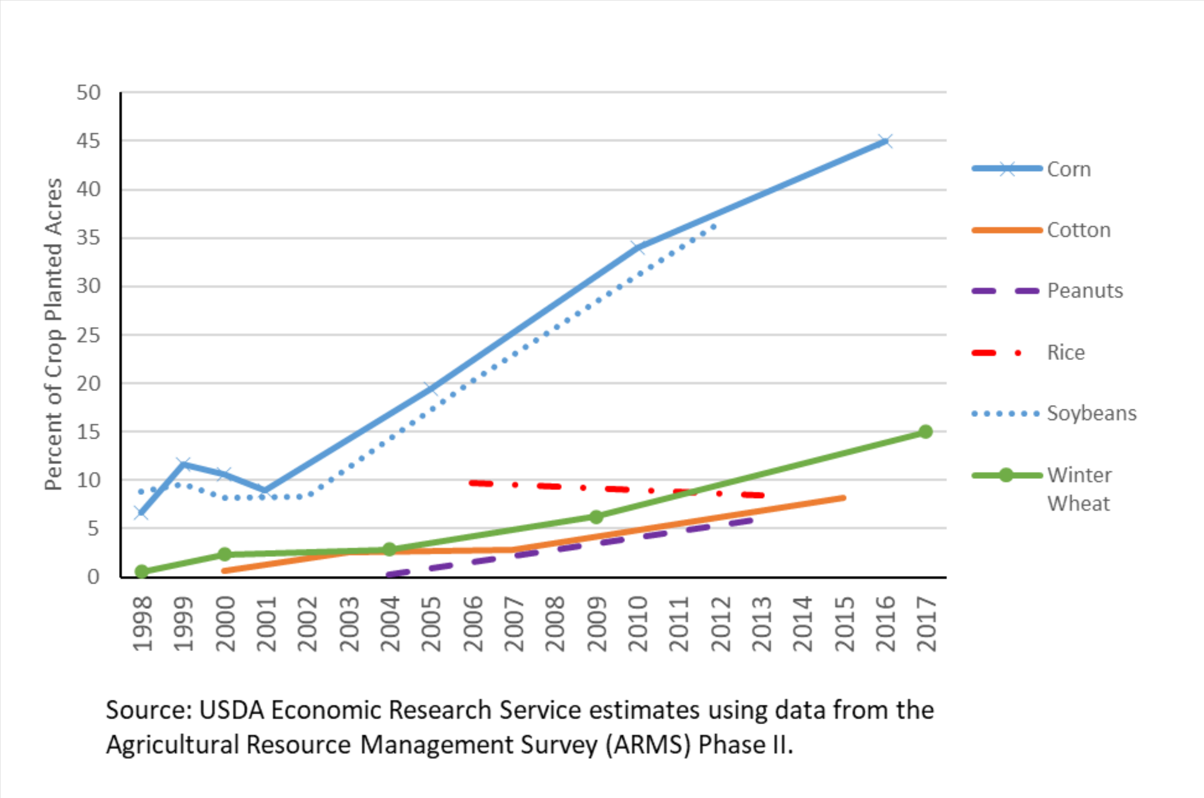


Figure 1: Adoption of yield mapping (1998-2017)

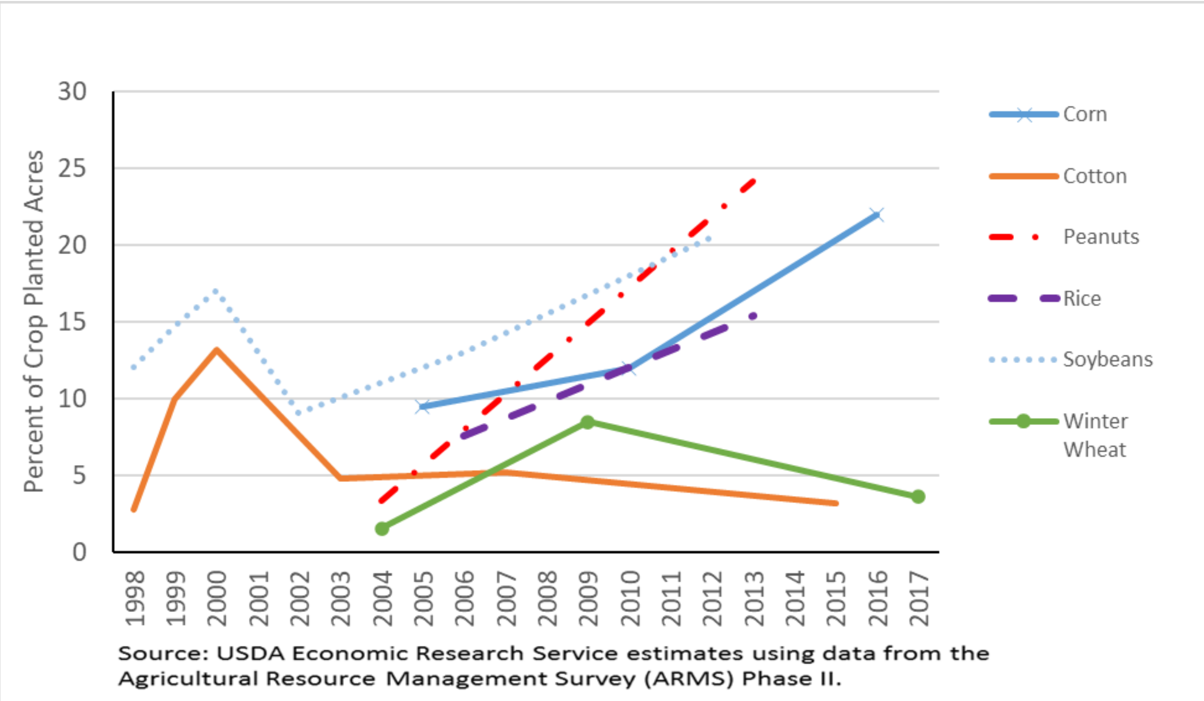
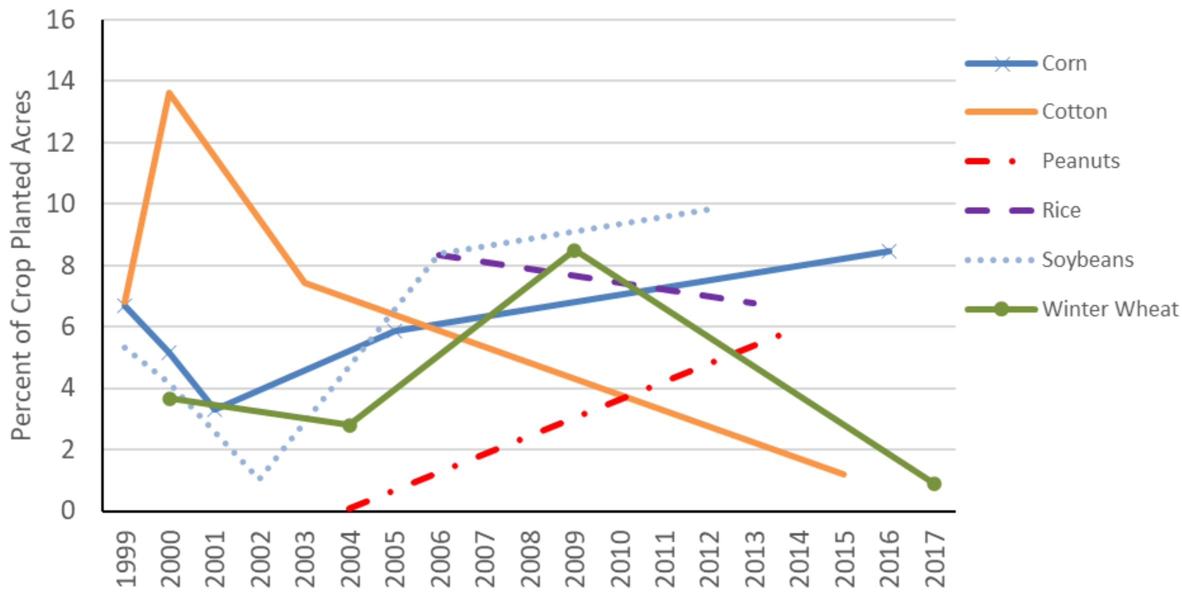
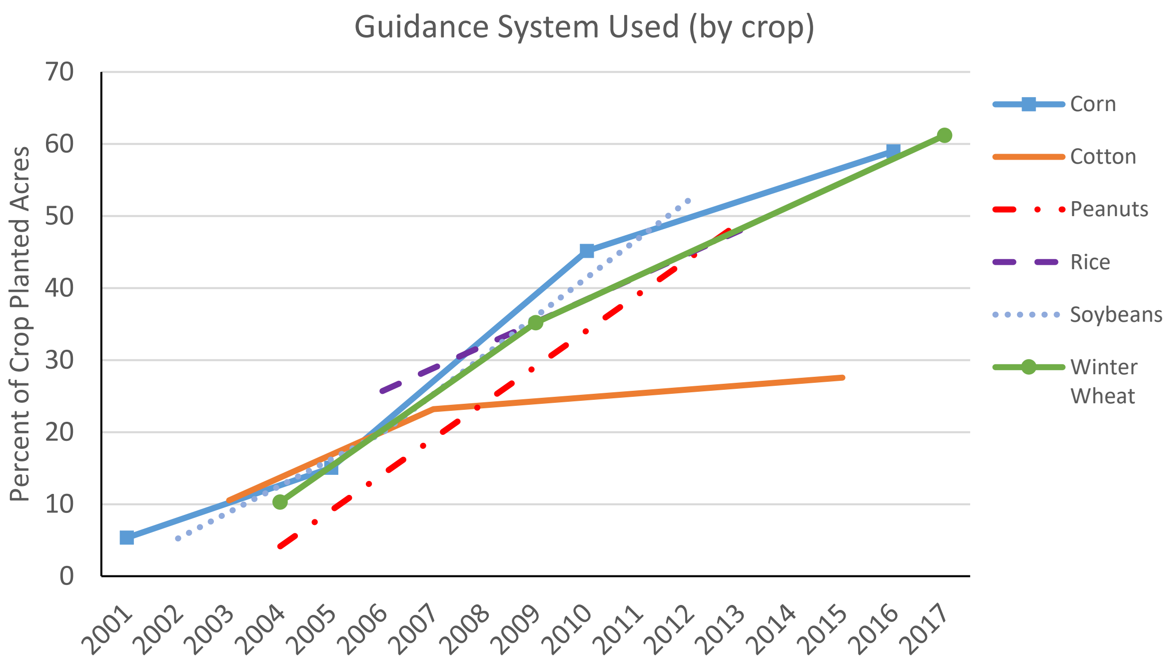


