ESTIMATING THE ECONOMIC BENEFITS OF AUTOMATIC SECTION CONTROL IN THE NORTH DAKOTA PRAIRIE POTHOLE REGION

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MASTER OF SCIENCE

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ABSTRACT

The impact of Automatic Section Control (ASC) as a tool of Precision Agricultural Technology is considered in more efficient application of inputs to produce the four major crops, corn, soybean, HRSW, and canola in the North Dakota Prairie Pothole Region. Reduction in machinery overlap in the sample 105 fields were calculated by simulating the routing paths of a 60-feet wide planter with 24 sections controlled and a 120-feet wide boom sprayer with individual nozzle control. The dollar and percentage seed and chemical costs that a farm can save by reducing overlapping area were calculated. Impact of field parameters on net savings were estimated by developing and estimating an econometric model. Results show that ASC can save substantial cost in the sample fields while field shape had the highest significant impact on net cost savings.

Keywords: Precision agriculture, Automatic Section Control, machinery overlap, econometric model.

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And last but not the least, I am very much thankful and grateful to my dearest husband Mohammed Mizanur Rahman and my loving daughter, Mehjabeen Rahman Borisha who were always beside me with love and support so that I can complete my studies successfully.

DEDICATION

This Thesis is dedicated to

My Father, Late Subir Das, who would have been the happiest person in the earth to see me graduating if he was alive

My Mother

A strong soul, my first teacher and my mentor who have given me the most important lesson of life, “hard work pays off”

My Husband, Mohammed Mizanur Rahman

A man with the purest heart who was, and will always be by my side in the toughest times of life, without whose support this work would not be possible

My daughter, Mehjabeen Rahman Borisha,

Who is the inspiration for all the good works I do.

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CHAPTER 1. INTRODUCTION

1.1. Justification and Objective of the Study

Precision agriculture has a significant impact on inputs of agricultural production, crop yield and crop quality (Chunziang et al. 2003). Besides the benefits bestowed upon farmers in the form of more efficient use of inputs, precision agriculture technologies play a key role in maintaining the quality of the environment (Smith et al, 2013). Automatic Section Control is a special kind of precision agricultural technology which is used primarily to minimize input cost by reducing overlap and double-application of inputs like seed, fertilizer, herbicide etc. The amount of cost saved depends on how much double-planted area is eliminated because double-application of inputs is costly due to the increased cost of seeds and chemicals, and efficiency loss of the fields in terms of harvesting and plant-competition (Jernigan,2012). According to Mooney et al (2009), the amount of this input cost saving is at least 11% of the total cost of production. Again, the quantity of the double-planted area in a field depends upon several factors such as field size, field shape, number of obstructions in the field, the width of the equipment, the direction of the equipment in the field, and accuracy of the equipment operator (Velandia et al 2013). The overlapping areas occurring in the point, end rows, and headland are shown in the following figures:

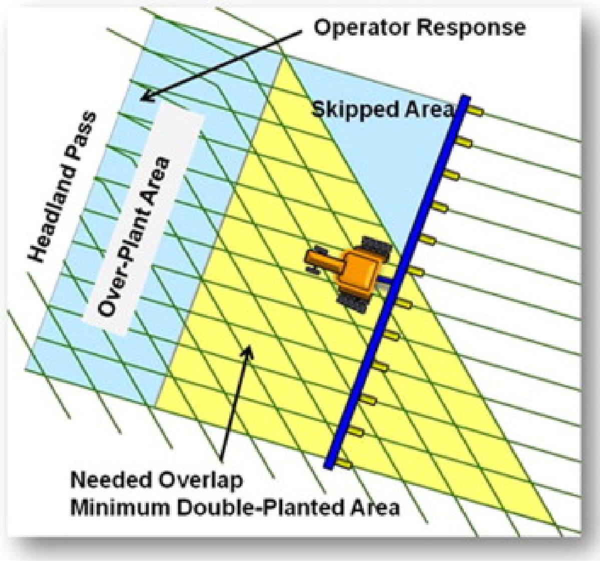

Figure 1. Double Planted Area in a Field

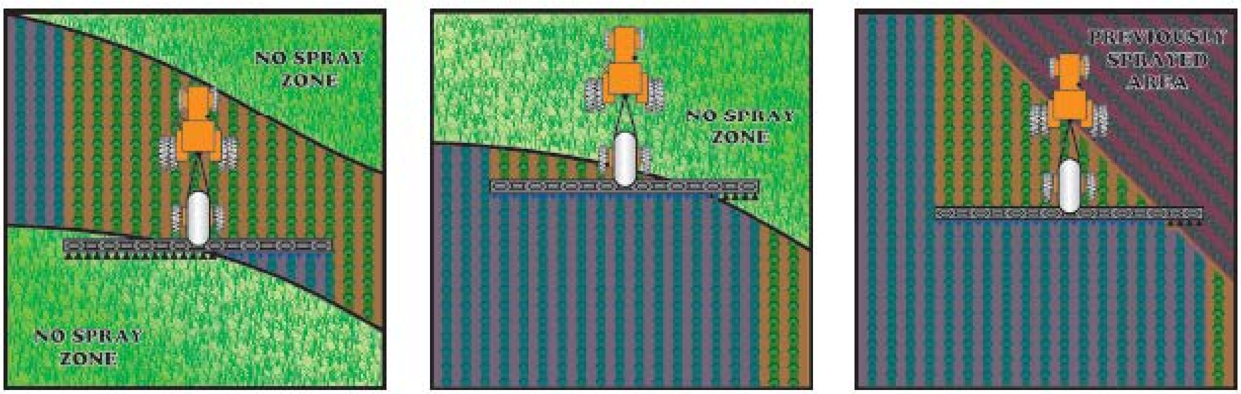

Figure 2. No-Spray and Double-Sprayed Areas in a Field

Agricultural equipment makes parallel passes across the fields for planting seeds or chemicals. In case of small and irregular shaped fields, these passes create application errors which become even more severe when approaching the point rows in the field margins, creating overlapping areas inside the field (Luck et al 2009). This leaves two choices for the machine operators: either they can skip the overlapping areas, which result in under application of seeds and chemicals or they can apply seed and chemicals twice in that part of the field, which creates both wastes of resources and may harm the cultivable land. Studies show that if a portion of a field remains uncultivated, it may result in low yield of crops, such as corn and soybean (Shafagh-Kolvanagh et al 2008). Again, double-application of herbicide can cause crop injury which may affect the production efficiency by increasing input costs (Luck et al 2010). It is evident from this discussion that reducing or eliminating overlapping areas and application errors of machinery are crucial to achieving the goal of profitability of the farming operation, which is almost impossible when manual section control of machinery is applied.

The Automatic Section Control (ASC) technology promptly utilizes GPS to identify the planter or sprayer location. As it moves through the fields, it clearly identifies the rows or section, where seed, fertilizers or herbicides are already applied and turns off those rows and sections at once. Use of ASC on planters also identifies the “no-plant zones” and can prevent the wastage of seeds in those areas (Velandia et al, 2013). Without the presence of ASC, farmers have to manually decide where to apply seed and chemicals, so there is always a possibility of double-application of input materials and also to waste these valuable input materials by applying these into “no-plant zones”. In this way, ASC can help to avoid overlapping and double application of seeds, fertilizer, and herbicides in the fields. Reduction in overlapping and double application of inputs result in substantial cost savings on seed and chemicals especially for those fields, which contain temporary seasonal wetlands, low-yielding saline areas, and/or other obstacles.

Role of ASC in input cost saving and thus maximizing net returns from the fields is supported by previous research. Troesch et al. (2010) found that when the prices of the agricultural commodity are low relative to input prices, ASC can reduce input use by 4.3%. Luck et al (2010) conducted a study on pesticide application in three fields by using ASC sprayer and showed that ASC results in substantial reduction in over application of inputs, where they found a positive correlation between the amount of cost savings and the number of section controlled. Furthermore, Shockley et al’s (2012) whole farm analysis on Kentucky fields showed that ASC increased net returns up to $36/ha.

1.1.1. Justification of the Study

Though the profitability of a farm depends both on the revenue and the cost, the cost is the factor more controllable by the farm. Hence, it is necessary for the farms to put emphasis on the minimization of cost to maintain the profitability of the farm. To do this, farms must identify areas where they can achieve a cost advantage. Machinery cost advantage can be a determining factor in the farm’s profitability and long-term business sustainability. Through an empirical analysis on the profitability data of 699 farms in Kansas, Dhuyvetter and Smith (2010) showed that the role of income difference is less important in determining profit difference among high, medium, and low profit farm enterprises, whereas cost-control plays a severe role in ascertaining profitability difference. They further emphasized that the profit position of the farms can be improved if the farms focus on machinery management. This viewpoint has also been duly acknowledged by Smith et al (2013). They opine that compared to the other determining factors of profit such as crop price and yields, machinery costs are more tenacious and thus adopting modern technologies can improve the profit position of the farms by lowering the production cost.

The Prairie Pothole Region of North America consists of North Dakota, South Dakota, Wisconsin, and Minnesota and is comprised of depressional wetlands [Figure 3]. The distinguishing feature of this land area is that it contains an enormous number of potholes, which during the spring season are filled with snowmelt and rain (U.S. Environmental Protection

Agency). This region is considered one of the most important wetland regions in the world since it provides shelter for more than 50 percent of North America's highly productive species such as migratory waterfowls. The ecological importance of this region calls for agricultural practices which bring out not only the most economic benefits but also ensure environmental conservation.

Figure 3. Prairie Pothole Region

Figure 4. States in the Prairie Pothole Region

Kiel (2016) suggested that in soybean and corn field, in the period of 2006 to 2014, pothole areas had a greater economic loss in four of the nine years and in eight of the nine years pothole areas had lower ROI than the upland areas. They also expressed the opinion that in poorly drained areas like pothole regions, it is necessary to find out better management and cropping practices to get rid of economic loss. Again, past researches suggest that producers can improve their profit positions if more focus is placed on efficient machine management, specially the cost side of it. Precision agricultural technologies such as ASC can solve this economic-ecological dilemma since, in one way, ASC can reduce seed cost by avoiding the previously planted and “no-plant zone”, and in another way, it helps to maintain the quality of the soil by eliminating double-spraying of chemicals. For this reason, it is important to investigate into the matter whether ASC will bring substantial economic benefits to the farmers of North Dakota counties which fall into the Prairie Pothole Region.

It is interesting to note that though there are lots of studies available about the economic benefits of ASC in distinct parts of North America, only a few attempts have been taken to find out the potential economic benefits of implementation of ASC in North Dakota farms. A survey conducted by Bora, Nowatzki, and Roberts (2012) revealed that the 34% of the respondent farmers who reported using GPS guidance, and the 27% of the farmers who reported using both GPS guidance and the auto steer were able to reduce the fuel and labor usage by 6%.

Considering the above situation, this paper attempts to find out the economic benefit in the form of potential cost savings by using ASC in the farms of 15 counties of North Dakota which are situated in Prairie Pothole region. Using ArcGIS modelling, this paper finds out different geometric attributes of 105 fields (7 fields from each county) such as field area, field perimeter, field shape, number of obstacles and investigates their impact on the overlap in planting and spraying operation. This study also shows how much cost savings farmers can achieve if ASC is applied in the form of 60 feet wide row crop planters and 120 feet wide self-propelled sprayers.

1.1.2. Objectives of the Study

Considering a crop mix of corn, soybean, Hard Red Spring Wheat (HRSW), and canola, the objectives of the study are as follows:

1. Finding the overlapping area that could be reduced in each of the 105 fields by using ArcGIS modelling.
2. Identifying the input cost savings due to the elimination of double-application of seeds by using ASC on a 60 foot row-crop planter.
3. Identifying the input cost savings due to the elimination of double-application of chemicals (herbicides and pesticides) by using ASC on a 120 foot self-propelled sprayer.
4. Estimating the impacts of field parameters on the net seed and chemical cost savings of each of the four crops (corn, soybean, canola, and Hard Red Spring Wheat [HRSW])

Findings obtained from this research have important implications for the farmers of the Prairie Pothole Region of North Dakota. These findings will assist farmers in making some very important investment decisions by generating answers to the following questions:

1. Is the cost savings obtained from ASC substantial to invest in this technology?
2. What is the reduction in overlapping area and input cost savings that the farmers can expect by adopting ASC in their farms?
3. Which of the four crops (corn, soybean, canola, and HRSW) provides the highest input cost savings?

1.2. Background Study and Review of Literature

Adoption of Precision Agricultural Technologies such as Auto Steering and Automatic Section Control among the farmers is a well discussed issue among renowned agricultural and natural resources economists. Previous studies performed by numerous scholars provide the evidence of substantial cost savings and sustainable use of natural resources through the adoption of the technology of Automatic Section Control since this technology can eliminate double application of input materials such as seeds and chemicals. However, scholarly works suggest that the amount of cost savings depend upon several factors such as the parameters of the field and varies among the types of the crops. This review of literature will entail an overall discussion on Precision Agriculture, the technology of Automatic Section Control and its importance in reducing the double application of input materials through the elimination of double planted areas. This section is thus divided into three parts: 1) Precision Agriculture and its importance, 2) The technology of Automatic Section Control, 3) Role of Automatic Section Control in input cost savings through the elimination of double planted areas.

1.2.1. Precision Agriculture and Its Importance

The scope and significance of Precision Agriculture are so broad that its definition and importance have been addressed by different scholars in numerous ways, each of which expresses a unique characteristic of this agricultural method. In its Agronomy Technical Note 1, Natural Resources Conservation Service (NRCS) of United States Department of Agriculture (USDA) describes Precision Agriculture as a method of "as needed" farming, an idea which is influenced by a widely accepted definition of Precision Agriculture given by Precision Ag. 2003, "a management system that is information and technology based, is site specific and uses one or more of the following sources of data: soils, crops, nutrients, pests, moisture, or yield, for optimum profitability, sustainability, and protection of the environment". This study also expresses the opinion that the goal of Precision Agriculture should be to assist farmers in identifying productive and problematic areas and to help them decide which areas they should cultivate or avoid considering economic and environmental factors. This technical note also enlists the technologies such as Auto Steer, RTK (Real Time Kinematic), Differential GPS, Remote Sensing etc. as the correlating technologies of Precision Agriculture and discusses how these technologies accelerate the benefits associated with this method. Current study also describes Precision Agriculture as a management and decision-making tool which assists the farmers in making important farming decisions such as providing the optimum level of nutrients to plants, yield monitoring, identifying in-season nutrient deficiencies, and locating environmentally sensitive areas such as waterways, streams, ditches, wetlands, high leach potential soils and tile inlets so that over-application of nutrients can be avoided.

Bongiovanni and Lowenberg-Deboer (2004) see Precision Agriculture as a tool for achieving sustainability in crop production. According to them, this sustainability stems from the environmentally friendly production methods associated with Precision Agriculture. These methods can preserve environmental quality by reducing the unnecessary application of fertilizers and pesticides and more targeted use of nutrients. For this reason, Bongiovanni and Lowenberg-Deboer (2004) intend to denote Precision Agriculture as a tool of Sight Specific Management (SSM), “to do the right thing, at the right place and at the right time”. Through an on-farm trial with the application of N fertilizer in Argentina, Bongiovanni and Lowenberg-Deboer (2004) showed that using precision agriculture as an SSM tool can still maintain profitability though the input is reduced. The researchers conclude that Precision Agriculture is a more profitable and beneficial method than whole field management in that application of N can be reduced in sensitive areas while maintaining profitability by using this method. However, the study was unable to show how PA can contribute to long-term sustainability of agricultural production through empirical analysis.

In an earlier study, Precision Agriculture was addressed as a tool of site-specific crop management in Australia by S.E. Cook and R.G.V. Bramley (1998). They discussed not only the opportunity and benefits of PA but also the drawbacks associated with it in the context of a case study in the Western Australia wheatbelt. The uniqueness of the study is that, instead of denoting Precision Agriculture as a single technique, it sees this method as a range of methodologies or a process or continuing response-control-response cycle which is comprised of four stages: 1) improved observation, 2) interpretation, 3) evaluation, and 4) implementation. Besides, Cook and Bramley (1998) suggest and enlist technologies such as Global Positioning System (GPS), Remote Sensing, Variable Application Technology and Geographic Information System (GIS) to collect and manage the flow of information and yield maps for the farm decision-making process. Furthermore, this study also suggested a number of models such as Experimental intuitive models, mechanistic models simulation models, expert systems and artificial intelligence models and statistical models for the prediction of the future likelihood of events based on the current information. In this way, this study helps us to understand the actual role that the technology like remote sensing, GPS, and GIS play in the Precision Agricultural methods. This study clearly points out the benefits of managing within-padlock variability which was earlier considered as noise and thus was not observed or explained.

Ganesh C Bora, John F Nowatzki and David C Roberts (2012) see Precision Agriculture as an effective tool for energy savings. According to them, Precision Agriculture works as knowledge-based technical management systems which can reduce input costs by reducing overlapping of equipment and tractor passes through the use of GPS guidance and auto-steering systems. This study about energy savings through Precision Agriculture is important because of the increased use of agricultural energy over the last 50 years which is about 17% of total national energy use. The researchers also mentioned in their study that a substantial return on investment can be achieved with a pay-back period of 1 year if the GPS guidance system is used to reduce the overlapping areas in a field. Conducting a survey over 1000 farmers of North Dakota, this study was successful to show that farmers who used GPS guidance system of Precision Agriculture in their field were able to save 65 hours of machine operating time, which accounts for about 6% of the total farm operation time, and could curtail the fuel use by 435 gallons, accounting for 6.3% of total fuel use for the average farmer. This savings in fuel usage causes a monetary savings of US$ 1,305 per farm. Bora, Nowatzki, and Roberts (2012) also showed that use of autosteering systems in farming operations could save 75 hours of farming time, which resulted in a fuel savings of 493 gallons with a monetary value of US$1,475 per farm. However, this study limits its analysis and conclusion in energy savings only and does not show how much seed and chemical costs can be saved if GPS guidance and autosteering systems are used in farming operations.

It is noteworthy that to ascertain the farming success through the utilization of Precision Agricultural Technology it is necessary to find out the total number and the percentage of farmers who adopt this technology in farming. Through a survey method called "Audience-Response" in a conference attended by two hundred and thirty-seven participants of nine representing states of the U.S., Griffin and Fulton (2009) were able to show in their study that about one-fourth of the Alabama farmers and four-fifths of Florida farmers used GIS mapping software to view, store, manage and analyze the information regarding farming. Whereas, 37% of Alabama and 80% of Florida farmers used GPS guidance system for taking the decision of applying lime and fertilizer in their fields. Whereas, Bora, Nowatzki, and Roberts (2012) found that 34% of the farmers of Upper-Midwest region of the U.S. used GPS guidance and 27 % of the farmers use both GPS and autosteering system and thus were able to reduce machine operating time and save energy cost.

The benefits of Precision Agriculture discussed in the preceding paragraphs suggest that more farmers should come forward to adopt this technology to gain maximum benefits from farming. The above discussion also clarifies the benefits of GPS guidance, autosteering system, RTK, and Swath Control technologies and the importance of reducing overlapping areas in the fields to save input costs. However, all the Precision Agricultural technologies are not cost effective and cannot generate substantial cost savings for the farmers. So, it is a very crucial decision for the farmers whether to adopt the Precision Agricultural Technologies and especially, which technology to adopt. The benefits of Automatic Section Control (ASC) as a method of Precision Agriculture stems from this dilemma.

1.2.2. The Technology of Automatic Section Control- The Way It Works

Fulton et al (2011) define Automatic Section Control (ASC) as a precision agricultural technology that the farmers adopt primarily to save the cost of production. According to them, this cost savings occurs primarily because this technology allows the planter to turn off the sections in the areas previously planted, or in the areas of the turning alongside the headland of a field. Furthermore, this technology turns off the machinery when it approaches a non-navigable obstacle such as point row, terraces, and waterways, and thus can reduceoverlap and minimize double or triple planted area particularly in small and irregular shaped fields containing grass waterways and terraces. This trait of ASC also helps to improve the efficiency of the planter and increase operator efficiency, especially during night time. Since the operator does not have to turn on and off the machine manually, this may increase the efficiency of the operator. Fulton et al (2011) further stated in their study that these benefits of Automatic Section Control can be increased if GPS-based guidance system is introduced along with ASC. In this regard, they recommended using Real-Time Kinematic (RTK), Trimble's new RTX Technology or decimeter level accuracy correction services as GPS/GNSS Receiver. However, using GPS as a data collection tool during planting is not a new idea at all. In a study involving three different planter widths (15 feet/6-row), 30 feet/12-row and 40 feet/16-row) over 2700 acres of corn producing field, Taylor et al (2001) used GPS for logging latitude and longitude position of the equipment to measure field efficiencies and capacities of row crop planters. Furthermore, Grisso et al (2002) used GPS to log time-in-motion data in their study of measuring field efficiencies of two crop production systems in two different field traffic patterns.

In an earlier study, Batte and Ehansi (2006) provided an estimate of the benefits of a farm when precision guidance is used along with an auto-boom control for agricultural sprayers. Taking three hypothetical fields with the size of 40.47 ha each, and of different shapes, they made a comparison between a traditional, non-precision spraying technology with a precision spraying technology that involved Real Time Kinematic (RTK) and GPS to provide both guidance and individual nozzle control. The precision sprayer was also equipped with a computer-aided nozzle controller which could turn off the nozzles when they approached any area which was previously sprayed. Thus, the precision sprayer could reduce overlapping in the fields. Batte and Ehsani showed that the irregular shaped fields contain more overlapping areas than the regular shaped fields. In the absence of individually controllable spray nozzle the sprayer operator makes a pass across the irregularly shaped field end. Thus, a sprayer overlap occurs in this area with every sprayer swath. Also, the fields which contained a greater number of non-navigable obstacles tend to contain more overlapping areas when a non-precision sprayer, that is, a sprayer without individual nozzle controller is used. Batte and Ehsani (2006) concluded that introducing a computer-aided individual nozzle control sprayer was the most beneficial in case of irregularly shaped fields with a greater number of non-navigable obstacles where the sprayer cannot pass through. In other words, they have introduced the impact of field shape and number of non-navigable in-field obstacles in determining the overlapping area in the field. However, some major limitations in their study are: instead of considering each field independently, they assumed that all the fields of a farm are of the same size and the number of non-navigable obstacles is same for each field. These factors may underestimate the reduction of overlapping areas and cost savings in irregularly shaped fields. Current study overcame this limitation by considering the actual number of non-navigable obstacles inside every sample field and estimated the effect of these non-navigable obstacles in reducing the overlapping area of that field and on the changes in net savings.

