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Precision Profits: The Economics of a Precision Agricultural Sprayer System

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Precision agricultural is not a single technology, but rather a set of many component technologies from which farmers can select to form a system that meets their unique needs and management style. As a result, the rate of adoption for these component technologies varies widely (Batte, *et al.).* Precision guidance is a relatively new addition to the suite of precision farming technologies. Although it has been commercially available only since about 2000, it is increasingly being adopted by farmers, commercial agrichemical applicators, and other agricultural service providers. Batte *et al*. estimated that 5.2% of Ohio commercial farmers had adopted some form of precision guidance as of March 2003. The adoption percentage was nearly 25% for the farmers with greater than $250,000 of annual sales.

Precision guidance is markedly different from many of the existing precision farming systems. It requires a larger fixed investment than many. Precision guidance also is more of a *turn-key* technology than many of the previous precision farming technologies. Whereas variable rate application of fertilizers requires a systematic data collection (e.g., grid or zone soil sampling) and analysis (fertilizer recommendations my be based on soil testing as well as knowledge of location-specific variables such as elevation, slope, soil type, drainage, etc.) before an effective fertilizer application map can be developed and fertilizers applied at variable rate, precision guidance is much more transparent and easily understood. This is especially true for simple systems such as lightbar navigation or parallel swathing systems. Because precision guidance offers benefits without a steep learning curve, it can be adopted quickly and produce benefits nearly immediately.

Precision control of mechanical application of inputs is merely an extension of precision guidance methods. For instance, precision spraying allows zones or individual spray nozzles to be regulated by a map-based controller, potentially saving chemicals, fuel, and time during the application process. Anecdotal evidence suggests that precision guidance and precision spraying may allow faster operation of equipment, will reduce operator fatigue, and allow longer periods of operation without increased error rates. Precision guidance also allows equipment operation in low light conditions, thus extending operating hours per machine/day. In addition to the private benefits to the adopting farmer, society may also benefit through reduced agrichemical pollution, and ultimately, through reduced cost of food and fiber.

To date, there have been few estimates made of the private benefits of precision guidance systems. In this article we provide preliminary estimates of the magnitude of private benefits for a precision guidance system combined with auto-boom control for agricultural sprayers (precision spraying) system. Hypothetical farm fields will be analyzed, allowing comparison of the performance of the precision system to a traditional, non-precision system for different field shapes. An analysis of the impact of size of farm on system profitability also will be explored.

Literature review

Many different types of technologies such as radio frequency, laser, machine vision, and GPS have been attempted for use in navigation of agricultural vehicles (Zuydam et al. (1994), Choi et al. (1990), Nagochi et al. (1997). GPS-based navigation systems are the only navigation technologies that have become commercially available for navigation of farm vehicles. There are two types of GPS based guidance systems; GPS guidance-aided systems and fully automated or "hands-free" GPS guidance systems that actually steer the tractor with the driver only supervising it. The fully automated system is capable of driving the tractor through the field in a straight line with a lateral accuracy of less than one inch. This system uses highly accurate Real Time Kinematic (RTK) GPS receiver. This system can work with any field and operation, including planting, cultivating and harvest. Since modern agricultural machinery is equipped with many controls, operator fatigue is a serious concern (Tillett, 1991; Noh and Erbach, 1993). Automatic guidance can reduce operator fatigue and improve machinery performance by reducing overlap or skips during field operations such as tillage and chemical application (Tillett, 1991; Klassen et al., 1993).

Many tractor manufacturing companies are now offering the RTK GPS based auto-steering system as an option on their tractors. The position information from RTK GPS can be used for both guidance and other applications such as seed mapping, controlled traffic, and controlled tillage (Reeder, 2002). Ehsani et al. (2004) retrofitted a planter with a series of optical sensors and two single board computers. Using a RTKGPS receiver, they were able to create a seed map. The information from a seed map can be later used for weed control. Abidine et al. (2002) showed that a tractor equipped with an auto-guidance system can be used to cultivate or spray very close to the plant line (about 5 cm or 2 in) at very high ground speed (up to 11 kph or 7 mph) and chisel or subsoil a field very close to buried drip tapes without damaging them, allowing the grower to use drip tapes for several years with the need to replace them every year. This application of autosteering could result in a significant cost saving for vegetable growers.

Crop inputs such as chemicals and fertilizers are applied with large application equipment with boom widths of 18.2 to 36.5 meters. In order to maintain a quality application with no gaps in coverage, the operator commonly uses a foam marker as a reference point to steer the sprayer through the field. There are errors and limitations associated with using a foam marker system. The foam may drop below the canopy; there may also be uneven distribution on a windy day; it freezes during the winter months, and is hard to see with reduced visibility and evaluate from pass to pass as the spray booms have become wider with more boom bounce. There are several factors that influence the overall accuracy of a foam marker system namely, speed of the machine, elevation of the ground, width of the machine, type of equipment, experience of the driver and type of field. Under an optimal simulated spraying condition, a 2-3% efficiency was observed using a lightbar guidance system compared to a foam marker with an experienced applicator (Ehsani et. al., 2002, Buick and White, 1999). Much higher error (up to 10%) has been observed using a foam marker compared to a guidance system (Medlin and De-Boer, 2000). Simulated and observed error can not fully explain all the error associated with a foam marker system during the real application of chemical inputs. Ehsani et. al (2004) studied the accuracy of a spraying application of two custom applicators with the foam marker system under field conditions. They found a significant variability in terms of pass-to-pass and overall accuracy error between different drivers. For a given driver, the range of overlap was from 0.6% to 26%. They also found that a driver with the average overlap of less that 5% also had many occurances of skips in application.