Figure 2: Adoption of soil mapping (1998-2017)



Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Figure 3: Adoption of remote sensing (1999-2017)



Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Figure 4: Adoption of guidance systems (2001-2017)

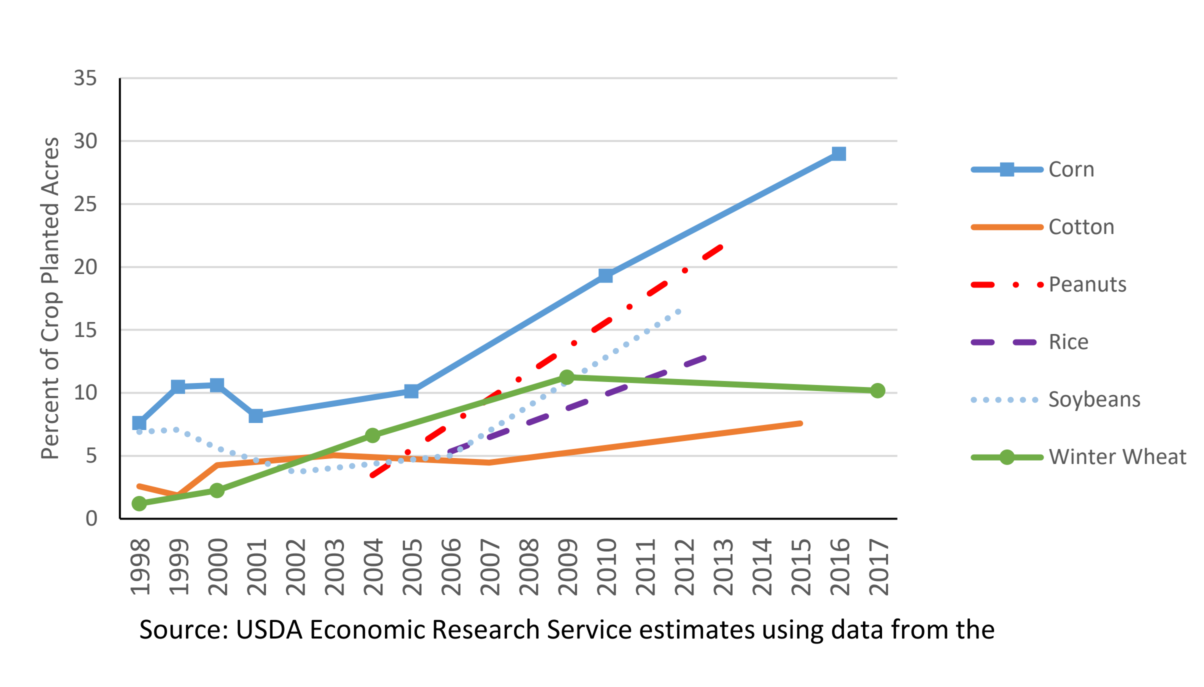


Figure 5: Adoption of fertilizer variable rate applications (VRT) (1998-2017)

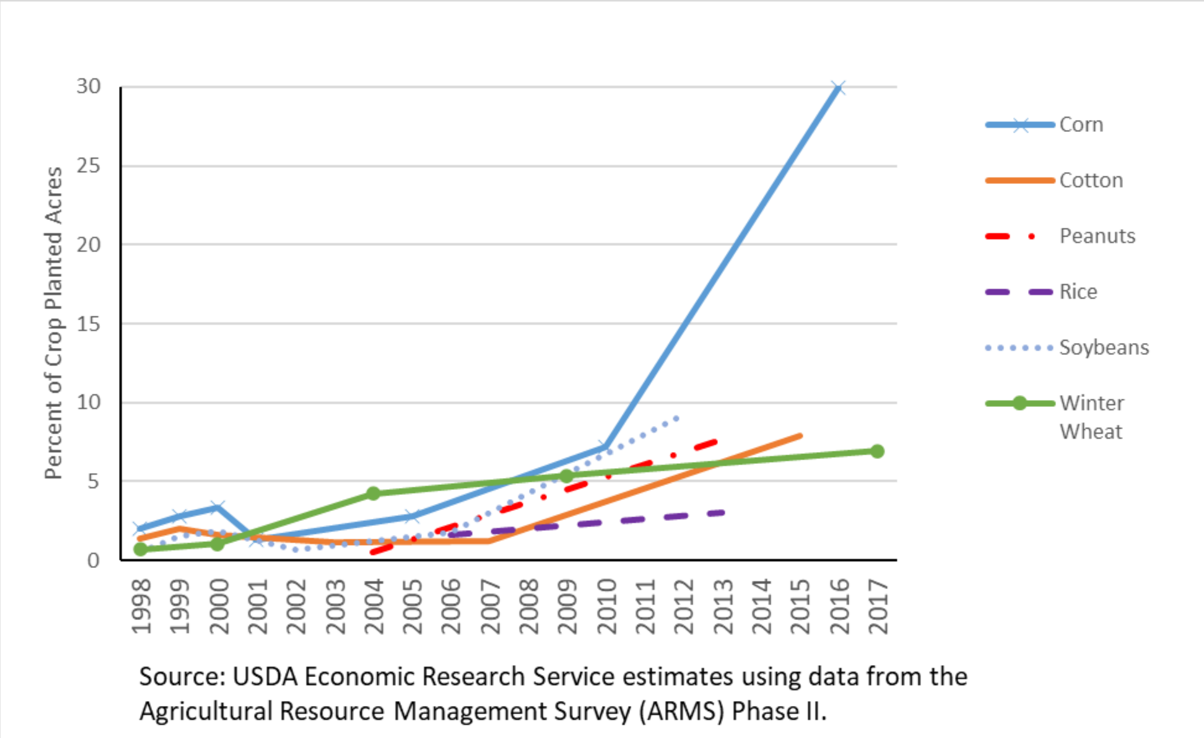
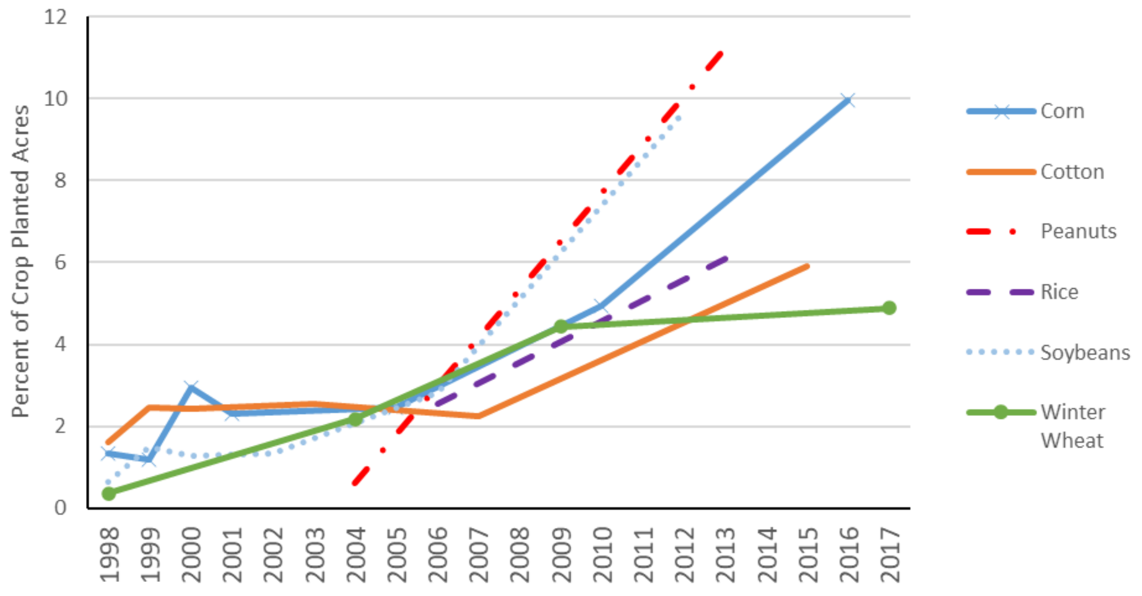


