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Economics of Precision Agricultural Technologies Across the Great Plains

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ABSTRACT

Precision agricultural technologies, such as guidance systems and automatic section controllers, have given farmers the ability to more effectively apply crop inputs such as fertilizer, pesticides, and seed. More efficient use of inputs often can be translated into higher yields and/or lower costs, but the costs and benefits likely vary across regions. Our research incorporates over 500 real-world cropland fields from farms in Colorado, Kansas, and Nebraska to help answer the research question: What are the economics of investing in guidance systems and automatic section controllers for sprayers, and how do these vary across different regions of the Great Plains?

Introduction

Precision technologies in agriculture have given farmers the ability to more effectively apply crop inputs such as fertilizer, pesticides, and seed. More efficient use of inputs often can be translated into higher yields, lower costs, and/or greater environmental benefits. Over the past decade, the adoption and uses of different precision agricultural (PA) technologies among producers and commercial agricultural businesses have been steadily increasing (Whipker & Akridge, 2009). However, a survey in 2009 revealed that only 30 percent of respondents actually believed that the benefits of PA services were greater than the costs (Whipker & Akridge, 2009). Clearly, questions remain regarding the usefulness and cost-effectiveness of certain PA technologies. In part, this may be due to the challenging task of properly quantifying the economic benefits and costs associated with adopting these technologies. This paper provides the framework and analyses necessary for estimating the private economic impact of adopting two technologies for agricultural sprayers: guidance systems and automatic section controllers (ASCs). More specifically, this analysis examines the impact of farm size (number of acres covered for field operations) and field characteristics (i.e., size and shape) on the returns to investment in these technologies. Real-world field data are used which allow for economic comparisons across several regions in the Great Plains.

For long-term business sustainability it is important to recognize which management and farm characteristics determine relative differences in farm profitability among producers. Past research has shown that much of the differences between high- and low-profit farm enterprises can be traced to machinery cost advantages (Dhuyvetter & Smith, 2010). Further, machinery costs were found to be very persistent across years relative to other profit-driving factors such as crop prices and crop yields. Because of the persistent nature and relative importance of machinery costs, machinery management is one of the areas where producers should focus their efforts to improve their relative profit positions. Adopting new machinery technologies is an important way that farm managers lower their machinery costs to distinguish themselves from others for the purpose of increasing profit.

Guidance Systems and Automatic Section Controllers

Guidance systems provide a means to precisely apply crop inputs. In a basic form, this may be as simple as a mechanical marker on a planter or foam marker on a sprayer. Guidance systems reduce the amount of overlap and/or skips within the field. Over the past 10-15 years, more sophisticated guidance systems have been developed; these systems rely on satellite-based global positioning systems (GPS) and provide more accuracy than the mechanical methods. A GPS gives the current location of the implement and past traffic patterns, providing direction to maintain proper swath width to match adjacent traffic pattern (Groover & Grisso, 2009). Autoguidance systems have an auto-steer component synchronized with the precision guidance system to automatically and precisely steer the machinery. GPS guidance systems can range in price from less than $2,000 for a light bar navigation system with an accuracy of approximately 12inches to nearly $40,000 for a real time kinematic (RTK) autoguidance system with less than one inch accuracy (Groover & Grisso, 2009). Groover and Grisso (2009) estimated a range in savings of two to seven percent (with an average of 5%) in input costs due to GPS guidance systems.

Automatic section control, or auto-swath technology, turns machine sections OFF in areas that have been previously covered or ON and OFF at headland turns, point rows, terraces, waterways, and other areas marked for no-application of nutrients, pesticides, or seed (Fulton et al., 2010a). ASC technology utilizes a user-defined map for location of the predefined no-application areas and for keeping the implement from over-applying in the headlands. ASC technology can be adapted to crop sprayers in either an individual nozzle or section (a set of nozzles) fashion. Planters with ASC technology usually have the automatic controllers on individual rows. The cost for these technologies generally starts around $2,000 for an eight-row planter (or approximately $250/row) but depends upon existing technology and equipment already being used. A study at Auburn University indicated input savings from one to twelve percent for each pass across a field when using ASC on a planter or sprayer (Fulton et al., 2010b). This study indicated that on average a 4.3 percent savings on input costs could be observed for a farm with a payback of around two years. If the savings due to GPS guidance were included, the total cost savings could be in the 20 to 30 percent range. The authors noted that cost savings are dependent upon field shape and size.

Batte and Ehsani (2006) provided private economic benefit estimates of guidance systems combined with ASC for agricultural sprayers. They found that the value derived from these technologies can be substantial when sprayer patterns become more complex due to non-rectangular fields and due to the presence of waterways, and as input (e.g., chemical) costs increase. Further, economies of scale exist, which is to say that the net benefits of precision spraying increase with increased farm size.

Batte and Ehsani (2006) considered three different 100 ac. field shapes: a rectangular field; a parallelogram with field ends that were 10 degrees off perpendicular; and a trapezoid. While the analysis was very rich, the real-world usefulness is somewhat limited due to the fact that most fields do not fall neatly into one of the aforementioned geometric shape categories. Our study builds upon and extends the Batte and Ehsani (2006) paper by using actual field sizes and shapes for different regions in the Great Plains.

Shockley et al. (2011) and Shockley et al. (2012b) demonstrated that auto-steer technologies can influence machinery selection and replacement decisions, increase net returns, and reduce production risk. Shockley et al. (2012b) utilized a machinery management mixed integer programming model to analyze hypothetical farmer scenarios to reveal the importance of auto-steer in machinery and land management decisions. While these studies are quite comprehensive, alternative field sizes and shapes were not included in their analyses.

Shockley et al. (2012a) examined the effects of various field types and navigational scenarios to determine the impact of ASC. More specifically, the researchers chose four fields and two implement widths to reflect the influential attributes critical in determining the profitability of ASC. They concluded that smaller field sizes resulted in greater potential for profitability and that field shape becomes less important as the field area increases.

Our research builds and extends upon Shockley et al. (2012a) by examining the profitability of both guidance and automatic section controllers. Further, our research incorporates over 500 actual crop fields from farms in Colorado, Kansas, and Nebraska to help answer the research question: What are the economics of investing in guidance systems and ASC for sprayers, and how do they vary across the Great Plains?

