Determining the Economically Optimal Level of Control on Sprayers and Planters

By Craig M. Smith & Kevin C. Dhuyvetter

ABSTRACT

The capabilities of planter and sprayer technologies that link GPS navigation with application control continue to expand. Current technology permits varying levels of control for sprayers and planters down to the individual nozzle and row. The economics of various levels of control have not been reported in the literature. This research incorporates over 1,400 real-world cropland fields to examine the effects of region, crops grown, and acres covered on the returns to investment in these technologies. While the technologies generally are found to be quite profitable, the relative returns varied considerably across these factors. The marginal return of investing in individual nozzle (sprayer) or row (planter) control is less obvious and thus it is important for producers and farm managers to consider their own unique situations.

Introduction

The capabilities of planter and sprayer technologies that link GPS navigation with application control continue to expand. In general, the adoption rates of these types of precision agricultural technologies continue to increase nationwide. However, it has been observed that rates of adoption vary significantly across technologies, crops, and regions of the country (Keller, 2013). Two technologies that have been available to producers for several years, but which have seen varying levels of adoption are section control for sprayers and row control for planters. According to Erickson and Widmar (2015), crop input dealers estimated that GPS enabled sprayer boom section or nozzle controls have been adopted by 33.1 percent of producers while GPS enabled planter row controls/shutoffs have been adopted by 24.2 percent of producers. A separate study by Castle et al. (2015) focused solely on Nebraska (and in particular eastern Nebraska) reported that about 70 percent of producers have adopted automatic section control (broadly defined).

Craig Smith is an Assistant Professor with the Department of Agriculture at Fort Hays State University in Hays, Kansas. Kevin Dhuyvetter is a Technical Consultant with Elanco Animal Health in Manhattan, Kansas.

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Controlling sections of nozzles across a spray boom has been shown to be profitable (Smith et al., 2013). However, as technology has advanced, it has become possible to control all nozzles individually, but the economics of this level of control have not been reported in the literature. Thus, an analysis that looks at varying "levels" of section or row control for both sprayers and planters is needed to help producers and farm managers make optimal investment decisions. While there are several possible explanations for why these technologies may not be adopted (e.g., learning curve, "hassle" factor, risk of malfunctions, initial investment, etc.), it is likely the economic attractiveness of these technologies, whether perceived or real, plays an important role in their adoption rate. This research incorporates over 1,400 real-world cropland fields from farms in Colorado, Kansas, and Nebraska to examine the effects of region, crops grown, and acres covered on the returns to investment in these technologies. This research builds upon and extends related research by Smith et al. (2013) that examined the economics of investing in guidance systems and automatic section controllers for sprayers across the Great Plains.

Level of Control (number of nozzles or rows)

Individual-nozzle control for sprayers is more efficient than controlling sections of nozzles (referred to as "section control") or the entire boom as a single section. Rather than automatically controlling a group or section of nozzles harmoniously, individual nozzle control operates each nozzle along the spray boom independently with the ability to turn sprayer nozzles 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 pesticides or nutrients (Fulton et al., 2010). Row control operates similarly for planters and is typically set up to operate "sections of rows" automatically. For example, a 12-row planter might be split into two sections where there are six rows per section. More commonly a 12-row planter with auto-control is set up with pairs of rows (i.e., a 12-row planter controlled in six 2-row sections) (Ethan Ziegler, Carrico Implement – Hays, KS, personal communication, August 27, 2014).[1] These technologies also allow for variable rate application (with spraying and planting), but this research only considers the case of ON or OFF control.

Investing in these technologies can result in reduced input costs (e.g., less seed, pesticide, fertilizer, etc.) and revenue enhancement through improved yields. The magnitude of revenue enhancement via yield improvement will depend upon crop rotation and the input (e.g., seed, pesticide, fertilizer) being applied.[2] For the case of individual-nozzle control for sprayers, revenue enhancements are assumed to be zero. However, a yield reduction due to the over-application (double-planting) of seed in the case of planters is likely a large issue across most types of row crops. For this reason, yield reductions and thus impact on revenue will be considered at various levels for the planter auto-row control analysis. These benefits will be compared to the incremental costs associated with investing in the technology.

Smith et al. (2013) incorporated field shape and size information from over 500 actual cropland fields from farms in Colorado, Kansas, and Nebraska to evaluate the economics of investing in guidance systems and automatic section controllers for sprayers. They found that the economics vary considerably across the study region. For example, given their assumptions, a west-central Kansas farmer must farm five times the amount of acres as an east-central Kansas farmer to have similar payback periods due to field geometry (size and shape) in the region.

Previous analysis of auto-row technology for planters is limited to two studies. Shockley et al. (2012) examined the effects of various field types and navigational scenarios to determine the impact of auto-row control. The authors chose four general field shapes and two implement widths to determine the profitability of auto-row control. They concluded that relatively smaller fields resulted in greater potential for profitability and that field shape becomes less important as the field area increases. While this study provides valuable insight into some of the factors affecting the profitability of auto-row control, there are some limitations on its real-world applicability because only four field shapes were considered, varying levels of row controller were not examined, and any yield losses due to double-planting were ignored.

Velandia et al. (2013) analyzed the potential losses from double-planted areas across 52 fields in middle- and west-Tennessee. From this, the authors were able to evaluate the potential savings associated with an investment in auto-row control for planters. Depending on the size and shapes of their fields, they found that double-planted areas ranged from 0.1 to 15.5 percent of the total field area. Savings (from reductions in seeding costs and yield losses which they assumed to be 5% for cotton and corn and 0% for soybeans) from the adoption of auto-row control technology ranged from \$4.04/ac to \$10.52/ac depending on the distribution of field types in the farming operation. Given the initial cost of this technology, this equated to an approximate 4-year payback period.

Our research builds upon the three studies discussed previously. This research will use the same analysis model and methods as the Smith et al. (2013) study, but will focus on level of control for nozzles (sprayer) and rows (planter). Specifically, economic returns are analyzed for two types of nozzle-control configurations (5-sections vs. individual-nozzle) for sprayers and two auto-row control configurations for planters (6-row vs. 2-row control). These are compared to base configurations of no section control for both the sprayer and planter. This research will incorporate data from over 1,400 actual fields across three different states in the Great Plains region to more effectively analyze the economics of investing in these technologies. Specific results that will be presented are the value of wasted inputs (i.e., seed) and potential reduced yield from over-application (without using these technologies) and how these vary across regions and across crops, specifically corn and grain sorghum.