There are several other studies which have also shown the magnitude of effects ASC can impose on minimizing the application error of the machine in the form of reduction in machinery overlap. Luck et al (2010) estimated that adaption of ASC can reduce the overlapping area occurring in a field by 15.2% to 17.5% in case of 30 sections controlled, 11.2% to 11.5% if 5 sections are controlled, and 8% to 8.5% in case of a boom sprayer with 3 sections controlled as compared with Manual Section Control (MSC). The study of Luck et al covered 21 fields of Kentucky which were of varied sizes and irregularly shaped. The total land area of the sample 21 fields was 578 ha. They created GDX map files of the fields under study, and by importing them in ArcMap (ArcGIS v9.3ESRI, Redlands, California) they transformed the coordinates of the field maps into a Universal Transverse Mercarator (UTM) projection. Thus, Luck et al (2010) showed a realistic simulation of the routing path of a 24.76m boom self-propelled sprayer. Overlapping area incurred in the fields was calculated by creating a simple geometric model.

This model selected and evaluated three coordinates by fitting a circle to each of the coordinates. After that, the radius of each circle was calculated, and this radius was considered as the turning of the sprayer while spraying chemicals in the fields. An annular region was also considered in the turning point of the sprayer. All the annular regions and radius were summed up together to produce the “on” control section state or overlapping area in case of using a map-based automatic boom section control. This overlapping area or “on” control section states were then compared with actual field area to compute the percentage of overlapping are of a field. Current study also followed the same methodology of calculating percentage overlapping area of the sample 105 fields. In another study, Luck et al calculated six geometrical factors such as field area (A), field boundary perimeter (P), length of longest parallel pass (L), perimeter-to-area ratio(P/A), field circularity (C), and square-perimeter index (SPI) by using the geometrical tool of ArcGIS and estimated the impact of those geometrical factors on sprayer overlap (Luck et al 2011). They also compared those geometrical factors to the percentage of sprayer overlap for each of the configurations of the sprayer (5,7, and 9 sections controlled). Multiple regression equations were estimated for the above three configurations of the sprayer and the highest R-square could be obtained was 0.647. This study finds that the impact of field shape is the greatest in reducing sprayer overlap in a field which is characterized by the highly significant P/A ratio. Their study revealed a very important factor sprayer overlap does not reduce significantly when the number of sections increase (Luck et al 2011).

Jernigan et al (2011) conducted a study in the 28 cotton fields of West Tennessee totaling 1122 acres to estimate the effects of planter width on the reduction in overlapping area. They found in their study that when an 18-row (57 feet) planter is used, the overlap reduction was 12.2 acres or 39% of the total arable area in the last planter pass of the field. When the planter width increased, and a 24-row (76 feet) planter was used, the reduction in overlap area increased up to 18.5 acres or 42% of the total arable area. These findings indicate that as the machinery width increases, the percentage reduction in overlap area also increases.

Zandonadi et al (2011) estimated the off-target application errors or machinery overlap in agricultural fields by developing a computational method. This study analyzed GIS formatted shape files of fields in a software program named Field Coverage Analysis Tool (FieldCAT) and calculated the machinery overlap in a field caused by the swaths of the machine across the headlands. Zandonadi et al (2011) also considered the navigable obstacles (obstacles which the machine can pass through), and non-navigable obstacles (where the machine cannot pass through but can make a headland pass along the boundary of the obstacle) along with the overlap created in headlands in calculating total overlapping area. Results show that the off-target application errors, or the areas where the inputs should not be applied could be reduced by 9.1%-27%, 6%-13.1%, 0.5%-1%, and 0.2-0.5% when the controlled section widths were 27m, 13.5m, 1m, and 0.5m respectively. FieldCAT is also used as an analysis tool in a study where the researchers developed a whole farm decision-making framework to analyze the impact of ASC installed sprayer and planter on reducing the overlapping area of a field (Shockley et al, 2012). Shoekley et al (2012) found that when ASC is coupled with Auto-Steer, it can reduce off-target application error as the planter/sprayer makes parallel passes across a field. They considered a 24m sprayer and 16 row-planter where the ASC was installed and the reduced overlapping area in case of an ASC installed planter/sprayer was compared with a base case (no ASC). Results show that when ASC was implemented on a 24m sprayer, field overlap was reduced by 9%, and when ASC was implemented on a 16m planter with 16 rows and 16 sections controlled, the overlap reduction was less than that of the sprayer (6% only). The reason is, implementation of ASC can result in greater reduction in overlapping if the machine width is greater. However, greater overlap reduction does not necessarily ensure greater savings because input cost should also be considered in calculating cost savings. These findings of Shockley et al (2012) were also reflected in our study, where we found a greater overlap reduction when ASC was implemented on a 120 feet wide sprayer than on a 24-row planter (60 feet wide). But, the savings were more in case of the implementation of ASC on planter because seed cost is greater than chemical cost. Shockley et al (2012) also found that the impact of field size on reducing overlap is more than the impact of field shape. According to them, a smaller sized and irregularly shaped field generates more overlap reduction. Also, the field which contains a greater number of obstacles is worthier of being selected to implement ASC because ASC can reduce more overlapping area in a field that contains a substantial number of obstacles.

Velandia et al (2013) conducted a study to identify the potential savings by reducing overlapping areas inside 52 fields in Middle and West Tennessee farms when ASC is introduced. According to them, the reduction in overlapping areas inside the field is virtually same for both planter and sprayer. The only difference is that, farmers can save seed cost when ASC is installed in a planter, whereas farmers can save chemical cost when ASC is installed in a sprayer by avoiding double application of seed and chemicals in the areas previously planted. In this study, Velandia et al (2013) also attributed the reduction of production cost of a field to the reduction of the overlapping area of that field by saying that substantial seed cost could be saved if the overlapping area could be reduced by adopting ASC in planters. Valendia et al (2013) collected geo referenced data of 52 agricultural fields from Mid and West Tennessee area which totaled an area of 700 ha. The field data were provided by eight Tennessee Producers. A Data acquisition system was used to collect Real Time Kinematic (RTK) and GPS planting data. The geo referenced data were then imported into ArcGIS and routing path was created by drawing parallel lines considering the same planter width (111.6 and 12.2 m) for each field. Centerlines were created by creating a polyline shapefile in ArcGIS which were used as a realistic simulation of the passes of the planter across the field. Planting boundaries of half a width of the planting pass were created outside each planter pass. Overlapping areas were calculated by drawing perpendicular lines creating manual polygons where the parallel lines passed across the end row. The area of these polygons was calculated by using the geometric feature of ArcGIS and added together to calculate the area of total overlapping area of a field. Again, the field parameters such as field area, field perimeter, perimeter to area ratio, double-planted area, the percentage of the double-planted area were calculated using the geometry feature of ArcGIS (v9.3, ESRI). Velandia et al (2013) found a reduction in double-planted area ranging from 0.04% to 15.57%. Using a partial budgeting technique, these field attributes were used in a regression equation to estimate the changes in net revenue due to the elimination of overlapping area by adopting ASC. Changes in net revenue generated from each field were used as dependent variable and field area, perimeter, price of crops, number of fields in double-planted area category (low, medium, high), percentage of over-lapping area that can be eliminated by ASC and the reduction in seed cost by adopting ASC were used as independent variables. It was estimated that the changes in net return were equivalent to changes in savings by adopting ASC. Velandia et al (2013) also suggested that smaller sized and irregularly shaped fields have higher overlapping areas than large-sized and rectangular shaped field and therefore, savings will be more in the fields with smaller area and larger perimeter-to-area ratio (P/A ratio). These findings of Velandia et al (2013) clearly indicates a negative relationship between savings and field area, and a positive relationship between savings and field perimeter and P/A ratio.

Craig et al (2013) describe ASC as a precision agricultural technology which promptly utilizes satellite-based Global Positioning Systems to "automatically and precisely steer the machinery". Therefore, ASC can mark the areas of over application of chemicals inside the field such as headland turns, point row, terraces, waterways etc. by shutting off the machine sections as the machine approaches to the area previously covered. Craig et al (2013) conducted their study over 553 fields (of total 49,095 acres) in Kentucky and calculated the overlapped area in each field by using *Guidance and Section Control Profit Calculator-Excel Version*. They found that controlling the sections of a sprayer automatically has a major impact on eliminating at least some over-application of input materials, and the angle of approach of the machinery is a key determinant of the quantity of over-application that can be eliminated. One major limitation of Craig et al (2013) is that they estimated the impact of field size and shape on the reduction of overlapped area and over-application of inputs in a field, but they did not consider the impact of in-field navigable and non-navigable obstacles, which may otherwise produce a different output.

1.2.3. Economic Benefits of Automatic Section Control

The unique characteristic of ASC of shutting off the sections near the overlapped area of a field results in substantial economic benefits. These findings have been supported by a lot of previous studies. When ASC is installed in a planter, it can save a great deal of seed cost by reducing the over-application (Velandia et al 2013; Shockley et al 2012). ASC can save a substantial quantity of chemicals when installing in a sprayer which results not only in economic gains but also in environmental benefits (Craig et al 2013; Shockley et al 2012). However, in current study, only the economic benefits of ASC are considered. Environmental benefits of ASC are excluded from the scope of this study. Therefore, only the previous studies are discussed in the following paragraphs where there are empirical analysis and well-evidenced results of the economic benefits associated with ASC.

Batte and Ehsani (2006) determined the magnitude of the benefits that an auto-boom control system imposes on a set of hypothetical fields in case of an agriculture sprayer. They concluded that in a field with no water ways (non-navigable obstacle), ASC can save $4.36 to $4.39 per hectare of input cost. The amount of savings becomes higher when non-navigable obstacles (here, waterways) are included in the field. These savings range from $5.94 to $7.41 per hectare. However, the limitation of the analysis of Batte and Ehsani is that it calculates the savings based on some hypothetical fields and arbitrary shapes of the fields such rectangular, parallelogram and trapezoid. But in the real world, fields do not come in exact shapes that are mentioned in this study. Current study overcomes this limitation by analyzing maps of real fields of North Dakota Prairie Pothole region which gives a more realistic estimate regarding input cost savings generated by ASC.

Mooney et al (2009) developed an economic framework for ascertaining the economic benefits of variable rate application and targeted application of chemical inputs. Using a partial budgeting technique, Mooney et al (2009) showed that targeted application of inputs by using automated guidance and RTK can enhance the profitability of the farm by reducing application cost of chemicals and the cost of equipment. Level of this savings reached 11% or above when an agricultural sprayer is combined with ASC.

Fulton et al (2011)'s study conducted in Auburn showed that ASC can save 1% to 12% (4.3% on average) seed costs by reducing the double-planted area in the fields. This amount of input cost savings allows the farmer to recover the cost of investment in the installation of ASC within 2 years. This study also showed that field parameters such as field size and field shape have a profound impact on savings. Furthermore, fields containing non-navigable obstacles such as terraces and waterways generate more cost savings. This finding is commensurate with the regression results of our study where it is shown that number of non-navigable obstacles has a positive impact on input cost savings.

Shockley et al (2011) developed a whole-farm economic analysis model to ascertain the economic benefits of ASC for Kentucky grain farmers. Shockley et al (2011) incorporated economic framework of Kentucky corn and soybean producers under no-till conditions in a resource allocation model and implemented the model under a mean-variance (E-V) quadratic equation formulation. Results obtained from this study showed that installation of sub-meter auto steer and auto guidance on the existing equipment resulted in an increase of 0.58% ($2.14/acre) in expected net return of the farm. However, Shockley et al (2011) did not measure the cost savings obtained from the reduction in overlapping area by applying ASC. Rather, this study put more emphasis on the net return that the farm can achieve if technology such as auto guidance system and sub meter auto steer are adopted along with the existing equipment.

Shockley et al (2012) adopted the whole-farm analysis model of Shockley et al (2011) and conducted a more specific analysis of the input cost savings that could be achieved by the implementation of ASC. This study also estimated the impact of field size, shape and navigational scenario of a field on the profitability of a farm. Shockley et al (2012) opined that the economic benefit stemmed from ASC is dependent on the input cost that is saved by adopting ASC. Furthermore, Shockley et al (2013) suggested that input cost savings resulted from the adoption of ASC are dependent not only on the overlap reduction but also on the cost of the input. For instance, the reduction in overlap area was 6% in case of a planter and 9% in case of a sprayer when ASC was adopted. But, chemical cost savings were less than seed cost savings since the cost of seeds was greater than the cost of chemicals. Shockley et al (2012) concluded that in all scenarios, ASC could increase the net returns of a farm by $36/acre and adoption of ASC produced greatest economic benefit when it was implemented on both planter and sprayer. However, Shockley et al (2012) only considered four types of field size and shapes whereas, in the real world, numerous shapes and sizes of fields can be observed. Current study overcomes this limitation by considering the shape and size of each of the sample 105 fields separately and estimating the parameters of each field on net input cost savings.

Smith et al (2013) estimated the impact of field size and shape on net input cost savings by installing ASC on an agricultural sprayer. Using a partial budgeting approach, they showed in their study that net benefits of ASC are more intensive in the irregularly shaped field and adoption of ASC can bring at most 77.2% net return for farms by saving chemical costs. They also estimated that smaller sized and irregularly shaped fields will generate more return on investment if ASC is implemented.

Velandia et al (2013) estimated the potential losses that arise due to the overlapped areas in 52 fields and divided the fields into three categories based on the overlapped areas they contain. These categories are: low, moderate and high double-planted area. Velandia et al (2013) estimated savings obtained by reduced overlapping areas by developing an analytical framework with partial budgeting technique. Considering three crop-mix scenarios (cotton, cotton and corn, corn and soybean) Velandia et al (2013) estimated the changes in savings due to the elimination of double planted area in each of the field categories (low, moderate and high overlapping) by developing an equation taking the savings variable as the dependent variable. Assuming seed cost as double in the overlapped areas,Velandia et al (2013) showed that a reduction in overlapping area ranging from 1.2% to 9% could save corn and cotton seed costs by $3 per ha to

$38 per ha depending on the size and shape of the fields. The seed cost savings in soybean fields were less than those of corn fields since the seed cost of soybean is lower than seed cost of corn (Velandia et al). In our study, the seed cost savings of corn is greater than savings in case of the other three crops soybean, HRSW, and canola, and HRSW showed the least cost savings since the seed price of corn is the highest and the seed price of HRSW is the lowest among the four crops. Though Velandia et al (2013) developed an insightful economic model to estimate the seed cost savings resulted from the reduction of overlapping area, they only discussed the impact of the field parameters on the reduction of the overlapping area. The impact of field parameters on savings obtained from a field is skipped from their study.

Current study not only estimates the overlapping area that could be reduced by adopting ASC but also shows the respective input cost savings that resulted from the overlap reduction. Unlike the previous studies, current study did not limit the analysis by showing the impact of different field parameters on overlap reduction only. Rather, this study also estimates the impact of field parameters, and the magnitude and direction of the impacts on net cost savings that can be achieved by adopting ASC. Moreover, this study also includes a Discounted Net Present Value analysis to ascertain the economic benefits that an ASC equipped row-crop planter and a boom sprayer will bring for a farm throughout the machine's useful life.

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CHAPTER 2. DATA

In this study, both map data and input price data set were used to calculate the overlapping area in the sample fields of North Dakota Prairie Pothole Region. Data set on the field parameters such as field area, field perimeter, perimeter-to-area ratio (P/A ratio), number, and area of navigable and non-navigable obstacles inside the fields were prepared by using the geometric tool of ArcMap (ArcGIS v10.5, ESRI).

2.1. Collection of Map Data

During the cropping season of 2014, the georeferenced map data of the fields were obtained from North Dakota GIS Hub Data Portal. Imagery data was obtained from USDA-FSA-APFO Aerial Photography 2003-GISPreview-Map of the fields. 8-12 fields were collected from each county of ND, but for this study, 105 field maps of 15 counties of North Dakota Prairie Pothole Region were used. All the map data were georeferenced to make them eligible for further analysis. The ND counties which fall under the Prairie Pothole Region are shown in the following figure:

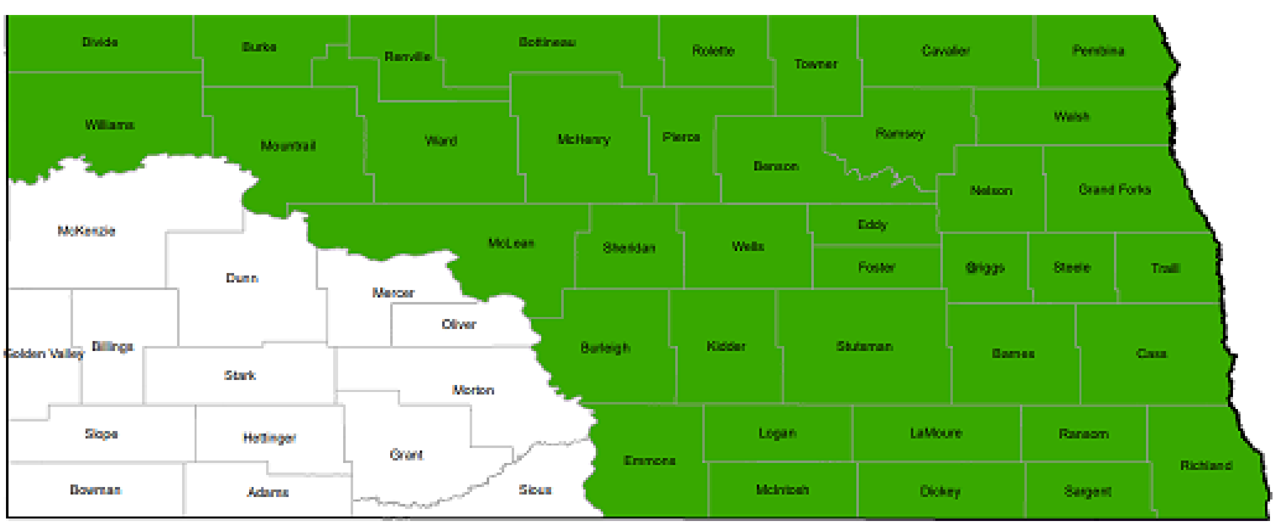

Figure 5. Counties in ND Prairie Pothole Region

Fields which are significantly different from each other in attributes such as arable area, the presence of obstacles inside the field etc. were selected randomly. Fields that appeared to include multiple crops and fields which are ploughed north-south or east-west directions, contained natural obstructions like low lands, water, trees, and rocks were selected. The selection was random. Any two fields with the same attribute were not selected. Fields included in the map of a county were separated from the map of that county and separate maps were formed from each field based on the field attributes. Figure 6 and figure 7 show a map of a county in the Prairie Pothole Region and a field under that county respectively.

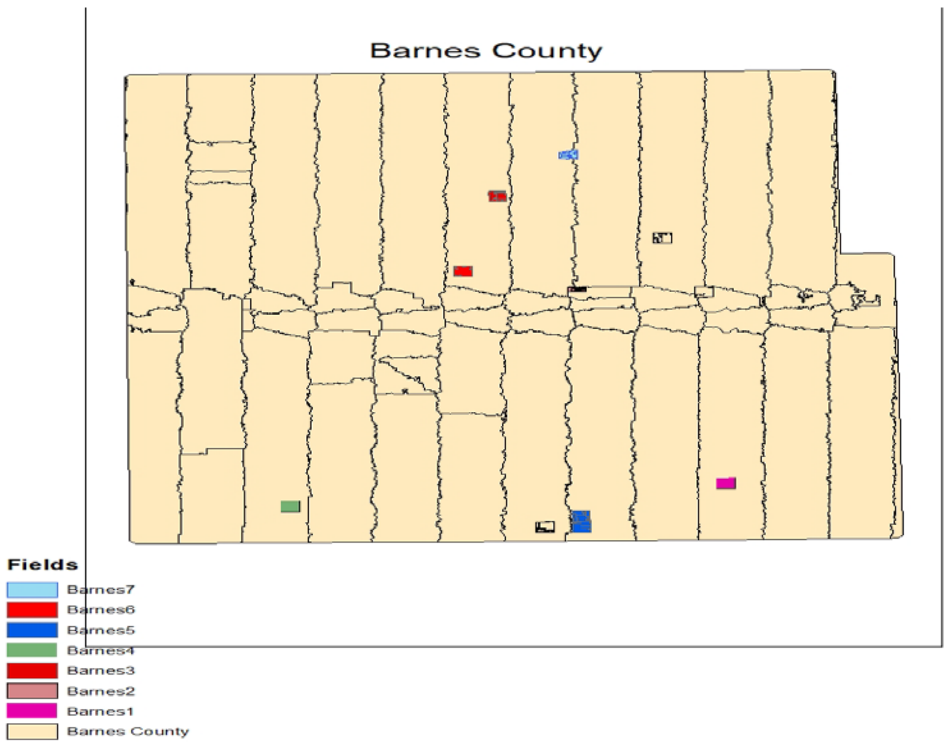

Figure 6. A County in the ND Prairie Pothole Region with All of its Fields

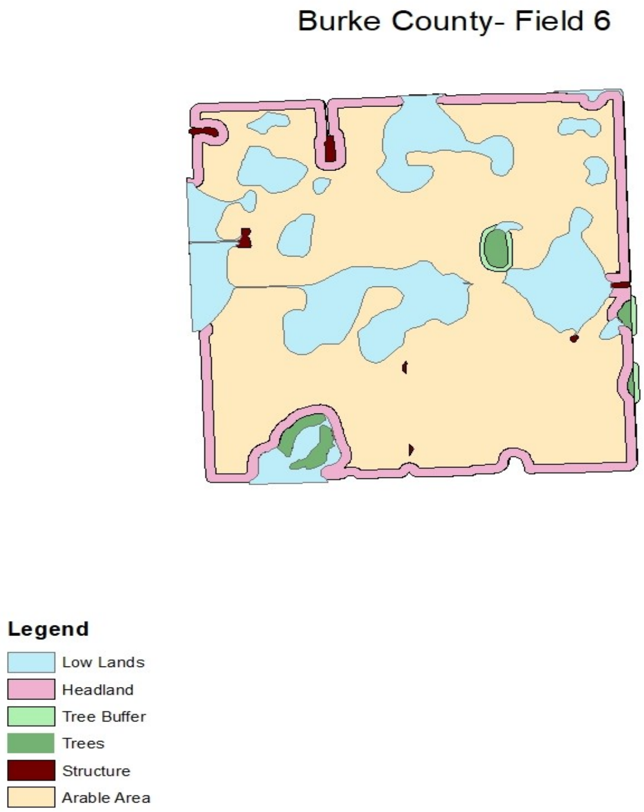

Figure 7. Map of a Field in Burke County with All of Its Attributes

The attributes of the fields were assigned based on physical observation of county images. Every attribute was given a unique number which was given arbitrarily. For example,99 for all rock attribute, 88 for all tree attributes etc. Similar number was assigned to a similar set of attributes. For example, if 88 denotes for Low Lands, then all the low lands of all the fields will be denoted with the similar number. The reason behind using this technique is, for the research purpose sometimes it is needed to aggregate the number of obstacles or area of rocks, low lands or structure or find the percentage of obstacles in each field. If a unique numerical identity is given to each field attribute, it is easier to search it with that unique identification number.