Figure 6: Adoption of seed variable rate applications (VRT) (1998-2017)



Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Figure 7: Adoption of pesticide variable rate applications (VRT) (1998-2017)

Guidance system use grew the fastest and reached the highest levels of any of the PA technologies across all the field crops (Figure 4, 0-70 percent adoption rates on axis). Guidance systems are now standard equipment on most new tractors and combines in the USA, and used equipment for sale often mentions "guidance ready" if a guidance steering system is not already operational. Adoption of guidance steering systems grew the fastest of all the PA technologies across all field crops, until the late 2000's when adoption in cotton production began to plateau.

In the data VRT fertilization (Figure 5, 0-35 percent adoption rates on axis) was the most popular field crop variable rate application with 30 percent of corn planted acres, and between 10 and 20 percent of peanuts, soybeans, rice and winter wheat planted acres. Over the last decade VRT seeding (Figure 6, 0-30 percent adoption rates on axis) rose dramatically in corn to 30 percent of planted acres, possibly reflecting the increased selection and price of stacked trait biotech corn seeds (McFadden, et al., 2018; Shi, et al., 2010). All of the field crops in the data period were using variable rate for pesticide applications on between 5-10 percent of planted acres (Figure 7, 0-12 percent adoption rates on axis). GPS yield and soil mapping started upward adoption trends in the early 2000's for most field crops, and VRT fertilizer and pesticide adoption followed in the late 2000's. Two factors probably contributed to this time lag. Mapping became easier on a wider range of computers. Also, VRT largely overcame reliability and ease-of-use difficulties after maps that help inform VRT became easier to create and interpret. This report investigated if the adoption slowdown of all three types of VRT for wheat was specific to farm sizes or growing regions.

Farm Types and PA Technology Adoption

Larger farms often have higher adoption rates for the PA technologies in the previous section. When the national percentage of crop planted acres using a PA technology is greater than the percent of farms growing that crop, it means that more of the larger farms are applying the technologies. In 2016 this was particularly true in corn production (top row of Table 1) with guidance systems showing 34 percent higher adoption when measured as acres planted (67 percent) over the percent of corn farms using guidance (33 percent). Guidance adoption for rice production in 2013 was also higher as percent of acres compared to percent of rice farms, but spatial information technology and VRT in rice production were the only exceptions on table 1 that showed percent of farms greater than percent of acres. This meant that at that time smaller rice farms had higher adoption rates for mapping and VRT than larger rice farms. Winter wheat and soybean farms were like corn farms in the sense that they had higher adoption rates on larger farms.

To help understand this relationship between larger farms and greater PA adoption (Table 1) the study considered farm characteristics in addition to farm size measured as acres planted. These additional characteristics were field sizes, number of fields per farm, and the region where the farm was located. Depending on the crop, larger farms may have more fields and more acres per field than smaller farms. Larger wheat farms have larger fields than similarly sized corn and soybean farms. In contrast, there were more fields on larger corn farms than on larger wheat farms. This means that farmers on larger corn farms have to contend with changing field conditions and more fields. Corn farmers would have to move their equipment between fields more often, compared to farmers on larger wheat farms. In addition to farm sizes, adoption rates also vary by production regions made up of states with similar growing conditions for each crop. In the following section remote sensing with satellites, aircraft and UAVs; soil maps created using GPS and yield mapping are together are referred to as "spatial information technology" and the three types of VRT are simply labeled "All VRT". Adoption of the three core PA technologies depends on farm characteristics for farms growing winter wheat, corn and soybeans and the details of these relationships appear in the next few sections. Wheat, corn and soybeans are the crops with the most recent, complete sets of data from ARMS.

In addition, soybeans have a soil variability measure that requires other sources of data discussed in Appendix A.

Table 1: PA technology use by crop, measured as percent of farms and percent acres planted

Crop Percent of Farms & Acres Planted	Spatial information technology	Guidance System	VRT
	Percent of farms adopting each technology		
Corn (2016)			
Percent of Farms	31%	33%	24%
Acres Planted	48%	67%	50%
Rice (2013)			
Percent of Farms	22%	52%	19%
Acres Planted	18%	61%	17%
Soybeans (2012)			
Percent of Farms	29%	34%	19%
Acres Planted	43%	52%	23%
Winter Wheat (2017)			
Percent of Farms	16%	41%	13%
Acres Planted	32%	61%	31%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Wheat Farm Types and PA Technology Adoption

Using data from the 2017 USDA ARMS survey of winter wheat growers, this section considered characteristics of winter wheat farms in each of the size categories and by growing region to investigate how PA adoption rates changed on larger winter wheat farms with more planted acres in different parts of the U.S. with different field sizes and numbers of fields. For each of the size classifications, winter wheat farms had about the same number of total acres planted (between about four and six million acres -- Table 2, col. 6). Note that the size categories were based on the wheat area planted, not on total farm area. What distinguished larger farms was their higher number of fields per farm (Table 2, col. 2) and higher average field acreage (Table 2, col. 3). In the largest size category, the average field size was 290 acres, which was larger than entire farms in the smallest category. There were over twice as many wheat fields in the smallest category of farms compared to any of the larger farm size categories because of the larger number of farms in the smallest category (Table 2, col. 4). The smallest farm category had almost six times as many farms as the next larger size category. The average number of fields per farm (Table 2, col. 5) was only 3 fields on the smallest farms and 20 on the largest farms that have over 3,000-planted acres. This meant that in the data period PA adoption seemed to favor larger average field sizes and more fields per farm in winter wheat production.

Table 2: Winter wheat acreage and number of fields per farm by planted acres[1]

Winter Wheat Acres Planted	Number of fields	Average Field Acreage	Number of Farms	Average Number of Fields/farm	Total Acreage Planted
		Total U.S. winter wheat for each size category			
Up to 250 acres	132,785	45.3	59,522	3	4,645,533
250 – 500 acres	49,066	102.3	10,174	5	3,889,682
500 – 1,000 acres	51,693	119.8	7,094	8	4,700,217
1,000 – 1,500 acres	34,574	161.8	3,510	10	4,536,421
1,500 – 3,000 acres	45,644	203.2	3,673	12	6,107,043
Over 3,000 acres	21,352	290.0	1,034	20	4,243,730

[1] Farm acres were all acres planted to winter wheat on the operation in 2017. Categories of acres planted created from Census NASS (2012) categories with adjustments to have similar numbers of acres of winter wheat in each category.

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

These wheat-farm size characteristics were important for PA adoption. A higher percentage of larger winter wheat farms (by acres planted) used spatial information technology. Specifically, farms that planted over 500 acres of winter wheat had higher adoption rates of yield maps (Table 3). Yield mapping appeared on almost four times the percentage of planted acres that used soil maps on farms over 3000 acres. Farms that planted over 1,000 acres of winter wheat had slightly higher adoption rates of soil maps. Only half as many acres used remote sensing images as had soil maps on large farms and the adoption rate was lower on small farms. From Table 2, the average field size on wheat farms over 250 acres in size was over 100 acres each field. Since each field on wheat farms in the sample tended to be large, and soil-map data collection required core sampling that was a labor and time-intensive activity, part of the explanation for the relative popularity of yield maps was that they used data collected during harvesting and did not require separate field operations.