Methods

Before discussing the details of the analysis, it is necessary to understand the tangible effects of having GPS guidance and ASC technologies. Using Figure 1, consider an operator who is spraying and begins by making two passes around the perimeter of the field. Without guidance technologies, there will be some amount of overlap between the two passes as shown in Figure 1. This results in a reduction of machine operation efficiency as well an over-application of inputs on the overlapped portion of ground. Thus, the economic effects of overlap are two-fold: an over application of inputs; and a loss of machine efficiency, thus an increase in machine cost. Additionally, there could be lost crop yield due to overlap of chemicals. Guidance has the potential to reduce this amount of overlap in the headlands as well as in the pass-to-pass trips throughout the rest of the field.

Now consider the sprayer as it approaches the headlands at some angle less than 90 degrees, as in Figure 1 (which will be the case in a non-rectangular field). Without section control capabilities, the operator will not turn off the applicator until the very last nozzle on the far right of the boom reaches the headlands. This results in an over-application of inputs across area A. Further, assuming the operator does not have perfect reaction time, there also will be over-application on area Q. Section controllers have the potential to eliminate some if not all of this over-application of inputs. As one can see from the diagram, the angle of approach plays a key role in determining the amount of over-application that can be avoided with section control technologies. The machinery and field data determine the areas and distances shown in Figure 1, which play a major role in the ensuing economic analyses. These important values were calculated as shown in Appendix A.

The reductions in overlap are determined from the *Guidance and Section Control Profit Calculator – Excel Version* (Dhuyvetter et al., 2010). This decision-tool estimates the overlapped area in a particular field using the equations above along with several user-identified parameters. It is assumed that field work is done using straight parallel paths in which overlaps occur due to encroachment in the headlands and in the pass-to-pass trips in the field.

Investing in PA systems can result in reduced input costs and yield revenue savings as well as machinery cost savings. Yield revenue savings from PA systems may be more or less significant depending upon cropping rotations. For example, over-application of atrazine on grain sorghum in one year may have a deleterious impact on yields of the following crop (e.g., yellow peas), whereas over-application of glyphosate in one crop will not have detrimental impacts on the following crop. Because of the wide variability in potential effects on yields, yield revenue savings are assumed to be zero for this analysis. Yield reductions due to over-application of inputs are likely a larger issue for planters with crops, such as corn, that can be sensitive to plant population.

A partial budgeting approach will be used to estimate the annual net benefits, payback, and return on investment (ROI) in guidance and ASC for a sprayer. With partial budgeting, profitability is calculated as the difference in revenues and costs for the two alternatives (Batte and Ehsani, 2006). Here, it is the difference between the non-precision and precision spray systems.

Data

The field data for this analysis come from farms located in Colorado, Kansas, and Nebraska. As part of a course project, 40 students in Fort Hays State University's "Technology in Agriculture" (AGRI 400) course provided detailed information regarding field size and shape for 553 crop fields totaling 49,095 acres. The students were asked to define field boundaries and calculate certain metrics of interest for a minimum of 10 fields for their farms. They were instructed to choose fields that are representative (in terms of size and shape) of all of the fields in their operation. For example, if approximately 20 percent of the fields on their farm are center pivots, then 2 of the 10 fields analyzed should be circular fields. If approximately 40 percent are rectangular or square, then 4 of the 10 fields analyzed should be of these shapes. Finally, if 40 percent of their fields are "irregular" shaped, then 4 of the 10 fields analyzed should be "irregular" shaped. For "square" shaped fields, students were instructed to include ¾ of the perimeter distance (3 of the 4 sides) as the "running distance of headlands" value. This is because no field is ever perfectly square. And, because even square fields typically involve a partial swath as the last swath. The individual field data metrics were calculated via Farm Works Mapping software and consisted of: field size; maximum width perpendicular to direction of travel; and running distance of headlands to cover the field. Figure 2 displays the particular measurements for an individual 40.18-acre field and the calculated average angle of approach of 37.5 degrees.

Field data are divided into USDA crop reporting districts (Figure 3). Thirteen districts are represented by the data across the three states including all nine Kansas districts, three Nebraska districts, and one Colorado district (Table 1). All districts include a minimum of 10 fields and 441 acres. (From this point forward, abbreviations for crop reporting districts will be used. Abbreviations include the directional attribute (e.g., southeast = SE) followed by the two-letter state abbreviation (e.g., Colorado = CO)). The greatest amount of data are from NWKS, where there are information on

132 fields representing 11,251 acres. Field size varies widely across districts. For example, only 15 fields from SECO are documented, but these fields represent nearly 5,000 acres, whereas there are 24 fields from SEKS totaling 455 acres.

For this analysis, measurements from a single "representative" field are needed. Therefore, acre-weighted averages across the fields in each district will be used to calculate the measurements for a "representative" field. This method gives more weighting to the larger fields because a typical field-acre comes from a larger field. Thus, the weighted average field size for NCKS is 153 acres with 2,564-foot maximum width and 15,278-foot of headlands (Table 1). The fields in this district tend to be quite "irregularly" shaped, which is evidenced by an average angle of approach of 19.6 degrees. This compares to an average angle of 39.3 degrees for WCKS where fields appear to be less "irregular" in nature.

In order to pinpoint the effects of field size and shape, NWKS data are first compared to several standard geometric shapes (other crop reporting districts will be brought in later). An acre-weighted average field size of 135.3 acres is treated as the base, and the other measurements are calculated for a perfectly square field, a circular field, and an equilateral triangular-shaped field (Table 1). While the probability of a farm consisting of entirely square fields (or circles or triangles, for that matter) is very low, this field type is included as the best-case, most efficient scenario. The circular field is representative of center-pivot irrigated fields. And, the equilateral triangle scenario is between a square and circle in terms of average angle of approach.

The following analyses are based upon certain assumptions regarding the current, non-precision system in use and the new precision spray system being evaluated. Table 2 displays the descriptions and parameter assumptions of the two systems.

The different scenarios will be compared in terms of payback, net benefits, and return on investment. Payback is defined as the length of time until the investment makes an amount of money equal to the original amount invested (with interest) at an assumed interest rate. Net benefits consider the machine operation costs, input costs, and annual non-ownership costs (i.e., annual subscriptions, fees, and support) while accounting for the time value of money. The return on investment again accounts for the time value of money and is essentially the net benefits divided by the amount of the required investment. These analyses implicitly assume 100 percent depreciation (i.e., salvage value is zero) of the PA technology. Thus, results are likely to be on the conservative side.