Methods

The analyses conducted here will estimate the value of inputs saved for a precision spraying system as compared to a traditional, non-precision system. The approach is to use a set of hypothetical fields, each of 100 acres size, which differ in shape. We will also estimate the impact of field features, such as grass waterways, on the costs for these two systems.

Real Time Kinematic (RTK) global positioning systems (GPS) are accurate to within one inch. The RTK system requires a base station. The correction signal from the base station is transmitted to the tractor using a radio transmitter. The maximum communication distance is currently about 6 miles and requires line-of-sight between the base station and receiver. A repeater can be used to increase the distance or reach over a ridge. The cost for an RTK GPS system is about $30,000.

Autosteering systems involve the use of three main components; the hydraulic components that will be added to the steering system, RTK GPS system, and a display monitor with guidance algorithm. A typical hydraulic component system might cost $7,000 for a single tractor or sprayer. Finally, the precision sprayer uses a nozzle controller that uses location information from the GPS system to precisely calculate the location of each nozzle on the sprayer boom. A shut-off valve must be installed on each nozzle. The computer can turn each nozzle on or off based on the exact location. For example, if a nozzle is positioned over an area that already has been sprayed, that nozzle will turn off to avoid overlap. The controller also can be programmed to avoid spraying certain sections of the field such as grass waterways or outside the field boundary. The extra cost for a sprayer with a sixty-foot boom would be about $7,500.

The following analyses are based on a set of assumed parameters of system accuracy, spray material costs, number of annual spray passes, fuel efficiency and cost, and opportunity cost of operator labor (table 1). We use partial budgeting techniques to estimate the profitability of the precision spraying system. With partial budgeting, profitability is calculated as the difference in revenues and costs for the two alternatives -- in this case the change from traditional to precision spraying.

In our analyses, we assume that the operator of the non-precision system drives conservatively so as to minimize the chance of sprayer skip between swathes. The cost of this driving strategy is wasted time, fuel, and spray material due to overlap. We assume that application of the material at double-the-intended-rate (overlap) has no impact on the performance of the crop. The other possible driver error is sprayer skips due to too wide a swath. The costs of this error are much more difficult to quantify because yield is likely to be impacted in the skipped area. To quantify this impact would require the use of a biological model to estimate the impact of pests, and detailed assumptions about pest or weed population, etc. This is beyond the scope of our approach. We also do not address other potential impacts on the farming operation that might be facilitated by adoption of the precision spraying system. For instance, the ability to spray longer days due to reduced operator fatigue, the ability to operate in low-light conditions, or the ability to operate at higher speeds may suggest that a smaller, lower investment spray equipment set may be possible with precision spraying, or that a larger farm size may be possible with precision spraying (and other precision guidance applications) due to the increased acreage capacity per day.

Our analyses consider only private costs and benefits. That is, we consider only the change in input costs, revenues and costs associated with ownership of the precision spraying system. We do not consider benefits to society, including the benefits of reduced pollution that might arise from a more precise application of spray materials with less overlap. Our analyses considers three field shapes: A rectangular field (figure 1), a parallelogram with field ends that are 10 degrees off perpendicular (figure 3), and a trapezoid that requires point rows in the spraying pattern (figure 4). For each field type, we also consider the presence of two grass waterways that cross the field at angles of 45 degrees or 30 degrees relative to the direction of travel.

Figure 1 represents a 100 acre field of rectangular shape. The field is 2,000 feet wide and 2,178 feet long. Because the field ends are perpendicular to the row, there is no inherent overlap of spray area due to the angle of the field end. However, there is potential for either sprayer overlap or skip in the parallel swathing of the sprayer without precision guidance. To add richness to the analysis, we have also added two grass waterways to the field design. One of these is 1,700 feet in length and has a 45 degree incidence relative to the row direction. The second waterway is 1,500 feet in length and has a 30 degree angle of incidence.

Figure 2 illustrates the two waterways in the context of the rectangular field A. With a non precision spraying system, the operator will typically spray the field by first outlining the waterway with a single boundary spray pass. Because the non-precision system does not allow individual control of spray nozzles, spray overlap is inevitable. Figure two illustrates the amount of overlapped spray area that might occur. For a 60 foot spray boom, the area of overlap is 0.083 acres per swath for the waterway with 45 degree incidence, and 0.048 acres per swatch for the 30 degree waterway. These areas increase to 0.186 and 0.107 acres for a 90 foot spray boom, and 0.330 and 0.191 acres for a 120 foot spray boom for the 45 and 30 degree waterways, respectively. For a precision spraying system with individually controllable spray nozzles, this overlapped area is assumed to be zero. In addition to wasted spray material due to overlap, the outline spray pass for the waterway boundaries means additional fuel and operator time is required to complete the spray task. This outline spray pattern is not needed for the precision spray system.

Figure 3 depicts Field B -- a parallelogram-shaped field of 100 acres. This field has ends that are not perpendicular to the rows -- they are 10 degrees off-square. The sprayer operator will typically make a spray pass across the field end. However, without precision control of individual spray nozzles, sprayer overlap will occur in this end area with each sprayer swath. The area of overlapped spray is 0.015, 0.033, and 0.058 acres per swath for 60, 90 and 120 foot spray booms, respectively. This field has the same potential for parallel swathing errors (overlap or skips) as does rectangular field A.

Field C (Figure 4) is trapezoidal in shape and totals 100 acres in area. The trapezoidal shape creates the need for point rows in the spray pattern, which inherently create an overlapping of spray areas for non-precision spraying systems. The insert in figure 4 illustrates the incidence of sprayer overlap for a spray machine with three controllable spray zones. The area of overlap with the non-precision system would be 0.004 acres for a 60 foot boom with 3 equal-width manually-controllable zones, 0.005 acres for 90 foot boom with 5 controllable zones, and 0.007 acres for a 120 foot boom with 6 controllable zones. For a precision spraying system with individually controllable spray nozzles, this overlapped area is assumed to be zero.