For PA technologies used to carry out field operations, the highest adoption was on wheat farms over 1,500 acres (Table 4). Guidance system adoption showed a 12 to 15 percent increase on each farm size category up 3,000 acres where guidance reached a peak of 80 percent adoption. VRT fertilizer applications were higher than both VRT seeding and pesticide applications on all wheat farm sizes by acres planted. VRT fertilization was used on one-fifth of wheat acres on farms over 1,500 acres large. VRT pesticide applications were the least used, except on the largest farms, and still were used on only 9 to 15 percent of planted acres on farms over 1,000 acres. Even on the smallest wheat farms under 250 acres, guidance systems appeared on almost one-fifth of acres. These small wheat farms had average field acreages of only about 45 acres each (Table 2), but smaller fields often had irregular sizes and might have been easier to manage with GPS guidance.

Table 3: Adoption of spatial information technology for winter wheat by acres planted in 2017

Winter Wheat Farm Acres Planted	Yield Mapping	Soil Mapping	Remote Sensing
	Percent of farms adopting each technology		
Up to 250 acres	8%	2%	0.1%
250 – 500 acres	12%	4%	0.5%
500 – 1,000 acres	24%	3%	0.1%
1,000 – 1,500 acres	13%	5%	2%
1,500 – 3,000 acres	23%	6%	3%
Over 3,000 acres	29%	6%	3%
All Wheat Farms	15%	4%	1%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Table 4: Adoption of PA production technologies for winter wheat by acres planted

Winter Wheat Farm Acres Planted	Guidance System	VRT Seeding	VRT Fertilizer	VRT Pesticides
		Percent of farms adopting each technology		
Up to 250 acres	18%	2%	4%	1%
250 – 500 acres	35%	10%	11%	5%
500 – 1,000 acres	47%	6%	11%	3%
1,000 – 1,500 acres	59%	7%	10%	10%
1,500 – 3,000 acres	74%	17%	20%	9%
Over 3,000 acres	80%	11%	20%	15%
All Wheat Farms	61%	7%	10%	5%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

A central finding of this section was that regional patterns of PA technology adoption differed slightly from the larger farm, greater adoption relationship discussed. The West region (represented by data from Idaho, Montana, Oregon and Washington) had the largest wheat farms on average with over 580 planted acres each (Table 5), but not the highest adoption of yield maps. Farms in the Lower West and Western Midwest were smaller but still covered over 380 to 440 acres of planted wheat per farm and did not have the highest adoption of yield maps either. The Lower West was represented by data from Colorado, Oklahoma, and Texas. The Western Midwest region was represented by data from Kansas, Nebraska, North Dakota, and South Dakota. It was the Midwest region (represented by data from Illinois, Michigan, Missouri and Ohio) with average wheat farms of only 310 acres (less than one-quarter the number of acres in the other regions), that had the highest number of acres covered by yield mapping. Soil mapping was most popular in the Midwest and the West, and remote sensing use was highest in the West. Remote sensing using satellite, light aircraft and drones was used by only a small percentage of wheat farmers, but was more than three times more popular in the West than in other regions.

Field operations technologies (guidance steering, and all three types of VRT) were the most popular in the West, and guidance and VRT fertilization in the West appear on a higher percentage of wheat acres in the West than any of the types of spatial information technology in any region (comparing percentages on Table 5 to 6). The West had the largest average wheat-farm sizes partially explaining the popularity of guidance systems for navigating these large farms. Guidance and VRT pesticide applications appeared on the smallest number of acres in the Midwest, which had the smallest average wheat farms.

Table 5: Adoption of Spatial information technology for winter wheat by region in 2017

Winter Wheat Region	**Average Farm Size** (acres planted)	**Number of Farms**	**Yield Mapping**	**Soil Mapping**	**Remote Sensing**
			Percent of farms adopting each technology		
West (Idaho, Montana, Oregon, Washington)	587	8,324	17%	8%	3%
Lower West (Colorado, Oklahoma, Texas)	444	25,813	11%	2%	1%
Western Midwest (Kansas, Nebraska, N. Dakota, S. Dakota)	381	25,441	17%	2%	0
Midwest (Illinois, Michigan, Missouri, Ohio)	82	25,428	18%	5%	0.5%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Table 6: Adoption of PA production technologies for winter wheat by region in 2017

Winter Wheat Region	**Guidance System**	**VRT Seeding**	**VRT Fertilizer**	**VRT Pesticides**
	Percent of farms adopting each technology			
West (Idaho, Montana, Oregon, Washington)	58%	14%	22%	13%
Lower West (Colorado, Oklahoma, Texas)	35%	9%	11%	6%
Western Midwest (Kansas, Nebraska, N. Dakota, S. Dakota)	50%	4%	5%	3%
Midwest (Illinois, Michigan, Missouri, Ohio)	25%	4%	12%	2%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Corn Farm Types and PA Technology Adoption

Like the previous section, characteristics of corn farms in terms of numbers of fields and acreage planted in each field varied with farm size and growing region, and these farm structural factors varied systematically with PA adoption rates. The ARMS estimate showed that there were 122,000 total fields on 1,500 to 3,000 acre corn farms, and about 45,000 fields on corn farms over 3,000 acres (Table 7). This number of fields on large farms added up to about 12 million acres of corn on 1,500 to 3,000 acre corn farms, and about 5 million acres on farms over 3,000 acres. Larger farms over 1,000 acres had a total 27 million planted-acres and 36 percent of the total number of bushels of corn produced in the U.S. (Census of Agriculture, 2012 (2014)). This means that farms over 1,000 acres produced an average of 136 bushels per acre.

In contrast, there were a large number of small corn farms with under 250-planted acres. There were over 214,000 corn farms this size category in the U.S. (Table 7, col. 4). These farms had an average of four fields that were 34 acres each. On the largest corn farms with over 1,500 acres of corn, there were between 22 and 47 fields on each farm, and each field had between 115 to 157 acres of corn each (Table 7). Despite the small field sizes on farms with under 250-planted acres, there were over 18 million acres of corn on these small farms and they had almost 820,000 fields. These smaller farms produced about 20 percent of the total number of bushels of corn produced in the U.S. (Census of Agriculture, 2012 (2014)) and they produced an average of 108 bushels per acre. This means that farms with over 1,000 acres of corn produced an average of 26 percent more bushels per acre. The next few tables considered how high the percent adoption of precision technologies was on larger farms that were likely using PA to obtain some part of their 26 percent yield advantage over small farms.

Table 7: Corn farm acreage and number of fields per farm by acres planted[1]

Corn Farm Acres Planted	Number of fields	Average Field Acreage	Number of Farms	Average Number of Fields/farm	Total Acreage Planted
	Total U.S. corn for each size category				
Up to 250 acres	819,775	34.1	214,110	4	18,673,204
250 – 500 acres	363,668	65.6	45,765	8	17,686,343
500 – 1,000 acres	368,937	85.3	31,930	12	23,542,332
1,000 – 1,500 acres	135,156	96.1	8,228	16	10,484,076
1,500 – 3,000 acres	122,130	114.7	5,620	22	11,774,257
Over 3,000 acres	44,652	156.9	951	47	4,696,029

[1] Farm acres were all acres planted to corn on the operation in 2016. Categories of acres planted created from Census NASS (2012) with adjustments to match the categories used for winter wheat in the previous section.

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

A higher percentage of corn farms with over 1,000 planted-acres used GPS yield mapping than smaller U.S. corn farms (Table 8). Yield and soil mapping plateaued on 1,000-acre farms and remained at that level on the largest farms. On these larger farms, yield mapping was about twice as popular as soil mapping, while remote sensing was highest on the largest farms, over 3,000 acres (Table 8). Average field acreage on these largest farms was almost 160 acres per field (Table 7) and the benefits of remote sensing was higher on these very large fields. Yield maps were popular because they used geolocated data collected automatically during harvesting, and software helped farmers interpret year-to-year variation in mapped yield data. High and low yielding areas on a farmer's field fluctuate from one year to the next because of annual yield differences caused by changes in planting dates, moisture availability, and changes in cropping practices from one year to the next. Yields on different parts of a farmer's field do not respond equally to changes in these factors driving inter-annual yield variability.