Field parameters such as total area and perimeter of the cultivable land (here denoted as arable land), headland, and all other navigable obstacles (low-lands) and non-navigable obstacles (water, non-agricultural lands, trees, and structures) were calculated using “calculate geometry” feature of ArcMap. A data set was prepared from the attributes of each field. These attributes were used as dependent variables in the regression analysis discussed in the methodology section.

2.2. Collection of Input Price Data

Estimated input costs per acre for the year 2017 were collected from ND crop budget provided by NDSU extension. For this study, only the data on the cost of seeds, and the cost of chemicals such as herbicides, insecticides, and fungicides were used. In some previous studies, input cost of fertilizer was also used to calculate the input cost savings that the farms can achieve by installing ASC in boom sprayers. But in current study, cost of fertilizer is not considered. The main reason for not using fertilizer cost data in this study is, only a small portion of ND farmers use the sprayer to apply fertilizer in the field. For corn and soybean, farmers apply fertilizer in the form of coulter (digging soil, apply fertilizer and close the soil) and stream bar just to enhance the quality of the crop, not the yield. For wheat, canola, and barley, use of sprayer is not very effective since the row spacing is very low. Hence, the only costs that North Dakota farmers can save from sprayer are the costs of herbicides, insecticides, and fungicides (Dr. Frayne Olson, NDSU Extension Service Crop Economist/Marketing Specialist and Associate Professor of the Department of Agribusiness and Applied Economics, NDSU). It is noteworthy that the data on estimated input cost provided by ND crop budget (NDSU extension) is region-wise. That is, the whole North Dakota is divided into 9 regions and each region has its own set of input prices. In current study, same input prices are considered for the counties which fall in the same region. For example, Eddy, Foster, and Griggs are three of the fifteen sample counties in our study. All the three counties fall in the East Central region of North Dakota. Therefore, seed and chemical costs/acre are held as similar for all the fields which fall under the span of these counties. The counties which fall in different North Dakota Budget region are shown in the following figure:

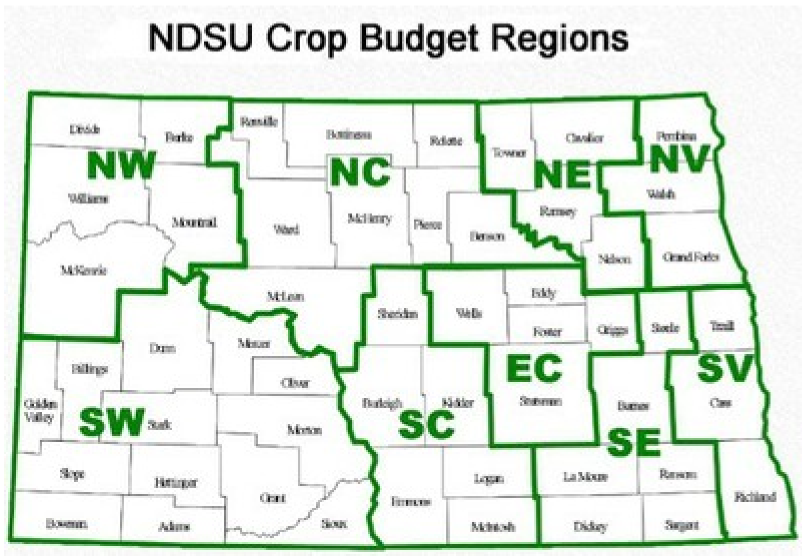

Figure 8. ND Crop Budget Regions with Counties inside Each Region

All the per acre seed and chemical costs were converted into per hectare costs by multiplying the per acre cost by a factor 0.404686 since 1 acre = 0.404686 hectares. Only the 2017-dollar prices of inputs were considered to represent a more realistic measurement of cost savings.

CHAPTER 3. METHODOLOGY

Tendency of the farmers to save production cost stems from the rational behavior of the producers to minimize the cost of production. Hence, the theoretical framework of this study is based on the micro-economic theory of cost of production, especially the impact of technical change on input costs.

Geometrical features of the field such as total arable area and total overlapping area of a field and data on costs of seeds and chemicals were used to calculate the total savings and net savings corresponding to each field. Method of calculating the cost of the implementation of ASC in a 60-feet wide 24-row crop planter with 24 sections controlled and in a 120-feet wide boom-sprayer with individual nozzle control was obtained from Shockley et al (2011).

The empirical analysis estimated a fixed-effect model with cross-sectional data, which estimates the impact of independent field attributes and the regional dummies (the ND crop budget regions) on net savings obtained from each field.

3.1. Theoretical Framework: Theory of Cost and Impact of Technical Change

The theoretical framework of this study was obtained from the book "Microeconomic Theory: Basic Principles and Extensions" by Walter Nicholson and Christopher Snyder. Nicholson and Snyder define the economic cost of production as "the cost of any input is given by the size of the payment necessary to keep the resource in its present employment". This definition considers the opportunity costs of input along with the actual cost of them.

3.1.1. Economic Costs

Economic costs of production include labor costs and capital costs, where the labor costs include the wages of the labor measured in labor-hours and capital costs include the cost of materials and entrepreneurial and investment costs. If w denotes the rate of wages of labor, l

denotes the current labor usage in production, *v* denotes the per unit cost of capital input, and *k* denotes the total quantity of capital used during the production period, the total costs for the farm during a period is given as,

$$total\ costs = C = wl + vk \tag{3.1}$$

Where, *l* and *k* are the current input usage and represent labor and capital respectively. Whereas, w and v are the per unit cost of input.

Though some scholars such as Dewett (2005) opines that the cost of production includes both fixed and variable elements, these two types of elements of cost can be distinguished only in the short run. In the very long run, there is no existence of fixed costs and all the costs become variable (Dewett, 2005). As a result, equation (1) shows only the variable elements of total costs.

Equation (1) shows that total costs are primarily divided into two parts: cost of labor and cost of capital. In our study, labor units are assumed to be unchanged, that is, farms are not supposed to make a change in the existing quantity of labor. For the capital part of equation (1), the total cost of acquiring capital input includes the cost of materials needed for production (here, seed and chemical) and the entrepreneurial and investment costs (here, cost of investing in ASC). Cost of investment in ASC further includes the annualized cost of acquiring the machinery, opportunity cost of capital or the interest cost, and maintenance cost of the machine. If *s* denotes the per unit seed cost, *ch* denotes the per unit chemical cost, *r* represents the opportunity cost of capital, *d* represents the rate of depreciation, *m* represents the unit maintenance cost of the machinery, and *I* denotes the total annualized cost of investment in machinery, equation 1 can be expanded as,

$$total\ costs = C = wl + (s + ch + r + d + m + I)k \tag{3.2}$$

3.1.2. Minimizing Economic Cost

To minimize the cost of production, a farm must choose to produce that level of output at which the rate of technical substitution of the quantity of labor (*l*) for the quantity of capital (*k*) is equal to the ratio of the per unit cost of labor (*w*) and the per unit cost of capital (*k*).

Mathematically, to minimize the total costs given the production function $q = f(k, l) = q_0$, first a Lagrangian expression needs to be set like the following,

$$\mathcal{L} = wl + vk + \lambda[q_0 - f(k, l)] \tag{3.3}$$

The first-order conditions for a constrained minimum are,

$$\frac{\partial \mathcal{L}}{\partial l} = w - \lambda \frac{\partial f}{\partial l} = 0, \tag{3.4}$$

$$\frac{\partial \mathcal{L}}{\partial k} = v - \lambda \frac{\partial f}{\partial k} = 0, \tag{3.5}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = q_0 - f(k, l) = 0 \tag{3.6}$$

Dividing the first two equations (dividing *w* by *v*) we have,

$$\frac{w}{v} = \frac{\partial f/\partial l}{\partial f/\partial k} = RTS\ (l\ for\ k). \tag{3.7}$$

This means that to minimize the cost, a farm should equate the RTS for the inputs with their price ratio.

3.1.3. Impact of Technical Improvement in the Downward Shifting of Cost

When input prices remain constant, technical improvement shifts total costs downward, that is, the farm can produce a given level of output with fewer inputs. In this way, the introduction of modern technology in production process allows the farm to save input costs.

The total cost function before the technological improvement enters the process is given by,

$$C_0 = C_0(s, ch, r, d, m, I, w, q) = qC_0(s, ch, r, d, m, I, w, q, w, l) \tag{3.8}$$

Where, C_0 represents the total cost in the base case when advanced technology is not introduced.

Suppose, an innovative technology enters the production process. In this case, the same inputs will produce an increased quantity of output A_t at period *t*. Hence the cost function becomes,

$$C_t\big(s, ch, r, d, m, I, w, q, w, A(t)\big) = A(t)C_t(s, ch, r, d, m, I, w, q, w, l)$$
$$= C_0(s, ch, r, d, m, I, w, q, w, l) \tag{3.9}$$

Therefore, the total cost function after the introduction of technology becomes,

$$C_t(s, ch, r, d, m, I, w, q, w, q) = qC_t(s, ch, r, d, m, I, w, q, w, I)$$
$$= \frac{qC_0(s, ch, r, d, m, I, w, q, w, l)}{A(t)}$$
$$= \frac{C_0(s,ch,r,d,m,I,w,q,w,q)}{A(t)} \tag{3.10}$$

Hence, it is proved theoretically that if the improved technology is introduced, cost of inputs of production fall over time. It is noteworthy that, current study does not consider the increased quantity of production of crops that can be achieved by the improvement in technology. Rather, this study considers the quantity of overlapping area that can be reduced by introducing ASC in the farming process. The more the reduction in overlap area, the more the reduction in production cost. Therefore, q denotes the quantity of overlap reduction that can be obtained by introducing ASC for the scope of this study.

3.2. Empirical Approach

The empirical approach of this study is divided into three parts. The first part showed the process of calculating the overlapping area in each of the 105 sample fields by creating simulated routing path in ArcMap of a 60 feet wide row crop planter with 24 sections controlled and a 120 feet wide sprayer with individual nozzle controlled along the sample fields. The second part showed the necessary calculations and adjustments to identify the amount and percentage of input cost (seed for planter and chemical for sprayer) savings.

The last part of the empirical approach consists of estimating a fixed-effects model taking the net savings obtained from each field as dependent variable and field parameters as independent variables. The 9 budget regions of ND crop budget area were included in the regression analysis as regional dummies.

3.2.1. Calculation of Overlapping area in the Sample Fields

ArcMap (ArcGIS v10.5 ESRI) was used to create the simulated routing paths of a 60 feet wide 24-row crop planter with 24 sections control, and a 120 feet wide sprayer with individual nozzle control. The number of rows and the number of sections of the planter were determined based on the row spacing of the crops. For soybean and corn, planting space between the rows is 30 inches (as per expert opinion, Dr. Frayne Olson, and Professor John Nowatzki). As the width of the planter is 60 feet, therefore, the number of rows of the planter will be (60*12 =720 inches/30 inches) or 24 rows. In case of corn and soybean, we assume that single row will be controlled in a section.

On the other hand, the most acceptable row spacing for canola is 6 inches to 14 inches (Canola Program, OSU) and for HRSW, the ideal row spacing is 18 cm or 7.08 inches (McLeod et al 1996). If the row spacing for canola and HRSW is considered as 7.5 inches, the number of rows to be controlled will be (60*12= 720 inches/7.5) or 96 rows. If we consider 4 rows to be controlled in one section for the crops canola and HRSW, the number of sections controlled for canola and HRSW will be same as corn and soybean. This will help to avoid complications and save time in formulating simulated routing path in ArcMap.

The procedures for creating the routing paths of a 60-feet wide planter and a 120-feet wide sprayer and the process of calculating the overlapping area in each field are discussed in the following steps:

1. Geo-referenced county maps of ND were imported to ArcMap (ArcGIS v10.5, ESRI). All the maps of the counties of ND appeared in the format of Ortho file in ArcMap. Since routing paths of the planter and sprayer were simulated in the sample fields, all the sample fields included in the maps of different 15 counties were separated from the Ortho file. To do this, all the features of a single field (attributes such as arable area, low lands, trees, structures, and waterways) were separated from the map of that county by copying them from the attribute table of that county. A shape filewas created to save the attributes of that field. The shape files were named as field 1, field 2, etc. 7 field maps from each of the sample 15 counties (105 in total) were created from the ortho files. The area and parameter of all the attributes were calculated by using the “calculate geometry” tool of ArcMap.

2. Each field was considered as a separate map. The arable area and the navigable and non-navigable obstacles were shown in the separate layers. The arable area was used to simulate the routing path of a 60 foot planter and a 120 foot sprayer. When the arable area was shown in a separate layer, some gaps and holes were seen inside the arable land for the existence of navigable obstacles such as low lands inside the arable area. This problem was solved by using cut polygon tool of ArcMap. The gap areas were cut and merged with the arable land so that the

layer “arable land” seems continuous. When the layer of the navigable obstacles (low lands) was kept “on”, the low-lands seemed to be appearing on the arable land. This technique of cutting polygons and merging them with the arable land layer helped to create a continuous headland around the arable land.

3. After making the arable land layer smooth and continuous, an inverse buffer was created around the arable land. The length of the buffer was 120 feet for a 60 foot planter and 240 feet for a 120 foot sprayer. This inverse buffer served as the headland of that field. A separate shapefile and a layer were created for the headland of each 105 field. A smoothed arable land with its headland is shown in figures 6 and 7 for planter and sprayer respectively.

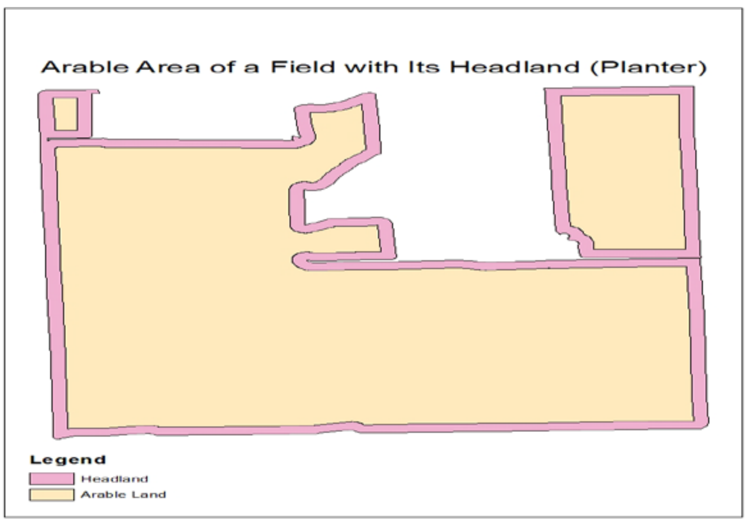

Figure 9. A Smoothed Arable Land with Its 120 feet Inverse Buffer (Headland)-Planter

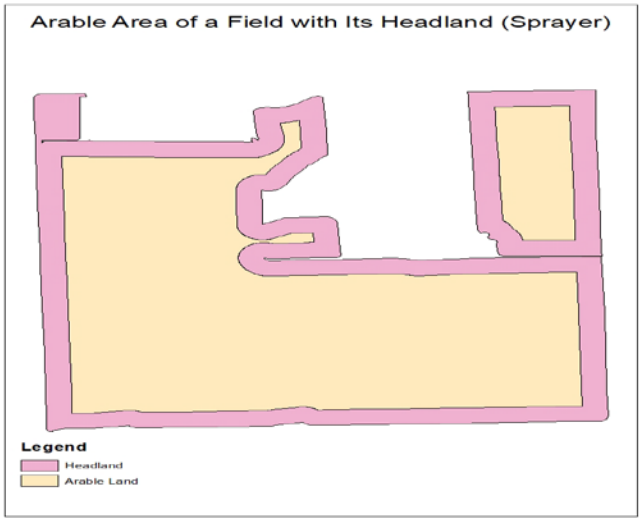

Figure 10. A Smoothed Arable Land with Its 240 feet Inverse Buffer (Headland)-Sprayer

4. The next step was to create a buffer around the non-navigable obstacles inside the arable land. The buffers around the non-navigable obstacles such as trees, structures, water inside the arable land were created to simulate the turning of the machine around the non-navigable obstacles. The length of the buffer was 60 feet when the routing path of a 60 foot wide row crop planter and the length was 120 feet in case of the 120 foot wide sprayer with individual nozzle control. A field with all the non-navigable obstacles buffered around is shown in figure 11:

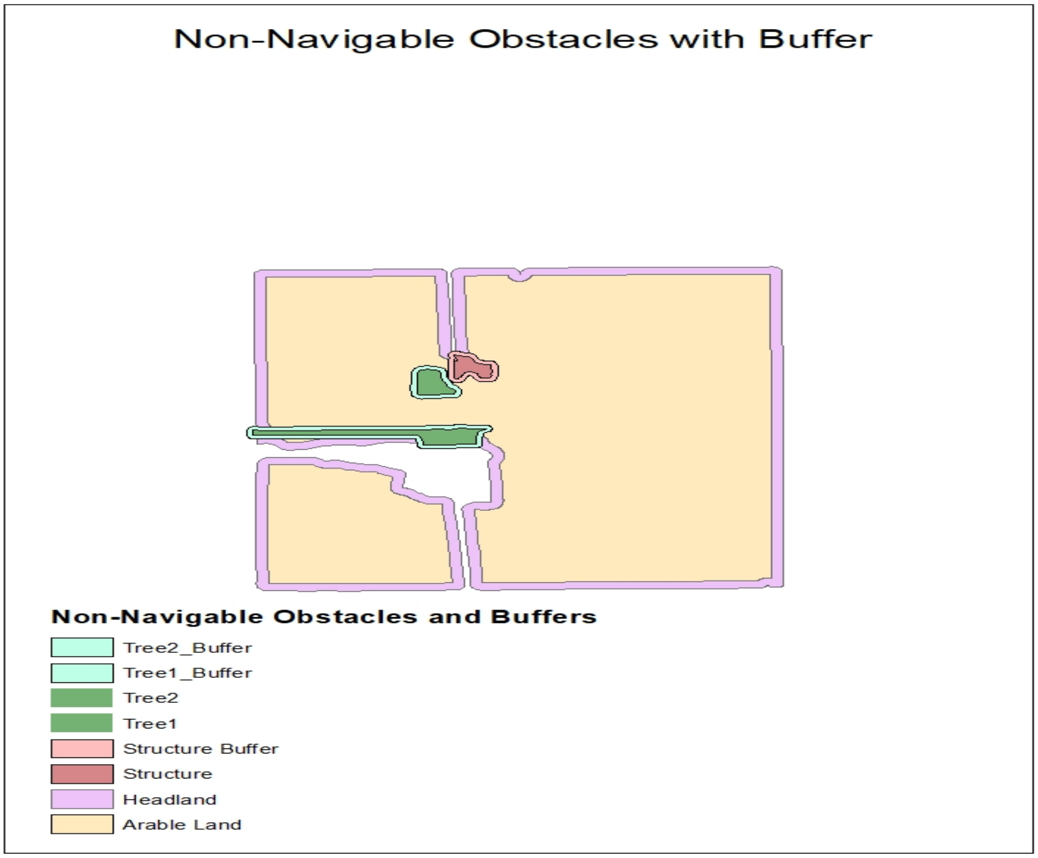

Figure 11. Arable Land of a Field with Non-Navigable Obstacles and Buffers

5. In this step, a polyline shape file was created for each of the 105 sample fields. These polyline shape files were used to create parallel lines along the field maps to show the routing paths of the 60-feet planter and 120-feet sprayer. The polyline shapefiles appeared in the field maps as a separate layer and named as "tractorline" for the 60 foot planter and "sprayerline" for a 120 foot sprayer. The parallel lines were created by editing the "arable land" layer. From the "edit" option in ArcMap, the "polyline" feature was selected, and parallel lines were drawn along the fields to show the planting and spraying paths of the machines. The distance of the first line from the headland for a 60 feet wide planter was 30 feet (9.144 meters) and for the 120 foot sprayer, the distance was 60 feet (18.288 meters). The parallel lines were drawn either North-

South or East-West directions of the fields. For a field which appeared to be horizontally spread, parallel lines were drawn in the East-West direction, and for a vertical looking field, parallel lines were drawn in the North-South direction. For a 60 feet wide planter, the gap between the lines will be 60 feet (18.288 meters). To maintain the distance equal distance between the lines and to show the turnings of the planter path, the lines were joined by arcs. To draw arcs in ArcMap, the chord and arc lengths of the arcs needs to be determined. The chords and arc lengths of the arcs in case of a 60-feet planter and a 120-feet wide sprayer are calculated in the following way by using geometric concept about the calculation of area and diameter of a circle: For a 60-feet (18.288 meters) planter, the chord of the arcs will be 18.288 meters. It is to mention here that the arc length is nothing but a half circle. Since the diameter of the circle is 18.288 meter, the radius (r) will be (18.288/2) or 9.144 meters.

Therefore, Circumference of a circle = $2\pi r = 2*3.14*9.144 = 57.4243$ meter.

Hence, arc length, $\pi r = 57.4243/2 = 28.726$ meter. Since the arc length is a half-circle, we are just dividing the circumference of a circle into two parts. The chord is the diameter of the circle in the same sense.

In case of a 120-foot sprayer, the concept is virtually the same. The only difference is that, the chord and arc length of the arcs will be different. Therefore, for a 120-foot sprayer, the chord and arc length of the arcs or turning of the parallel lines are 36.576 meters and 57.424 meters respectively, just twice the value of the chord and arc lengths of planter lines.