Benefits of the Precision System

Table 1 provides estimates of sprayer overlap, material wastage, and extra fuel and operator time required for the non-precision spraying system relative to the RTK-based precision spraying system for the rectangular-shaped field A. Estimates are provided for three sprayer widths for the field both without (Panel A) and with (Panel B) grass waterways. The operator of the non-precision sprayer is assumed to exercise caution to avoid skipped spray areas, and as a result, is assumed to make a sprayer overlap of 5% of the sprayer width on parallel swathes. The RTK-based precision guidance system is assumed to be accurate within 2 inches, hence a 2 inch sprayer overlap is applied. Based on this difference in swathing accuracy, the non-precision system requires two additional passes across the field with a 60 foot spray boom, and one additional pass for the 90 and 120 foot sprayer widths. The additional distance traveled to compensate for the increased overlap means greater fuel usage and operator time. Additionally, the overlapped spray area means a higher cost of spray material.

Our estimate of spray material savings for the precision system relative to the traditional system for 100 acre Field A is $109.45 for the 60 foot sprayer. The fuel savings and operator labor savings adds another $1.34 - 2.68 per 100 acre field, depending on sprayer width. Thus, total savings for the 100 acre field ranges from $111 to $112. for the 120 and 60 foot sprayer widths, respectively.

The magnitude of input savings for the precision system rises as grass waterways are added to the field. The extra travel required to spray around the waterways more than doubles the difference in travel between precision and non-precision systems relative to Field A without waterways. Overlapped spray areas increases to as much as 10.5 acres (more than one tenth of the field area) for the 120 foot sprayer width. There is a concomitant increase in the wastage of spray materials, fuel and operator labor. Total savings attributable to precision spraying in Field A with waterways ranges from $175 to $233 per 100 acres for the 60 and 120 foot sprayer widths, respectively.

Table 2 summarizes the measures of input usage for precision and non-precision spraying systems for Field B. The field arrangement results in spray overlap in the end areas that can be avoided with the precision spraying system. The precision system also allows reduction in parallel swathing errors just as for Field A. Overlapped spray areas for this 100 acre field range from 0.133 acres for the precision spray system with 120 foot boom to 6.071 acres for the non-precision system with 120 foot spray width. When waterways are present (Panel B), the overlapped area increases for the non-precision system to nearly 11.5 acres for the largest sprayer width.

Cost of wasted spray material increases proportional to overlapped acreage. Savings with the precision spraying system ranged from $120 to $130 per acre for the 60 and 120 foot widths, respectively, in the absence of waterways, and increased to range from $179 to $249 per acre for Field B with waterways. Total input savings were as large as $132 for the 120 foot sprayer in the absence of waterways, and $254 per acre for the largest sprayer when waterways were present.

Table 3 reports estimates of input savings with the precision spraying system relative to the non-precision system for Field C. This field is wider at one end, and thus requires point rows, and resulting overlap spraying as the rows "point off". We do assume that each non-precision sprayer has multiple manually-controlled zones, thus limiting the amount of sprayer overlap with good operator control. The same 2 inch precision and individual nozzle control is assumed for the precision system. For Field C without waterways, the overlapped spray areas range from

0.158 acres for the precision system to 6.214 acres for the non precision system, both for the widest sprayer configuration. This translates to a cost savings for spray material of $133.23 for the precision spraying system with 120 foot width. Total input savings ranged from $130 for the narrowest sprayer configuration to nearly $135 per 100 acres for the widest sprayer configuration. When waterways are considered, overlapped spray area increases dramatically for non-precision system (to more than 11.5 acres for the 120 foot width). The cost of wasted spray material was $254.79 per 100 acres for the 120 foot width non-precision system as compared to $3.48 per 100 acres for the precision spray system. Total input savings in Field C with grass waterways was $193 for the 60 foot wide system, and more than $256 for the 120 foot wide system.

The previous tables have illustrated that the magnitude of input savings with precision spraying varies greatly with the complexity of sprayer travel patterns. Our next step is to consider net returns to the precision spraying investment. Because ownership costs of the system are fixed and are spread over the entire cropped acreage, it is necessary to make an assumption about farm size. We begin by assuming a farm of 600 acres size, represented by fields of varying complexity of sprayer patterns. Specifically, we assume one field of each type to comprise the 600 acre farm. The rightmost column of table 5 shows the farm total savings attributable to precision spraying. This amount ranges from nearly $920 for the 60 foot spray system to $1,120 for the 120 foot width.

Sensitivity Analysis

Our analysis of input savings relies on a number of assumptions. In order to explore the sensitivity of our results to these assumptions, we have solved the model with alternative values for selected parameters, in each case with all other parameters held constant at their base-case levels. These results are summarized in table 6. The leftmost column shows the results for the base case. The second column displays results when only the driver precision parameter is changed -- from a 5% error rate to 2.5%. This substantially reduces the parallel swathing errors (and concomitant wasted spray, fuel and labor). Under this assumption, total input savings decline substantially, to a maximum of $755 per 600 acres for the 120 foot sprayer width.

The cost of the materials being sprayed is expected to have substantial impact on the value of precision spraying. In the base case, the materials have a cost of $22 per acre sprayed. In column 3, this parameter is doubled. Clearly, this doubles the material savings associated with precision spraying, which is by far the largest source of value to the precision spraying system. Under this scenario, the input savings from precision spraying are as large as $2,220 per 600 acres.