Results and Discussion

Effects of field shape

Table 3 provides estimates of payback, net benefits, and return on investment for guidance and ASC systems individually as well as the return on investment for both systems combined. Estimates are provided across the different field types (Square, Circle, Equilateral Triangle, and NWKS).

Returns from investing in guidance are the greatest for square fields followed by triangular, circular, and NWKS fields. In other words, as the average angle of approach decreases (fields become more "irregular" shaped), the net benefits of guidance also decrease. At first this result appears to be counterintuitive, however, upon closer inspection, it can be seen that the amount of excess area covered due to machinery overlap (under the non-precision system) is greater in the more "regularly" shaped fields. This is because more of the field area is contained in the field "proper" versus in the headlands. Overlap is of most concern in the pass-to-pass trips across the field.

The net benefits due to ASC are much greater in cases of "irregularly" shaped fields, which have smaller average angle of approach values. As Table 3 depicts, the net benefits for NWKS fields are $0.85/ac. followed by circular, triangular, and square fields, which have net returns of $0.59/ac., $0.34/ac., and -$0.07/ac., respectively. If a farm consists of many square shaped fields, ASC is likely not a profitable investment (unless the farm is of sufficient scale as shown later or other "intangible" benefits are considered). Here, the net benefits are greater for fields which have a higher proportion of the total field area contained in the headlands. Unlike guidance systems, which generate payback in the field "proper", ASC systems generate more value in the headlands area.

Since ASC and guidance system technologies often work in tandem on crop sprayers, it may be most useful to analyze the economics of investing in both systems together. Table 3 shows a substantially positive return on investment across all field shapes, but the greatest return (77.2 percent for NWKS) occurs on the most irregularly shaped fields.

Effects of field size

Up to this point, only farms in NWKS which have a weighted average field size of 135.3 acres have been considered. While this is a good "average" representation of fields for NWKS, other farms and other regions may have significantly smaller or larger fields. For this reason, additional analyses are run to determine the effects of field size in NWKS on the economics of investing in these PA technologies.

The 132 fields in NWKS are sorted by size (smallest to largest) and assigned a number of 1 through 132. These fields are then divided into four quartiles (33 fields in each). Thus, the first quartile contains the smallest 25 percent (fields #1 - #33) of NWKS fields while the second group contains the next largest 25 percent (fields #33 - #66) of NWKS fields. The third and fourth quartiles contain fields #66 - #99 and #99 - #132, respectively. Weighted average values are calculated for a "representative" field as before. Table 4 shows the field measurements for these new groups. A notable characteristic of NWKS fields is that the larger fields tend to be more "irregular" shaped as evidenced by the angle of approach statistic. Field measurements for square, circular, and equilateral triangular shaped fields also are calculated based on 21.10-acre, 53.98-acre, 104.27-acre, and 188.15-acre fields for benchmark purposes, but these data are not shown here. It should be noted that the average angle of approach varies across the NWKS quartiles, but remains constant for the "stylized" fields.

As before, it is assumed that 10,000 acres are covered by the 90 foot sprayer in all scenarios. Figure 4 illustrates the impact of average field size on the net benefits of investing in ASC across the four field-size categories. In all cases, the net benefits per acre decrease (at a decreasing rate) as average field size increases. This is because a lesser percentage of the field is contained in the headlands area - the area in which ASC "pays." The per acre net benefits level off at around $0.77, -$0.10, $0.46, and $0.25 for NWKS, square, circular, and equilateral triangular shaped fields, respectively. Based on the assumptions of this analysis, ASC has positive net benefits on square fields when the fields are smaller than about 80 acres in size.

Where there are less than 50-acre, non-square shaped fields, the payback from investing in ASC is less than one year (Figure 5). For NWKS fields, the payback is less than one year all the way up to around 120 acres in size. In the case of small, square fields the payback is 2.38 years. But, it jumps to nearly 10 years as the average field size increases to 188 acres. The other three field shapes examined do not exhibit this steep rate of change. There are similar increasing relationships between payback and average field size for NWKS, circular, and triangular fields as evidenced by the slopes of the curves in Figure 5.

Effects of Farm Scale (or Acres Covered)

Since precision agriculture investment costs are largely fixed and therefore not dependent upon the amount of usage, it is probable that there are additional benefits from covering more acres. That is, investing in PA technologies is not likely to be a scale-neutral prospect. Using 10,000 acres as the base, sensitivity analyses are used to examine how the economics of ASC change as the number of acres covered changes. The "what-if" scenarios consider -66.7, -33.3, 0.0, +33.3, and +66.7 percent changes from the base acres covered of 10,000. Note, that this particular analysis assumes a "representative" field size of 135.3 acres.

Figure 6 shows the effect of acres covered on net benefits and return on investment for NWKS and square fields. Net benefits increase at a decreasing rate as the amount of acres covered increases. There is a leveling off of net benefits for ASC of just below $2.40/acre for NWKS. The net benefits are negative for the square field scenario covering less than 13,333 acres annually. At the largest scale of square fields, the net benefits are positive ($0.08/ac.), but miniscule in magnitude.

Return on investment increases in a near-linear fashion as more acres are covered for both types of fields. Even in the smallest farm size scenario (3,333 ac. covered), there were substantially positive returns on investment (24.5 percent) for NWKS; however, positive returns for square fields do not occur until at least 11,111 ac. are sprayed. Thus, "larger" farms can benefit economically from ASC technologies regardless of the shapes of the fields. But, more "irregular" shaped fields will provide a much greater return on investment.

Comparisons Across Crop Reporting Districts

The effects of field shape and size on the economics of guidance and ASC systems have been demonstrated. Because field shapes and sizes vary across regions, it is reasonable to presume that these PA technologies will be more economical in some regions than in others. Given the previously discussed parameter assumptions, Table 3 shows the economics of investing in PA technologies across 13 different crop reporting districts in Colorado, Kansas, and Nebraska when 10,000 acres are covered with the sprayer and the representative field shape and size calculated from the actual fields.

Payback for the guidance system is quickest in SECO, WCKS, and SWKS where fields tend to be larger in size and less "irregular" in shape. Conversely, ROI of guidance systems are lowest in ECKS, SENE, and SEKS where fields are smaller and more "irregular" in shape. However, it must be noted that all ROI values are significantly high, indicating profitable returns across all regions given these parameters. That is, even the worst ROIs are still relatively high. Figure 7 shows the variation in payback for guidance systems investments across regions and scale (acres covered). (Not all districts' results are graphed in order to keep the figures "clean" and readable. All of the other districts' results are bounded by (or fall in between) the selected results shown in the figures.) It will take over eight years for a farmer in ECKS to payback his initial investment if he is only covering 3,333 acres each year. However, as more acres are covered, the payback period drops quickly. Large farms (e.g., those covering 16,667 or more acres per year), regardless of location, achieve a payback of less than 1.50 years with guidance.