A marginal analysis will be used to analyze the profitability of adopting individual-nozzle control for sprayers. From this, we will be able to project whether and under what conditions a farmer should adopt this technology versus the less expensive, albeit less efficient, option of 5-section control of nozzles for a sprayer. Likewise, for planters the marginal analysis is used to compare auto control of a planter in two 6-row sections (hereafter referred to as 2 x 6-row) versus six 2-row sections (hereafter referred to as 6 x 2-row). To our knowledge, no study has ever analyzed the economics of upgrading from auto-section control to individual nozzle control for sprayers or compared different auto-row control configurations for planters.

Methods

The following methods have been adapted from Smith et al. (2013) as this research uses the same basic procedure. Before discussing the details of the analysis, it is necessary to understand the tangible effects of having section or individual-nozzle and/or auto-row control technologies. Using Figure 1, consider a planter operator who approaches the headlands at some angle less than 90 degrees, which will be the case in a non-rectangular field. Without auto-row control capabilities, the operator will not raise (or turn off) the planter until the very last row on the far right of the planter reaches the headlands. This results in the double-planting of seed across area A. Further, assuming the operator does not have perfect reaction time, there also will be double-planting on area Q. Auto-row controllers have the potential to eliminate some if not all of this double-planting of seed. As one can see from the diagram, the angle of approach plays a key role in determining the amount of double-planting that can be avoided with auto-row control technologies. As the number of rows or sections controlled independently increases, area A, i.e., the area of double planting, decreases. 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 in Appendix A 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.

A partial budgeting approach will be used to estimate the annual net benefits, payback, and return on investment (ROI) for each technology. With partial budgeting, profitability is calculated as the difference in revenues and costs for the two alternatives (Batte and Ehsani, 2006). For the 90-foot boom sprayer analysis, it is the difference between manual control of the entire boom (i.e., no sections) versus five automatically controlled sections versus 60 automatically controlled sections (i.e., individual nozzle control).[3] For the 12-row, 30-inch spacing (30 feet) planter analysis, it is the difference between the entire planter controlled manually versus 2 x 6-row sections versus pairs of rows (i.e., 6 x 2-row sections) being controlled automatically. In all sprayer and planter configurations, it is assumed that differential GPS guidance has already been adopted.

Data

The field data for this analysis come from farms located in Colorado, Kansas, and Nebraska. As part of a course project, 103 different students in Fort Hays State University's "Technology in Agriculture" (AGRI 400) course over five semesters provided detailed information regarding field size and shape for 1,445 crop fields totaling 135,755 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 fields in their operations. 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 three-quarters of the perimeter distance (3 of the 4 sides) as the "running distance of headlands" value. This is because very few fields are 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.

For reporting purposes, field data are divided into USDA crop reporting districts (Figure 3). Sixteen districts are represented by the data across the three states including all nine Kansas districts, four Nebraska districts, and three Colorado district (Table 1). 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 is information on 347 fields representing 29,579 acres. Field size varies widely across districts. For example, the simple average of ECCO fields is 397 acres whereas the average field size in ECKS is only 26 acres.

For this analysis, measurements from a single "representative" field are needed. Therefore, acre-weighted averages across the fields in each district are 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. The weighted average field size (acres), maximum width (feet), and feet of headlands for each of the crop reporting districts are reported in Table 1.

The following analyses are based upon certain assumptions regarding the non-precision system (i.e., manual control of entire spray boom and planter) with the alternative precision spray/planting control system being evaluated. Tables 2 and 3 display the descriptions and base assumptions for the sprayer and planter analysis, respectively. An estimate of the investment required for each level of technology are shown in the bottom row of each table.

The different scenarios will be compared in terms of net benefits, return on investment (ROI), and payback years. Net benefits consider the machine operation costs, input costs, and yield revenue while accounting for the time value of money. The ROI accounts for the time value of money and is essentially the net benefits divided by the amount of the required investment. Ignoring risk, an acceptable ROI for these analyses would be anything greater than eight percent (i.e., ROI greater than the interest rate used in the analysis). Managers that are risk averse will require an ROI that is greater than the interest rate, however because the level of risk aversion varies considerably between decision makers, comments regarding ROI will focus on how it compares relative to the eight percent interest rate. Payback years 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. Given our assumptions, an acceptable payback period for these analyses would be anything less than five years (once again, reflecting a risk neutral position). These analyses implicitly assume 100 percent depreciation (i.e., salvage value of controller investment is zero) of the precision agricultural technology. Thus, results are likely on the conservative side.

Results and Discussion

Section/Nozzle Control for Sprayers

In many cases, there will be sizeable gains achieved when going from whole boom to auto-section control (e.g., 90 ft. boom controlled in 5 sections), and less substantial gains when going from auto-section to individual-nozzle control. In other words, there will be diminishing returns as the number of nozzles controlled independently increases. For this reason, it is important to analyze the marginal effects, which are the additional benefits compared to the additional costs of going from auto-section control to individual-nozzle control.

Using NWKS as an example, the benefits of these sprayer technologies can be seen. A typical field acre in NWKS comes from a 134.4 acre field (Table 1). If the entire boom is controlled manually (in one "section"), the total number of acres sprayed will be 143.2 acres. In other words, there are almost nine acres sprayed twice, which increases chemical cost due to over-application. However, if the 90-foot boom is automatically controlled using five sections, there will be a total of 136.2 acres sprayed. Finally, if the sprayer is equipped with individual-nozzle control, there will be 134.6 acres sprayed, which is essentially the actual size of the field resulting in very little over application. The question that many farmers and custom applicators are facing, or will face in the future, is whether this gain in efficiency is worth the additional investment of $15,000 (Table 2) (Jay Simpson, Simpson Farm Enterprises – Hays, KS, personal communication, May 14, 2014).

Given the assumptions in Table 2, the ROI of going from one section to five sections for a typical field acre in NWKS is 94.7 percent (Table 4). This is a very good ROI, especially considering there is little risk associated with achieving this, and thus is a major reason why auto-section control technology for sprayers has been adopted rapidly over the past decade. The ROI of going from one section to 60 independently controlled nozzles is 36.7 percent (Table 4). Again, an excellent ROI, but it is not exactly clear if a choice to upgrade to individual-nozzle control from auto-section control is a profitable one. Marginal analysis is required to answer this question.

Given the initial assumptions in Table 2, the marginal ROI of upgrading to individual-nozzle control from auto-section control is -15.1 percent (Table 4). This converts to a nearly 15-year payback period. These values would likely be unacceptable for most farmers and custom applicators in NWKS.