6. After drawing the parallel lines and joining them by arcs, the next step was to create buffers around the parallel lines to simulate the planting and spraying boundaries outside the parallel passes of the machine. These planting and spraying boundaries were half a width of the planting and spraying passes. A similar methodology was used by Velandia et al (2013) to

calculate overlap area of 52 fields in the Mid and West Tennessee area. Therefore, a 30-feet (9.144 meters) long buffer was created around the planter lines (60-feet of 18.288-meter-wide) and a 60-feet (18.288 meters) buffer was created around the sprayer passing lines (120 feet or 36.576 meters wide). A separate layer was created for the buffer and the layer was named as "tractor buffer" for the buffer around the planter passes and "sprayer buffer" for the buffer around the sprayer passes. The intersection feature of ArcMap was used to determine the overlapping areas of the sample 105 fields. To calculate the overlapping area in the turning areas of the planter and sprayer along the headland, an intersection between the headland and the "tractor buffer" layer and "sprayer buffer layer" was taken. The overlapping areas were calculated separately for planter and sprayer. For a 60-feet wide planter, the intersection was taken between the 120 feet headland and the 30 feet buffer of the planter lines. This intersection created a separate layer in the field and was saved as a polygon file named "headland intersection". Separate intersections were also taken between the buffer around each of the non-navigable obstacles such as trees, structure, non-agricultural lands, and water and the "tractor buffer". Each of the intersection was named after the name of that non-navigable obstacle. For instance, the intersection between the buffer around the trees and the buffer around the planter lines was named as "tree intersection". In this way, all other intersections were named as "water intersection", "non-agricultural land intersection", and "structure intersection". All the intersections were saved as polygon files and were shown in the maps as separate layers. The area of all the intersection polygons was calculated by using the "calculate geometry" feature of ArcMap. After that, all the intersections areas were added together to calculate the overlapping areas in each field. Such parallel lines and intersections inside the arable land of a field are shown in figure 9 in the following:

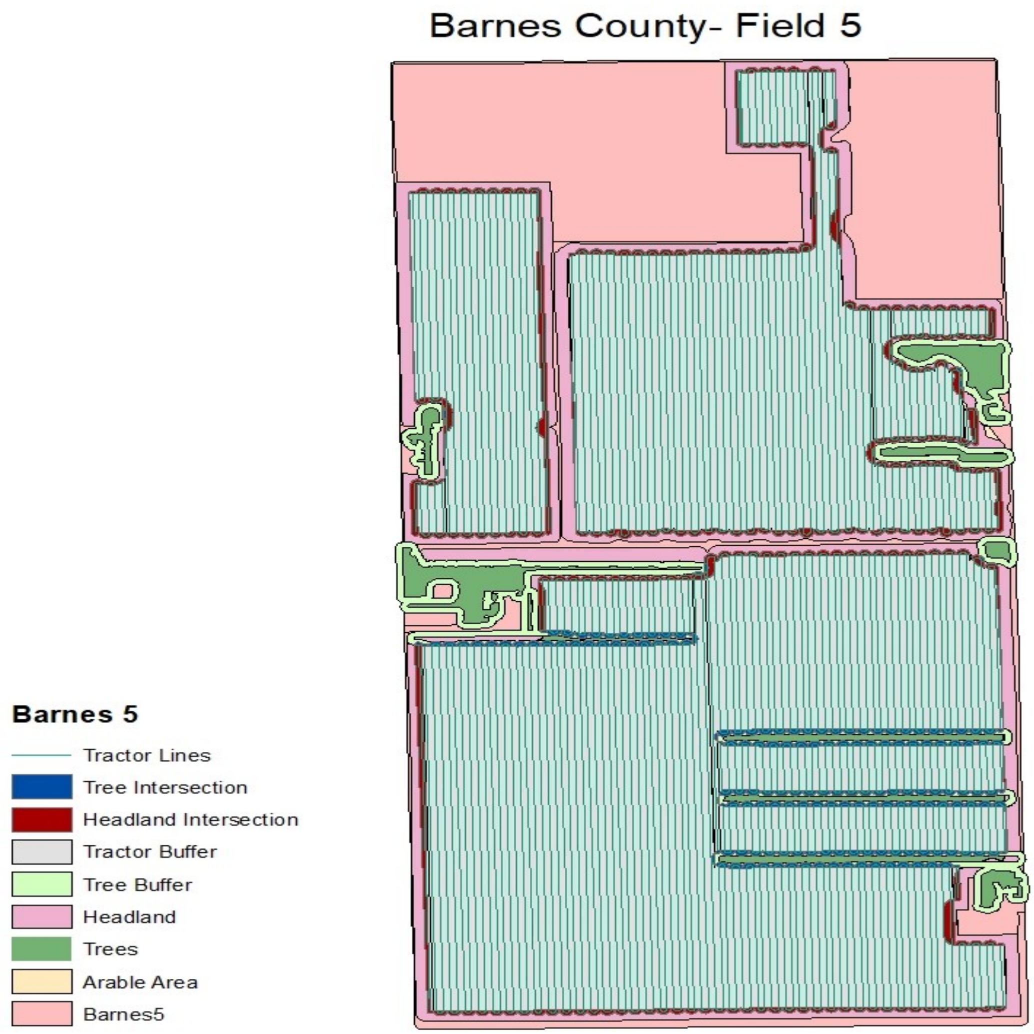

Figure 12. Simulation of Tractor Lines, Intersections around Headland and Non-Navigable Obstacles

It is noteworthy that there are some navigable obstacles in each of the field's arable land. These navigable obstacles are named as "low lands". The planter and sprayer can pass through the navigable obstacles, but it is not rational to plant seeds or spray chemicals inside these low lands. Installation of ASC helps machine operator to turn off the sections or nozzles of the planter and sprayer when the machine approaches these navigable obstacles so that the machine can pass through the navigable obstacles but do not plant seeds or spray chemicals. Hence, the area of the navigable obstacles of a field was also added to the total area of the intersection polygons of a land. Percentage of the overlapping area reduction in a field was calculated by dividing the overlapping area of the field by the arable area of that field and multiplying by 100.

Though some previous studies used different techniques and software to calculate the overlap in the fields, such as FieldCat by Shockley et al (2012) and Velandia et al (2010), and Guidance and Section Control Profit Calculator- Excel Version by Craig et al (2013), this study relies on Arcmap (ArcGIS v10.5, ESRI) rather than FieldCat to calculate the overlap reduction by adopting ASC for the following reasons:

1. Manual method to draw arc segment in ArcGIS can capture the lateral deviations of the farmers from the intended headland paths, through curves, and near end rows which are beyond consideration of FieldCat. Again, the Manual procedure adopted in ArcGIS can capture the additional overlapped area created by unexpected maneuvers in planting operations which cannot be done If FieldCat is used. (Velandia et al 2013).

2. FieldCat requires a spatially accurate boundary file compatible with ASC technology prior to planting which is difficult to obtain. ArcGIS does not require it. The arable land of a field could be easily shown from the attribute table of that field and could be taken as a separate polygon. Also, ArcGIS only requires a specific file format to upload it into the display rather than a specific field boundary which is much easier to do (Alabama A&M and Auburn Universities Extension).

3. The manual procedure in GIS shows how the tractor or planter turns around the field border and headland, and around any non-navigable obstacles like grassed waterways, rock, trees, and structures which is not possible to show when using FieldCAT.

3.2.2. Calculation of Cost Savings Generated by ASC

Total Savings: Field-wise total cost savings generated by installing ASC in the 60 feet wide 24 row crop planter and 120-feet wide sprayer were calculated by the following formula,

$$Total\ Savings = Input\ cost\ per\ hectare * OA$$

Where "OA" denotes the overlapping area (in hectares) of each field.

Net Savings: Though each of the sample fields shows some overlapping in case of both planter and sprayer passes, and thus at least some savings incur in each of the field, the farm must consider whether the savings will be fair enough to recover the cost of the planter or sprayer itself. Again, it should also be noted that in the base case (without ASC) there will be no overlapping reduction, and thus, no savings is possible. Therefore, the net savings is the amount which considers the cost of installing ASC in the planter and the sprayer and is the difference between the cost in the base case (without ASC) and the cost incurred after installing ASC. The formula for calculating net savings is thus given as,

$$Net\ Savings = Total\ cost\ without\ ASC - Total\ Cost\ With\ ASC$$

$$= Total\ Cost\ without\ ASC - (Total\ Cost\ without\ ASC + Cost\ of\ ASC - Total\ Savings)$$

$$= Total\ Savings - Cost\ of\ Installing\ ASC \tag{3.11}$$

The above formula shows that net savings are simply the difference between the total cost savings and the cost of installing ASC in a 24 row-crop planter with 24 sections controlled and a 120 feet wide sprayer with individual nozzle control. Therefore, to calculate net savings, it is necessary to calculate the total cost of installing ASC in a 60 feet wide planter with 24 sections control and a 120 feet wide sprayer with individual nozzle control.

Cost of installing ASC in the planter and sprayer has been calculated by using the methods used in Shockley et al (2011). The calculations of the cost of ASC installation in a 60-feet wide planter and in a 120 feet wide sprayer are shown in the following table:

Table 1. Cost of the Implementation of Automatic Section Control on Both Planter and Sprayer (US$)

24 Row Planter		36 m (120 feet) sprayer	
In Cab Controller	6000	In Cab Controller	6000
Row Clutches ($300 per row) (300*24)	7200	Solenoid Valves ($160 each) (72*160)	11520
Wiring and Harness	470	Wiring and harness	470
		Salvage value of the old controller	1050
Total Investment Cost (Section Control Only)	13670	Total Investment Cost (Section Control Only)	16940
Annualized Cost	2255.55	Annualized Cost	2795.10

The costs of the parts of the machinery have been obtained from Shockley et al (2012). For this study, we assume only "Section control only cost", not the section control and auto-steer cost. We didn't count here sub-meter auto steer and RTK auto steer because in the base case it is assumed that the machine is already equipped with navigational aids. We consider only ASC is adopted to determine cost savings and ASC is always paired with a navigational aid. (Shockley, 2012). Hence, only the costs of the installation of ASC are considered in the calculation of equipment costs. Total investment cost is the sum of the cost of in cab controller, row clutches, and wiring and harness. The total investment cost has been annualized by using the following techniques which were also used by Shockley et al (2011) and Shockley et al (2012) in calculating the cost of a 24 m sprayer and 16 row planters:

$$Annualized\ Cost = \frac{(Total\ Investment\ Cost\ /8)+(Total\ Investment\ Cost*0.08)}{2} \quad (3.12)$$

The above formula comes from the following formula stated in Shockley et al (2011):

Annualized Cost = (Total investment cost -salvage value)/useful life)+(Total investment cost +salvage value)*interest/2.

We considered 0 salvage value and 8% interest rate for the current study.

After determining the annualized cost for both planter and sprayer, the total annualized costs are divided by the average farm size of a county to calculate the per acre costs of installing ASC in that county. These per acre costs have been allocated among the arable land of a field to find the cost of ASC in that field. A maintenance cost of $2.27/acre and $0.64/acre was added to the per acre cost of planter and sprayer respectively. These per acre maintenance costs are obtained from the University of Minnesota Machinery Cost Estimates (2015). The per acre maintenance costs were taken into per hectare cost by multiplying the per acre costs with a factor 0.404686 (since 1 acre = 0.404686 hectares). All the equipment costs were taken into 2017 dollars by using GDP deflator of 2017.

Field-wise ASC installation costs were calculated by multiplying per hectare planter and sprayer cost with the arable area of a field. These equipment costs were then subtracted from the total savings to calculate the net savings in each field. The cost of the planter was subtracted from the total seed cost of each field to calculate the net seed savings, whereas the cost of sprayer was subtracted from the total chemical cost to calculate the net chemical savings in each field. In this way, the net seed and chemical savings were calculated for each of the sample 105 fields, and for all the four crops corn, soybean, HRSW, and canola. Percentage cost savings of each field were calculated by dividing the net savings of each field by total seed and chemical costs of that field and multiplying by 100. All the total and net seed and chemical savings along with their respective percentages for all the four crops are shown in table 4 and 5 in the "Appendix" section of this study.

3.2.3. Estimating the Effect of Field Parameters on Net Savings

Field parameters such as field area, field parameter, area of navigable obstacles, and area of non-navigable obstacles were calculated by using "calculate geometry" feature of ArcGIS. The feature, perimeter to area ratio (p/a ratio), which is a measure of the field shape was calculated from the basic parameters. Number of navigable and non-navigable obstacles were calculated by manual observation of the maps. The net savings of the 105 sample fields were regressed over the field parameter variables and regional dummies by estimating a fixed-effects model.

Name and definition of the variables are shown in table 2:

Table 2. Name and Descriptions of the Variables

Name	Definition	Unit and Method of Determination
Field_Area_Ha	A measure of the arable area of a field.	Hectare; calculated by using "calculate geometry" feature of ArcGIS.
PA_Ratio	Perimeter to area ratio of the fields	Calculated by dividing the field area with the field parameter.
Area_non_navig_ha	The total area of all the non-navigable obstacles in a field	Hectare; calculated by adding areas of the non-navigable obstacles such as tree, structures, water, and non-agricultural lands inside the arable area of a field.
Area_Navig_ha	The total area of all the navigable obstacles inside the fields	Hectare; calculated by adding the area of all the navigable obstacles (low lands) inside the fields.
No_Non_Navig	Total number of non-navigable obstacles such as trees, structures, water, and non-agricultural land inside the fields	Manual observation and calculation of non-navigable obstacles.

Table 2. Name and Descriptions of the Variables (Continued)

Name	Definition	Unit and Method of Determination
No_Navig	Total number of navigable obstacles such as low-lands inside the fields	Manual observation and calculation of navigable obstacles.
SE	A dummy variable to capture the effect of the South-East region on net savings	----
SW	A dummy variable to capture the effect of the South-West region on net savings	----
NW	A dummy variable to capture the effect of the North-West region on net savings	----
NC	A dummy variable to capture the effect of the North-Central region on net savings	----
SC	A dummy variable to capture the effect of the South-Central region on net savings	----
SV	A dummy variable to capture the effect of the South-Valley region on net savings	----
NE	A dummy variable to capture the effect of the North-East region on net savings	----
EC	A dummy variable to capture the effect of the East-Central region on net savings	----
NV	A dummy variable to capture the effect of the North-Valley region on net savings	----

In several previous studies (such as Velandia et al 2010) impact of field parameters on net savings were estimated using partial budgeting techniques and least-squares. One problem of using least-squares with only the field parameters is that the assumption of the intercept and slope of the regression may be unreasonable (Pindyck and Rubinfeld). Moreover, the data set contains a set of fields with differentiable attributes so that no two fields contain the same attributes. This may raise the variance of the estimation. A fixed-effects model can solve this problem by enabling the intercept term to vary over cross-sectional units by introducing dummy variables into the model. The basic fixed-effects model to capture the responsiveness of the dependent variable *net savings* is represented as,

$$Y_{it} = \alpha + \beta X_{it} + \gamma_2 W_{2t} + \gamma_3 W_{3t} + \cdots \gamma_N W_{Nt} + \delta_2 Z_{i2} + \delta_3 Z_{i3} + \cdots + \delta_T Z_{iT} + \epsilon_{it} \quad (3.13)$$

Where,

$$W_{it} = \begin{Bmatrix} 1\ for\ ith\ individual, i = 2, \dots, N \\ 0\ otherwise \end{Bmatrix}$$

$$Z_{it} = \begin{Bmatrix} 1\ for\ ith\ time\ period, t = 2, \dots, T \\ 0\ otherwise \end{Bmatrix}$$

In this study, the data are cross-sectional, and the dummies are the regional dummies. Since this study does not consider time component, the dummies for the time variables are skipped from the equation and we add (N-1) dummies in the model to measure the changes in the cross-section intercepts with respect to the first individual. Pindyck and Rubinfeld stated that it is wise to estimate fixed effects on a cross-sectional data because, in cross sectional data, the reduction in the degrees of freedom is less than that in panel data.

1 regional (cross-sectional) dummy is omitted to avoid collinearity. Therefore, the equation becomes,

$$Y_i = \alpha + \beta X_i + \gamma_2 W_2 + \gamma_3 W_3 + \cdots \gamma_N W_N + \epsilon_i \quad (3.14)$$

Where we consider only the coefficients and the regional dummies.

The equation of regression of this study is formulated taking the “net savings” variable as the dependent variable and the field parameters and regional dummies as regressors. The equation thus becomes,

$$Net\ Savings = \alpha + \beta_1 Field\_Area\_Ha + \beta_2 PA\_Ratio + \beta_3 Area\_Non\_Navig\_Ha + \beta_4 No\_Non\_Navig + \beta_5 Area\_Navig\_Ha + \beta_6 No\_Navig + \gamma_1 SE + \gamma_2 SW + \gamma_3 NW + \gamma_4 NC + \gamma_5 SC + \gamma_6 SV + \gamma_7 NE + \gamma_8 SE + \gamma_9 NV \quad (3.15)$$

Where one dummy variable (γ_i) is always omitted while estimating the equation to avoid perfect collinearity.

The above equation was estimated in STATA (SE 15 64-bit). The “robust” command of OLS regression was used to overcome the problem of variability in the data and to reduce standard deviation. The hypotheses were,

$$H_0: Field\ parameters\ and\ regional\ dummies\ have\ no\ effect\ on\ net\ savings$$

With the alternative hypothesis that,

$$H_1: Field\ parameters\ and\ regional\ dummies\ have\ effect\ on\ net\ savings$$

The effects of the regressors on the net savings are commensurate with their respective coefficients.

3.2.3.1. F-Statistic

The appropriated test statistic for F-test of this study is,

$$F_{N-1,NT-N-T} = \frac{(ESS_1 - ESS_2)/(N-1)}{(ESS_2)/(NT-N-T)} \tag{3.16}$$

Where, ESS_1 and ESS_2 are the error sum of squares using the ordinary least-square model and the fixed-effects model respectively and (N-1) and (NT-N-T) represent the degrees of freedom. The significance of this statistic (ability to reject the null) proves that fixed-effects model will be appropriated for estimating the equation of our study (Pindyck and Rubinfeld).

3.2.3.2. Root Mean Square Error (RMSE)

The Root Mean Square Error (RMSE) tells us about the differences between the actual and predicted values of the observations. RMSE is presented for a model with the assumptions that the errors in the model are unbiased and normally distributed (Chai and Draxler, 2014).

When we have *n* number of sample and ε model errors such that (e_i, i = 1,2,….,n), RMSE is calculated as,

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} e_i^2} \tag{3.17}$$

Since RMSE shows the difference between the actual and estimated values of the observations, a lower value of RMSE shows a better fit of a model.

3.2.4. Marginal Effects of Field Parameters on Net Savings

Marginal effects of field parameters on net savings were calculated by taking the differentiation of the net savings equation mentioned in the previous section with respect to the field parameters. It is to be noted that, in this equation, the only interacting variable is the perimeter to area ratio, which is calculated by dividing the field area by field perimeter. Therefore, the marginal effects of field area and field perimeter will be different on net savings from the coefficients of the regression. For other field parameters such as number and area of navigable and non-navigable obstacles, the marginal effects of these field parameters will be constant. Therefore, in this study, only the marginal effects of field area and field perimeter on net savings were calculated.

The marginal effect of field area on net savings is given by,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = \frac{\partial}{\partial Area}(\alpha) + \frac{\partial}{\partial Area}(\beta_1 Field\_Area\_Ha) + \frac{\partial}{\partial Area}(\beta_2 PA\_Ratio) + \frac{\partial}{\partial Area}(\beta_3 Area\_Non\_Navig\_Ha) + \frac{\partial}{\partial Area}(\beta_4 No\_Non\_Navig) + \frac{\partial}{\partial Area}(\beta_5 Area\_Navig\_Ha) + \frac{\partial}{\partial area}(\beta_6 No\_Navig)$$

$$= \beta_1 - \beta_2 * Perimeter * Area^{-2} \tag{3.18}$$

And the marginal effect of field perimeter on net savings is given by,

$$\frac{\partial Net\ Savings}{\partial Field\ Perimeter} = \frac{\partial}{\partial Perimeter}(\alpha) + \frac{\partial}{\partial Perimeter}(\beta_1 Field\_Area\_Ha) + \frac{\partial}{\partial Perimeter}(\beta_2 PA\_Ratio) + \frac{\partial}{\partial Perimeter}(\beta_3 Area\_Non\_Navig\_Ha) + \frac{\partial}{\partial Perimeter}$$

$$(\beta_4 No\_Non\_Navig) + \frac{\partial}{\partial Perimeter}(\beta_5 Area\_Navig\_Ha) + \frac{\partial}{\partial Perimeter}(\beta_6 No\_Navig)$$

$$= \frac{\beta_2}{Field\ Area} \tag{3.19}$$

CHAPTER 4. RESULTS AND DISCUSSIONS

4.1. Reduction in Overlapping Area by Adopting ASC

The overlapping area in the 105 samples fields of 15 counties in North Dakota Prairie Pothole Region was calculated along the headland and point rows and avoiding the non-navigable obstacles by adding all the intersection areas of the headland, non-navigable and navigable obstacles of each field, considering a 60-feet wide planter and a 120-feet wide sprayer. 24 Sections were controlled on the planter for each of the following crops: corn, soybean, canola, and HRSW. Individual nozzle control was considered for the sprayer. It is assumed that both the machines make straight parallel paths in the fields and overlap occurs when the machines approach the headlands and pass along the navigable and non-navigable obstacles inside the fields. The fields parameters such as field area, field perimeter, and perimeter to area ratio (P/A ratio) were calculated by ArcGIS "Calculate Geometry" feature. The number of non-navigable and navigable obstacles and percentage of the overlapping area were calculated using MS Excel (Office 365) worksheet. The arable area of the fields ranged from 56.76 to 468.82 hectares. Though the planter and sprayer pass through the navigable obstacles instead of avoiding those obstacles, they are not supposed to plant seeds or sprayer chemicals inside the navigable obstacles such as low-lands. Therefore, the navigable obstacles inside the field were also considered while calculating the overlapping area in a field. Table A1 shows the overlapping area of each field that could be reduced by using ASC in a 60-feet planter and 120-feet sprayer along with the percentage overlap reductions.