Figure 8 shows the payback for ASC across five crop reporting districts. A small farmer in WCKS should expect a very long payback period for ASC systems unless his fields are much smaller and more "irregular" in shape than the average WCKS field. By doubling the amount of acres covered (i.e., going from 3,333 to 6,667 acres), the payback decreases from over 22 years to less than 7 years. At 16,667 acres covered, all of the regions are below a two-year payback with the exception being WCKS. Even at this large scale, WCKS farms still have a 2.32 year payback period for ASC investments. To put this in perspective, for the same dollar investment, a small ECKS farm (i.e., covering 3,333 acres per year) has a much quicker payback at 1.37 years than a WCKS farm that covers five times the amount of acres.

Focusing on the combination of guidance and ASC systems investments, ROI values are positive across all regions when 3,500 acres or more are covered annually (Figure 9). Assuming most crop acres are sprayed two to three times per year, this equates to a 1,167-1,750 acre crop farm. An ECKS farm with 1,111 acres that sprays all acres three times per year (3,333 acres covered) would have a return on investment of 31.6 percent on guidance and ASC purchases. To achieve this same level of return, a WCKS farm would need to have approximately 2,600 acres (or cover 7,800 acres). Thus, even when both technologies are considered in combination, there still remains wide variability across regions.

Implications for Farmers and Custom Applicators

To this point, the findings indicate that the combination of guidance systems and ASC systems generate the greatest net benefits or returns on investment when the sprayer is operated on small, "irregular" shaped fields. Also, the more acres that one can cover each year the more profitable the investment but net benefits do level off at large scales. One must be careful and note that this analysis does not imply that farmers and custom applicators should seek out to manage or spray small, "irregular" shaped fields because they generate the greatest returns on investment. The results presented thus far are simply the differences in economics between non-precision and precision spray systems. There are other considerations that must be taken into account regarding the economics of spraying small versus large and "irregular" versus "regular" fields.

Farmers and custom applicators considering adopting guidance and ASC technologies should understand that the majority of benefits will be derived from the input cost savings stemming from the more efficient use of inputs (e.g., herbicide). Without guidance and ASC technologies, the amount of input used across the different field shapes varies quite drastically. As Table 5 illustrates, input use efficiency varies from about 82 percent in the case of smaller ECKS fields up to nearly 94 percent with larger WCKS fields. In other words, only six percent of the total herbicide applied is "wasted" or over-applied on the WCKS field compared to eighteen percent on the ECKS field. Assuming that at 100 percent efficiency herbicide costs are $15.00/acre, spraying a smaller ECKS field would cost an additional $2.73/acre to achieve full coverage (no skips or windows, but with some over-application).

With precise guidance and ASC technologies, the amount of input (e.g., herbicide) used should be nearly equal across different field shapes. Stated differently, the input use efficiency should approach 100 percent regardless of field shape (or size). However, machine efficiency will be different across different shapes and sizes of fields. Efficiency increases on more "regular" shaped fields and as field size increases. Suppose a custom rate for spraying is $5.00/ac. and this rate is based on fields with an average angle of approach of approximately 40 degrees (e.g. circle) and 135 acres in size. Theoretically, a custom rate of $6.03/ac. should be charged for the smaller ECKS fields and $4.46/ac. should be charged for an average WCKS field (Table 5). Actual custom rate survey data from 2009 (this is the last time survey-based custom rates were reported for Kansas) indicates that this trend appears to hold in the business world. According to this report, the average custom chemical application rate for the entire state of Kansas was $4.98/acre with values of $4.61/acre for the WCKS district and $5.60/acre for the ECKS district (KDA, 2010).

Farmers and custom applicators should consider these implications when making decisions regarding the management of additional cropland. The sizes and shapes of these additional fields should be taken into consideration in the determination of purchase agreements, lease/rental rates paid, or custom rates charged.

This analysis has shown that investing in PA technologies is not scale-neutral. However, as input costs increase and/or the investment costs for PA tools decrease, these technologies will have shorter payback periods and will likely be beneficial to smaller operations.

While this analysis considered actual crop fields in Colorado, Kansas, and Nebraska and compared those to several standard geometrically shaped fields, the reality is that every farming operation will be unique in terms of fields, farm size, accuracy of guidance systems, crop input costs, and machinery operations. To aid in these calculations interested individuals are directed to an online customizable spreadsheet decision-making tool, *Guidance & Section Control Profit Calculator*, which incorporates the methods of analyses described in this paper (Dhuyvetter et al., 2010). It allows its user to approximate the benefits to GPS-based guidance and section control systems for farm machinery.

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Table 1. Field Measurements for the 13 Crop Reporting Districts and Alternative Field Types

Crop reporting district	Number of fields	Total acres	Acre-wtd. avg. size of fields (ac.)	Maximum width (ft.)	Headlands distance (ft.)	Angle of approach (degrees)
Square	n/a	n/a	135.3	2,428	4,856	90.0
Circle	n/a	n/a	135.3	2,740	8,607	39.5
Eq. Triangle	n/a	n/a	135.3	3,196	7,380	60.0
NWKS	132	11,251	135.3	2,758	10,884	30.4
WCKS	36	5,705	730.1	5,267	16,630	39.3
SWKS	75	9,414	240.2	3,005	11,328	32.0
NCKS	74	5,002	153.1	2,564	15,278	19.6
CKS	60	3,281	91.3	1,497	7,237	24.4
SCKS	59	5,015	136.2	2,589	10,430	29.8
NEKS	10	769	117.8	2,295	7,001	41.0
ECKS	24	455	28.4	1,014	4,876	24.6
SEKS	10	489	68.2	1,708	7,122	28.7
SWNE	12	559	76.4	1,960	6,766	35.4
SNE	32	1,725	143.3	2,719	10,260	32.0
SENE	14	441	45.1	1,278	6,390	23.6
SECO	15	4,988	476.9	3,773	18,261	24.4

Table 2. Precision and Non-precision Spray System Descriptions and Parameter Assumptions

Parameter	Non-precision system	Precision spray system
Precision guidance	None	Differential GPS
Sprayer control	Entire boom controlled manually	5 equal length sections controlled automatically
Width of machine	90 ft.	90 ft.
Number of swaths needed to cover headlands	2	2
Reaction distance on manual shutoff of boom	15 ft.	0 ft.
Cost of machine operation	$5.00 / application ac.	$5.00 / application ac.
Cost of input (fertilizer, herbicide, etc.)	$15.00 / application ac.	$15.00 / application ac.
Overlap	7.00%	1.50%
Total ac. of use annually (base case)	10,000	10,000
Guidance investment	None	$15,000
ASC investment	None	$10,000
Annual subscriptions, fees, support	None	$800
Interest rate	8.00%	8.00%
Amortization period	5 yrs.	5 yrs.