Finally, the fourth column changes the assumption of number of sprayer passes annually from a single annual pass to two passes annually. Under this assumption, the impact on saved spray material is the same as for the case of doubling the spray material cost, however, the savings associated with fuel and operator time also are increased. The total value for the precision spraying system under this scenario is as large as $2,241 per 600 acres.

Economies of scale

The previous analyses have shown substantial input savings for the precision spraying systems. However, there also are costs associated with owning the precision system. Table 7 presents fixed investment requirements, and given an assumed 10 year service life, estimates of the fixed costs of depreciation and interest on invested capital. The RTK GPS receiver, base station, and one replicator are estimated to cost $45,000. However, this investment can be used to support precision guidance and other GPS related activities other than spraying. We have assumed that 10 percent of the usage of this system is for precision spraying, and thus allocate only 10 percent of the cost of the RTK system to the spaying activity. On the other hand, the autosteer controller hardware and precision sprayer controllers are assumed to be permanently mounted on the sprayer, and hence the full fixed costs of these components are charged to the precision spraying activity. Given this assumed total investment of $57,500, a weighted cost of capital of 9% per annum, and a straight line depreciation method, total fixed costs for the 60 foot precision sprayer are $2,465 per year. This fixed cost rises to $2,828 and $3,190 for the 90 and 120 foot sprayers, respectively.

Table 8 summarizes total input savings by category and net return to the precision guidance and spraying system (profit) for various farm sizes. Four farm sizes are assumed. The six hundred acre farm is as previously described. A 1,200 acre farm is simply double the six hundred acre farm (2 fields of each type with and without grass waterways). The 1,800 and 2,400 acre farms are three and four replicates of the 600 acre base farm. We ignore possible pecuniary economies -- the potential that larger farms may be able to purchase inputs at lower cost per unit or market outputs at higher net price. Our analysis considers only the technical efficiencies of spreading the fixed costs of machine ownership over more acreage.

For the smallest two farm sizes, total net returns to precision spraying are negative -- that is, the value of input savings are smaller than the annual fixed costs of precision system ownership for these farm sizes. However, if the material being applied is substantially more expensive that that modeled, or if multiple spray passes are done each year, then breakeven occurs at a smaller acreage. For instance, the 1,200 acre farm earns a positive return to precision spraying under two of the scenarios presented in table 6 -- the $44 per acre material cost and 2 spray passes per year. The largest two farm sizes earn a profit to precision spraying even with the base case scenario. That net return would be larger -- nearly $5,800 per year for the largest farm size -- under the scenarios of twice-annual spraying.

Summary and Conclusions

The results of our analyses suggest that, even when considering only private benefits of input savings, the value derived from a precision spraying system can be substantial. These benefits will increase proportional to the cost of the spray material being applied and will increase with the number of annual applications and with the driver error rate for the non-precision system. Because most of the costs of the precision spraying system relate to the fixed investment, these costs diminish per acre as farm size increases. Hence, the precision spraying system will make most sense economically for larger farms who make several applications annually of relatively expensive spray materials. These estimates clearly are in alignment with the relatively rapid adoption of precision guidance systems by large farmers in the past few years.

Although our study provides valuable insight into the economics of such systems, more research is needed. Our study starts with assumptions of driver accuracy followed by sensitivity analyses. It would be useful for researchers to quantify the actual error rates for skilled machine operators. This could be done by asking them to steer without guidance, but using GPS systems to trace their actual path. This method also could also examine the impacts of driver fatigue on error rates.

Our study also ignored driver errors that resulted in sprayer skips. This is a thorny problem that will require careful biological modeling. For instance, the impact of insect pests may be quite small if the areas of skips are small and infrequent, but may increase exponentially as the skip patterns become large. In the case of weed pests, the impact of sprayer skips may be largely a linear function of area. Although research to quantify this impact may be interesting, it may be moot if the precision system is profitable in most cases even ignoring this potential added value.

Finally, our work ignores externalities, the largest being the potential reduction in surface or ground water contamination from agricultural chemicals. Again, this research will be site specific, depending on local hazards for groundwater contamination and the local area's assimilative capacity for the specific chemical applied. However, such work may be useful to policy makers who may consider policies to speed the adoption of precision spraying methods as a strategy to mitigate pollution.

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Table 1. Precision and non-precision spray system descriptions and parameter assumptions.

	Non precision system	Precision Spray System
Precision Guidance	none	RTK
Sprayer Control	Controlled manually by zones (60 ft sprayer has 3 equal-length zones, 90 ft sprayer has 5 zones, and the 20 ft sprayer has 6 zones).	Each nozzel is GPS-controlled
Accuracy (swath overlap)	7.5% of sprayer width	2 inches
Travel speed (mph)	5 mph	5 mph
Fuel consumption per hour (gallon)	5 gallon/Hour	5 gallon/Hour
Fuel cost ($/gal)	$1.85/gallon	$1.85/gallon
Cost of Spray materials (at intended application rate) $/acre	$22	$22
Opportunity wage rate for machine operator ($/hour)	$10	$10

Table 2. Estimates of sprayer overlapped area, wasted time and materials and total savings for field A with and without waterways.