The results indicate that, given the base assumptions, ECKS is the only district that exhibits positive net benefits (and positive ROI) of upgrading from 5-section control to individual nozzle control. Here, the smaller and more irregular shaped fields result in a payback of less than five years. In all other cases given the base assumptions, it does not appear that upgrading to the more precise level of control is a profitable investment.

As outlined in Table 2, values reported above are based on spraying 10,000 acres per year. But there are a number of producers who spray more than 10,000 acres each year (especially in the more western part of the Great Plains) and arguably most custom applicators cover many more acres than this annually. Table 5 shows the marginal ROI values across differing amounts of acres covered annually and different additional investment costs (the additional costs of upgrading to individual-nozzle control from auto-section control) for NWKS.

A producer or custom applicator must cover just over 21,000 acres annually to have an ROI of eight percent given a $15,000 investment, which would be desired to make this a "profitable" investment.[4] From this table, one can see the impact economies of scale have on the likelihood of adopting individual-nozzle control.

Now suppose a producer feels that there is some benefit (e.g., crop yield improvement) to not double-applying chemicals. This may be more likely the case when applying nitrogen fertilizer versus applying glyphosate. If one assumes a $0.50/acre "benefit" annually, the ROI values change rather drastically as shown in Table 6.[5] The -15.1 percent ROI is now equal to 4.9 percent with a 5.5 year payback period. Thus, one's views on the existence of additional "benefits" (beyond the already accounted for chemical savings) may affect their decision on whether to upgrade to individual-nozzle control.

Auto-Row Control for Planters

The benefit of auto-row control for planters is two-fold: amount of seed wasted is reduced and yields are preserved by not double-planting. The values of these benefits are going to vary across crops. In the Great Plains region, two common row crops grown are corn and grain sorghum.

Table 7 shows the value of seed saved by using auto-row controllers for corn and grain sorghum. Two auto-row controlled configurations are considered: 2 x 6-row sections and 6 x 2-row sections. It is assumed that the seed costs for corn and grain sorghum are $110.00 and $15.00/acre, respectively. This drastic difference in seed costs, along with field size and shape, logically translates into wide differences in values of seed saved by using auto-row controllers. In the corn fields of ECKS, $5.03/acre of seed is saved by the 6 x 2-row configuration compared to only $0.69/acre of grain sorghum seed saved in ECCO.

Table 7 also shows the value of yields preserved by using auto-row controllers. Here, it is assumed that the (likely irrigated in the western part of the region) corn averages 200 bushels per acre and the price of corn is $4.00/bushel. For grain sorghum, it is assumed that yields average 80 bushels per acre and the price of grain sorghum is $3.50/bushel. Further, it is estimated that where double-planting occurs there will be a 25 percent yield loss in those areas which amounts to a $200.00/acre loss for corn and a $70.00/acre loss for grain sorghum in those specific areas. According to Iowa State (Darr, 2012), a conservative estimate for yield loss in double-planted areas is 12 percent. This (yield loss due to double-planting) is a very difficult if not impossible factor to estimate. In conversing with producers across the country and visiting online agricultural forums, the authors have found that most of the estimates fall in the 25 – 75 percent range. A 25 percent yield loss was chosen as the baseline level for yield loss due to double-planting. For corn with the 6 x 2-row planter setup, the yield revenue preserved ranges from $1.32 to $9.14/acre across regions, and for grain sorghum the range is $0.46 to $3.20/acre.

On a per acre basis, the benefits of auto-row control are greatest in ECKS. For corn (6 x 2-row), $5.03/acre is saved in corn seed and $9.14/acre in revenue enhancement because of reduced double-planting. The total benefit of auto-row control in ECKS equal $14.17/acre per year. On the other end of the benefit spectrum is ECCO. The large fields of ECCO result in only $2.05/

acre total benefit of (6 x 2-row) auto-row control if (irrigated) corn is being grown.

Most of the region's grain sorghum production takes place in the more arid and dryland locations. Given the much lower cost of grain sorghum seed and the (typically) slightly lower sales price, the benefits of auto-row control is much less. For example, the total benefits of auto-row control for an ECKS grain sorghum farm is \$3.88/acre (compared to \$14.17/acre for corn). For an ECCO grain sorghum farm, the benefit is only \$0.56/acre.

From this, one can see that the fastest adopters of auto-row control should be corn farmers located in areas of the country where fields are smaller and more irregular shaped. The benefits are greater for fields which have a higher proportion of the total field area contained in the headlands.

To determine whether or not the benefits in Table 6 are "acceptable", it is necessary to consider the investment cost. Recall from Table 3 that the cost for the 2 x 6-row setup is \$6,500 while the cost for the 6 x 2-row setup is \$10,000 (Phil Bealby, BTI Equipment - Greensburg, KS, personal communication, August 13, 2014). Consider the case of corn farmers in WCKS, SCKS, and ECKS. Assuming 1,500 acres are planted each year, one can see that both configurations of auto-row controls are an economically sound investment compared to manual control in each of the three regions, where each has a 3-year or less payback period (Table 8). Unlike the sprayer scenario, however, increasing precision by upgrading to the 6 x 2-row setup from the 2 x 6-row setup appears to be a profitable decision across all three crop reporting districts when corn is the primary crop as the ROI values are all greater than 28.7 percent. Even ECCO has a lucrative 14.8 percent ROI when upgrading to the higher level of precision.

While the 6 x 2-row configuration is profitable across all regions when corn is the primary crop, this does not appear to be the case when sorghum is the main crop. Table 9 shows the economics of investing in the two different planter control configurations when sorghum is being planted on the 1,500 acres. In 10 out of the 16 districts, upgrading from the 2 x 6-row to the 6 x 2-row system is profitable with ROI's greater than eight percent. At the extremes, ECKS has a 48.9 percent ROI while ECCO has a -24.0 percent ROI.

From the results in Table 9 and given the base assumptions, one would conclude that sorghum producers in WCKS, SWKS, SECO, and ECCO would maximize their profits by going (or staying) with manual control of the planter. Sorghum producers in SCKS and SENE would maximize profits by selecting the 2 x 6-row setup and all other districts would maximize profits by selecting the 6 x 2-row control setup for their planter.

Since the costs of auto-row controls are largely fixed and therefore not dependent upon the amount of usage, the benefits increase as more acres are covered. Because corn producers in all districts would benefit from going with the most precise planter control setup, we consider the case of grain sorghum farmers in WCKS, SCKS, and ECKS. Assuming the base case of 1,500 acres planted annually, 6 x 2-row auto-control appears to be a profitable investment in ECKS only, where there is an approximate 2-year payback period (Table 9). Over 1,520 acres must be covered in SCKS for the 6 x 2-row investment to be economically sound. In WCKS, one would have to plant

3,420 acres annually for this investment to have a 5-year payback. Planting this many acres, in a short-time period, with a 12-row planter would likely not be feasible.