Table 3. Economics of PA technologies Across Districts and Field Types Assuming 10,000 Acres Covered

	Guidance System			ASC System			Both Systems
Crop reporting district or field type	**Payback years**	**Net benefits ($/ac.)**	**Return on investment (%)**	**Payback years**	**Net benefits, ($/ac.)**	**Return on investment (%)**	**Return on investment (%)**
Square	1.58	0.67	64.1	7.59	-0.07	-3.3	40.1
Circle	1.70	0.60	58.9	1.30	0.59	79.6	67.3
Equilateral Triangle	1.67	0.62	60.1	1.88	0.34	52.2	57.0
NWKS	1.77	0.57	56.0	0.98	0.85	107.6	77.2
WCKS	1.55	0.69	65.6	4.14	0.04	14.3	46.4
SWKS	1.64	0.64	61.4	1.74	0.39	57.3	59.8
NCKS	1.84	0.53	53.6	0.77	1.13	136.6	87.9
CKS	1.76	0.57	56.5	0.98	0.85	107.0	77.2
SCKS	1.75	0.58	56.9	1.03	0.80	102.2	75.5
NEKS	1.69	0.61	59.0	1.41	0.53	72.8	64.6
ECKS	2.17	0.40	43.4	0.44	2.15	239.1	124.8
SEKS	1.87	0.52	52.4	0.74	1.19	142.6	89.7
SWNE	1.81	0.55	54.5	0.90	0.95	117.3	80.3
SNE	1.74	0.58	57.3	1.11	0.73	94.3	72.4
SENE	2.03	0.46	47.4	0.54	1.72	196.5	109.4
SECO	1.60	0.66	63.1	2.15	0.27	43.9	55.6

Table 4. Representative Field Measurements for Original, Small, and Large NWKS Fields

	Acre-weighted average			
Field Type	**Size of field (ac.)**	**Maximum width (ft.)**	**Headlands distance (ft.)**	**Angle of approach (degrees)**
Original	135.35	2,758	10,884	30.4
Smallest 25%	21.10	1,440	4,637	38.4
Mid-Small 25%	53.98	1,743	6,274	33.8
Mid-Large 25%	104.27	2,667	8,987	36.4
Largest 25%	188.15	3,234	13,934	27.7

Table 5. Effects of Average Field Size and Shape on Input Use Efficiency Without ASC (Assuming 10,000 ac. Covered)

Crop reporting district or field type	Non-precision system input use efficiency (%)	Amount of herbicide wasted with non-precision system ($/ac.)	Overall machinery efficiency (%)	Custom rates that "should" be charged ($/ac.)
Square	94.88	0.77	86.01	4.63
Circle	90.41	1.44	79.68	5.00
Equilateral Triangle	92.10	1.19	80.37	4.96
NWKS	88.77	1.68	77.69	5.13
WCKS	93.76	0.94	89.27	4.46
SWKS	91.56	1.27	84.06	4.74
NCKS	87.06	1.94	76.91	5.18
CKS	88.75	1.69	79.20	5.03
SCKS	89.06	1.64	78.89	5.05
NEKS	90.79	1.38	80.45	4.95
ECKS	81.77	2.73	66.05	6.03
SEKS	86.83	1.98	74.06	5.38
SWNE	88.30	1.76	75.47	5.28
SNE	89.53	1.57	79.08	5.04
SENE	83.91	2.41	70.03	5.69
SECO	92.24	1.16	86.87	4.59