	Overlap (ft)a	Required tranverses of field	Extra travel distance (ft)	Overlapped spray area (acre)	Cost of wasted sprayb	Material savings per 100 acre field ($)	Fuel Savings ($)c	Operator time savings ($)d	Total savings ($)
		Per 100 acre field							
Panel A - Field without waterways									
60 foot spray boom									
RTK System	0.17	34	--	0.275	$ 6.05	$ 109.45	$ 1.03	$ 1.65	$ 112.13
Non-precision system	3.00	36	4,356	5.250	$ 115.50				
90 foot spray boom									
RTK System	0.17	23	--	0.183	$ 4.03	$ 109.82	$ 0.52	$ 0.83	$ 111.16
Non-precision system	4.50	24	2,178	5.175	$ 113.85				
120 foot spray boom									
RTK System	0.17	17	--	0.133	$ 2.93	$ 109.27	$ 0.52	$ 0.83	$ 110.61
Non-precision system	6.00	18	2,178	5.100	$ 112.20				
Panel B - Field with waterways									
60 foot spray boom									
RTK System	0.17	34	--	0.275	$ 6.05	$ 168.59	$ 2.55	$ 4.07	$ 175.21
Non-precision system	3.00	36	10,756	7.938	$ 174.64				
90 foot spray boom									
RTK System	0.17	23	--	0.183	$ 4.03	$ 198.65	$ 2.03	$ 3.25	$ 203.93
Non-precision system	4.50	24	8,578	9.213	$ 202.68				
120 foot spray boom									
RTK System	0.17	17	--	0.133	$ 2.93	$ 227.34	$ 2.03	$ 3.25	$ 232.62
Non-precision system	6.00	18	8,578	10.467	$ 230.28				

a Assumes a 5% overlap on non-precision systems, 2 inch overlap on precision system

b Assume $22.00/acre material cost, no extra benefit for double spray

c Fuel cost is $1.25/gallon, travel speed is 5 mph, fuel usage per hour is 5 gallon.

d Opportunity cost of operator labor is $10/hour.

Table 3. Estimates of sprayer overlapped area, wasted time and materials and total savings for field B with and without waterways.

	Per 100 acre field								
	Overlap (ft)a	Required tranverses of field	Extra travel distance (ft)	Overlapped spray area (acre)	Cost of wasted sprayb	Material savings per 100 acre field ($)	Fuel Savings ($)c	Operator time savings ($)d	Total savings ($)
Panel A - Field without waterways									
60 foot spray boom									
RTK System	0.17	34	--	0.275	$ 6.05	$ 120.14	$ 1.03	$ 1.65	$ 122.82
Non-precision system	3.00	36	4,356	5.736	$ 26.19				
90 foot spray boom									
RTK System	0.17	23	--	0.183	$ 4.03	$ 125.85	$ 0.52	$ 0.83	$ 127.19
Non-precision system	4.5	24	2,178	5.904	$ 129.88				
120 foot spray boom									
RTK System	0.17	17	--	0.133	$ 2.93	$ 130.64	$ 0.52	$ 0.83	$ 131.98
Non-precision system	6.00	18	2,178	6.071	$ 133.57				
Panel B - Field with waterways									
60 foot spray boom									
RTK System	0.17	34	--	0.275	$ 6.05	$ 179.28	$ 2.55	$ 4.07	$ 185.90
Non-precision system	3.00	36	10,756	8.424	$ 85.33				
90 foot spray boom									
RTK System	0.17	23	--	0.183	$ 4.03	$ 214.68	$ 2.03	$ 3.25	$ 219.96
Non-precision system	4.50	24	8,578	9.941	$ 18.71				
120 foot spray boom									
RTK System	0.17	17	--	0.133	$ 2.93	$ 248.72	$ 2.03	$ 3.25	$ 254.00
Non-precision system	6.00	18	8,578	11.439	$ 251.65				

a Assumes a 5% overlap on non-precision systems, 2 inch overlap on precision system

b Assume $22.00/acre material cost, no extra benefit for double spray

c Fuel cost is $1.25/gallon, travel speed is 5 mph, fuel usage per hour is 5 gallon.

d Opportunity cost of operator labor is $10/hour.

Table 4. Estimates of sprayer overlapped area, wasted time and materials and total savings for field C with and without waterways.

	Overlap (ft)a	Required tranverses of field	Extra travel distance (ft)	Overlapped spray area (acre)	Cost of wasted sprayb	Material savings per 100 acre field ($)	Fuel Savings ($)c	Operator time savings ($)d	Total savings ($)
			Per 100 acre field						
Panel A - Field without waterways									
60 foot spray boom									
RTK System	0.17	39	--	0.317	$ 6.97	$ 127.39	$ 1.03	$ 1.65	$ 130.07
Non-precision system	3.00	41	4,356	6.107	$ 134.36				
90 foot spray boom									
RTK System	0.17	26	--	0.208	$ 4.58	$ 127.65	$ 0.52	$ 0.83	$ 128.99
Non-precision system	4.50	27	2,178	6.011	$ 132.24				
120 foot spray boom									
RTK System	0.17	20	--	0.158	$ 3.48	$ 133.23	$ 0.52	$ 0.83	$ 134.57
Non-precision system	6.00	21	2,178	6.214	$ 136.72				
Panel B - Field with waterways									
60 foot spray boom									
RTK System	0.17	39	--	0.317	$ 6.97	$ 186.53	$ 2.55	$ 4.07	$ 193.15
Non-precision system	3.00	41	10,756	8.795	$ 193.50				
90 foot spray boom									
RTK System	0.17	26	--	0.208	$ 4.58	$ 216.48	$ 2.03	$ 3.25	$ 221.76
Non-precision system	4.50	27	8,578	10.048	$ 221.07				
120 foot spray boom									
RTK System	0.17	20	--	0.158	$ 3.48	$ 251.31	$ 2.03	$ 3.25	$ 256.59
Non-precision system	6.00	21	8,578	11.581	$ 254.79				

a Assumes a 5% overlap on non-precision systems, 2 inch overlap on precision system

b Assume $22.00/acre material cost, no extra benefit for double spray

c Fuel cost is $1.25/gallon, travel speed is 5 mph, fuel usage per hour is 5 gallon.

d Opportunity cost of operator labor is $10/hour.