Implications for Farmers, Farm Managers, and Custom Operators

This research used actual field data from 1,445 fields across three states in the Great Plains to evaluate the costs and returns of investing in varying levels of automatic control for sprayers and planters. Past research has shown that machinery costs advantages and technology adoption are important factors that differentiate high- and low-profit farm enterprises (Dhuyvetter and Smith, 2010). This research, along with the publicly available Excel decision-tool, assists producers in estimating the economics of these relevant technologies.

The results demonstrate how the economics of automatic control technologies depend greatly on field sizes and shapes and types of crops grown. All of these vary across regions indicating that the adoption rate of these technologies likely will vary geographically. A key finding of this research is that it is important for producers to evaluate the marginal benefit of investing in more intensive control systems. For example, the ROI of investing in individual nozzle control on a sprayer might appear attractive when compared to the entire boom, but when compared to a 5-section control system it may actually be a negative return due to diminishing returns indicating individual nozzle control would not be the economic optimal choice. It is impossible to make blanket statements about what the optimal system is because of the many profitability drivers (e.g., farm size, field shape and size, crops grown, inputs used, risk tolerance, etc.). Thus, as with many investment choices, it is important producers and farm managers evaluate their individual unique situations.

This analysis also has shown that investing in these technologies, which have a relatively large fixed cost component, is not scale-neutral. However, as input costs increase and/or precision agricultural investment costs decrease, these technologies will have shorter payback periods and will be more economically attractive to smaller operations. Economies of scale and input and investment costs are only a few of many important factors that producers and custom operators must consider when deciding whether or not to adopt these technologies and to what level of precision should be purchased.

For example, other factors that likely impact the decision on whether to invest in auto-row control for planters are one's views on future commodity prices and the effect double-planting has on yields. Considering the base scenario assumptions, if one believes that double-planted areas produce one-quarter as many corn bushels as single-planted areas, 6 x 2-row control is a wise investment with corn price at $3.00/bushel or higher, as all regions result in a one-year or less payback period. If, however, one foresees "lower" priced corn and/or feels that double-planted areas aren't significantly impacted, then the decision becomes more challenging. Obviously, future commodity prices and/or yield losses from double-planting are very difficult to project, but nevertheless one's outlook may have an impact on their decision to adopt auto-row control. The Excel decision tool can assist with these and many different types of situation-specific analyses.

Farm managers are in another sector of the agricultural industry that can benefit from having a greater understanding of the economics of section controllers for sprayers and planters. Specifically farm managers, who are managing farm ground on share leases and/

or custom farming arrangements, have the potential to increase profits by using these technologies on the farm ground they manage. Furthermore, technologies such as these that increase profitability, through higher yields and lower input costs, can also increase returns to cash rented land over time as the increased profits are bid into cash rents.

The incentives for custom operators to adopt these technologies are the potential to retain existing and attract new clientele, lower input costs, and the possibility of charging a higher rate than competitors who do not employ these technologies. Farm managers and producers should be willing to pay a "premium" which would be an amount equal to a portion of their projected increased profits from higher yields and/or lower input costs.

Two other factors not directly considered in our analyses are the potential for variable rate application and other "intangible" benefits. While our analysis considered only ON and OFF control of sections, nozzles, and rows, virtually all of the sprayer and planter setups considered here have the ability to variably apply inputs. If there is value in being able to variably apply inputs, this should be factored into the decision making process.[6] Intangible benefits also may arise due to the adoption of these technologies. These could include the "comfort" of having controls automated, environmental protection provided by reduced input usage, and other social benefits (e.g., these technologies can be touted by the agricultural industry as reducing nutrient and chemical runoff resulting in less eutrophication of surface water bodies).[7]

End Notes

1. It is possible to configure a planter with individual control on each row, but this is not typically done due to potential problems associated with GPS "drift" which could result in skips.
2. Increased yield is the result of a reduction in yield penalties associated with non-optimal rates of input. This analysis considers herbicide application with sprayers and seed with row-crop planters, however, the mathematical approach could also be used for fertilizer, whether applied with a sprayer or a separate fertilizer applicator.
3. The comparison of the entire boom (no section control) and the five-section scenario is similar to what was done by Smith et al. (2013) but it is included here for completeness.
4. A minimum ROI of eight percent is arbitrarily used here as the definition of a "profitable" investment as this is the interest or discount rate that is used.
5. The $0.50/acre "benefit" is across all field acres not just the "doubled-up" acres.
6. At this point in time, there does not seem to be a consensus that variable rate application unambiguously increases profits. As the science of crop production and yield-response modelling continue to progress, it is expected there will be more defensible support of profit-enhancing variable rate application, thus making precision control investments more attractive.
7. Our analysis calculates the amount reduced nutrient and chemical "waste" for input savings, but quantifying the benefits to the environment from such reductions is beyond the scope of this analysis.

References

Batte, M.T., and M.R. Ehsani. "The economics of precision guidance with auto-boom control for farmer-owned agricultural sprayers." *Computers and Electronics in Agriculture* 53, no. 1 (2006): 28-44.

Castle, M., B.D. Lubben, and J. Luck. *Precision Agriculture Usage and Big Agriculture Data*. Lincoln, NE: University of Nebraska, 2015.

Darr, M. *Precision Ag Technology Savings*. Ames, IA: Iowa State University Extension and Outreach, 2012.

Dhuyvetter, K.C., and C.M. Smith. *Differences Between High-, Medium-, and Low-Profit Producers: An Analysis of 2007-2009 Kansas Farm Management Association Crop Enterprises*. Manhattan, KS: Kansas State University Research and Extension, 2010.

Erickson, B. and D.A. Widmar. *2015 Precision Agricultural Services Dealership Survey Results*. West Lafayette, IN: Purdue University, 2015.

Fulton, J., D. Mullenix, A. Brooke, A. Sharda, A. Winstead, and B. Ortiz. *Precision Agriculture Series Timely Information: Automatic Section Control (ASC) Technology for Agricultural Sprayers*. Auburn, AL: Alabama Cooperative Extension System, 2010a.

Keller, R. "Precision Ag Survey and Manufacturer Views." *AG Professional Magazine*, (March 2013): 30-32.