The overlapping area that can be reduced by using a 60-feet wide planter with 24 sections controlled in the sample 105 fields ranged from 3.25 ha (occurring in field number 15 in Billings County) to 95.58 ha (occurring in field number 30 in Dunn County) depending on the field shape and size. Table A1 in the appendix section shows that fields with smaller size and more irregular shape have more area and percentage of overlap reduction. The percentage of the reduction in overlapping area was calculated with respect to the total cultivable area in the fields and ranges from 2.73% (occurring in Bottineau county) to 25.73% (occurring in Cavalier County). The range of overlap reduction in the fields is much greater than that of a similar study of Luck et al (2010) where they found a 15.2% to 17.5% reduction in overlap with 30 sections controlled in a planter and was less than that was found in the study of Jernigan et al (2011), where the overlap reduction was 39% for an 18-row crop planter and 42% for a 24-row crop planter. In current study, the variation in overlap reduction is greater because a larger sample of 105 fields was used in this study. Moreover, current study includes fields of all highly variable size and shape. On an average, ASC in a 60-feet wide 24-row crop planter could reduce an overlapping area of 17.73 acres which is 8.44% of the total arable land.

While considering ASC adoption in a 120-feet sprayer, the percentage reduction in overlap ranged from 4.18% to 45.37%, with the area of overlap reduced ranging from 6.68 ha to 177.57 ha. It is noteworthy that the percentage of overlap reduction was greater in case of a 120 feet wide sprayer than a 60 feet wide planter because the implementation of ASC can result in greater reduction in overlapping if the machine width is greater (Shockley et al, 2012). All the area and percentage overlap reduction in the 105 fields of the North Dakota Prairie Pothole Region by adopting ASC in a 120-feet sprayer are shown in table A1 in the appendix section of this study. Table A1shows that the highest percentage reduction in overlap area occurred in Dicky County (field number 11) and the lowest percentage of overlap reduction occurred in Grand Forks (field number 99). On an average, ASC in a 120-feet wide individual nozzle control boom sprayer could reduce an overlapping area of 26.54 acres which is 12.89% of the total arable land.

A profound investigation into the field characteristics reveals that fields with smaller size and more irregular shape have more area and percentage overlap reduction for both the planter and the sprayer. It is noteworthy that the irregularity in field shape is also considered as a major determinant of the overlap area reduction in that field by Luck et al (2011), and Shockley et al (2012) where these scholars found that ASC could reduce more overlapping in the fields with the more irregular shape. Furthermore, fields that contain a greater number of non-navigable obstacles inside them and which have more area of navigable obstacles seem to be more eligible for ASC because more overlap reduction is possible in these fields (Luck et al, 2011 and Shockley et al, 2012).

4.2. Seed Cost Savings by Adopting ASC in 24-Row Crop Planter

Field-wise seed cost savings were calculated by multiplying seed cost/ha with the total overlapping area in a field that could be reduced when a row crop planter with an implement width of 60-feet (24-row) is used. The number of sections controlled is 24. The overlapping area of each field came from the parallel routing path of the machine when the machine encroached in the headland and point row areas and when the machine avoided the in-field non-navigable obstacles. Current study also considered the area of navigable obstacles, such as low-lands inside the fields since it is not rational for the machine operator to plant into the low-lands despite the planter can pass through the low-lands. The cost of acquisition of the planter or the fixed cost was allocated among the total arable area of a field and was subtracted from the total savings of that field to calculate the net savings. Since the cost of seeds of the four crops considered in this study is not same, we found different amount and percentage of net cost savings for corn, soybean, HRSW, and canola. These savings from each field varied according to the field characteristics, too. The field-wise cost savings, net cost savings, the percentage of cost savings of corn, soybean, HRSW, and canola are presented in table A2 in the appendix section of this study and are discussed in the following paragraphs.

Table A2 in the appendix section shows the total and net seed cost savings in dollars and percentages. 9(nine) budget regions of North Dakota were considered. 15 counties from the budget regions were selected and seven fields from each county, in total 105 fields were selected as sample. The costs savings gained from each field by adopting ASC were shown. The counties associated with each field were also listed in the table so that we can understand from which county a farm could obtain substantial cost savings.

We can see from table A2 that ASC could save \$0.68/ha to \$8.41/ha corn seed costs in the sample 105 fields of the North Dakota Prairie Pothole region depending on field shape, size, the number and area of navigable and non-navigable obstacles inside the fields, and on the budget region where they are located. On an average, ASC was able to reduce corn seed costs by \$2.60/ha in corn fields. For soybean, the number of sample fields was 70 because soybean is not grown in all budget regions of North Dakota. Therefore, the counties and fields where soybean is not grown were skipped from this study. There was a reduction in soybean seed costs ranging from \$0.73/ha to \$6.84/ha due to ASC. ASC was able to reduce soybean seed costs by \$2.20/ha on an average in the sample fields of North Dakota Prairie Pothole Region. For HRSW, the total savings ranged from \$0.15/ha to \$1.59/ha depending on the field parameters. On an average, ASC was able to reduce HRSW seed costs by \$0.50/ha. For Canola, the range of seed costs reduction due to ASC was \$0.61/ha to \$5.73/ha with the average seed cost reduction of \$1.94/ha. It should be noted that the total cost savings were calculated by multiplying the overlapping area occurring in a field by the per hector cost of seeds. Table A2 shows that the percentage of total cost savings is commensurate with the percentage of overlapping area that can be reduced by adopting ASC (shown in table A1). It is to be noted that some scholars found the similar relationship between percentage reduction in overlap area and the percentage total cost savings (Shockley et al,2012). Since ASC was able to reduce overlap in the sample fields ranging from 2.73% to 25.73%, the percentage of total seed cost savings of each of the crop was the same, that is 2.73% to 25.73% for all the four crops. It can be noticed that fields which are of smaller size and more irregular shapes had more total savings due to ASC. Field parameters such as number and area of navigable and non-navigable obstacles also had a profound impact on the total savings obtained by adopting ASC. It is also noticeable that ASC could save more seed costs for corn than all other crops where the cost savings for HRSW was the least. The reason is that input cost savings resulted from the adoption of ASC are dependent not only on the overlap reduction but also on the cost of the input itself (Shockley 2012). Since the per hectare seed costs for corn is the highest among the four crops, (ND crop budget data), ASC could save more costs for corn seeds. The reason for the lowest total cost savings for HRSW is the lowest seed costs of this crop among the four crops. The average total seed costs savings on each of the four crops are close to the findings of Shockley et al (2012) where the seed costs could be reduced by $2.16/ha by adopting ASC. Whereas some other researchers such as Batte and Ehsani (2006) and Velandia et al (2010) found more input savings by adopting ASC ($5.95 to $7.41 and $3 to $38 respectively). However, these researchers did not try to find the average savings per hectare in their study.

From the above discussion it can be said that ASC will generate at least some reduction in seed costs by reducing overlapping areas in the fields. However, whether a farm should adopt

ASC or not depends on the net cost savings. The net input cost savings is calculated by deducting the cost of the planter or the cost of initial investment from the total cost savings. Net savings was calculated in the current study because a farm should only adopt ASC if the benefit of ASC, that is, cost saved by ASC outweighs the cost of adopting it. The cost of the installation of ASC in a 24-row crop planter is calculated following the procedures of Shockley et al (2011) and Shockley et al (2012). This allocation cost of ASC was allocated among the fields. The calculations and allocation procedures are shown in Chapter 3 of this study. In table A2, we see some negative figures in net savings. These negative figures indicate that total savings generated by adopting ASC could not outweigh the costs of adopting it. On the other hand, the positive figures in net savings indicate that the total cost savings that were obtained from those fields due to ASC could outweigh the allocated cost of adopting ASC.

A profound investigation into the net savings in the sample of 105 corn fields reveals that adoption of ASC could save corn seed costs from -3.49% (occurring in field 36 of Bottineau county) to 20.73% (occurring in field 71 of Cavalier). This reduction in cost amounts to ($257.41) to $1,667.99 depending on field size and shape, and the number and area of navigable and non-navigable obstacles inside the fields. The per hectare seed costs savings due to ASC ranged from ($1.05) to $6.78, with an average seed cost savings of $0.86/ha (2.74% of the seed costs). Additionally, most of the net savings figure for corn seeds are positive. This fact indicates that farmers can consider adopting ASC in corn planting. In 70 soybean fields, the cost savings via ASC ranges from -2.99% to 19.59% and in dollar amounts ($-171.02) to $1,281.92 with the per hectare seed costs savings ranging from ($-1.33) to $5.21. Most of the net savings figure for soybean seed costs are positive. The positive sign of net soybean seed cost savings indicates that in most of the sample fields, benefits associated with ASC were able to outweigh the costs of adopting it. The average net soybean seed costs saving is found to be $0.34/ha. These findings indicate that farms may consider adopting ASC for soybean fields since total cost savings due to ASC could outweigh the costs of adopting ASC. For HRSW, ASC was able to save some seed costs but the negative figures in net savings indicate that these total savings were not enough to cover the cost of adopting ASC. In other words, the cost of adopting ASC is greater than the HRSW seed costs savings due to ASC. In table A1, we can find an average net seed costs savings of (-$1.24) per hectare with no positive figures in the net seed costs savings for HRSW. Therefore, it should not be rational for the farmers to adopt ASC in HRSW seed planting. The reason for the low amount of savings for HRSW is the low costs of HRSW seeds. For Canola, the average net seed costs savings amount to $0.20/ha, ranging from ($1.37) to $4.09 per hectare depending on the field parameters of each field. The net savings in each field varies between ($549.75) to $1371.60 depending on field size, shape and existence of navigable and non-navigable obstacles such as low-lands, trees, structures, non-agricultural lands water ways inside the fields. The positive net savings figures appearing in each field denote that it would be rational for the farms to adopt ASC while planting canola seeds.

Although ASC could save costs in all the sample fields for all four crops (corn, soybean, HRSW, and Canola), adoption of ASC is only feasible for farms for three crops (corn, soybean, and canola), since seed costs savings for these three crops could outweigh the costs of investment in ASC.

4.3. Chemical Cost Savings by Adopting ASC in a 120-Foot Boom Sprayer

Considering the implementation of a 120-feet wide boom sprayer, the chemical costs per hectare of each field was multiplied by the total reduction in overlapping area in that field to calculate the total costs savings possible in that field due to ASC installation. Same as the planter, the overlapping area of each field comes from the parallel routing path of the machine when it encroaches in the headland and point row areas and when it avoids the in-field non-navigable obstacles. Area of navigable obstacles such as low-lands inside the fields was directly added with the intersection areas of the parallel paths of the sprayer to calculate the total overlapping area in each field. The annualized installation cost of ASC in a 120-feet boom sprayer is calculated in the methodology chapter of this paper using the same technique as used by Shockley et al (2011). The total cost of acquisition of ASC in the sprayer is divided by the average farm size of each county and multiplied by the arable area of each field to allocate the cost among the fields. This allocated machinery cost was later deducted from the total cost savings obtained from each field to calculate the net cost savings. Since the cost of chemicals of the four crops under the consideration of the current study is not same, different amount and percentage of total and net cost savings could be found for corn, soybean, HRSW, and canola. Furthermore, these savings from each field also varied according to the field characteristics. The field-wise total seed cost savings, net cost savings, the percentage of cost savings of corn, soybean, HRSW, and canola are presented in table A3 in the appendix section of this study and are discussed in the following paragraphs.

Table A2 shows that installing ASC in a 120-feet boom sprayer could save the chemical costs for corn at least by $0.29/ha and maximum $7.63/ha in the sample fields. Depending on the field parameters, number and area of navigable and non-navigable obstacles, and the budget regions where the fields are located, these per hectare total savings caused the total savings in each field to vary between $62.19 to $1796.50. On an average, ASC was able to reduce chemical costs by $1.15/ha in corn fields. In 70 sample soybean fields of the North Dakota Prairie Pothole Region ASC could reduce the chemical costs by $1.39/ha on an average. These cost savings ranged from $0.29 to $8.55 depending on the nature of the fields. For HRSW, the total savings ranged from $0.51/ha to $11.91/ha depending on the field parameters. The average chemical cost reduction for HRSW was $1.85/ha. For Canola, the range of chemical costs reduction due to ASC varied between $0.32/ha to $6.87/ha among the sample 98 fields with the average seed cost reduction of $1.21/ha.

It should be noted that the total cost savings are calculated by multiplying the reduced overlapping area in a field due to ASC by the per hector cost of seeds. Table A3 shows that the percentage of total cost savings is commensurate with the percentage of overlapping area that can be reduced by adopting ASC (shown in table A1). Since the installation of ASC on a 120-foot boom sprayer could reduce the overlap in the sample fields ranging from 3.56% to 75.45%, the percentage of total chemical cost savings for each of the crop also varied between the same range. It can also be noticed that fields with smaller size and more irregular shapes had more total savings due to ASC. Field parameters such as number and area of navigable and non-navigable obstacles also had a profound impact on the total chemical cost savings generated by adopting ASC. Again, the total chemical cost savings per hectare was the greatest for HRSW than the other three crops despite having the same overlap reduction and same field characteristics. Highest chemical cost savings could be found for HRSW because the chemical cost of HRSW is greater than the chemical costs of all other crops (ND crop budget data).

Though installation of ASC on a 120-foot boom sprayer could save chemical costs for all the four crops, the managerial decision of adopting the ASC depends on the net savings, that is, the difference between the total cost saved by ASC and the cost of adopting the technology. A rational decision for the farms will be to adopt ASC when the net savings figures show positive values, that is, the benefits obtained from adopting ASC can outweigh the cost of adopting the technology. The cost of the installation of ASC in a 120 feet wide boom sprayer is calculated following the procedures of Shockley et al (2011) and Shockley et al (2012) and allocated among the fields. The calculations and allocation procedures are shown in the methodology section of this study. Table A2 shows some negative figures in net chemical cost savings. These negative figures indicate that total savings generated by adopting ASC could not outweigh the costs of adopting it. On the other hand, the positive figures in net savings indicate that the total cost savings obtained from those fields due to ASC could outweigh the cost of adopting ASC.

A profound investigation into the net savings in the sample 105 corn fields reveals that, despite having some chemical cost savings in all the fields, those savings were not enough to recover the cost of adopting ASC. We can understand this inadequacy of total chemical cost savings to outweigh the cost of investment in ASC by observing negative net savings figures in most of the fields resulting in an average net chemical cost savings of (-$0.09)/ha. This negative average net chemical cost savings indicate that farms may not be very optimistic in adopting ASC while applying chemicals in corn fields. However, most of the fields in some counties such as Barnes, Billings, and Bottineau showed positive net savings. These positive net savings in those fields indicate that farms in these counties can consider adopting ASC while spraying chemicals in the fields. For soybean, the net chemical cost savings due to ASC ranged from -14.30% to 63.73% with an average percentage net savings of 0.33%. The dollar amount of net chemical cost savings in soybean fields ranged from ($1.15)/ha to $7.22/ha with an average net savings of $0.03/ha. Since the average per hectare chemical cost saving due to ASC is positive and net savings is positive in most of the sample fields, farms can consider adopting ASC in the application of chemicals in soybean production. For HRSW we can see the highest amount and percentage of chemical cost savings due to ASC. The per hectare chemical cost savings ranged from ($1.07) to $10.58 with a percentage net cost savings ranging from -6.59% to 67.04% and an average net cost savings of $0.61/ha. Moreover, net cost savings were positive in most of the HRSW fields. These positive figures in net cost savings indicate that investment in ASC will be profitable for farms while spraying chemicals in HRSW fields. In the sample 90 canola fields, investment in ASC does not seem very profitable for the farms since the average net chemical cost savings for canola due to ASC were negative ($0.02) and negative net savings figures occur in most of the fields. However, fields which are more irregularly shaped and fields which contain a large area of low-lands show some positive net cost savings. Therefore, farms having more irregularly shaped fields and fields having large areas of navigable obstacles and a substantial number of non-navigable obstacles inside them can consider investing in ASC.

We can observe from the above discussion that, though installing ASC on a 120-feet sprayer can reduce more overlapping area in the fields than a 60 feet wide row crop planter, the cost savings due to ASC in the planter is more than that of a 120 feet wide boom sprayer. The reason is that the total and net cost savings generated by ASC depend not only on the reduction in overlapping area but also on the cost of the inputs (Shockley et al 2012). According to the ND crop budget data (price of 2017), seed costs of corn, soybean, and canola are greater than the chemical costs of these crops. Net cost savings was calculated by deducting the cost of installing ASC in a 120-foot sprayer. Table 1 in the chapter 3 of this study shows that the cost of installing ASC in a 120-foot sprayer is greater than that of a 60-foot planter. As a result, positive net cost savings were observed for corn, soybean, and canola when ASC was installed in the planter. Whereas, negative net cost savings could be observed for these three crops when ASC was installed in the sprayer. Again, seed costs of HRSW are lower than the chemical costs of this crop. Therefore, negative net cost savings can be observed while adopting ASC on a 60 feet wide planter, whereas we can see positive net cost savings while investing on the installation of ASC on a 120-feet wide boom sprayer.

4.4. Net Savings Considering a Rotation or Crop Mix Scenario and NPV Analysis

4.4.1. Net Savings Under a Crop-Mix Scenario

A crop mix or rotation scenario was considered where it was assumed that the farmer plants the seeds of all the crops corn, soybean, HRSW, and canola and sprays chemicals by rotation in the same field. It was also assumed that the same 60-foot planter with ASC and the 120-foot wide sprayer is used to plant seeds and spray chemicals for all the four crops. Instead of calculating the seed and chemical cost savings separately for each crop, the savings that can be generated by using ASC is calculated for all crops and are added together to ascertain the total seed cost savings that can be obtained by applying ASC in a field. For this purpose, the land use coverage of each crop was multiplied by the net seed and chemical cost savings obtained from each individual crop and then these weighted net cost savings of all the four crops were added together to calculate the net cost savings that could be generated by adopting ASC in a field. This analysis is more realistic since the farmers of North Dakota tend to plant crops by rotation instead of planting a single crop (Larsen and Ripplinger, 2015). The calculations of field-wise seed and chemical cost savings under a crop-mix scenario were shown in table A4 and A5 respectively in the appendix section of the current study.

The net seed and chemical cost savings for each field were different when a crop-mix scenario was considered from the net cost savings when each of the four crops was considered individually in the previous sections. One reason for this difference is, the negative cost savings of one crop is outset by the positive cost savings of another crop when the net savings obtained from each crop area added together. Another reason behind the difference in net cost savings is that the crop acreage weight is different for each of the crop and among the regions where the crops are grown.

When considering a crop mix scenario, we could see negative net seed cost savings in most of the fields ranging from (-$626.37) to $864.02 with a negative average seed cost savings of ($0.19/ha). It is interesting to note that in the previous sections, we found positive net cost seed cost savings for corn, soybean, and canola and negative cost savings for HRSW. Despite having positive cost savings in all the three crops, the seed cost savings considering a crop mix scenario indicates that the highly negative seed cost savings and high crop acreage weight of HRSW push the positive net cost savings of all the three crops downward. Therefore, when taking a decision regarding investment in ASC, a farm can consider a crop mix scenario with the crops where ASC generates positive net seed cost savings, such as a corn-soybean-canola, a corn-soybean, or a soybean-canola scenario.

On the other hand, the chemical costs savings showed that investment in ASC will be profitable for the farmers when a crop-mix scenario is considered. Because, in most of the fields we could see positive figures in net cost savings, that is, the benefits obtained from ASC can outweigh the cost of investment in ASC. The net chemical cost savings considering a crop-mix scenario ranged from ($1.15)/ha to $7.31/ha with an average positive net cost savings of $0.25/ha. It is noteworthy that when we considered the chemical costs savings due to ASC for the four crops individually, we found positive net cost savings for only soybean and HRSW, where the average net chemical cost savings of HRSW was higher. Hence, when considering saving chemical costs by adopting ASC under a crop-mix scenario, a farm should include HRSW and soybean in the rotation so that the farm can achieve positive net cost savings due to ASC.

It is noteworthy that for seed costs savings, the rotation or crop-mix scenario gave us a negative seed cost savings while the net cost savings of corn, soybean, and canola were positive and only the net seed cost savings of HRSW was negative. On the other hand, the positive net chemical cost savings of HRSW pushed the net chemical cost savings of the crop-mix scenario despite the other three crops having negative net chemical cost savings. This factor indicates that the input price of HRSW has the greatest impact among the four crops on determining the net input cost savings considering a crop-mix scenario. This impact of HRSW input price on determining net cost savings considering a rotation or crop-mix scenario stems from the highest crop acreage weight of HRSW in most of the counties of the North Dakota Prairie Pothole Region.

4.4.2. NPV Analysis

Barry et al (1995) define NPV analysis as "a tool to economically evaluate replacement gilt decisions". Net Present Value analysis is the process of taking a current investment, projecting the future net income (cash flows) from that investment, and discounting these future earnings to present-day value(s) (discounts)." This definition indicates that to calculate the net present value (NPV) of an investment we need the amount of the initial investment, net cash flows the investment generates each year, the salvage value of the investment, and the interest or the discount factor. NPV of an investment helps the investors to take the managerial decision of investing into an asset. An investor will only accept an investment with the positive and highest net present value. The formula for calculating NPV of an investment is given as,

$$NPV = -R + \frac{P_1}{1+i} + \frac{P_2}{(1+i)^2} + \cdots + \frac{P_n}{(1+i)^n}$$

Where,

R= Initial Investment

P= Present value of the cashflow generated by the investment each year

i = Rate of interest or the discount factor

n= Useful life of the investment

In this study, the initial investment is the cost of installing ASC in a 60-foot 24-row crop planter and a 120 feet wide boom sprayer with individual nozzle control. The installation cost was calculated in table 1 in chapter 3. The useful life of both the machines was assumed as 8 years with a zero-salvage value. The interest rate or discount factor was assumed as 8%.

The cash flows of each year of the investment in the planter and the sprayer are the total weighted seed and chemical cost savings generated by the planter and the sprayer respectively when a crop-mix/rotation scenario is considered. These total cost savings were used for NPV analysis as the present values of each year of the machine's useful life of 8 years. The installation cost of ASC in the existing machinery was considered as the initial investment and was deducted from the total present value.

The net present values of both the machines are shown in table A5 of the appendix section of this study. Since the NPV of the cost savings were positive in most of the cases, it can be said that in the long run, investment in ASC will be profitable for the farms. If the ASC installed machinery is used in the fields up to its whole useful life, the investment in ASC will be beneficial for the farms since the investment will generate a $1433.99 net present value for the farm on average. The NPV of seed cost savings generated by investment in planter ranged from $25.69 to $6955.30. The highest NPV of the investment in planter occurred in a field in Dicky county (field 61). Therefore, ASC is supposed to bring greatest benefits for the farms in this field if NPV is considered.