Table 5. Total input savings for a 600 acre farm comprised of the six case study fields.

	Field A - 100 acre field, no waterways	Field A - 100 acre field with waterways	Field B - 100 acre field, no waterways	Field B - 100 acre field with waterways	Field C - 100 acre field, no waterways	Field C - 100 acre field with waterways	Total for 6 fields (600 acres)
60 foot spray boom							
Material savings ($)	109.45	168.59	120.14	179.28	127.39	186.53	891.38
Fuel Savings ($)	1.03	2.55	1.03	2.55	1.03	2.55	10.73
Operator time savings ($)	1.65	4.07	1.65	4.07	1.65	4.07	17.17
Total savings ($)	112.13	175.21	122.82	185.90	130.07	193.15	919.29
90 foot spray boom							
Material savings ($)	109.82	198.65	125.85	214.68	127.65	216.48	993.12
Fuel Savings ($)	0.52	2.03	0.52	2.03	0.52	2.03	7.64
Operator time savings ($)	0.83	3.25	0.83	3.25	0.83	3.25	12.22
Total savings ($)	111.16	203.93	127.19	219.96	128.99	221.76	1,012.98
120 foot spray boom							
Material savings ($)	109.27	227.34	130.64	248.72	133.23	251.31	1,100.50
Fuel Savings ($)	0.52	2.03	0.52	2.03	0.52	2.03	7.64
Operator time savings ($)	0.83	3.25	0.83	3.25	0.83	3.25	12.22
Total savings ($)	110.61	232.62	131.98	254.00	134.57	256.59	1,120.37

Table 6. Sensitivity analyses for the 600 acre case farm.[a]

	Base Case[b]	Base case with modified overlap parameters.[c]	Base case with increased cost of spray materials.[d]	Base case with spraying twice annually.[e]
60 foot spray boom				
Material savings ($)	891.38	518.48	1,782.77	1,782.77
Fuel Savings ($)	10.73	7.64	10.73	21.47
Operator time savings ($)	17.17	12.22	17.17	34.35
Total savings ($)	919.29	538.35	1,810.67	1,838.58
90 foot spray boom				
Material savings ($)	993.12	626.82	1,986.24	1,986.24
Fuel Savings ($)	7.64	5.58	7.64	15.28
Operator time savings ($)	12.22	8.92	12.22	24.45
Total savings ($)	1,012.98	641.32	2,006.10	2,025.97
120 foot spray boom				
Material savings ($)	1,100.50	737.50	2,201.01	2,201.01
Fuel Savings ($)	7.64	6.61	7.64	15.28
Operator time savings ($)	12.22	10.57	12.22	24.45
Total savings ($)	1,120.37	754.68	2,220.87	2,240.73

a The 600 acre farm is comprised of the six 100 acre case study fields.

b Base case assumes a 2 inch overlap for the precision spraying system, 5% overlap for the non-precision system; material costs of $22/acre; and one spray application per year.

c Overlap of the non-precision system is reduced from 5% to 2.5%.

d Cost of applied spray materials is increased from $22/acre to $44/acre.

e Two spray applications are assumed each year, each with spray material costs of $22/acre.

Table 7. Additional investment in RTK guidance and precision spraying equipment with associated annual fixed costs.

			Total			Allocated to Spraying	
	Investment	Life (years)	Depreciation[a]	Midlife Interest[b]	Percent usage for spraying[c]	Depreciation[a]	Midlife Interest[b]
RTK GPS Receiver, Base Station and replicators	30,000	10	4,500	2,025.00	10%	450	202.50
Autosteer hardware	7,000	10	500	225.00	100%	500	225.00
Precision Spray controller - 60 ft width	8,700	10	750	337.50	100%	750	337.50
Precision Spray controller - 90 ft width	9,300	10	1,000	450.00	100%	1,000	450.00
Precision Spray controller - 120 ft width	9,900	10	1,250	562.50	100%	1,250	562.50
Total Fixed costs - 60 ft						2,465	
Total Fixed costs - 90 ft						2,828	
Total Fixed costs - 120 ft						3,190	

a Straight line depreciation. Assumed zero salvage value

b Weighted cost of capital is 9%

c Assumes only the specified percentage of useage (and cost) is attributable to the spraying activity.

Table 8. Profitability of precision spraying by size of farm.

Farm Size (Acres)a	Material savings	Fuel Savings	Operator time savings	Total savings[b]	Additional Fixed Costs of Precision Guidance and Spraying	Net return to Precision Guidance and Spraying - Farm Total	Net return to Precision Guidance and Spraying - per Acre
60 foot spray boom				Dollars per Farm			
600	891	11	17	919	2,465	-1,546	-2.58
1,200	1,783	21	34	1,839	2,465	-626	-0.52
1,800	2,674	32	52	2,758	2,465	293	0.16
2,400	3,566	43	69	3,677	2,465	1,212	0.51
90 foot spray boom							
600	993	8	12	1,013	2,828	-1,814	-3.02
1,200	1,986	15	25	2,026	2,828	-801	-0.67
1,800	2,979	23	37	3,039	2,828	212	0.12
2,400	3,972	31	49	4,052	2,828	1,225	0.51
120 foot spray boom							
600	1,101	8	12	1,120	3,190	-2,070	-3.45
1,200	2,201	15	25	2,241	3,190	-949	-0.79
1,800	3,302	23	37	3,361	3,190	171	0.10
2,400	4,402	31	49	4,482	3,190	1,292	0.54

a A six hundred acre farm is comprised of one of each of the hypothetical fields. A 1200 acre farm is comprised of two of each fields, etc.

b Our analysis assumes that yields are not impacted by sprayer overlap, and hence the change in total revenues is the same as input savings.