Shockley, J., C.R. Dillon, T. Stombaugh, and S. Shearer. "Whole farm analysis of automatic section control for agricultural machinery." *Precision Agriculture* 13 (2012):411-420.

Smith, C.M., K.C. Dhuyvetter, T.L. Kastens, D.L. Kastens, and L.M. Smith. "Economics of Precision Agricultural Technologies Across the Great Plains." *Journal of American Society of Farm Managers and Rural Appraisers*, 76(1) (2013): 185-206.

Velandia, M., M. Buschermohle, J.A. Larson, N.M. Thompson, and B.M. Jernigan. "The economics of automatic section control technology for planters: A case study of middle and west Tennessee farms." *Computers and Electronics in Agriculture*, 95(2013): 1-10.

Table 1. Field measurements for the 14 crop reporting districts.

Crop reporting district	Number of fields	Total acres	Simple average field size (acres)	Acre-weighted averages			
				Field size (acres)	Maximum width (feet)	Headlands distance (feet)	Angle of approach (degrees)
NWKS	347	29,579	85.2	134.4	2,528	9,543	32.0
WCKS	109	15,314	140.5	394.7	3,497	12,510	34.0
SWKS	187	21,413	114.5	191.2	2,715	10,164	32.3
NCKS	228	15,270	67.0	126.6	2,418	10,659	27.0
CKS	153	8,788	57.4	108.3	2,113	8,523	29.7
SCKS	96	8,282	86.3	129.0	2,405	9,018	32.2
NEKS	37	1,259	34.0	82.8	1,758	6,853	30.9
ECKS	50	1,311	26.2	41.0	1,220	6,068	23.7
SEKS	10	489	48.9	68.2	1,708	7,122	28.7
CNE	2	264	132.0	132.0	2,558	11,484	26.4
SWNE	21	1,580	65.5	108.1	2,156	9,469	27.1
SNE	90	5,893	65.5	118.9	2,252	9,012	30.0
SENE	24	1,663	69.3	110.2	2,218	7,499	36.3
SECO	27	5,351	198.2	447.0	3,594	17,382	24.4
ECCO	45	17,849	396.7	1,598.2	7,111	34,195	24.6
SCCO	19	1,448	76.2	103.5	2,147	7,689	34.0

Table 2. Base assumptions for sprayer analysis.

Precision guidance		Differential GPS	
Width of machine		90 feet	
Cost of machine operation		$6.00 / acre	
Average cost of input (fertilizer, herbicide, etc.)		$15.00 / acre	
Total use annually		10,000 acres	
Interest rate		8.0%	
Amortization period		5 years	
	Manual control	Section control	Individual nozzle control
Sprayer control	Entire boom controlled manually	5 equal-width sections controlled automatically	60 nozzels controlled automatically
Reaction distance in headlands	15 feet	0 feet	0 feet
Investment for controllers	$0	$10,000	$25,000

Table 3. Base assumptions for planter analysis.

Precision guidance		Differential GPS	
Width of machine		30 feet (12-row, 30")	
Cost of machine operation		$18.00 / acre	
Average cost of seed -- corn		$110.00 / acre	
Average cost of seed -- sorghum		$15.00 / acre	
Total use annually		1,500 acres	
Interest rate		8.0%	
Amortization period		5 years	
	Manual control	Two sections	Six sections
Planter control	Entire planter controlled manually	Two 6-row sections controlled automatically	Six 2-row sections controlled automatically
Reaction distance in headlands	5 feet	0 feet	0 feet
Investment for row controllers	$0	$6,500	$10,000

Table 4. ROI, payback years, and annual benefits for 5-section and individual nozzle control on sprayer.*

District	Annual Benefit, $/ac 5-Section	Annual Benefit, $/ac Individual Nozzles	Annual Benefit, $/ac Marginal Change**	Return on Investment (ROI), % 5-Section	Return on Investment (ROI), % Individual Nozzles	Return on Investment (ROI), % Marginal Change**	Payback Years 5-Section	Payback Years Individual Nozzles	Payback Years Marginal Change**
NWKS	0.73	0.53	-0.20	94.7	36.7	-15.1	1.1	2.5	14.5
WCKS	0.19	-0.11	-0.30	33.2	0.9	-32.8	2.6	6.4	>30.0
SWKS	0.48	0.24	-0.24	68.0	21.8	-22.1	1.5	3.4	29.9
NCKS	0.93	0.77	-0.15	115.2	48.1	-9.2	0.9	2.0	10.1
CKS	0.84	0.67	-0.17	106.6	43.3	-11.8	1.0	2.2	11.6
SCKS	0.72	0.52	-0.20	93.1	35.8	-15.6	1.1	2.5	15.0
NEKS	0.90	0.73	-0.16	112.3	46.3	-10.7	0.9	2.1	10.9
ECKS	1.82	1.85	0.03	206.7	95.6	10.6	0.5	1.1	4.6
SEKS	1.21	1.10	-0.10	143.9	63.1	-3.2	0.7	1.6	7.6
CNE	0.97	0.82	-0.14	119.4	50.4	-8.1	0.9	1.9	9.5
SWNE	0.97	0.83	-0.14	120.1	50.8	-8.1	0.9	1.9	9.5
SNE	0.80	0.62	-0.18	102.3	41.0	-12.9	1.0	2.3	12.4
SENE	0.68	0.46	-0.21	88.9	33.2	-17.4	1.2	2.6	17.3
SECO	0.29	0.02	-0.27	46.4	9.4	-27.2	2.1	4.8	>30.0
ECCO	0.05	-0.27	-0.32	15.2	-10.2	-37.9	4.0	10.6	>30.0
SCCO	0.77	0.58	-0.19	98.9	38.8	-14.5	1.1	2.4	13.9

* Based on field size and shape assumptions as outlined in Table 1 and economic inputs and assumptions in Table 2.
** The additional benefits compared to the additional costs of going from auto-section control to individual-nozzle control.