For the chemical cost savings generated by sprayer, the NPVs of the savings ranged from $254.52 to $11364.41 with an average NPV of $1,463.91. The highest NPV occurred in the field 61 in Dicky county, where the lowest NPV could be seen in field number 78 of Eddy County. Therefore, investment in ASC is going to be most profitable for the farm in field 61, where the farm can experience the highest NPV. On the other hand, investing in ASC brought lowest cost benefits for the farm in field 78 of Eddy county since NPV was the lowest for this field. Since we can see all positive NPVs for the chemical cost savings generated by installing ASC in a 120 foot sprayer, investment in ASC seems to be a rational managerial decision for the farm.

We can also notice from the previous discussion and table A5 that though the seed cost savings generated by planter was more than the chemical cost savings obtained from investment in ASC for the sprayer, ASC installation in the 120-foot sprayer seems to be more profitable for the farm in the long run since the NPVs for the chemical cost savings by the sprayer were more than the NPVS for the seed cost savings generated by the 60-feet planter.

4.5. Sensitivity Analysis

A sensitivity analysis was conducted by varying the input prices between +/-10% to ascertain the effects of input price changes on the net seed and chemical cost savings of corn, soybean, HRSW, and canola.

Results obtained from the sensitivity analysis by varying the seed and chemical costs between +/-10% were shown in table A6 and A7 respectively in the appendix section of this study. A 10% increase in corn seeds shifted the net corn seed cost savings due to ASC by 34.20%, whereas a 10% in the seed costs decreases the net seed cost savings by the same rate. In the base case, the net seed cost savings obtained from the investment in ASC averaged $158.81. This net seed cost savings became $104.48 when the per hectare seed cost of corn decreased by

10% and it reached up to $213.13 with a 10% increase in seed cost per hectare. It could be observed that ASC could generate positive net seed cost savings for corn even if the seed price per hectare fell by 10%. For soybean, the net cost savings showed greater sensitivity to per hectare seed cost changes. A 10% increase or decrease in soybean seed costs changed the net cost savings by 121%. In the base case, the net savings showed a positive amount of $36.77 on average, but with the seed price decrease, the net savings fell to ($7.82). Therefore, we can say that investment in ASC will be profitable for the farm when the soybean seed cost remains at the same level or increases to 10%. When the soybean cost falls, the cost savings due to ASC will no longer be able to outweigh the cost of adopting ASC in the planter. Net savings for HRSW seed costs showed the least sensitivity to the price change, only 3.77% due to a 10% change in seed costs. However, even a 10% increase in HRSW seed costs could not generate positive net savings for HRSW seed costs. Whether the seed costs increased or decreased, the net cost savings obtained from ASC for HRSW remained negative which means that the cost savings due to ASC was not enough to outweigh the cost of investment in ASC. The net cost savings due to ASC for canola showed the highest sensitivity to seed cost changes. When the canola seed cost increased or decreased by 10%, the net seed cost savings for canola due to ASC increased or decreased by 153.17%. This high sensitivity indicates that a farm is supposed to achieve more cost savings for canola, when the canola seed costs increase. Also, a farm will face loss when the seed cost decreases since the net savings showed a negative value (-$13.97 on average) when the price of canola seeds went down by 10%.

The net chemical cost savings due to ASC for corn showed a negative amount of ($38.10) in the base case and a negative amount of ($61.75) on average at 10% decrease in per hectare chemical cost. But when the chemical cost of corn increased by 10%, the farm incurred an average net savings of $56.50. This upward trend in savings due to increase in per hectare chemical price indicates that when the chemical cost of corn increases, a farm will obtain sufficient net cost savings due to ASC to outweigh the cost of investing in ASC. Furthermore, a 10% change in chemical cost savings of corn is going to change the net savings by 62.07%. For soybean, in the base case, a negative net saving value was observed which further shifted down with a 10% decrease in per hectare chemical price. But when the chemical cost of soybean increased by only 10%, the net chemical cost savings of soybean increased by 1051.30% and became so high that the net savings outweighed the cost of investment in ASC. Therefore, even a slight increase in soybean chemical costs is going to be very profitable for the farm. For HRSW, a 10% increase in chemical price increased the net cost savings by 143.66%, whereas, a 10% decrease shifted the net savings down by 35.91%. We can see that even in the condition of extreme chemical price fall, ASC is supposed to bring substantial economic benefit for the farm because the net savings can outweigh the cost of installing ASC on the 120 foot sprayer. A 10% increase in chemical price for canola increased the net savings obtained from canola fields due to ASC by 447.60%. It should be noted that in the base case, the net savings obtained due to ASC for canola was negative (-$21.94). The high sensitivity of net chemical cost savings for canola to the chemical price pushed net cost savings in the base case in such a way that this negative net savings became positive with an average value of $76.28. On the other hand, a fall in the chemical cost of canola by 10% decreased the average net savings by 111.90% and the average net savings became (-$46.50). Therefore, a farm should decide to invest in ASC when the chemical costs of canola increase.

4.6. Regression of Net Seed Cost Savings on Field Parameters

One of the objectives of this study is to estimate the different field parameters on the net savings that can be achieved by adopting ASC in the farming operation. To fulfill this objective, a multiple regression analysis was conducted using a fixed-effects model. Net seed cost savings on the four crops (corn, soybean, canola, and HRSW), that could be obtained by adopting ASC in each field are regressed over several field parameters. It is to be noted that all the counties under a budget region of North Dakota represent the same per hectare seed cost in case of all the four crops mentioned above. Therefore, the input cost of the crops varies according to the budget region. The net savings obtained from each field is different because every field has its own unique field characteristics and different allocated machinery cost. Hence, the budget regions of North Dakota were considered as dummy variables in the regression to keep their effects "fixed" on net savings. Another reason for including regional dummies is to ascertain the difference between net savings among different regions.

The regression analyses were conducted using StataSE 15 (64-bit) statistical software. The dependent variable net savings (referred to as savings in the regression equation) was regressed upon different linear and interactive field parameters to estimate the direction and magnitude of the effects of these field parameters on the net savings. The independent variables or the regressors are field area, perimeter to area ratio, the area of non-navigable obstacles, area of navigable obstacles, number of non-navigable obstacles, number of navigable obstacles, and nine regional dummy variables South-East, South-West, North-Central, North-West, South-Central, South-Valley, North-East, East-Central, and North-Valley (addressed in the regression as SE, SW, NC, NW, SC, SV, NE, EC, and NV). It is to be mentioned here that soybean and canola are not grown in all the budget regions. So, these regional dummies were omitted when regressing net savings obtained from planting soybean and canola. Four separate regressions were run for the four crops corn, soybean, canola and HRSW. The regressions results are presented in table 3:

Table 3. Impact of Field Parameters on Net Seed Cost Savings of Corn, Soybean, HRSW, and Canola

	Savings			
Field Parameters	Corn	Soybean	HRSW	Canola
Constant	-103.857	-129.859	-79.761	-284.458
	(83.257)	(210.581)	(73.293)	(274.779)
Field Area	-0.692***	-0.501	-1.313***	0.120
	(0.181)	(0.333)	(0.153)	(0.580)
P/A Ratio	3.029***	2.720**	0.996***	3.665***
	(0.630)	(1.385)	(0.382)	(1.362)
Area of Non-Navigable Obstacles	-4.637	-4.092	-1.520	-2.661
	(4.846)	(10.147)	(2.638)	(9.396)
Area of Navigable Obstacles	26.092***	-0.340	0.066	0.257
	(1.993)	(0.483)	(0.202)	(0.739)
Number of Non-Navigable Obstacles	-1.501	9.074	2.719	10.515
	(2.513)	(10.131)	(2.643)	(9.958)
Number of Navigable Obstacles	131.791**	-141.468**	9.982	-42.171
	(59.991)	(176.966)	(43.877)	(157.755)
South-West	23.884	Excluded	82.314*	91.205
	(51.201)		(49.045)	(178.765)
North-Central	0 (Omitted for Collinearity)	0 (Omitted for Collinearity)	0 (Omitted for Collinearity)	0 (Omitted for Collinearity)
North-West	-56.388	Excluded	19.183	35.323
	(44.143)		(41.513)	(154.996)
South-Central	-9.149	-262.662	-68.618	-133.746
	(67.515)	(166.415)	(49.109)	(160.547)
South-Valley	78.731	-309.633*	-6.072	Excluded
	(63.574)	(180.505)	(45.643)	---
North-East	99.817	-59.956	51.457	46.508
	(78.038)	(300.373)	(68.273)	(241.086)

Table 3. Impact of Field Parameters on Net Seed Cost Savings of Corn, Soybean, HRSW, and Canola (Continued)

	Savings			
Field Parameters	Corn	Soybean	HRSW	Canola
East-Central	124.099*	-207.545	-7.851	-69.202
	(64.701)	(172.082)	(42.679)	(152.558)
North-Valley	-15.738	-401.815**	-92.490**	-228.486
	(51.906)	(171.600)	(46.139)	(158.705)
R-Squared	0.886	0.403	0.842	0.298
RMSE	125.17	253.98	68.773	248.68
F-Statistic	41.41	9.78	39.77	4.46
No. of Observations	105	70	105	98

Note:
Standard errors are reported in parentheses.
*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively.

The regression results for all the four crops, corn, soybean, HRSW, and canola are presented in the above table. The estimated coefficients represent the effect of the selected field parameters and regional dummies on the net savings obtained by adopting ASC with 24-section controlled. It should be noted that there is a difference between the number of observations among the four crops. This happened because soybean and canola are not grown in all regions of North Dakota. Hence, fields or observations which were included in those regions were omitted at the time of regression analysis. The estimated effects of the field parameters on the net savings of each crop are discussed in the following paragraphs.

4.6.1. Correlation among Variables

The correlation between the variables used in the regressions are measured by using correlation matrices and measuring Variation Inflation Factor (VIF) test. The correlation matrix and VIF test both are conducted in STATA (StataSE 15 64-bit). The correlation matrix for all the four regressions along with the results of VIF test are shown in the following tables:

Table 4. Correlation Matrix for Corn Net Savings Regression

	Savings	Field Area	P/A Ratio	Area of Non-Navigable Obstacles	Area of Navigable Obstacles	No. of Non-Navigable Obstacles	No. of Navigable Obstacles
Savings	1.000						
Field Area	-0.045	1.000					
P/A Ratio	0.343	-0.570	1.000				
Area of Non-Navigable Obstacles	0.086	0.223	-0.570	1.000			
Area of Navigable Obstacles	0.836	0.287	-0.004	0.036	1.000		
No. of Non-Navigable Obstacles	0.195	0.275	0.069	0.616	0.113	1.000	
No. of Navigable Obstacles	0.278	-0.010	0.204	-0.079	0.304	-0.081	1.000

Table 5. Correlation Matrix for Soybean Net Savings Regression

	Savings	Field Area	P/A Ratio	Area of Non-Navigable Obstacles	Area of Navigable Obstacles	No. of Non-Navigable Obstacles	No. of Navigable Obstacles
Savings	1.000						
Field Area	-0.348	1.000					
P/A Ratio	0.477	-0.604	1.000				
Area of Non-Navigable Obstacles	-0.016	0.142	0.127	1.000			
Area of Navigable Obstacles	-0.024	0.045	-0.098	-0.104	1.000		
No. of Non-Navigable Obstacles	0.067	0.141	0.104	0.580	-0.121	1.000	
No. of Navigable Obstacles	0.336	-0.075	0.260	-0.099	0.024	-0.138	1.000

Table 6. Correlation Matrix for HRSW Net Savings Regression

	Savings	Field Area	P/A Ratio	Area of Non-Navigable Obstacles	Area of Navigable Obstacles	No. of Non-Navigable Obstacles	No. of Navigable Obstacles
Savings	1.000						
Field Area	-0.849	1.000					
P/A Ratio	0.619	-0.570	1.000				
Area of Non-Navigable Obstacles	-0.185	0.223	0.091	1.000			
Area of Navigable Obstacles	-0.052	0.084	-0.091	-0.058	1.000		
No. of Non-Navigable Obstacles	-0.153	0.275	0.069	0.616	-0.048	1.000	
No. of Navigable Obstacles	0.096	-0.010	0.204	-0.079	0.038	-0.081	1.000

Table 7. Correlation Matrix for Canola Net Savings Regression

	Savings	Field Area	P/A Ratio	Area of Non-Navigable Obstacles	Area of Navigable Obstacles	No. of Non-Navigable Obstacles	No. of Navigable Obstacles
Savings	1.000						
Field Area	-0.105	1.000					
P/A Ratio	0.356	-0.570	1.000				
Area of Non-Navigable Obstacles	0.098	0.223	0.091	1.000			
Area of Navigable Obstacles	0.039	0.084	-0.091	-0.058	1.000		
No. of Non-Navigable Obstacles	0.205	0.275	0.069	0.616	-0.048	1.000	
No. of Navigable Obstacles	0.096	-0.010	0.204	-0.079	0.038	-0.081	1.000

The correlation matrices shown in the above tables show that the regressions models for the four crops do not suffer from severe correlation. For corn net savings regression, the correlation among the independent variables is not very strong except for two, where the P/A ratio is highly negatively correlated with the field area (-0.5703), and where the number of non-navigable obstacles is highly correlated with the area of non-navigable obstacles. However, these correlations are expected because the variable P/A ratio is a measure of the irregularity in field shape and it is calculated by dividing the field perimeter with field area. Therefore, there is an inverse relationship between P/A ratio and field area. As a result, we can observe a highly negative correlation between P/A ratio and field area in all the regressions (-0.5703 for corn, HRSW and soybean regression and -0.6039 for soybean regression). Another highly positive correlation can be observed between the number of non-navigable obstacles and the area of non-navigable obstacles which is also expected because the area of non-navigable obstacles is calculated by adding the area of every single non-navigable obstacle in the fields. We can observe this highly positive correlation between the number of non-navigable obstacles and the area of non-navigable obstacles in all the four regressions, and the correlation coefficients are 0.6155 for corn, HRSW, and canola net savings regression, and 0.5803 for soybean net savings regression. In all the regressions, we can see some highly positive and negative correlations among different independent variables and the dependent variable "savings" which is rational because the independent variables are supposed to be correlated with the dependent variable.

The results obtained from the VIF test for measuring the existence of multicollinearity in the four regression models are shown in the following table:

Table 8. Results of VIF Test of the Regression Models of Net Seed Cost Savings

Variables	Corn Regression		Soybean Regression		HRSW Regression		Canola Regression	
	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF
SW	4.03	0.248	---	---	4.72	0.212	4.65	0.215
EC	3.99	0.251	4.24	0.236	4.71	0.212	4.62	0.216
NW	2.85	0.350	---	---	3.28	0.305	3.24	0.308
SE	2.81	0.355	3.06	0.326	3.22	0.311	3.19	0.314
SC	2.32	0.431	2.64	0.379	2.57	0.389	2.56	0.390
SV	2.27	0.441	2.50	0.399	2.53	0.396	---	---
NE	2.25	0.444	2.50	0.401	2.49	0.402	2.48	0.404
NV	2.18	0.459	2.22	0.449	2.25	0.444	2.25	0.445
Field Area	2.18	0.459	1.98	0.504	2.01	0.498	1.94	0.514
P/A Ratio	2.02	0.494	2.24	0.446	2.02	0.496	1.89	0.529
Area of Non-Navigable Obstacles	1.90	0.527	1.68	0.595	1.90	0.527	1.81	0.554
Area of Navigable Obstacles	1.33	0.750	1.26	0.795	1.24	0.807	1.24	0.808
No. of Non-Navigable Obstacles	1.91	0.524	1.81	0.553	1.90	0.526	1.88	0.532
No. of Navigable Obstacles	1.49	0.670	1.47	0.679	1.46	0.684	1.45	0.690

The above table shows the results of VIF test of the regression models of corn, soybean, HRSW, and canola net seed cost savings. VIF tells us about how much the variance of a regression model is inflated. The more the Value of VIF, the more inflated the variance is, and the more multicollinearity the model suffers from (Robinson and Schumacker 2009). The general rule of thumb of VIF test is that mean VIF value over than 10 indicates an unacceptable level of multicollinearity of the model and needs further investigation (Belsley, Kuh, & Welsch, 1980).

In this study, the mean VIF of all the four regression models of net seed cost savings for corn, soybean, HRSW, and canola are 2.40, 2.30, 2.59, and 2.55 respectively which indicates that there is a very small multicollinearity in the regression models. However, as the multicollinearities are at an acceptable level, we need not worry about the authenticity of the regression results.

4.6.2. General Model Fit

The net seed cost savings obtained by adopting ASC in corn farming operation are regressed on several field parameters. The number of observations is 105, which represent the sample 105 fields of North Dakota Prairie Pothole region where corn is grown. In case of soybean, the number of observations is 70 because soybean is not grown in all counties of North Dakota. Hence, 35 fields (5 counties) where soybean is not grown were skipped from the equation. The same thing happened in case of canola, where 7 fields are dropped from the regression since they are included in a county where canola is not grown. Since HRSW is grown in all the counties considered under the span of this study, the number of observations is same (105) as corn.

The Root Mean Square Error (RMSE) tells us about the differences between the actual and predicted values of the observations. Therefore, a lower RMSE represents a lower difference among the actual and predicted value of the observations and thus represents a better model fit. The regression equation of corn shows an RMSE of 125.17. This value of RMSE of corn regression model is less than the RMSE value of soybean, and canola regression models and greater than HRSW regression model. This fact indicates that corn regression model has a better model fit than the regression models of soybean and canola and worse model fit than HRSW regression model. The adjusted R-squared of the model is 0.8857, which indicates that the model has a very good fit and the independent variables, that is, the field parameters and dummy variables can explain 88.57% of the variability in the dependent variable net savings. The F-statistic tells us that the model is significant at 99% confidence level. That is, the model has a good explanatory power.

The RMSE value of soybean regression model is the highest of all the four regressions. This fact indicates that among the four regression models, the difference between the actual and predicted values of the observations is the highest and soybean regression model has the lowest model fit. The R-squared value of this model is lower than that of corn regression model. However, the R-squared value is 0.4030, which is not very uncommon in the researches relating to social sciences and economics. The R-square means that the variables can explain 40.30% of the variability in the model. The value of F-statistic is 9.78 which is significant at 1% level of significance. It indicates that the soybean seed savings regression model also has a very good explanatory power.

The RMSE of HRSW regression model is much lower than the regression models of the other three crops. Therefore, in HRSW regression model the difference between the actual and predicted values of the observations is the lowest which indicates a sound fitness of the model, at least to some extent. The high R-squared value of this model (0.8421) also denotes the high explanatory power of the independent variables, that is, the independent variables such as field parameters and the dummy variables can explain the changes in the net savings by 84.21%. The significant F-statistic value of 39.77 (significant at 1%) indicates that including independent variables in the model gives a better result than the intercept only model.

In case of Canola seed regression model, The RMSE is very high (248.68). This RMSE value is greater than that of the soybean regression model but less than the RMSE values of corn and HRSW regression models. This fact means that canola regression model can explain the observations better than the corn and soybean regression model but less than the HRSW regression model. However, The R-square value of this model is lower than the other three models. The reason for this low R-square value is the high variability of the data. The R-square value of this model 0.2984 indicates that the model explains only 29.84% of the response data.

4.6.3. Discussion Regarding the Sign and Magnitude of the Coefficients

The intercept of the all the seed savings regression model is negative, and it is -103.8572, -129.859, -79.7612, and -284.4581 for corn, soybean, HRSW, and canola respectively. The negative signs indicate that when all the field parameters are zero, the net savings go down and it reduces by $103.8572 in case of corn, $129.859 for soybean, $79.7612 in case of HRSW and $284.4581 for Canola. This sounds rational because the field parameters can become zero only when the farmer choose not to plant seeds on the fields but spends money on an initial investment to install ASC. In this case, there will be no cost savings, rather the farmer will incur additional cost to purchase ASC. All the constants are significant, which means that it should be rational to include the constants in the models.

In corn regression model, the relationship between field area and net savings is negative and significant at 1%. The value of the coefficient is -0.6921 which indicates that if the area of the field increases by 1-hectare, net savings decreases by $0.6921. The relationship between field size and net cost savings is also negative in case of soybean and HRSW regressions. The co-efficient of fields area in soybean regression model indicates that one hectare increase in field area reduces the net cost savings by $0.5013. However, the p-value of this coefficient failed to obtain significance even at 10% level of significance. The coefficient of the variable field area is -1.3132 in case of HRSW, which indicates that one unit increase in field area decreases the net seed cost savings of HRSW by $1.3132, which is greater than that of corn and soybean seed cost savings. This is a highly significant coefficient as the value of t-statistics is 8.61 at this level and therefore, this coefficient is significant at 99% confidence level. This relationship between field area and seed cost savings is also supported by the previous studies such as Shockley et al (2012) and Valendia et al (2010), which showed that smaller sized fields can generate more cost savings and vice versa. Finally, the coefficient of the variable "field area" in the canola regression model is 1.2041. However, we could not find the expected sign in this coefficient. The reason behind this is the high variability of the data set. When the field maps were selected, we tried to cover fields with all types of characteristics and selected some regular field, some irregular, some large fields, and some small fields, some with no obstacles inside them, some with numerous navigable and non-navigable obstacles so that we can estimate the impact of all the field parameters on the overlap reduction and net savings obtained from each field. This selection procedure was responsible for the high variability of the data set. Besides, when collecting the data for canola regression, we had to skip some field observations because canola is not grown in the South-Valley region of North Dakota, and therefore, no data was available for canola input price for the counties at South-Valley budget region in the North Dakota crop budget data set.

The second independent variable in this model is perimeter to area ratio, which is a measure of the irregularity of the shape of the field (Velandia et al). The coefficient is positive and significant in case of the regression models of all the four crops, corn, soybean, HRSW and canola. The positive sign of this variable indicates that the higher the perimeter to area ratio, the higher the savings, and vice versa. This estimation is justified because the amount of net savings depends on the quantity of overlapping reduced in a field. According to Luck et al (2011), an irregularly shaped field incurs more overlapping area inside the field area than a regularly shaped field and this overlapping area can be reduced by adopting ASC. In the regression model of corn seed savings, the coefficient (3.0294) is a measure of the movement of net savings along with P/A ratio, which tells that one unit increase in the P/A ratio causes a $3.3616 increase in net savings. This increment is $2.5741, $0.6323, and $2.3427 in case of soybean HRSW and canola respectively. This variable is significant at 99% confidence level for corn, HRSW, and canola and at 95% confidence level for soybean regression model. Therefore, we can reject the null hypothesis that changes in field shape do not have any impact on the net savings.