Figure 1. Representation of How Values are Calculated

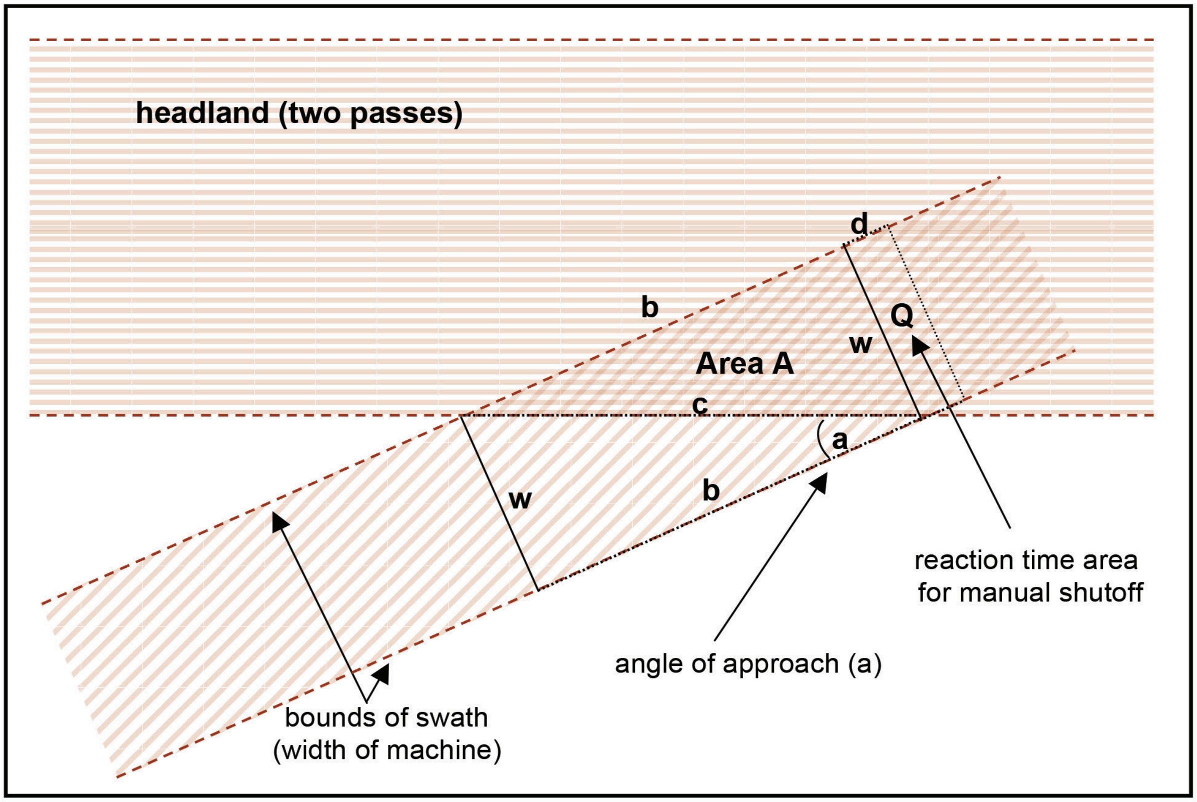

Figure 2. Representative Field Measurements

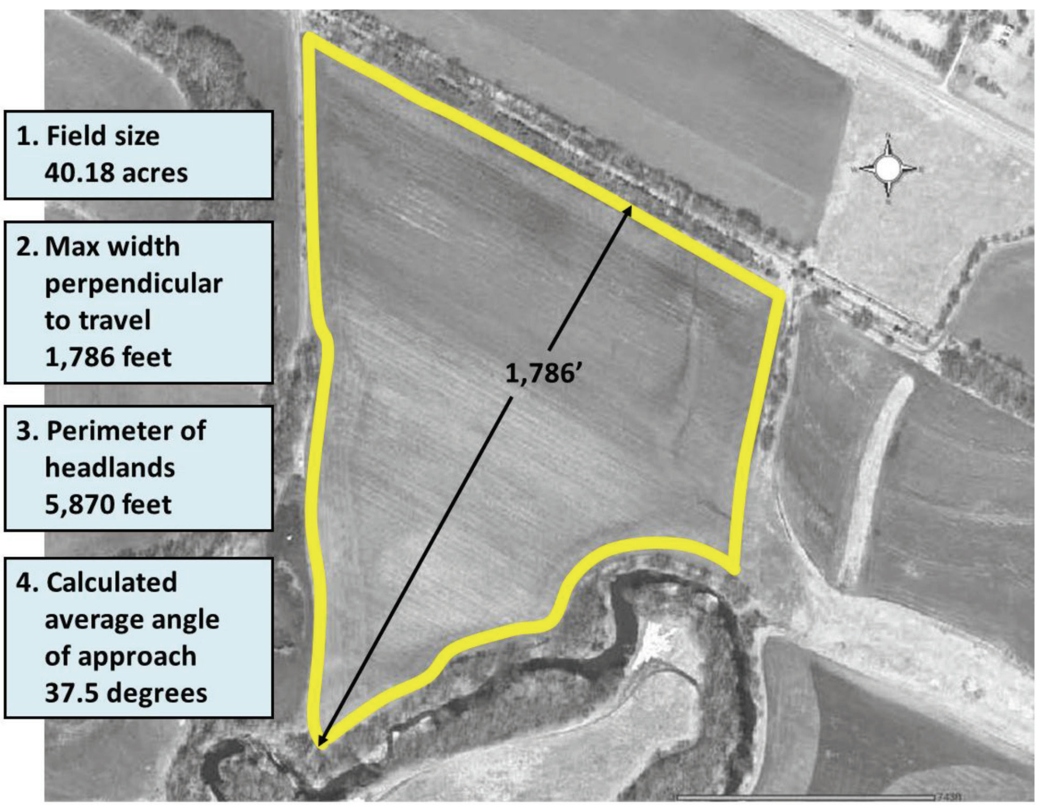

Figure 3. Colorado, Kansas, and Nebraska Study Region with Crop Reporting Districts

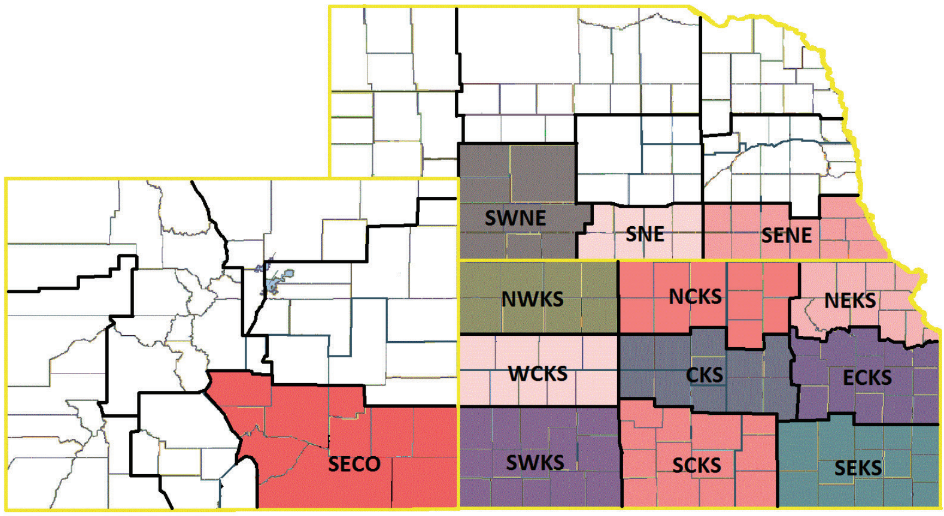

Figure 4. Impact of Average Field Size and Shape on Net Benefits of ASC (Assuming 10,000 ac. Covered)