Table 5. Marginal ROI (sprayer with 60 sections versus 5 sections – NWKS).*

Acres covered annually	Additional investment, $/machine: $5,000	$10,000	$15,000	$20,000	$25,000	$30,000
5,000	-3.7%	-22.0%	-30.3%	-35.5%	-39.1%	-41.9%
10,000	23.1%	-3.7%	-15.1%	-22.0%	-26.8%	-30.3%
15,000	45.3%	10.6%	-3.7%	-12.0%	-17.7%	-22.0%
20,000	65.7%	23.1%	6.1%	-3.7%	-10.3%	-15.1%
25,000	85.2%	34.5%	14.9%	3.8%	-3.7%	-9.1%
30,000	104.1%	45.3%	23.1%	10.6%	2.4%	-3.7%

* Values shaded as red are below the interest rate of 8.0%

Table 6. Marginal ROI with additional $0.50/acre annual "benefit" (sprayer with 60 sections versus 5 sections – NWKS).*

		Additional investment, $/machine					
		$5,000	$10,000	$15,000	$20,000	$25,000	$30,000
Acres covered annually	5,000	21.5%	-4.7%	-16.0%	-22.8%	-27.4%	-31.0%
	10,000	63.1%	21.5%	4.9%	-4.7%	-11.2%	-16.0%
	15,000	100.4%	43.2%	21.5%	9.3%	1.2%	-4.7%
	20,000	136.2%	63.1%	36.2%	21.5%	11.8%	4.9%
	25,000	171.5%	82.0%	50.0%	32.7%	21.5%	13.5%
	30,000	206.4%	100.4%	63.1%	43.2%	30.5%	21.5%

* Values shaded as red are below the interest rate of 8.0 percent

Table 7. Gross benefit of auto-row control ($/ac. across the whole field).

	CORN						SORGHUM					
	Seed saved		Revenue Preserved		Total Benefits		Seed saved		Revenue Preserved		Total Benefits	
District	2 x 6-row	6 x 2-row	2 x 6-row	6 x 2-row	2 x 6-row	6 x 2-row	2 x 6-row	6 x 2-row	2 x 6-row	6 x 2-row	2 x 6-row	6 x 2-row
NWKS	$1.61	$2.38	$2.94	$4.32	$4.55	$6.69	$0.22	$0.32	$1.03	$1.51	$1.25	$1.84
WCKS	$0.72	$1.05	$1.31	$1.91	$2.03	$2.97	$0.10	$0.14	$0.46	$0.67	$0.56	$0.81
SWKS	$1.21	$1.78	$2.20	$3.23	$3.41	$5.01	$0.16	$0.24	$0.77	$1.13	$0.93	$1.37
NCKS	$1.90	$2.85	$3.46	$5.18	$5.36	$8.03	$0.26	$0.39	$1.21	$1.81	$1.47	$2.20
CKS	$1.79	$2.65	$3.25	$4.82	$5.04	$7.47	$0.24	$0.36	$1.14	$1.69	$1.38	$2.05
SCKS	$1.59	$2.34	$2.89	$4.25	$4.48	$6.59	$0.22	$0.32	$1.01	$1.49	$1.23	$1.81
NEKS	$1.88	$2.78	$3.42	$5.05	$5.30	$7.83	$0.26	$0.38	$1.20	$1.77	$1.45	$2.15
ECKS	$3.32	$5.03	$6.03	$9.14	$9.35	$14.17	$0.45	$0.69	$2.11	$3.20	$2.56	$3.88
SEKS	$2.37	$3.52	$4.30	$6.41	$6.67	$9.93	$0.32	$0.48	$1.51	$2.24	$1.83	$2.72
CNE	$1.97	$2.95	$3.57	$5.36	$5.54	$8.31	$0.27	$0.40	$1.25	$1.88	$1.52	$2.28
SWNE	$1.98	$2.97	$3.60	$5.39	$5.58	$8.36	$0.27	$0.40	$1.26	$1.89	$1.53	$2.29

Table 8. ROI, payback years, and annual benefits for row control on 12-row planter – CORN.*

	Annual Benefit, $/ac			Return on Investment (ROI)			Payback Years		
District	2 x 6-row sections	6 x 2-row sections	Marginal Change**	2 x 6-row sections	6 x 2-row sections	Marginal Change**	2 x 6-row sections	6 x 2-row sections	Marginal Change**
NWKS	3.47	5.02	1.56	101.9	97.0	87.9	1.0	1.1	1.2
WCKS	0.95	1.30	0.35	37.3	34.3	28.7	2.4	2.6	2.9
SWKS	2.32	3.34	1.01	73.7	69.8	62.5	1.4	1.5	1.6
NCKS	4.28	6.36	2.08	121.4	118.0	111.7	0.9	0.9	0.9
CKS	3.95	5.80	1.85	113.6	109.2	101.0	0.9	1.0	1.0
SCKS	3.40	4.92	1.52	100.2	95.3	86.1	1.0	1.1	1.2
NEKS	4.22	6.16	1.94	120.0	114.9	105.4	0.9	0.9	1.0
ECKS	8.26	12.50	4.24	215.0	211.8	205.8	0.5	0.5	0.5
SEKS	5.59	8.26	2.68	152.5	147.4	137.9	0.7	0.7	0.8
CNE	4.45	6.64	2.19	125.6	122.4	116.3	0.8	0.9	0.9
SWNE	4.50	6.69	2.19	126.7	123.1	116.4	0.8	0.9	0.9
SNE	3.77	5.52	1.75	109.2	104.8	96.7	1.0	1.0	1.1
SENE	3.28	4.65	1.37	97.3	91.0	79.2	1.1	1.1	1.3
SECO	1.38	2.05	0.68	49.1	48.0	45.8	2.0	2.0	2.1
ECCO	0.27	0.38	0.11	17.0	16.2	14.8	3.8	3.9	4.1
SCCO	3.68	5.29	1.61	107.1	101.2	90.2	1.0	1.0	1.2

* Based on field size and shape assumptions as outlined in Table 1 and economic inputs and assumptions in Table 3.
** The additional benefits compared to the additional costs of going from 2 x 6-row sections to 6 x 2-row sections.

Table 9. ROI, payback years, and annual benefits for row control on 12-row planter – SORGHUM.*

	Annual Benefit, $/ac			Return on Investment (ROI)			Payback Years		
District	2 x 6-row sections	6 x 2-row sections	Marginal Change**	2 x 6-row sections	6 x 2-row sections	Marginal Change**	2 x 6-row sections	6 x 2-row sections	Marginal Change**
NWKS	0.16	0.17	0.00	13.5	11.7	8.2	4.2	4.5	5.0
WCKS	-0.53	-0.86	-0.33	-13.1	-14.5	-17.1	12.6	13.8	16.9
SWKS	-0.15	-0.30	-0.15	2.6	1.0	-2.0	6.0	6.4	7.2
NCKS	0.39	0.53	0.15	20.7	19.5	17.2	3.5	3.6	3.8
CKS	0.30	0.38	0.08	17.8	16.2	13.2	3.8	3.9	4.3
SCKS	0.14	0.14	-0.01	12.9	11.0	7.5	4.3	4.5	5.1
NEKS	0.37	0.48	0.11	20.2	18.3	14.8	3.5	3.7	4.1
ECKS	1.48	2.22	0.74	51.8	50.8	48.9	1.9	1.9	2.0
SEKS	0.74	1.05	0.31	31.5	29.7	26.5	2.7	2.8	3.0
CNE	0.43	0.61	0.18	22.2	21.0	18.8	3.4	3.5	3.7
SWNE	0.45	0.62	0.18	22.5	21.3	18.9	3.3	3.4	3.7
SNE	0.25	0.30	0.06	16.2	14.6	11.6	3.9	4.1	4.5
SENE	0.11	0.06	-0.05	11.8	9.4	4.8	4.4	4.8	5.6
SECO	-0.41	-0.65	-0.24	-7.8	-8.3	-9.3	9.4	9.6	10.1
ECCO	-0.71	-1.11	-0.39	-22.9	-23.3	-24.0	35.1	38.9	>30.0
SCCO	0.22	0.24	0.02	15.5	13.3	9.1	4.0	4.3	4.8