The next field parameter is the area of non-navigable obstacles, the coefficient of which is -4.6366, -4.0919, -1.5198, and -2.6612 for corn, soybean, HRSW, and canola net cost savings regression models respectively. However, none of the coefficients are significant even at 10% level of significance. The negative coefficients of this variable may seem confusing at the first glance. However, a critical investigation into the direction of this variable reveals that when there are a small number of larged sized non-navigable obstacles exist in the field, the planter must avoid less area and there is less overlapping, and thus savings will be less. The co-efficient suggests that one hectare change in the area of non-navigable obstacles in the field will cause $4.6366 inverse change in net cost savings in planting corn seeds, $4.0919 inverse change in soybean seed savings, $1.5198 in HRSW seed cost savings, and $2.6612 in canola seed cost savings. It is to be noted that the area of non-navigable obstacles has the least impact on the seed cost savings of HRSW and greatest impact on seed cost savings of corn. Differences in per hectare seed cost are the main reason behind this differences in impact. Corn seeds represent the highest seed cost in North Dakota Prairie Pothole region and seed price per hectare of HRSW is the least (ND crop budget).

The coefficients of the variable “area of navigable obstacles” are positive for corn, HRSW, and canola regression models which are 26.0919, 0.0662, and 0.2565 respectively. The sign and magnitude of the coefficients indicate that change in the area of navigable obstacles and change in net savings for the mentioned crops move in the same direction but at a different rate. That is, if the area of navigable obstacles increases by 1 hectare, the amount of net savings in corn seed increases by $26.09, whereas the increase in net savings due to the increase in the area of navigable obstacles are $0.066 and $0.26 for HRSW and canola respectively. However, none of the variables is significant event at 10% level of significance. This fact is truly rational because navigable obstacles are those where the planter can pass through but is not supposed to plant seeds. In other words, ASC will allow the planter to pass through the navigable obstacles but will shut off the sections at the time of passing. For this reason, the area of navigable obstacles (low-lands) was included while calculating the overlapping area of a field. As the area of navigable obstacles increases, the overlapping area that could be reduced using ASC also increases which, in turn, causes a rise in net savings. This is the reason behind the positive sign of the variable "area of navigable obstacles". However, we could not find expected sign for this variable in soybean regression model where the coefficient of the variable was -0.3396. The reason is, for soybean regression, we had to skip 35 observations since soybean is not grown in all parts of the North Dakota Prairie Pothole region. This drastic fall in observations might have changed the direction of the coefficient. The coefficient of this variable also failed to achieve significance even at 10% level of significance.

The coefficients of the variable named "number of non- navigable obstacles" are positive for the regression model of all the four crops. The coefficient implies that an increase in the number of non-navigable obstacles such as trees, structures, non-agricultural lands and water lands raises the net seed cost savings for all the crops and vice versa. In case of corn regression model, the magnitude of this change is 22.3405 for corn regression model, whereas, the coefficients are 18.6561, 6.5305, and 24.8686 for soybean, HRSW and canola regressions respectively. This relationship is logical if we take a closer look at the routing path of the planter around the non-navigable obstacles. When the planter approaches a non-navigable obstacle, it cannot pass through the obstacles, so it must take a turn outside the non-navigable obstacles. This creates overlap inside the field which can be reduced by adopting ASC. The more the number of obstacles, the more the number of turns the planter must take around the obstacles and thus the larger the area of overlapping. When we look at the calculation of field-wise total and percentage overlapping area (Table 1) we see that those fields show a great deal of overlapping area in them which represent a higher number of non-navigable obstacles. Since the cost savings obtained due to ASC were calculated by multiplying the area of overlap reduction with the input price of the crop, increased overlap area resulted in increased amount of cost savings. Therefore, as the number of overlap area increased, the net savings due to ASC also increased. From the coefficients associated with this variable, we can understand that one-unit change in the number of non-navigable obstacles changes the net cost savings obtained from corn, soybean, HRSW, and canola planting by \$22.3405, \$18.6561, \$6.5305, and \$24.8686 respectively. However, none of the coefficients are significant even at 90% confidence level.

The next variable is the number of navigable obstacles which showed a positive relationship with net savings for three of the four regression models by a positive co-efficient of 9.0741, 2.7187, and 10.5147 for soybean, HRSW, and canola respectively. However, for corn regression model we could not have the expected sign. The positive coefficients denote that when the number of navigable obstacles inside the field increases by one unit, the net savings increase by \$5.09, \$2.72, and \$10.51 soybean, HRSW, and canola respectively, and the opposite is also true. It is noteworthy that the net savings obtained from a field due to ASC increases along with the increase in the variable “area of navigable obstacles”, that is, navigable obstacles inside the field which we discussed in the previous paragraphs. As the number of navigable obstacles increases, the area of navigable obstacles also increases which, in turn, raises the net savings. As a result, we can see a positive coefficient for the variable “number of navigable obstacles”.

Nine regional dummies were added to the regression models of the four crops, corn, soybean, HRSW, and canola as intercept shifter into the regression models. These regional dummies are the ND budget regions which the sample fields and county belong to. The regional dummies were added to the regression equation to ascertain how the net savings vary across the regions. Since the input cost of seeds is same for all the fields belonging to a region, it is necessary to estimate how the impact of field parameters on net savings differ among different regions. It is necessary to mention that, the North-Central budget region was omitted from all the four regression models to avoid collinearity. Also, for soybean regression model, South-West and North-West budget regions were also omitted because soybean is not grown in these regions. For the same reason, South-Valley region was omitted for the regression model of canola seed cost savings.

For corn regression model, highest impact of field parameters on net savings could be seen in the South-East region. The coefficient of this dummy is 131.79 which is significant in 5% level of significance which means that in South-East region, the field parameters are going to impact the net savings higher than any other budget region at 95% confidence level. Whereas, the lowest negative coefficient of -56.3884 of the dummy variable NE reveals that Northwest region’s field parameters have the least impact on the net corn seed cost savings. The reason is, the net savings obtained from each field due to ASC depends not only on the field parameters but also the price of the inputs. In South-East region, the price of corn seeds is higher than any other budget region. Therefore, even a minor change in the field parameters is supposed to bring a substantial change in net savings. However, we did not get any significance for this coefficient even at 10% level of significance. Similar trend could be seen for all other regional dummies in the regression equation. Changes in net savings due to a change in the field parameters were higher in a region where the corn seed price is more, and lower where the corn seed price is less. In other words, the more the input price in a region, the more the effect of that region on the changes in net savings. However, for regional dummies, we could only find the significant coefficients in the Southeast and East-Central region which denotes that these two regions effect the net savings significantly at 5% and 10% respectively.

For soybean regression model, we could observe the regional dummies to affect the net savings based on prevailing corn seed price in these regions. In this case, the only significant dummies are South-Valley (at 10%) and North Valley (at 5%). The coefficients of these variables are negative with the lowest negative coefficient occurring in the North-Valley region (-401.8148). A closer observation into the price of soybean seeds in the counties of this region reveals that the soybean seed cost/per hectare is the lowest in this region (ND crop budget data, 2017 price). Therefore, whatever may be the change in field parameter, this region will have the lowest impact on the net savings. The highest coefficient could be seen along with the regional dummy NE, which is -59.9559. This region represents the highest soybean seed price of $26.61/ha. It is interesting to note that all the regional dummies have a negative impact on the net savings for soybean regression.

For HRSW, the region that had the most impact on the changes in net savings due to fields parameters in an ASC-application scenario is the NE or Northeast budget region. Though this region does not represent the highest seed price, it has comparatively higher HRSW seed price than the other regions. The highest positive value of the coefficient in this region means that for HRSW, net seed cost savings is the highest due to ASC for the counties and fields that belong to this region. The highest seed price was observed in the North-Valley and South-Valley region, where the effect of the South-Valley region is greater than the North-Valley region as measured by the coefficients associated with them. Though both dummies have negative coefficients, the coefficient associated with the dummy SV is a lower negative value (-6.0723) which means that net savings are going to change more due to a change in the fields parameters in the South-Valley region than in the North-Valley region. In this analysis, only the North-Valley region was observed to significantly affect the net savings due to the changes in field parameters since we can find a significant value at 5% only for this regional dummy.

For canola regression model, the highest positive coefficient could be seen in the Southwest region (91.2046) which indicates that this regional dummy shifts the intercept by 91.2046 and denotes that this is the region where the net savings due to ASC will be the highest and the field parameters will have the greatest impact on the dependent variable net savings. The lowest negative value could be seen in the region North-Valley which indicates that net savings due to ASC will be least among all region in this region and the field parameters will also have the least impact on the dependent variables net savings. However, in this regression model, we did not find any significant value for the regional dummies even at % level of significance.

4.7. Marginal Effects of Field Parameters on Savings

The marginal effects of a unique field parameter on the savings generated from each field are determined by differentiating the regression equation with respect to that field parameter. More precisely, the marginal effect of field area on corn seed savings is determined by,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = \frac{\partial}{\partial Area}(-103.8572) + \frac{\partial}{\partial Area}(-0.6921 Area) + \frac{\partial}{\partial Area}\left(3.0294 * \frac{Perimeter}{Area}\right) + \frac{\partial}{\partial Area}(\text{-4.6366*Area of Non-Navigable Obstacles}) + \frac{\partial}{\partial Area}(26.0919 * Area\ of\ Navigable\ Obstacles) + \frac{\partial}{\partial Area}(22.3405 * No.of\ Non-Navigable\ Obstacles) + \frac{\partial}{\partial area}(-1.5012 * No.of\ Navigable\ Obstacles) \quad (4.1)$$

Therefore, the marginal effect of field area on corn net seed savings becomes,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = -0.6921 - 3.0294 * Perimeter * Area^{-2} \quad (4.2)$$

Similarly, the marginal effect of field perimeter on net savings becomes,

$$\frac{\partial Net\ Savings}{\partial Field\ Perimeter} = \frac{3.0294}{Area} \quad (4.3)$$

Following the differentiation method in equation (1), the marginal effect of field area on soybean seed cost savings is,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = -0.5013 - 2.7199 * Perimeter * Area^{-2} \quad (4.4)$$

And the marginal effect of field perimeter on net soybean seed cost savings be,

$$\frac{\partial Net\ Savings}{\partial Field\ Perimeter} = \frac{2.7199}{Area} \quad (4.5)$$

The marginal effect of field area on net HRSW cost savings is given by,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = -1.3132 - 0.9960 * Perimeter * Area^{-2} \quad (4.6)$$

And the marginal effect of field perimeter on net HRSW seed cost savings be,

$$\frac{\partial Net\ Savings}{\partial Field\ Perimeter} = \frac{0.9960}{Area} \quad (4.7)$$

The marginal effect of field area on net canola seed cost savings is given by,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = 0.1204 - 3.6649 * Perimeter * Area^{-2} \quad (4.8)$$

And the marginal effect of field perimeter on net canola seed cost savings is given by,

$$\frac{\partial Net\ Savings}{\partial Field\ Perimeter} = \frac{3.6649}{Area} \tag{4.9}$$

It is noteworthy that marginal effects of other field parameters will be the coefficients associated with them. Since in the regression equation the only interactive variable is the P/A ratio which involves two field parameters, field area, and field perimeter, the marginal effects of these two parameters with net savings will be different from the coefficients associated with them. These marginal effects are calculated for each of the 105 sample corn fields and are averaged to find out a single effect. The averaged marginal effects of all the field parameters on the net savings of four crops are presented in the following table and are discussed in the following paragraphs:

Table 9. Average Marginal Effects of Field Parameters on Net Savings

Average Marginal Effects	Net Seed Cost Savings			
	Corn	Soybean	HRSW	Canola
Field Area	-1.828	-1.538	-1.687	-1.313
Field Perimeter	0.017	0.015	0.005	0.020
Area of Non-Navigable Obstacles	-4.637	4.092	-1.520	-2.661
Area of Navigable Obstacles	26.092	-0.339	0.066	0.257
No. of Non-Navigable Obstacles	22.341	18.656	6.531	22.341
No. of Navigable Obstacles	-1.501	9.074	2.719	-1.501

The marginal effects of field area on the net savings of the four crops denote that when the area of the field decreases by 1 hectare, the net seed cost savings increases by \$1.8282, \$1.5383, \$1.6867, and 1.3131 for corn, soybean, HRSW, and canola respectively. These marginal effects are quite different from the effects of the field area on the net savings which we obtained from the regression models. It is interesting to note that for canola regression model, we did not get the expected sign for the coefficient of the variable field area. Previous studies and researches tell us that field area has a negative impact on the net savings, that is, more savings can be generated due to ASC if the field area is small and vice versa. Therefore, there should be a negative coefficient along with the variable field area. In other words, the impact of field area on net savings should be negative which we could not achieve in canola regression. Rather, the variable showed a positive coefficient. However, when we calculated the marginal effect of field area on net savings we see that in case of all the four crops, we could achieve expected signs for the effect of field area on net savings which is commensurate with the findings of previous studies such as Luck et al (2010), Velandia et al (2010), and Shockley et al (2012) which also found an inverse relationship between field area and net input cost savings due to ASC. The marginal impact of field perimeter on the sample 105 fields in our study is positive in all the regression models and the values are 0.0165, 0.046, 0.0054, and 0.0203 respectively for corn, soybean, HRSW and canola which indicate that a 1-meter increase in field perimeter increases the net savings by $0.0165, $0.046, $0.0054, and $0.0203 respectively for corn, soybean, HRSW and canola and the opposite is also true. In the regression analysis, we have already shown that the P/A ratio is the measure of the irregularity in the field shape and as the P/A ratio increases, the net savings generated from the fields also increases. The P/A ratio is obtained by dividing the perimeter of a field by its area. Since the numerator in the ration is the perimeter of the field, therefore, the marginal impact of field parameter on the net savings should be positive. For the other field parameters, the marginal effects are the same as the coefficients of the variables as we obtained from the regression equations. Since we already discussed their impact, the discussion about the marginal effects of the variables other than the field area and field perimeter are skipped from this section.

Scatter plots are drawn taking the field parameters in the X-axis and the net savings of the fields on Y-axis. The scatter plots of each field parameter on the net seed cost savings of corn, soybean, HRSW, and canola are shown in the following figures:

4.7.1. Marginal Effects of Field Parameters on Corn Seed Savings

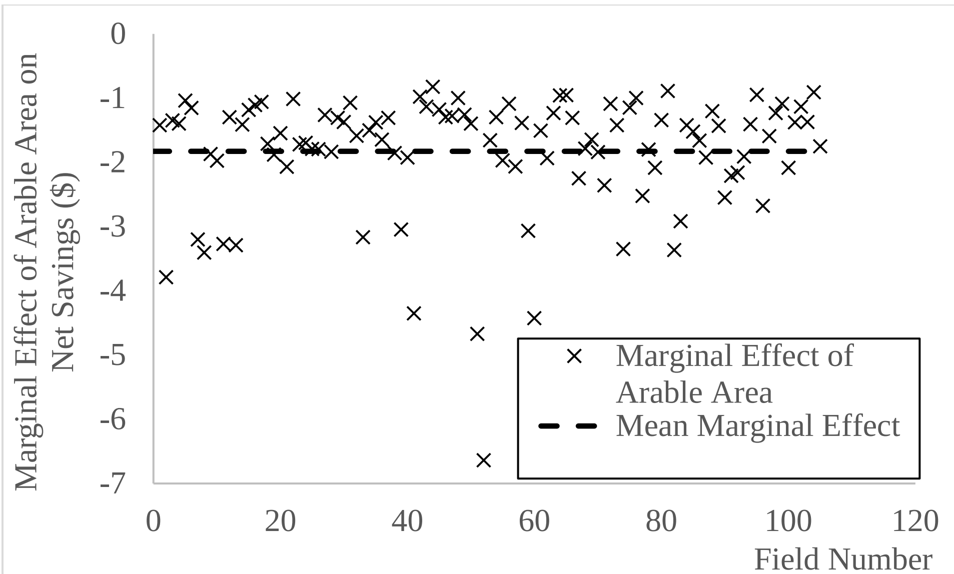

Figure 13. Scatter Plot of Marginal Effect of Field Area on Net Seed Cost Savings (Corn)

The field wise marginal effect of the field size (as measured by area in hectare) are presented in the above figure. From the scatter plot it is evident that with one hectare increase in the field area, net corn seed cost savings decreases by a dollar value between -1 and -2. More specifically, with one hectare increase in the field area, the net corn seed cost savings decreases by $1.83 (From table 9). We can also see from the scatter plot that for most of the fields, this decrease in net cost savings due to one hectare increase in field size most fall between the value of -1 and -1.5. We can see that highest decrease in net savings due to one hectare increase in field size (a value near -7) in field number 52 which falls in the county Cavalier. A closer observation into this field reveals that this field is highly irregular in shape (measured by the p/a ratio 142.58) and contains a huge area of non-navigable obstacles.

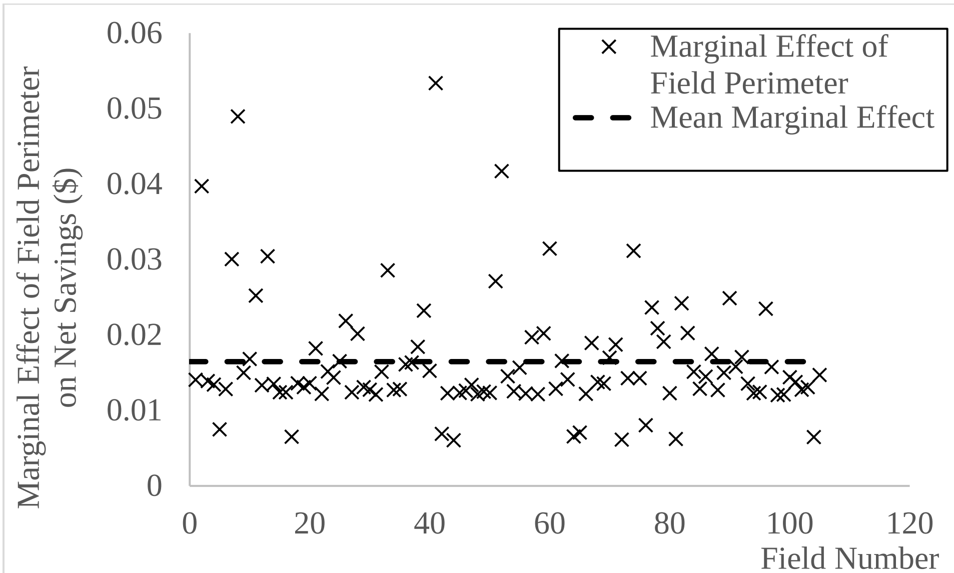

Figure 14. Scatter Plot of Marginal Effect of Field Perimeter on Net Seed Cost Savings (Corn)

From the above scatter plot, we can see that there are a positive relationship between field perimeter, that is, the field shape, and net seed cost savings. As the perimeter of a field increases by one meter, the net seed cost savings increases between \$0.01 to \$0.06 where most of the changes occur between \$0.01 to 0.02. The mean marginal effect of field shape on net seed cost savings of corn is \$0.017, which implies that when the field perimeter increases by 1 meter, the net seed cost savings goes upward by \$0.017 or about 2 cents. The highest marginal change in net savings due to field perimeter could be observed in field number 8 falling in Billings county. This field is very irregular in shape as measured by a large p/a ratio of 55.39.

4.7.2. Marginal Effects of Field Parameters on Soybean Seed Savings

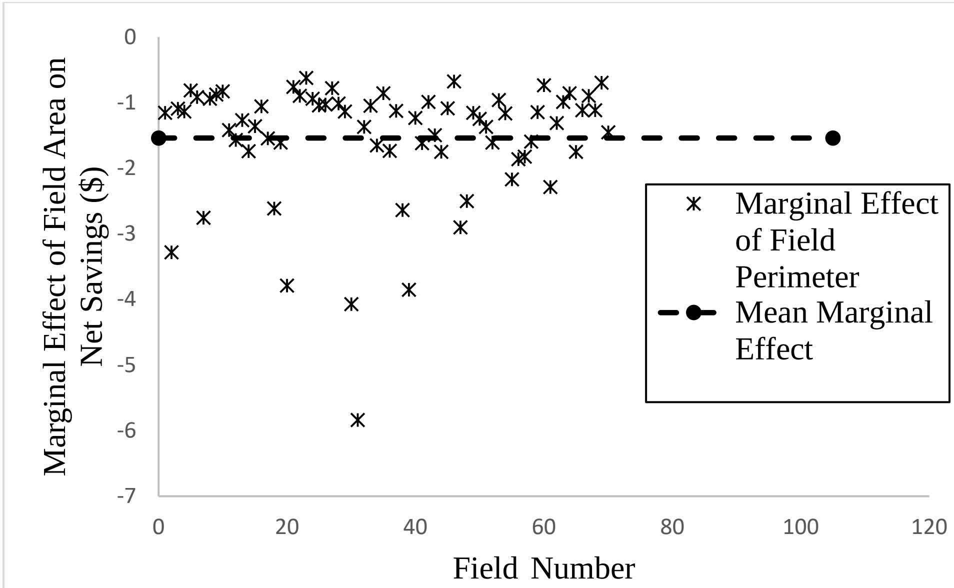

Figure 15. Scatter Plot of Marginal Effect of Field Area on Net Seed Cost Savings (Soybean)

Field wise marginal effects of the field size on the soybean seed savings are presented in the above scatter plot where the fields are presented in the X-axis and the marginal effects of field area on net savings are presented on Y-axis. From the above scatter plot, we can see that field area has an inverse marginal effect on net soybean seed savings, that is, when the field area increases by 1 hectare, the net seed costs savings of soybean decrease by $1.54 on an average. These changes in net seed cost savings vary between less than a value less than -1 to a value less than -6. From the scatter plot we can see that most of the changes in net savings occur between -0.5 to the mean value of -1.54, where the highest marginal effect is about -5.9 which occurs in a field number 31 which falls within cavalier county. This field has a high p/a ratio of 142.58. This high p/a ratio denotes that this field is highly irregular in shape. Furthermore, this field has a large area of non-navigable obstacles (about 10.72 ha).