For the field production technologies, guidance adoption increased steeply on larger farms. Only 9 percent of farms under 250 acres used guidance, while 70 percent or more of farms over 1,000 acres had the technology (Table 9). Guidance systems appeared on about twice the number of acres as VRT seeding and fertilizer applications, across all farm sizes

(Table 9). Guidance is popular for labor saving as well as field operation accuracy, and most new and used tractors and combines available for sale either have a steering system installed or are guidance ready. Once installed, these systems can be accurate to within a few inches in the field and seldom have technical problems. Farmers seem to appreciate the convenience of guidance and the freedom it provides to concentrate on other issues that arise during field operations. On farms up to 1,500 acres, VRT fertilization was the most popular variable input application technology, while VRT seeding had recently become the most popular VRT application on farms with over 1,500-planted acres. These farms had average fields over 100 acres each where conditions might to vary enough to warrant the use of more than one seed type in each field (Table 9). VRT pesticides appeared on 10-13 percent of corn planted acres on farms over 500 acres (Table 9).

Table 8: Use of remote images and mapping for corn by acres planted in 2016

Corn Farm Acres Planted	Yield Maps Created	Soil Mapping with GPS	Remote Sensing
	Percent of farms adopting each technology		
Up to 250 acres	11%	4%	0.7%
250 – 500 acres	27%	11%	2%
500 – 1,000 acres	45%	20%	3%
1,000 – 1,500 acres	60%	30%	6%
1,500 – 3,000 acres	59%	32%	5%
Over 3,000 acres	58%	30%	11%
All Corn Farms	45%	22%	8%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Table 9: Adoption of PA production technologies for corn by acres planted in 2016

Corn Farm Acres Planted	Guidance System	VRT Seeding	VRT Fertilizer	VRT Pesticides
	Percent of farms adopting each technology			
Up to 250 acres	9%	3%	6%	3%
250 – 500 acres	34%	13%	17%	4%
500 – 1,000 acres	53%	21%	32%	12%
1,000 – 1,500 acres	70%	33%	36%	13%
1,500 – 3,000 acres	71%	38%	34%	10%
Over 3,000 acres	78%	44%	40%	12%
All Corn Farms	59%	30%	29%	10%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

The most important regional finding of this section was that PA was important for corn production in the Midwest regardless of farm size. In the ARMS estimates there were more corn farms in the Midwest (about 168,000 farms, Table 10) than in the rest of the U.S. combined (139,000 farms). Even though the largest corn farms were in the Western Midwest (represented by Kansas, Nebraska, N. Dakota, S. Dakota, and Colorado, Table 10, col. 2) adoption of all three spatial information technologies (yield, soil, and remote sensing) was highest in the Midwest (represented by Illinois, Indiana, Iowa, Minnesota, Missouri, and Wisconsin). Soil mapping was almost as high in the South (represented by Georgia, Kentucky, N. Carolina and Texas) as in the Midwest probably because annual changes in yield maps were harder to interpret in the South, which has more marginal corn growing conditions than in the Midwest. In 2016 remote sensing using data from drones, light aircraft, and satellites was used on three percent of planted acres or less in all four U.S. corn regions (Table 10). Remote sensing could expand in the future as cost and data processing improves, especially on larger farms that often have slightly higher adoption rates for these technologies.

Table 10: Adoption of Spatial information technology for corn by region in 2016

Corn Growing Region	Average Farm Size (acres planted)	Number of Farms	Yield Mapping	Soil Mapping	Remote Sensing
			Percent of farms adopting each technology		
Midwest (Illinois, Indiana, Iowa, Minnesota, Missouri, Wisconsin)	282	167,708	33%	16%	3%
Western Midwest (Kansas, Nebraska, N. Dakota, S. Dakota, Colorado)	433	46,692	32%	10%	3%
South (Georgia, Kentucky, N. Carolina, Texas)	263	22,104	18%	15%	2%
Mid-Atlantic (New York, Pennsylvania, Michigan, Ohio)	193	70,101	17%	7%	1%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Table 11: Adoption of PA production technologies for corn by region in 2016

Corn Growing Region	Guidance System	VRT Seeding	VRT Fertilizer	VRT Pesticides
	Percent of farms adopting each technology			
Midwest (Illinois, Indiana, Iowa, Minnesota, Missouri, Wisconsin)	32%	14%	20%	7%
Western Midwest (Kansas, Nebraska, N. Dakota, S. Dakota, Colorado)	53%	23%	20%	6%
South (Georgia, Kentucky, N. Carolina, Texas)	34%	11%	19%	8%
Mid-Atlantic (New York, Pennsylvania, Michigan, Ohio)	18%	9%	10%	5%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

PA field operations technologies (guidance steering, VRT seeding and fertilization) were the most common in the Western Midwest, with VRT pesticide use the highest in the South which has high pest pressure partially due to warmer general weather conditions (Table 11). VRT fertilizer use in the Midwest and the South were about the same as in the Western Midwest appearing on about one-fifth of planted acres. Average corn farms in the Western Midwest had over 50 percent more planted acres than in other growing regions, and this was likely leading to higher adoption of guidance and VRT seeding and fertilization in the region. Table 9 showed that adoption of guidance and VRT was higher nationally on larger corn farms.

Soybean Farm Types and PA Technology Adoption in 2012

This section considered field and planted acreage characteristics of soybean farms in different size categories and growing regions, and extended the discussion of PA adoption in row crops to include a measure of the variability of soil productivity in soybean production by farm planted acres and region. Soil variability may contribute to PA adoption because maps can display soil variability that farmers can use to adjust their practices and VRT adjusts input applications to changing conditions. Ten farm-size categories by planted acres were used in this section instead of the six used for wheat and corn. An expanded number of size categories allowed consideration of adoption on smaller farms up to 150 acres. The smallest category in the previous analysis of corn was 250 acres, and over twice as many cornfields were in this category compared to any other. More size categories also allowed closer examination of larger soybean farms that have over 1,000 acres. These large soybean farms fell into six size-categories, where for corn and wheat there were three larger size categories. About half of U.S. corn farms reported also growing soybeans, so more size categories provided additional detail about both large and small farms in addition to the information in the corn section of this report.

The smallest soybean farms in the ARMS data (Table 12, 150 acres or less) had 14 percent of total U.S. soybean acres planted with over 10 million acres planted. The largest four categories (Table 12, over 1,700 acres planted) totalled less than this with 11 percent of planted acres (Census of Agriculture, 2012 (2014)). Larger farms operated many more soybean fields on each farm (Table 12, col. 5). There were over five times as many soybean fields on each farm over 2,900 planted acres in size, than on farms that operate 600 acres or less. The reason for this higher number of fields was that on all farms over 600 acres, average field size only varied between 53 and 82 acres each (Table 12, col. 3). Even though large farms had many fields per farm, there were a large number of fields on small soybean farms because there were so many smaller farms – over 429,000 fields on farms up to 150-acres in size (Table 12, row 1). This means that even with smaller average field sizes on farms up to 600 acres (24–56 acres, Table 12, col. 3) there were over 41 million acres of soybeans on farms of 600 planted acres or less, compared to 33 million acres on all farms over 600 acres.

Even though smaller farms have more acreage and fields planted overall, PA adoption in soybeans was the highest on larger farms that had fewer total acres in the national averages. A reason for this was that larger farms can apply the technologies to more acres on each farm. The highest adoption rates for all three information technologies was on farms of over 600 acres (Table 13). Among farm size classes, adoption of yield mapping peaked on farms with between 1,000—2,200 acres, and for remote sensing on farms of 1,000—1,300 acres. This meant that the highest adoption was on farms with fields that were on average between 66–82 acres each, and these were some of the largest soybean fields (Table 12, col. 3). The highest adoption of guidance was on farms with over 600 acres of soybeans planted (Table 14), and these farms had fields that peaked in size on 1,700—2,200 acre farms with 82 acres of soybeans on each field (Table 12, col. 3). The highest adoption of all VRT (seeding, fertilizer, and pesticides) was on farms over 1,300 acres. Peak adoption of VRT fertilization appeared on farms with 2,200—2,900 soybean acres, and VRT seeding and pesticides on the largest size category over 3,800 acre farms.