* Based on field size and shape assumptions as outlined in Table 1 and economic inputs and assumptions in Table 3.
** The additional benefits compared to the additional costs of going from 2 x 6-row sections to 6 x 2-row sections.

Figure 1. Representation of how values are calculated.

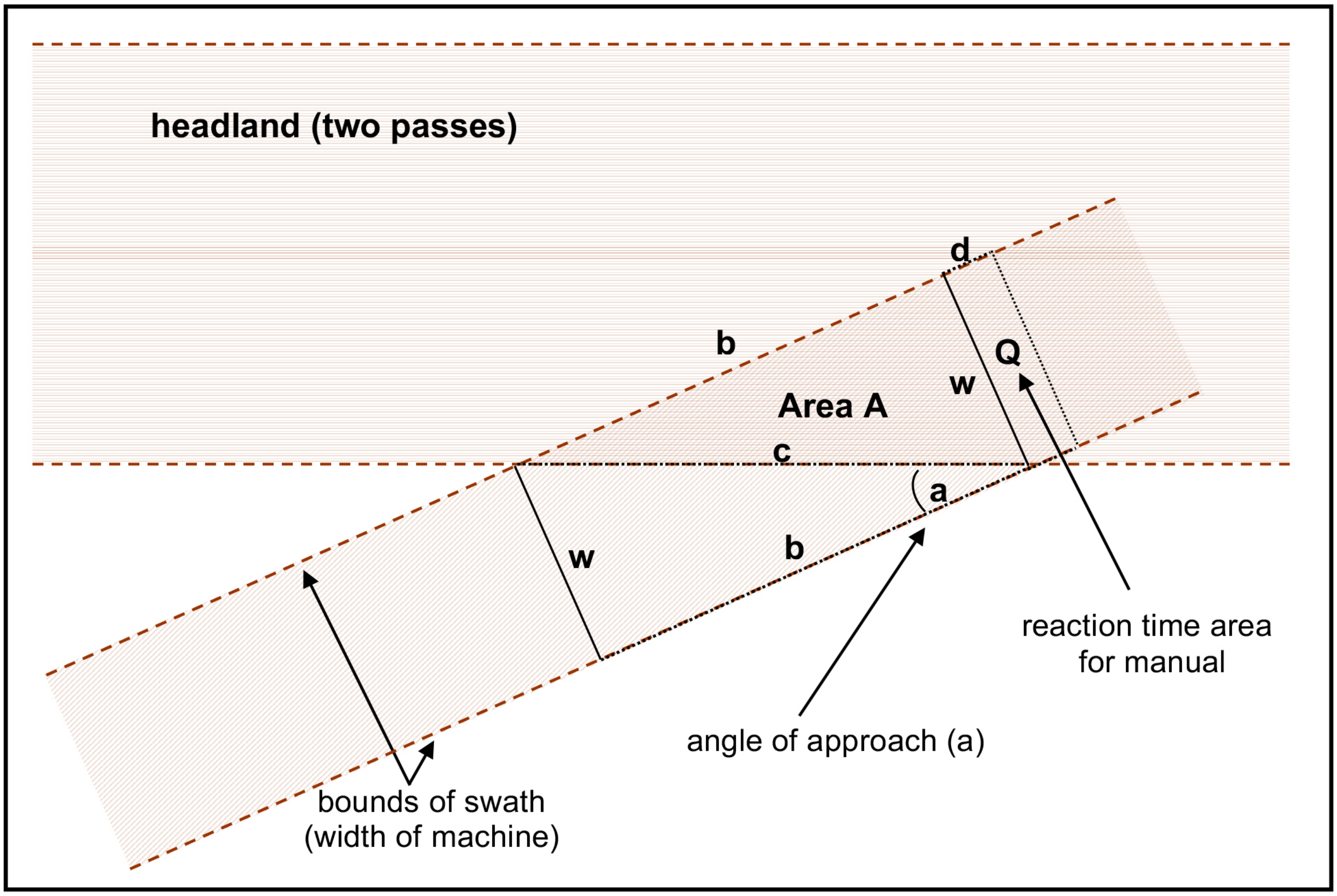


Figure 2. Representative field measurement.