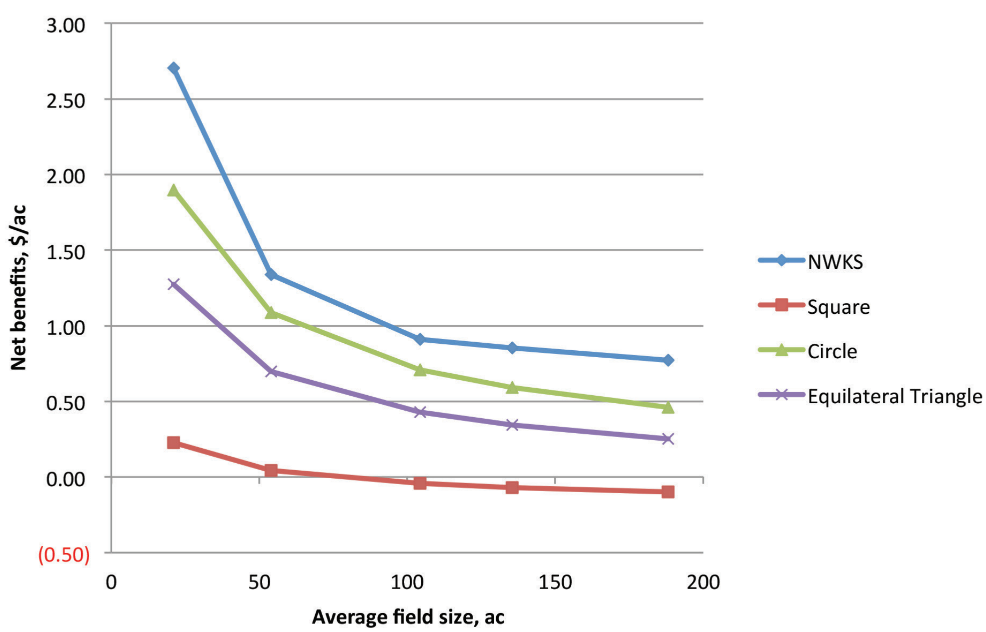

Figure 5. Impact of average field size and shape on payback years of ASC (Assuming 10,000 ac. Covered)

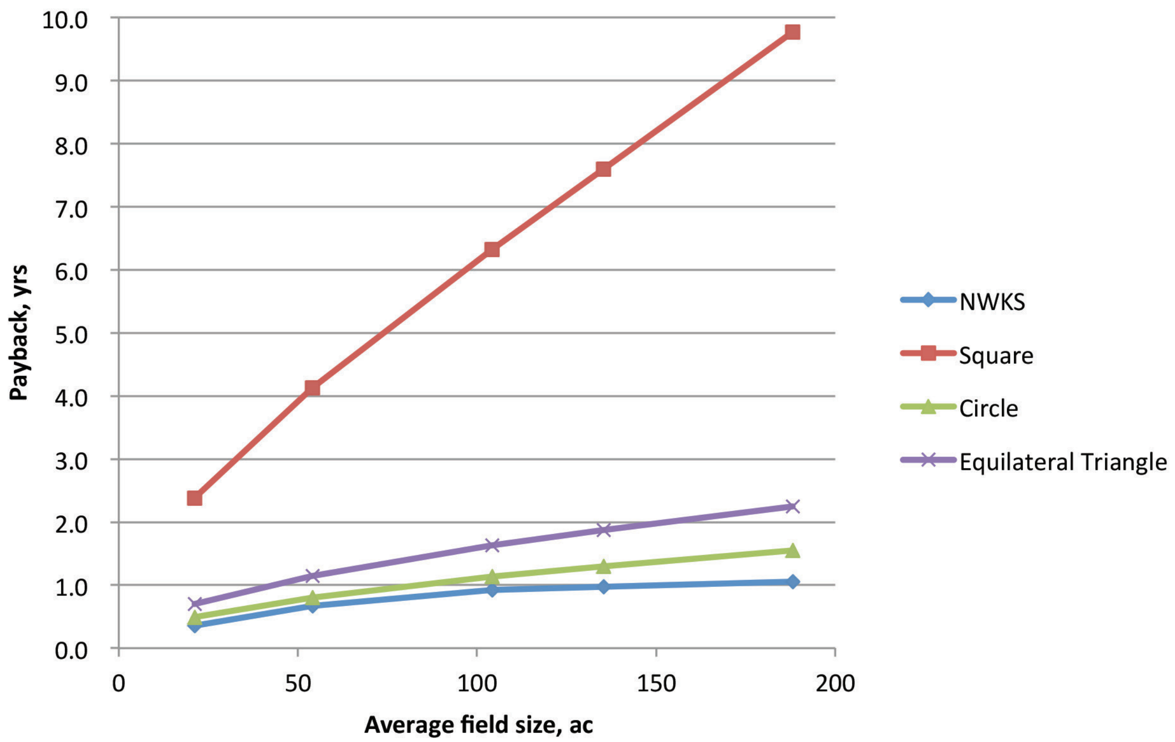

Figure 6. Impact of Covered Acres and Field Shape on the Economics of ASC

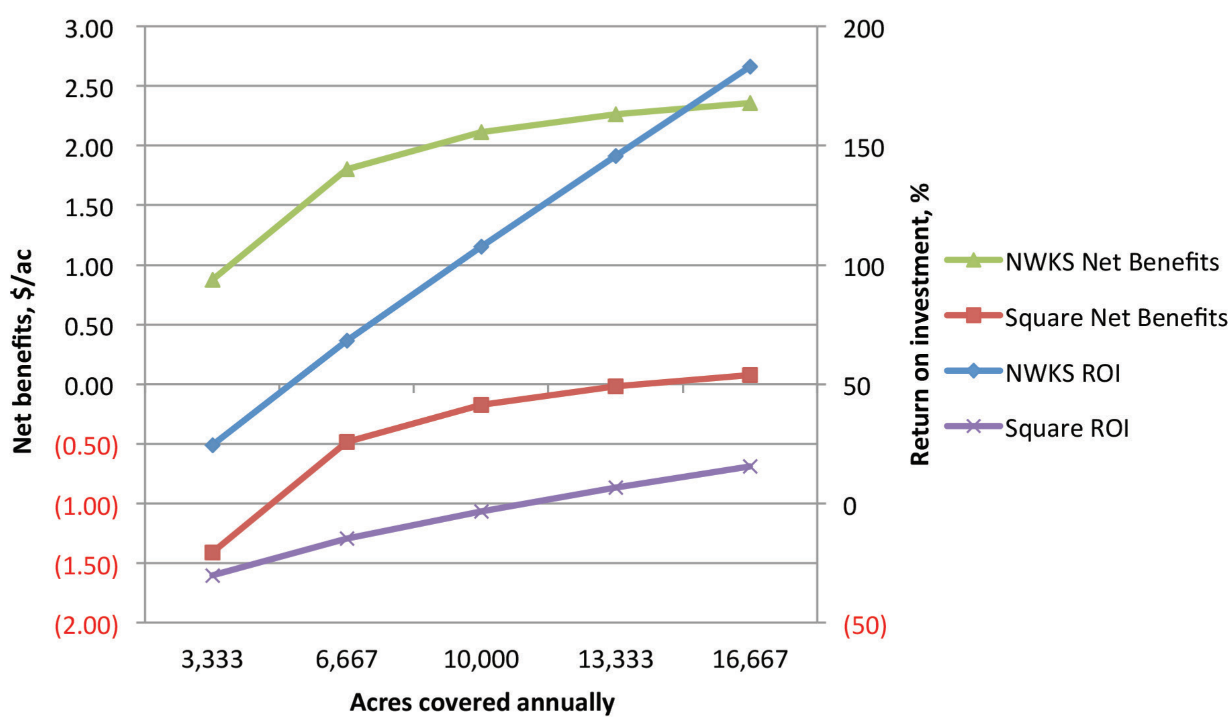

Figure 7. Payback for Guidance System on Sprayer from Five Crop Reporting Districts