Table 12: Soybean acreage and number of fields per farm by acres planted

Soybean Farm Acres Planted[1]	Number of fields	Average Field Acreage	Number of Farms	Average Number of Fields/farm	Total Acreage
	Total U.S. soybeans for each size category				
Up to 150 acres	429,066	24.0	148,141	3	10,299,624
150 – 300 acres	278,964	44.2	49,351	6	12,326,047
300 – 600 acres	334,638	56.2	42,259	8	18,807,337
600 – 1,000 acres	191,398	66.9	17,303	11	12,808,269
1,000 – 1,300 acres	98,163	66.2	5,773	17	6,496,077
1,300 – 1,700 acres	68,119	73.6	3,317	21	5,013,141
1,700 – 2,200 acres	38,011	82.1	1,920	20	3,120,155
2,200 – 2,900 acres	30,676	78.2	969	32	2,398,604
2,900 – 3,800 acres	30,125	52.7	613	49	1,588,833
Over 3,800 acres	19,388	71.6	339	57	1,388,864

[1] Farm acres were all acres planted to soybeans on the operation in 2012. Categories of farm sizes created from Census NASS (2012) categories with adjustments for detailed analysis.

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Table 13: Use of remote images and mapping for soybeans by acres planted in 2012

Soybean Farm Acres Planted	Yield Map Created	Soil Mapping with GPS	Remote Sensing
	Percent of farms adopting each technology		
Up to 150 acres	6%	8%	4%
150 – 300 acres	17%	13%	7%
300 – 600 acres	25%	15%	7%
600 – 1,000 acres	35%	24%	9%
1,000 – 1,300 acres	36%	17%	14%
1,300 – 1,700 acres	42%	28%	10%
1,700 – 2,200 acres	37%	18%	8%
2,200 – 2,900 acres	24%	40%	13%
2,900 – 3,800 acres	28%	17%	5%
Over 3,800 acres	33%	36%	9%
All Soybean Farms	37%	21%	10%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Table 14: Adoption of PA production technologies for soybeans by acres planted in 2012

Soybean Farm Acres Planted	Guidance System	VRT Seeding	VRT Fertilizer	VRT Pesticides
	Percent of farms adopting each technology			
Up to 150 acres	16%	3%	8%	5%
150 – 300 acres	28%	4%	16%	7%
300 – 600 acres	38%	6%	14%	8%
600 – 1,000 acres	50%	6%	15%	7%
1,000 – 1,300 acres	57%	7%	13%	9%
1,300 – 1,700 acres	54%	14%	22%	12%
1,700 – 2,200 acres	51%	8%	13%	9%
2,200 – 2,900 acres	68%	9%	37%	7%
2,900 – 3,800 acres	41%	7%	13%	8%
Over 3,800 acres	54%	20%	16%	17%
All Soybean Farms	52%	9%	17%	11%

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Larger farms are more likely to adopt PA for field crop production for several reasons. PA requires investment in equipment, and the capital cost of equipment applies to more crop-producing acres on larger farms (Schimmelpfennig, 2016). Guidance often reduces input costs with improved application accuracy, and reduces operator stress and fatigue, and the savings are larger the more acres and driver hours required. Another factor in PA adoption was growing condition variability, and the next several tables below consider the impact of soil variability on PA adoption. Since in the ARMS data average field-size did not increase much on larger farms, and they had more fields per farm (Table 12, cols. 3 and 5) which would likely add to growing condition variability, with fields on a single farm more likely to be several miles or more apart.

Helping to understand associations between farm size in planted acres and PA adoption for soybeans, the study developed a measure of within-field variability in soil productivity for every soybean farm surveyed (Appendix A). Soil variability and crop growing regions were used together to investigate patterns of PA adoption along with farm size (Table 15). There was enough variation in the adoption patterns for different PA technologies that it was possible to consider some hypotheses (Table 15, col. 4) for these patterns. Regional average farm size and regional soil variability for soybean production were different, making it possible to consider some adoption hypotheses to add to the larger farm, higher adoption pattern already discussed. The soil variability measure came from the National Commodity Crop Productivity Index (NCCPI) adapted to the ARMS data. The NCCPI is USDA's (Natural Resources Conservation Service) standardized measure from soil surveys of the productivity of soils for producing dryland commodity crops in different parts of the U.S. Appendix A describes the construction of a soil variability index from NCCPI data for each farm surveyed. The soil variability index ranges between 0.03 (least variable) and .98 (most variable) on U.S. soybean farms with a mean of 0.56, median of 0.62 and standard deviation of 0.17. Table 15 shows that the largest average farm sizes were in the South that also had the second lowest average variability. The lowest variability was in the West that had farm sizes closer to the Midwest. The Midwest had the highest soil variability. For farm classification purposes in this study high soil variability (h.s.v.) was a soil variability index above the median (0.62). Low soil variability (l.s.v.) was a soil variability index below the median.

These patterns of regions and soil variability suggested that different PA technologies might be favored in different regions, for different reasons than planted-acre farm size alone. VRT use might be the highest on the most variable soil because the technology allows farmers to change input application levels when growing conditions change. Soil maps may be favored on variable soil when farms are not too large, but less adopted on larger farms because of the investment required in soil testing. Results for PA adoption in wheat production, discussed above, showed that soil mapping adoption dropped on the largest farms, probably because of the labor and investment required to create a soil map on large farms. The Eastern and Great Lakes regions have the smallest average farms, and the second most variable soil, potentially favoring soil mapping. Guidance would likely be favored in regions like the South and West that have the largest farms and less by soil variability. These predictions (Table 15, col. 4) provided a framework for the interpretation of regional adoption and soil variability results presented next.

Table 15: Soybean farm types by region

Soybean Region (State average soil variability)[1]	**Average Farm Size** (acres planted)	**Regional Average Soil Variability**	**Favored Technology Hypothesis**
Midwest – Illinois (.7), Indiana (.6), Iowa (.8), Minnesota (.6), Missouri (.6)	250	0.67	VRT
East -- Kentucky (.6), Ohio (.6), Virginia (.5)	225	0.58	Soil Maps
Great Lakes -- Michigan (.6), Wisconsin (.6)	150	0.57	Soil Maps
South -- Arkansas (.5), Louisiana (.4), Mississippi (.4), N. Carolina (.6), Tennessee (.5)	760	0.50	Guidance
West -- Kansas (.5), Nebraska (.6), N. Dakota (.3), S. Dakota (.4)	300	0.46	Guidance

[1] Soil variability index ranges between 0.03 (least variable) and .98 (most variable) on U.S. soybean farms with a mean of 0.56, median of 0.62 and standard deviation of 0.17. Index calculated from the National Commodity Crop Productivity Index (NCCPI) on Common Land Units (CLU), approximating farmer's individual fields within a 3-kilometer radius. Surveyed farmers cannot be asked, by law, to reveal the geo-located boundaries of the individual field used for survey responses. See Appendix A for details.

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

The adoption predictions of technologies potentially favored were supported in some cases and not in others for probably the same, simple explanation. Spatial information technologies (yield maps, soil maps, and remote sensing) were the most popular in the Midwest and Great Lakes regions, and not in the East (Table 16). The explanation for the popularity of spatial information technologies in the Midwest being higher than predicted (Table 15) could be that Midwest farmers had been using maps for another crop, like corn, which was less prevalent in the East where the prediction was it would be higher. Guidance was higher in the Midwest and West, followed by the South (Table 17) which had the highest average farm sizes. The Midwest did not have large average farm sizes, so guidance might have been used in the

Midwest for the same reason as spatial information technology – its use in corn production. Even though guidance was not high in the Midwest for corn, many farms grow both corn and soybeans, and the technology would benefit both crops. VRT fertilizer was highest in the Midwest as predicted from its farm size and soil variability characteristics (Table 17), followed by the East and Great Lakes that also had relatively high soil variability.

Table 16: Adoption of PA for soybeans by region in 2012

Soybean Region (State average soil variability)[1]	**Guidance System**	**VRT Seeding**	**VRT Fertilizer**	**VRT Pesticides**
	Percent of farms adopting each technology			
Midwest – Illinois (.7), Indiana (.6), Iowa (.8), Minnesota (.6), Missouri (.6)	41%	4%	16%	7%
East -- Kentucky (.6), Ohio (.6), Virginia (.5)	24%	5%	15%	6%
Great Lakes -- Michigan (.6), Wisconsin (.6)	22%	7%	15%	10%
South -- Arkansas (.5), Louisiana (.4), Mississippi (.4),N. Carolina (.6), Tennessee (.5)	27%	6%	10%	6%
West -- Kansas (.5), Nebraska (.6), N. Dakota (.3), S. Dakota (.4)	42%	7%	9%	7%

[1] Soil variability index ranges between 0.03 (least variable) and .98 (most variable) on U.S. soybean farms with a mean of 0.56, median of 0.62 and standard deviation of 0.17. Index calculated from the National Commodity Crop Productivity Index (NCCPI) on Common Land Units (CLU), approximating farmer's individual fields within a 3-kilometer radius.