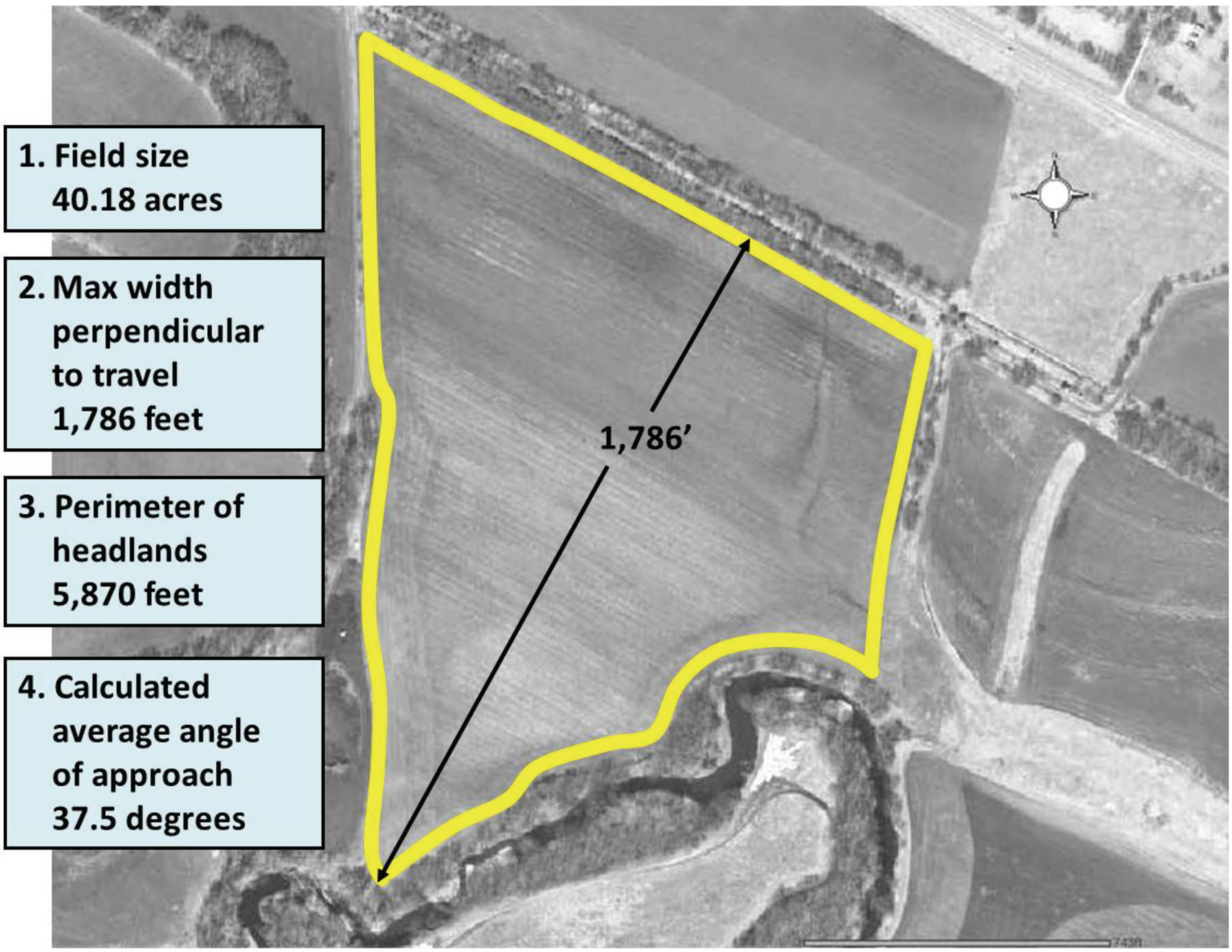
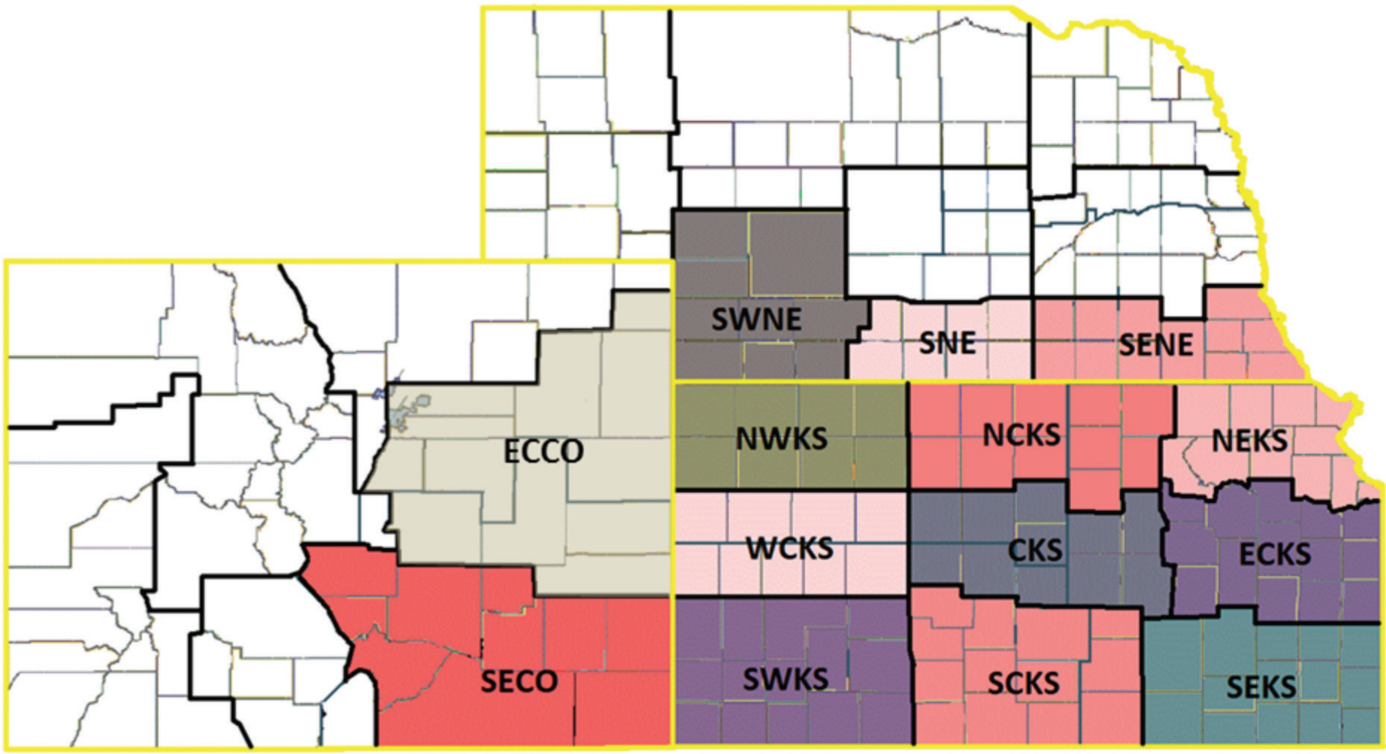


Figure 3. Colorado, Kansas, and Nebraska study region with crop reporting districts.



Appendix A.

Calculating average angle of approach

Given a perimeter distance (running distance of headland) and number of passes,

$$a = \sin^{-1}\left(\frac{2 * w}{p}\right)$$

where:
$a =$ calculated average angle of approach,
$w =$ effective swath width of machine accounting for overlap, and
$p =$ running distance of headland divided by number of passes.

Calculating distance traveled into headland before whole boom can be shutoff

$$b = \frac{w}{\tan\,(a)}$$

where:
$b =$ calculated distance traveled into headland before whole boom can be shutoff.

Calculating crop input overlap area per pass

$$\textit{Crop input overlap per pass} = 2 * (A + Q)$$
$$A = 0.5 * w * b$$
$$Q = w * d$$

where:
$d =$ reaction distance of travel before manually shutting off the boom.