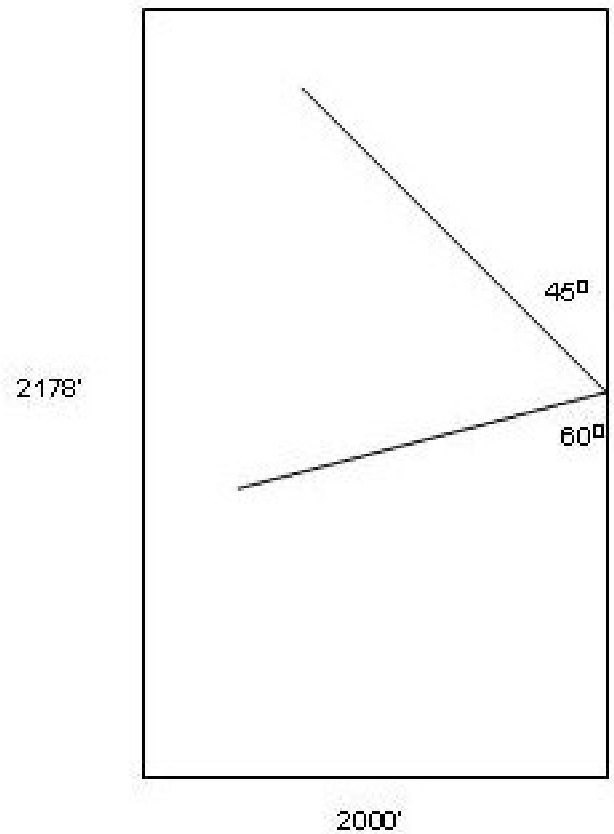

Figure 1. Field A - Rectangular field with grass waterways.

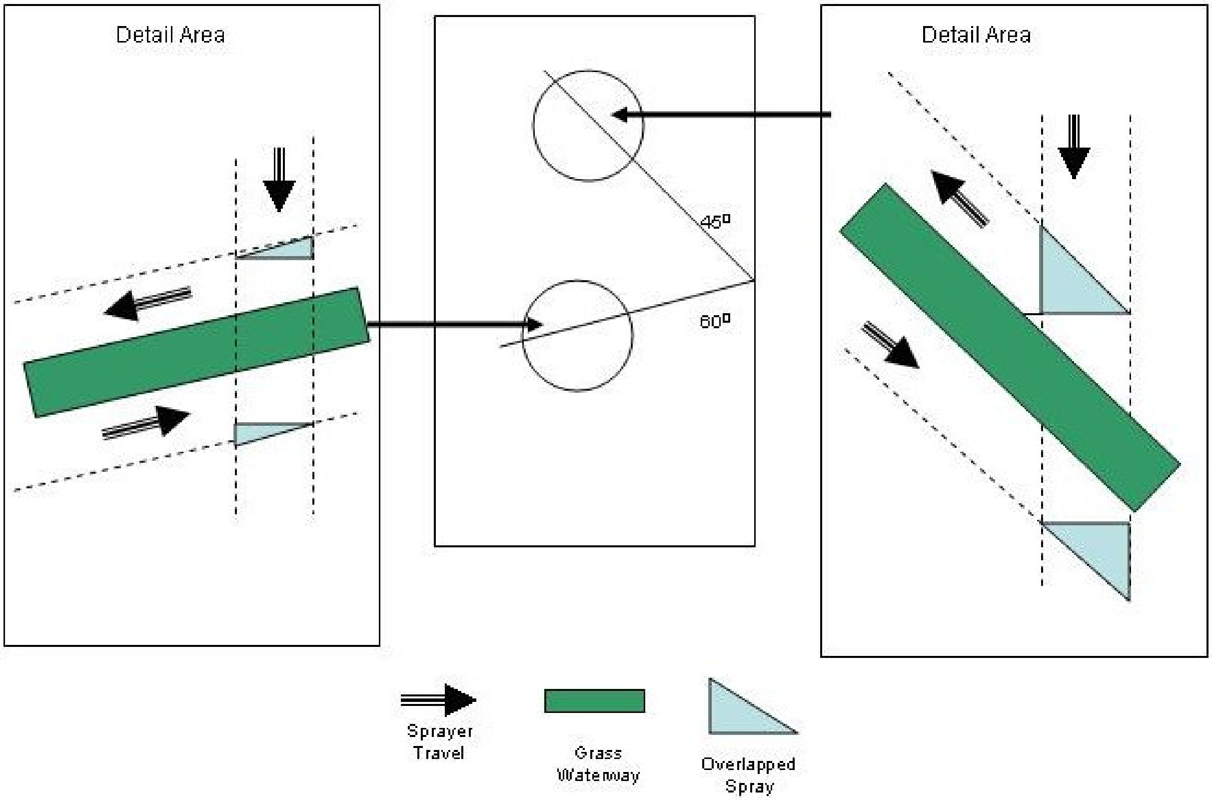

Figure 2. Illustration of sprayer travel and overlap with non-precision sprayers due to the presence of grass waterways.