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Table 17: Adoption of PA production technologies for soybeans by region in 2012

Soybean Region (State average soil variability)[1]	**Yield Mapping**	**Soil Mapping**	**Remote Sensing**	**Technology Prediction** (from table 15)
	Percent of farms adopting each technology			
Midwest – Illinois (.7), Indiana (.6), Iowa (.8), Minnesota (.6), Missouri (.6)	27%	19%	8%	VRT
East -- Kentucky (.6), Ohio (.6), Virginia (.5)	16%	14%	5%	Soil Maps
Great Lakes -- Michigan (.6), Wisconsin (.6)	19%	15%	6%	Soil Maps
South -- Arkansas (.5), Louisiana (.4), Mississippi (.4), N. Carolina (.6), Tennessee (.5)	10%	14%	6%	Guidance
West -- Kansas (.5), Nebraska (.6), N. Dakota (.3), S. Dakota (.4)	21%	10%	7%	Guidance

[1] Soil variability index ranges between 0.03 (least variable) and .98 (most variable) on U.S. soybean farms with a mean of 0.56, median of 0.62 and standard deviation of 0.17. The index calculated from the National Commodity Crop Productivity Index (NCCPI) on Common Land Units (CLU), approximating farmer's individual fields within a 3-kilometer radius.

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Adoption of Combinations of PA Technologies on Soybean Farms

To consider adoption of combinations of technologies it was useful to convert percent of acres to percent of farms, and combine yield and soil mapping into one variable called "GPS mapping" for simplicity. Any farm with either type of maps was included once. Remote sensing with satellites, aircraft or drones was not considered in this section. Likewise, "All VRT" included technology for seeding, fertilization, and pesticide applications. Adoption rates per farm for the resulting three PA technologies rose from 2006 to 2012 (Figure 8). Adoption rates of GPS maps probably rose faster than VRT because maps used to program VRT equipment could also help evaluate other production practices like uniform seeding rates, and fertilizer and pesticide applications besides VRT. GPS maps also provided the information necessary to evaluate the suitability of VRT itself for a specific soybean farm.

Increases in adoption of combinations of PA technologies per farm was striking (Figure 9). Soybean farm guidance adoption when GPS maps were in use more than doubled to 65 percent in 2012 from the level in 2006; VRT when maps were in use only rose to 40 percent in 2012. Guidance only requires field boundaries and does not require a complete GPS map for positioning and operation, and the implication was that GPS maps were crop-production management tools by themselves because the use of guidance with maps was greater than the use of VRT with maps. Guidance systems alone were used on 34% of all soybean farms (in 2012, Figure 8). VRT showed similar dramatic connections to the other technologies. When VRT was in use (right side of Figure 9), guidance adoption was on over 60 percent of farms in 2012, up from 23 percent in 2006. GPS map use with VRT only grew to 62 percent of farms from 40 percent in 2006. These percentages showed that GPS maps can inform both VRT adoption and non-adoption, as 20 percent fewer mappers adopt VRT (40 percent in 2012) than VRT users adopt mapping (62 percent in 2012).

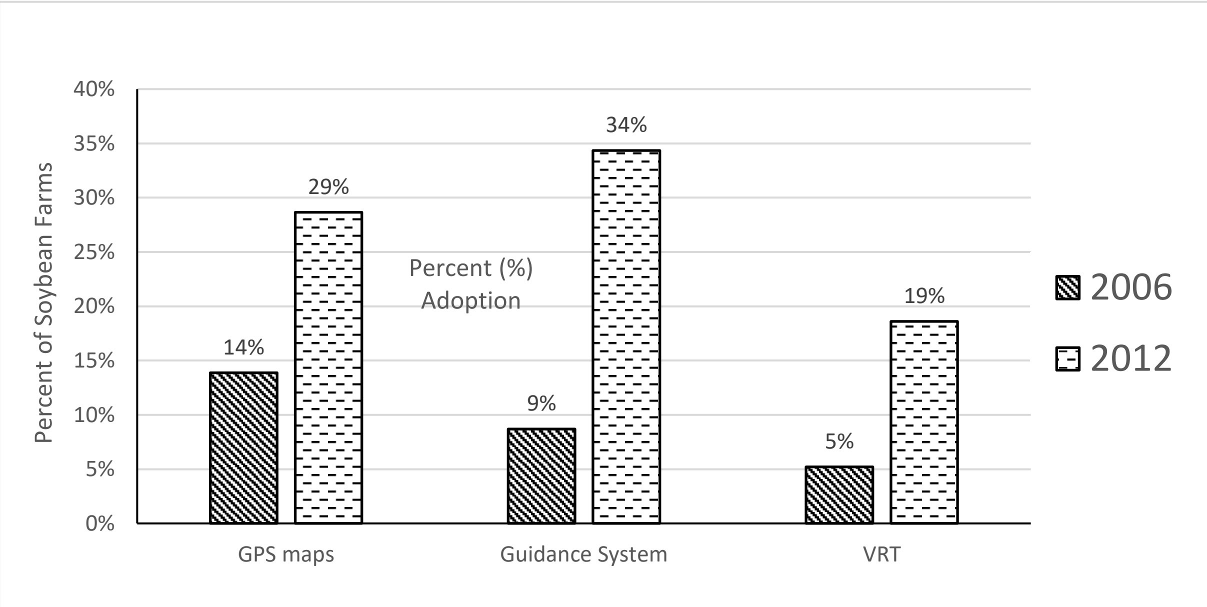


Figure 8: PA technology adoption by percent of soybeans farms (2006 to 2012)

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

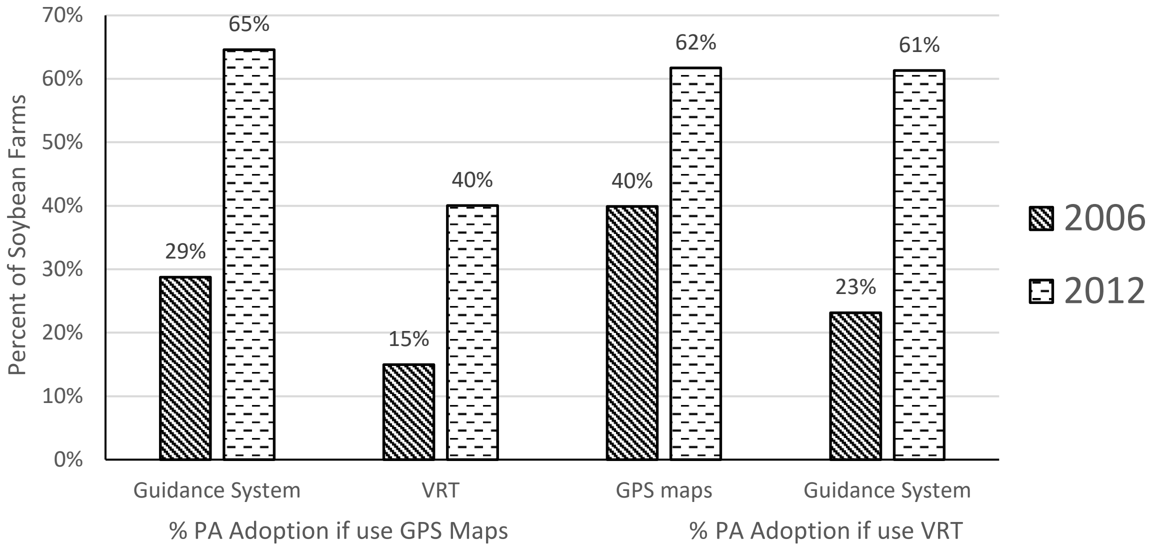


Figure 9: Adoption of pairs of PA technologies (2006-2012)

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Another way to exploit the information on the variability of farm soil productivity was to examine PA adoption and soil variability by farm size in planted acres. Farms with more variable soil conditions usually have a larger range of conditions for different crop management approaches. Each surveyed farm had one measure of soil variability for their representative field. Details on the calculation of the variability measure are found in Appendix A. PA adoption on farms with higher than average soil variability was compared to adoption on farms with lower than average soil variability. PA adoption rates was consistently lower for farms with under 300 acres (Tables 13 and 14), so on table 18 the smallest farm size category was up to 600-planted acres. GPS yield and soil mapping was favored by farms with higher soil variability (h.s.v.) in seven of the eight farm size categories. Soil variability influences GPS map use because farmers with more variable land can locate transition boundaries from one type of soil to another more easily using a GPS map, and this can help them make adjustments in production practices in the field.