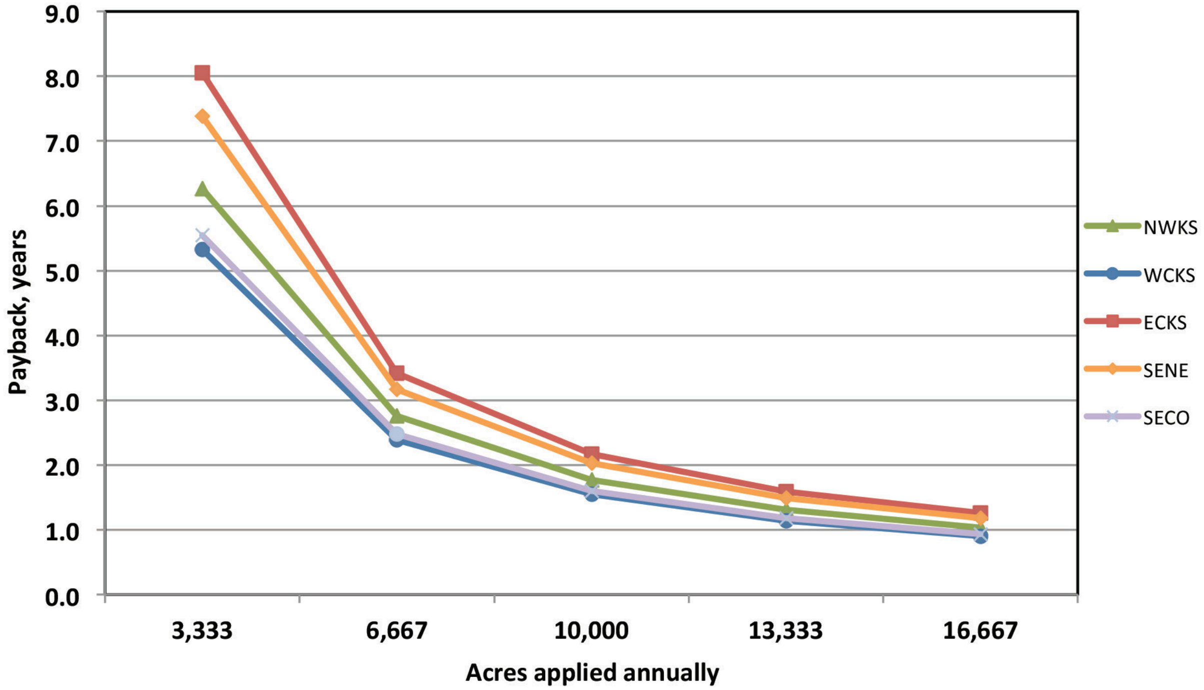

Figure 8. Payback for Section Control on Sprayer from Five Crop Reporting Districts

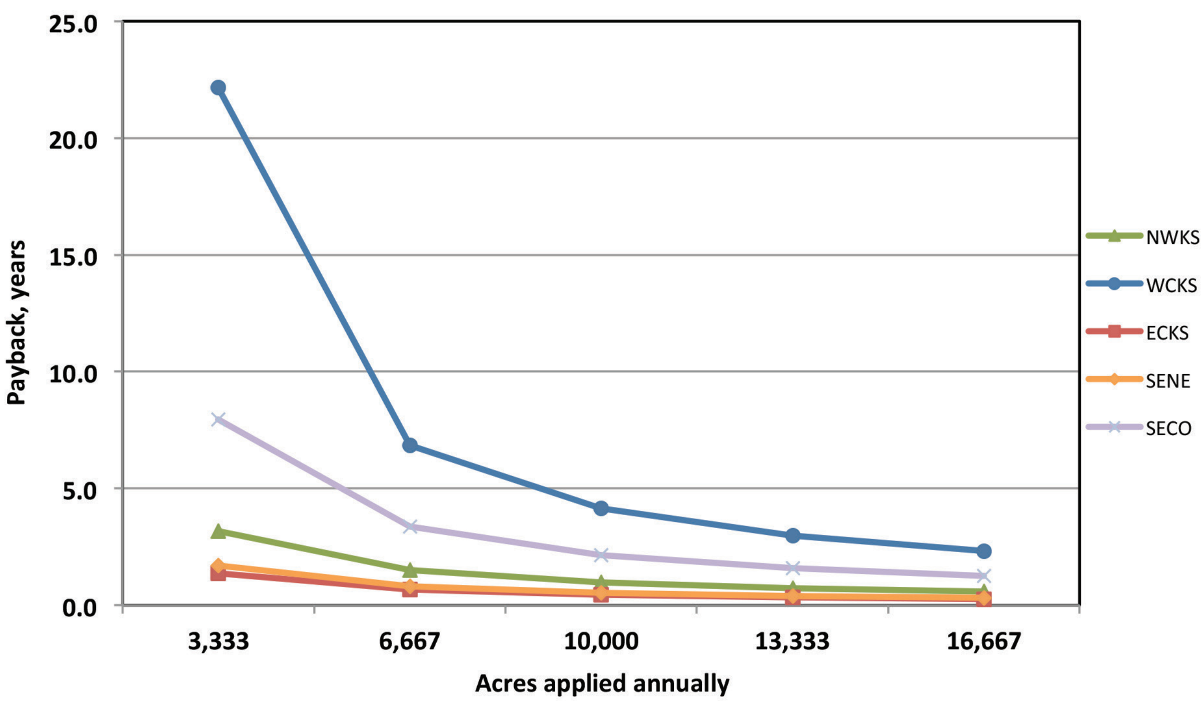

Figure 9. Return on Investment for Guidance System and Section Control on Sprayer from Five Crop Reporting Districts