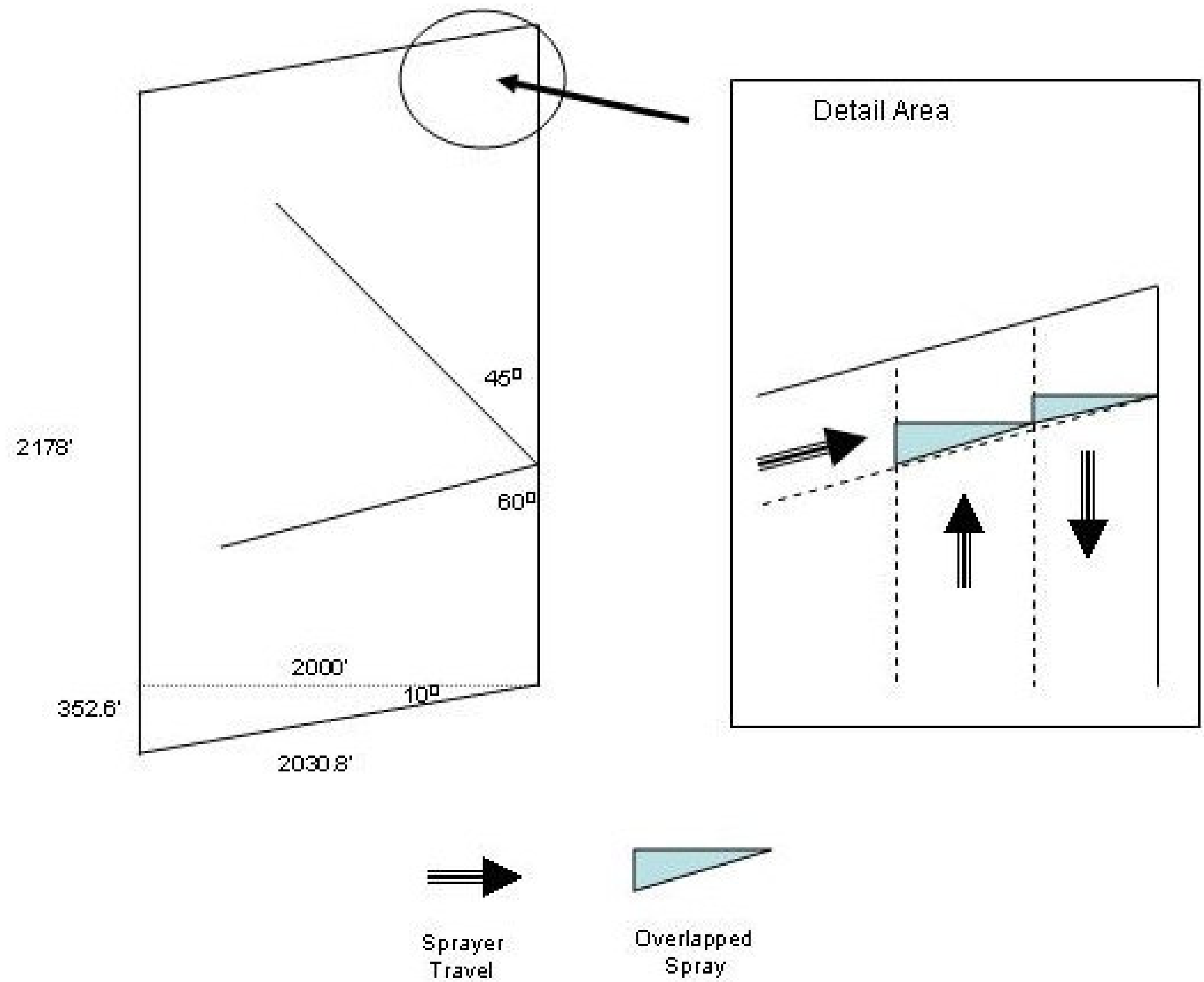

Figure 3. Example of overlap with non-precision sprayers due to non-perpendicular field ends.

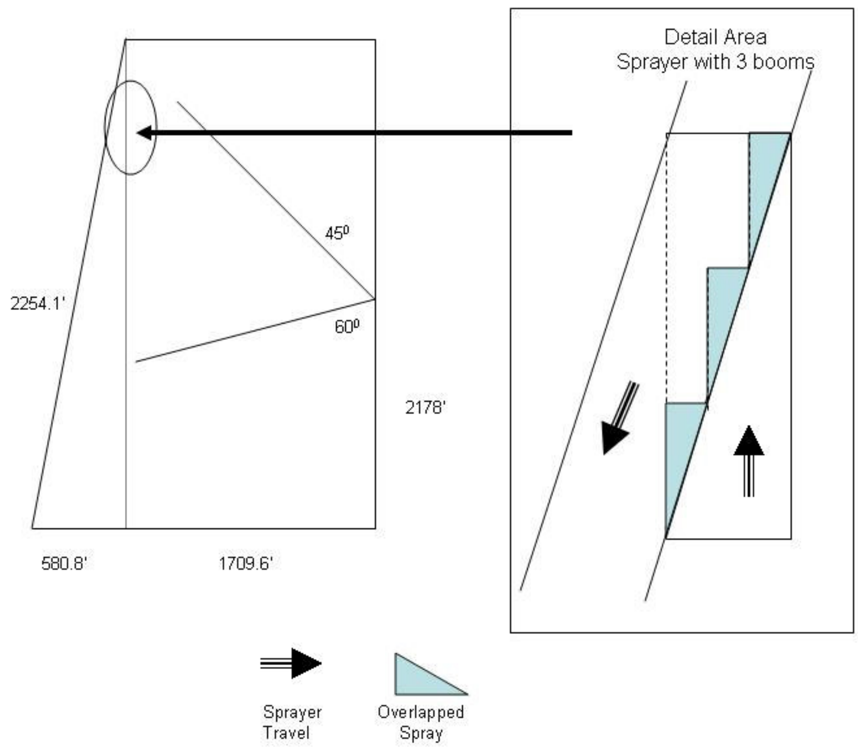

Figure 4. Field C - Trapezoid field shape with grass waterways.