VRT was favored by farms with h.s.v. in six of the eight size categories. This indicated that smaller farms under 1,700 acres made greater use of VRT as long as they had h.s.v. This means that the capital cost to use VRT was not as limiting a factor as the national VRT farm size adoption rates seemed to indicate (shown on table 14, with VRT split into seeds, fertilizer and pesticides). Both of the two size categories with lower soil variability (l.s.v.) and greater adoption of VRT are larger farms over 1,700 acres. Larger farms adopted VRT more often in the national averages (Table 14). Guidance systems did not have a consistent adoption pattern with soil variability. Four of the size categories had higher adoption on h.s.v. and four on l.s.v. farms. Guidance was more common than mapping or VRT on l.s.v. farms in all size categories. This higher guidance adoption rate on l.s.v. farms reflected the national averages noted on Table 14, indicating that guidance adoption was less dependent on soil variability than the other technologies for soybeans.

Table 18: Adoption of PA technologies for soybeans by level of soil variability in 2012

Soybean Farm Acres Planted[1]	GPS Soil and Yield Mapping	Guidance System	All VRT
	Percent of farms adopting each technology		
Up to 600 acres and low/high soil variability (l.s.v./h.s.v.)[2]	18/24%	24/27%	13/18%
600 – 1,000 acres, l.s.v./h.s.v.	29/52%	43/51%	12/27%
1,000 – 1,300 acres, l.s.v./h.s.v.	42/45%	62/53%	21/26%
1,300 – 1,700 acres, l.s.v./h.s.v.	28/75%	44/65%	18/41%
1,700 – 2,200 acres, l.s.v./h.s.v.	31/62%	55/45%	20/16%
2,200 – 2,900 acres, l.s.v./h.s.v.	36/74%	60/77%	32/52%
2,900 – 3,800 acres, l.s.v./h.s.v.	37/29%	50/35%	19/18%
Over 3,800 acres, l.s.v./h.s.v.	25/84%	67/41%	18/45%

[1] Farm acres were all acres planted to soybeans on the operation in 2012. Low soil variability (l.s.v.) farms have a lower than median distance-weighted soil variability index, and high soil variability (h.s.v.) have a higher index. Soil index construction discussed in Appendix A.

[2] High and low soil variability calculated from the National Commodity Crop Productivity Index (NCCPI). The index is measured on Common Land Units (CLU), which approximate farmer's individual fields within a 3-kilometer radius. Surveyed farmers were not asked, by law, to reveal the geo-located boundaries of the individual field used for survey responses.

Source: USDA Economic Research Service estimates using data from the Agricultural Resource Management Survey (ARMS) Phase II.

Conclusions

Adoption of precision agriculture (PA) Global Positioning System (GPS) mapping, guidance, and variable rate input application technologies (VRT) have generally risen since about 2010 in the U.S. These crop production technologies assist farmers by collecting, organizing, and applying farm data to production decision making. GPS maps of crop yields and soil characteristics can help guide production practice choices, guidance systems autonomously steer tractors and combine harvesters with inch-by-inch accuracy, and VRT can apply site-specific amounts of inputs that change as field conditions change. These PA information technologies help farmers increase farm production through intensive management of farm production inputs to reduce costs or increase profits, or both. Data from the Agricultural Resource Management Survey (ARMS) showed that these PA technologies have appeared on increasing numbers of farms and crop planted acres in field crop production. GPS soil mapping appeared on 15 to 25 percent of planted acres, guidance on 40 to 60 percent of planted acres, and VRT fertilization on 10 to 30 percent of planted acres for major U.S. field crops.

This study provided three main sets of results showing how the use of these technologies varied across crop growing regions and farm sizes measured as planted acres in fields of varying sizes and number of fields per farm. There was a separate set of results for winter wheat, corn, and soybeans, with levels of variability in soil productivity investigated for soybeans. Even though the West region had the largest average sized wheat farms, and PA was usually more common on larger farms, more wheat farms in the Midwest had yield mapping. Soil mapping for wheat production was popular in the Midwest and the West. Field operations technologies (guidance and all three types of VRT) were on the most wheat planted acres in the West, while guidance and VRT pesticide applications appeared on the smallest number of acres in the Midwest.

The largest corn farms were in the Western Midwest and these farms had about 50 percent more acres of corn each than farms in the Midwest or the South. The highest adoption of yield and soil mapping was in the Midwest, while guidance and VRT seeding were higher in the Western Midwest. VRT fertilization was at about the same level in the Western Midwest, Midwest, and South reaching about one-fifth of planted corn acres in these regions. The use of guidance was at 70 percent or higher of planted acres nationally, on farms with over 1,000 acres of corn. The use of VRT for pesticide applications was highest in the South where pest pressures are likely to be the highest.

Regional patterns of PA adoption in soybean production depended on soil variability and farm size by planted acres. The Midwest showed the highest soil variability and the highest adoption of all three spatial information technology technologies; yield mapping, soil mapping, and remote sensing. Guidance use was highest in the West, the Midwest, and the South, the three regions with the largest average farm sizes. VRT fertilizer use was highest in the Midwest that had the highest soil variability, followed closely by the East and Great Lakes that had the next highest soil variability. Guidance use was often the technology most influenced by farm size in planted acres, but the South with the largest soybean farms was only the third highest user of guidance.

The basis for the increasing popularity of PA technologies across crops, regions, soil productive variability, and farm sizes was that better information improved crop production-management decisions over a range of growing conditions. The analysis in this report indicated that in the future, as farmer access to their production data increases, along with the availability of new technologies and easier-to-use existing technologies, PA will likely spread across farm types. Larger farms have been the biggest beneficiaries of PA, but adoption may become more heavily influenced in the future by regional characteristics of crop production and soil productive variability in the region. Sensor technologies for crop plants and soil, as well as internet devices that collect and process more data, and produce crop practice recommendations in real-time, will increase the effectiveness of farmer investments in PA under a range of conditions, for a number of field crops. Farm equipment has traditionally been labor saving and in the future it may add new capabilities to monitor and troubleshoot production problems for a larger number of farmers while working in the field.

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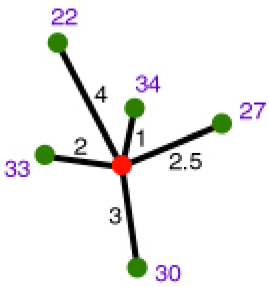
Appendix A – Measuring Individual Farm Soil Variability, a Geospatial Analysis

In-field soil variability for the 2012 ARMS individual farmer soybean-survey locations came from the National Commodity Crop Productivity Index (NCCPI). This index gave data on Common Land Unit (CLU) fields within a three-kilometer radius from each survey location, that were based on 2014 CLU measurements. ARMS survey locations were spatially inaccurate, by design, to protect the individual identity of surveyed growers, and therefore a direct intersection of survey locations with CLU soybean fields would not yield reliable data on the variability of soil productivity for the ARMS survey field. Average local soil variability comes from CLU data on soybean fields within three kilometers of the survey location, without using the exact coordinates of the field. CLUs are spatial units with data on fields planted in either corn or soybeans around the same time as the ARMS survey.

After compiling summary statistics for all the NCCPI corn/soybean data that have CLU locations near each survey location, the data showed the characteristics of soybean fields within three-kilometers of each survey location. The statistics used included mean, standard deviation, and coefficient of variation of the NCCPI. To assign a soil variability measure to each surveyed field without knowing its exact location, an inverse distance-weighted (IDW) average interpolated a local soil variability value from among the local CLU fields giving closer CLUs more weight than further CLUs from the survey location.

The IDW was calculated from the sum of all local individual corn/soybean field means divided by their respective squared distances from the survey point, which was further divided by the sum of one divided by all local individual corn/soybean field distances from the survey point. For example, in the following graphic, 34, 33, 27, 30, and 22 would be the mean NCCPI values of the local fields, with higher values having greater soil productivity variability, and 1, 2, 2.5, 3, and 4 would be distance units (not kilometers) to those fields, less than or equal to three kilometers. The IDW used one over the distance squared as the denominator to create a nonlinear distance weight that gave more weight to closer corn/soybean fields, and diminishingly less to the further ones up to the three-kilometer limit.



$$Z(x) = \frac{\Sigma w_i z_i}{\Sigma w_i} = \frac{\frac{34}{1^2} + \frac{33}{2^2} + \frac{27}{2.5^2} + \frac{30}{3^2} + \frac{22}{4^2}}{\frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{2.5^2} + \frac{1}{3^2} + \frac{1}{4^2}} = \mathbf{32.38}$$

Source: Penn State Department of Geography: https://www.e-education.psu.edu/geog486/node/1877