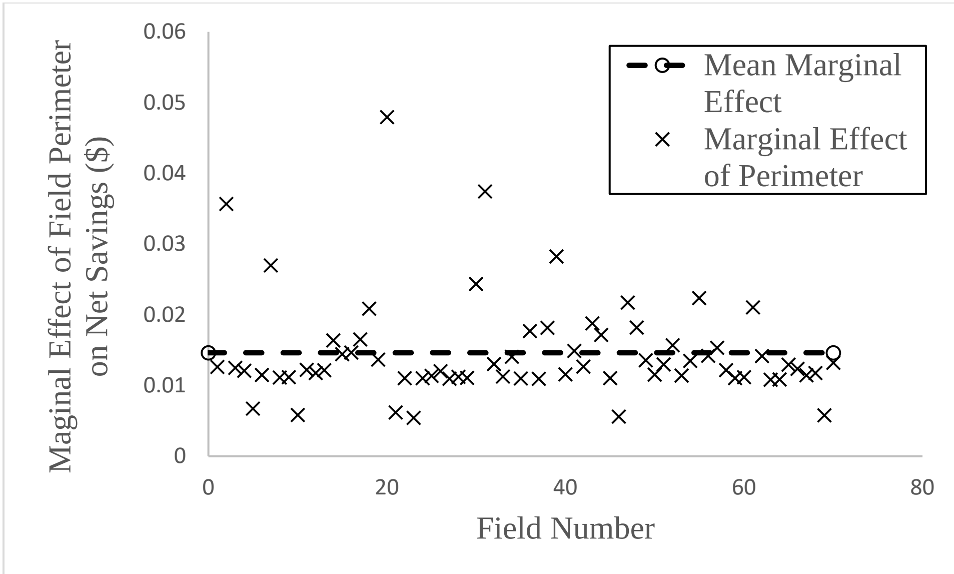

Figure 16. Scatter Plot of Marginal Effect of Field Perimeter on Net Seed Cost Savings (Soybean)

The above scatter plot shows the field-wise marginal effect of field perimeter on net seed cost savings of soybean. The mean marginal effect showed by a straight line implies that when the field perimeter increases by 1meter, the net seed cost savings of soybean increase by $0.015, where the marginal effects vary between 0 to 0.05 implying that 1-meter increase in the field perimeter raises the net seed cost savings of soybean between a value less than 1 cent to 5 cents. Here, we can see that in most of the fields, the marginal changes in net savings due to the changes in field size cluster around the mean.

4.7.3. Marginal Effects of Field Parameters on HRSW Seed Savings

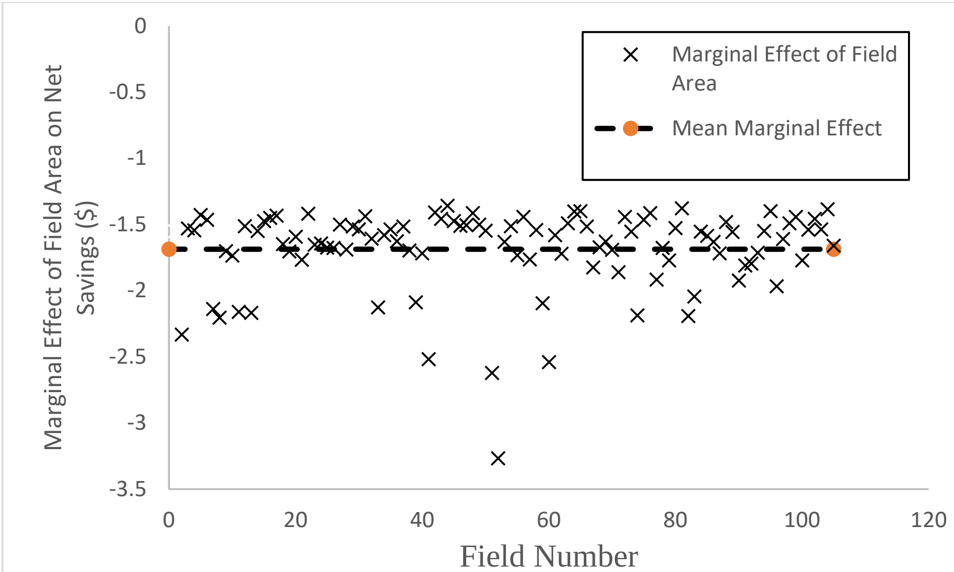

Figure 17. Scatter Plot of Marginal Effects of Field Area on Net Seed Cost Savings (HRSW)

The field wise marginal effect of the field size (as measured by area in hectare) are presented in the above figure. From the scatter plot it is evident that on an average, with one hectare increase in the field area, net HRSW seed cost savings decreases by a dollar value which falls between -1.5 and -2. More specifically, with one hectare increase in the field area, the net corn seed cost savings decreases by $1.69 (From table 9). We can also see from the scatter plot that for most of the fields, this decrease in net cost savings due to one hectare increase in field size is close to the mean. It is also observed that highest decrease in net savings due to one hectare increase in field size (a value close to -3.27) occurs in field number 52 which falls within Cavalier county of the North-East region of North Dakota.

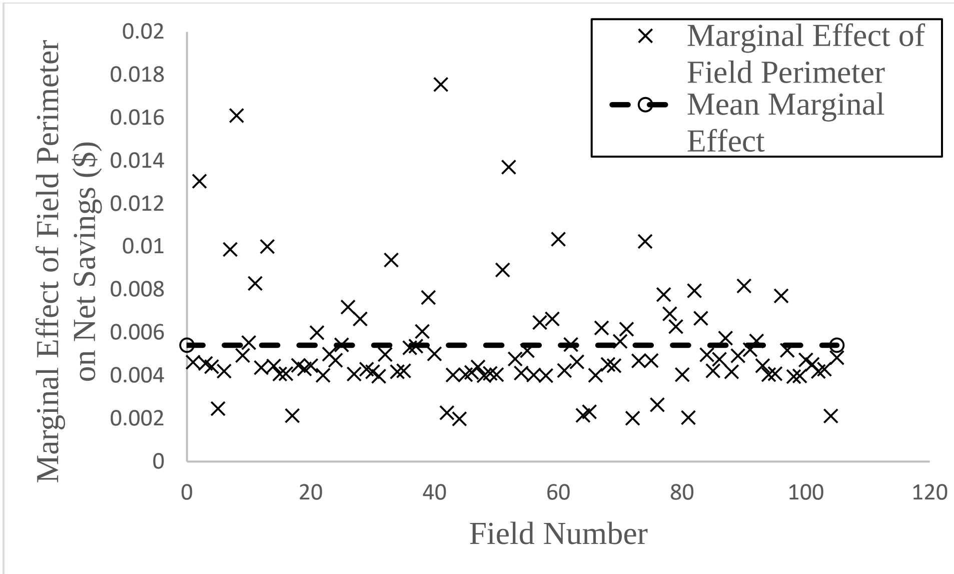

Figure 18. Scatter Plot of Marginal Effects of Field Perimeter on Net Seed Cost Savings (HRSW)

The above scatter plot depicts a positive relationship between field perimeter and net seed cost savings. We can see from figure 15 that as the perimeter of a field increases by one meter, the net seed cost savings increases between $0.002 to $0.018 where most of the changes occur around the mean, that is, a value between 0.004 to 0.006. From table 9 we know that this value is 0.0054 which means that a 1-meter change in the perimeter of the field changes the seed cost savings by $0.0054 and vice versa on average. The highest marginal change in net savings can be seen in field number 8 of Billings county. A profound investigation into the characteristics of this field reveals that this field has a high p/a ratio of 55.39, that is, this field is highly irregular in shape. Furthermore, this field has a comparatively smaller field area than other fields.

4.7.4. Marginal Effects of Field Parameters on Canola Seed Cost Savings

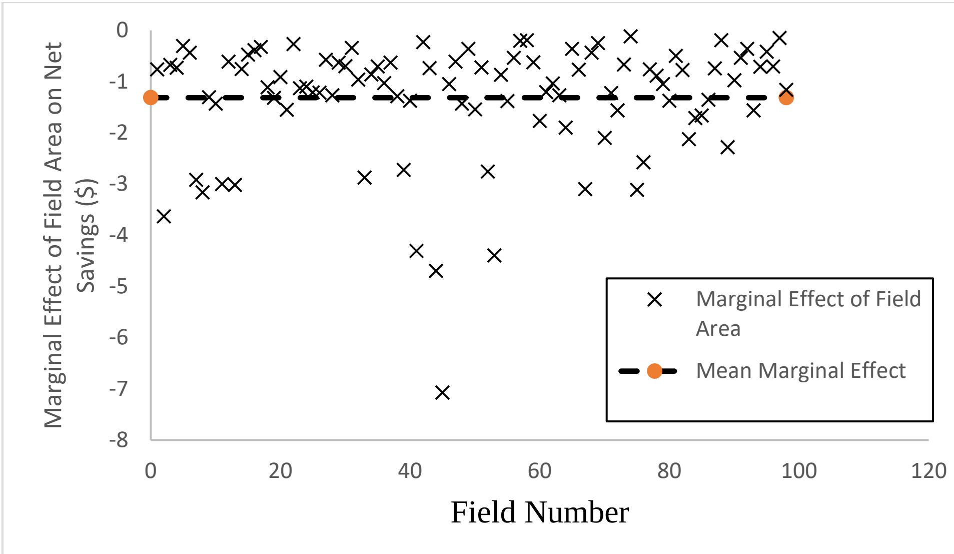

Figure 19. Scatter Plot of Marginal Effects of Field Area on Net Seed Cost Savings (Canola)

The above figure represents the marginal effect of field size on net seed cost savings of canola. Field number is represented in X-axis and marginal effect of field sizes on the Y-axis. From the figure, we see that the mean marginal effect occurs between -1 and -2. The mean marginal effect of -1.3131 implies that when the field area increases by 1 hectare, the net canola seed cost savings decrease by $1.31. In most of the fields, the net cost savings due to the unit change in field area are close to the mean value and fall between -1 to 0, where the highest marginal change occurs in a field between field number 90 to 100.

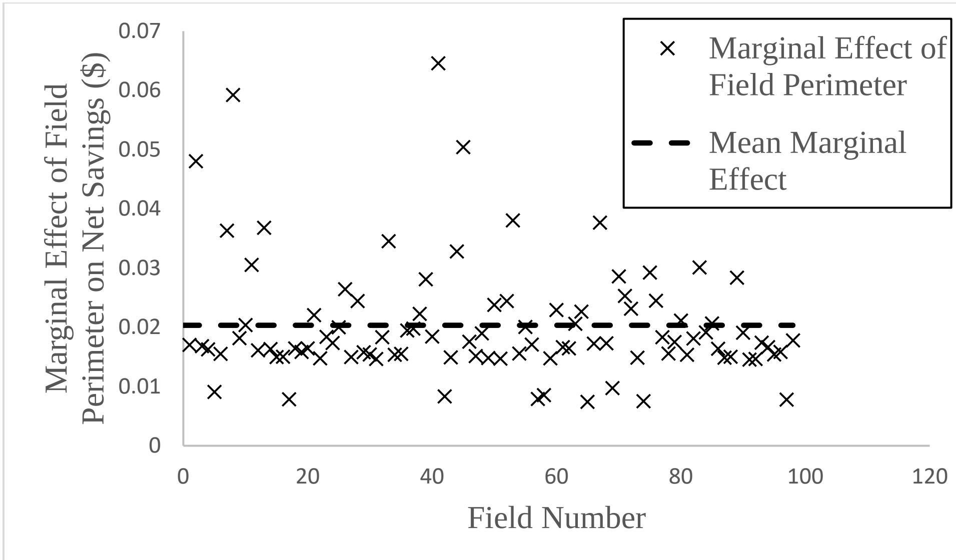

Figure 20. Scatter Plot of Marginal Effects of Field Perimeter on Net Seed Cost Savings (Canola)

In figure 17, the positive figures in the Y-axis, that is, the values of the marginal effect of field perimeter on net seed cost savings indicate that there is a positive relationship between the field perimeter and net seed cost savings of canola. The mean marginal effect occurs at 0.02 which means that on an average, 1-meter increase in the field perimeter escalates the net cost savings by $0.02 or 2 cents. The highest change in net savings due to the change in field perimeter is 0.065 which occurs in field number 41 in Burleigh county. This fact indicates that field perimeter has the greatest impact on net savings in this field. A profound investigation into the field characteristics reveals that this field has a high p/a ratio of 68.60. This high p/a ratio is the indicator of the high irregularity in shape of this field.

4.8. Regression of Net Chemical Cost Savings on Field Parameters

One of the four objectives of the current study is to estimate the impact of field parameters on net chemical cost savings when ASC is installed in a 120-foot sprayer. Hence, a multiple regression analysis is conducted using a fixed-effects model. Here, the dependent variable is the net chemical cost savings that the farms could obtain by installing ASC in a 120-

foot sprayer. Independent variables are the field parameters and the regional dummies. Net chemical cost savings on four crops (corn, soybean, canola, and HRSW) that could be obtained by adopting ASC in each field are regressed over several field parameters. It is to be noted that all the counties under a budget region of North Dakota represent the same per hectare chemical cost in case of all the four crops mentioned above. Net savings obtained from each field is different because every field has its own unique field characteristics which vary the overlapping area within the field, and the average farm size, which is a determining factor for calculation of machinery cost is different in case of each county. Furthermore, the cost of chemical of the crops is also a determining factor of the difference between the net savings obtained from each crop. Hence, the budget regions of North Dakota were considered as dummy variables in the regression to keep their effects “fixed” on net savings. Another reason for including regional dummies was to ascertain the difference between net savings among different regions.

The regression analyses were conducted using StataSE 15 (64-bit) statistical software. The dependent variable net savings (referred to as savings) was regressed upon different linear, interactive and quadratic field parameters to estimate the direction and magnitude of the effects these field parameters impose on the net savings. The independent variables or regressors are field area, perimeter to area ratio, the area of non-navigable obstacles, area of navigable obstacles, number of non-navigable obstacles, number of navigable obstacles, and nine regional dummy variables South-East, South-West, North-Central, North-West, South-Central, South-Valley, North-East, East-Central, and North-Valley. (addressed in the regression as SE, SW, NC, NW, SC, SV, NE, EC, and NV). It is to be mentioned here that soybean and canola are not grown in all the budget regions. So, these regional dummies were omitted when regressing net savings obtained from planting soybean and canola. Four separate regressions were run for the four crops corn, soybean, canola, and HRSW. The regressions results are presented in table 10:

Table 10. Impact of Field Parameters on Net Chemical Cost Savings of Corn, Soybean, HRSW, and Canola

Field Parameters	Net Savings			
	Corn	Soybean	HRSW	Canola
Constant	-191.702*	-158.704	-225.913	-192.133
	(117.725)	(145.990)	(181.695)	(124.571)
Field Area	-0.367	-0.376	0.151	-0.297
	(0.933)	(0.442)	(0.461)	(0.325)
P/A Ratio	1.775*	1.515	2.746*	1.877**
	(0.933)	(1.335)	(1.449)	(0.952)
Area of Non-Navigable Obstacles	-1.136	-1.920	-1.367	0.134
	(4.527)	(5.315)	(7.359)	(4.945)
Area of Navigable Obstacles	0.331	0.225	0.479	0.325
	(0.393)	(0.344)	(0.613)	(0.395)
Number of Non-Navigable Obstacles	7.189	7.867	10.814	7.879
	(7.936)	(13.599)	(12.371)	(8.208)
Number of Navigable Obstacles	2.151	1.829	3.851	2.709
	(6.452)	(7.485)	(10.395)	(6.417)
South-East	218.694	249.852	272.329	156.908
	(146.354)	(165.479)	(231.654)	(141.181)
South-West	167.101*	Omitted	129.617	168.231*
	(96.357)	---	(154.002)	(103.469)
North-Central	Omitted	Omitted	Omitted	Omitted
North-West	99.257	Omitted	65.008	103.527
	(90.631)	---	(145.417)	(98.223)
South-Central	73.807	102.638	76.992	70.634
	(91.404)	(99.005)	(147.693)	(97.416)
South-Valley	51.247	125.365	13.735	Omitted
	(94.700)	(99.188)	(153.317)	---

Table 10. Impact of Field Parameters on Net Chemical Cost Savings of Corn, Soybean, HRSW, and Canola (Continued)

Field Parameters	Net Savings			
	Corn	Soybean	HRSW	Canola
North-East	136.550	162.159	159.823	103.101
	(120.703)	(134.439)	(198.911)	(124.994)
East-Central	74.969	91.394	75.508	43.216
	(92.645)	(97.252)	(149.852)	(98.459)
North-Valley	-65.527	17.973	-82.711	-97.597
	(102.906)	(109.364)	(163.096)	(109.782)
R-Squared	0.289	0.204	0.170	0.274
RMSE	185.81	244.7	290.34	181.81
F-Statistic	6.35	3.24	3.21	5.57
No. of Observations	105	70	105	98

Note:
Standard errors are reported in parentheses.
*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively.

The regression results of the impact of field parameters on the chemical cost savings for all the four crops, corn, soybean, HRSW, and canola are presented in the above table. The estimated coefficients represent the effect of the selected field parameters and regional dummies on the net savings obtained by adopting ASC in a 120-feet boom sprayer. The estimated effects of the field parameters on the net savings of each crop are discussed in the following paragraphs:

4.8.1. Correlation Among Variables

Correlation Matrix among the variables is used to measure the correlation between the variables. The correlation between the variables used in the regressions is measured by using correlation matrices and measuring Variation Inflation Factor (VIF) test. The correlation matrix and VIF test both are conducted in STATA (StataSE 15 64-bit) which are presented in the following tables:

Table 11. Correlation Matrix for Corn Net Chemical Cost Savings Regression

	Savings	Field Area	P/A Ratio	Area of Non-Navigable Obstacles	Area of Navigable Obstacles	No. of Non-Navigable Obstacles	No. of Navigable Obstacles
Savings	1.000						
Field Area	-0.337	1.000					
P/A Ratio	0.360	-0.570	1.000				
Area of Non-Navigable Obstacles	-0.043	0.223	0.091	1.000			
Area of Navigable Obstacles	0.018	0.084	-0.091	0.058	1.000		
No. of Non-Navigable Obstacles	0.025	0.275	0.069	0.616	-0.048	1.0000	
No. of Navigable Obstacles	0.086	-0.010	0.204	-0.079	0.304	-0.081	1.000

Table 12. Correlation Matrix for Soybean Net Chemical Cost Savings Regression

	Savings	Field Area	P/A Ratio	Area of Non-Navigable Obstacles	Area of Navigable Obstacles	No. of Non-Navigable Obstacles	No. of Navigable Obstacles
Savings	1.000						
Field Area	-0.292	1.000					
P/A Ratio	0.286	-0.570	1.000				
Area of Non-Navigable Obstacles	-0.019	0.223	0.091	1.000			
Area of Navigable Obstacles	-0.016	0.084	-0.091	-0.058	1.000		
No. of Non-Navigable Obstacles	0.036	0.275	0.069	0.616	-0.048	1.000	
No. of Navigable Obstacles	0.088	-0.010	0.204	-0.079	0.038	-0.081	1.000

Table 13. Correlation Matrix for HRSW Net Chemical Cost Savings Regression

	Savings	Field Area	P/A Ratio	Area of Non-Navigable Obstacles	Area of Navigable Obstacles	No. of Non-Navigable Obstacles	No. of Navigable Obstacles
Savings	1.000						
Field Area	-0.123	1.000					
P/A Ratio	0.263	-0.570	1.000				
Area of Non-Navigable Obstacles	0.021	0.223	0.091	1.000			
Area of Navigable Obstacles	0.051	0.084	-0.091	-0.058	1.000		
No. of Non-Navigable Obstacles	0.092	0.275	0.069	0.616	-0.048	1.000	
No. of Navigable Obstacles	0.117	-0.010	0.204	-0.079	0.038	-0.081	1.000

Table 14. Correlation Matrix for Canola Net Chemical Cost Savings Regression

	Savings	Field Area	P/A Ratio	Area of Non-Navigable Obstacles	Area of Navigable Obstacles	No. of Non-Navigable Obstacles	No. of Navigable Obstacles
Savings	1.000						
Field Area	-0.289	1.000					
P/A Ratio	0.337	-0.570	1.000				
Area of Non-Navigable Obstacles	0.027	0.223	0.091	1.000			
Area of Navigable Obstacles	0.022	0.084	-0.091	-0.058	1.000		
No. of Non-Navigable Obstacles	0.078	0.275	0.069	0.616	-0.048	1.000	
No. of Navigable Obstacles	0.084	-0.010	0.204	-0.079	0.038	-0.081	1.000

Correlation coefficients among the variables used for the four regressions models of the net chemical cost savings of the four crops corn, soybean, HRSW, and canola are presented in the above matrix. The very small correlation coefficients among the variables denote that the regression models are free from severe collinearity. For net chemical cost savings regressions for all the four crops, the correlation among the independent variables are not very strong except for two, where the P/A ratio is highly negatively correlated with the field area (-0.5703), and where the number of non-navigable obstacles is highly correlated with the area of non-navigable obstacles (0.6155). However, these correlations are expected because the variable P/A ratio is a measure of the irregularity in field shape and it is calculated by dividing the field perimeter with field area. Therefore, there is an inverse relationship between P/A ratio and field area. As a result, we can observe a highly negative correlation between P/A ratio and field area in all the regressions. The highly positive correlation observed between the number of non-navigable obstacles and the area of non-navigable obstacles is also acceptable because the area of non-navigable obstacles is calculated by adding the area of every single non-navigable obstacle in the fields. In all the regressions, we could see some highly positive and negative correlations among different independent variables and the dependent variable “savings” which is rational because the independent variables are supposed to be correlated with the dependent variable.

The results obtained from the VIF test for measuring the existence of multicollinearity in the four regression models are shown in the following table:

Table 15. Results of VIF Test of the Regression Models of Net Chemical Cost Savings

Variables	Corn Regression		Soybean Regression		HRSW Regression		Canola Regression	
	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF
SW	4.72	0.212	---	---	4.72	0.212	4.65	0.215
EC	4.71	0.212	4.24	0.236	4.71	0.212	4.62	0.216
NW	3.28	0.305	---	---	3.28	0.305	3.24	0.308
SE	3.22	0.311	3.06	0.326	3.22	0.311	3.19	0.314
SC	2.57	0.389	2.64	0.379	2.57	0.389	2.56	0.390
SV	2.53	0.396	2.50	0.399	2.53	0.396	---	---
NE	2.49	0.402	2.50	0.401	2.49	0.402	2.48	0.404
NV	2.25	0.444	2.22	0.449	2.25	0.444	2.25	0.445
Field Area	2.01	0.498	1.98	0.504	2.01	0.498	1.94	0.514
P/A Ratio	2.02	0.496	2.24	0.446	2.02	0.496	1.89	0.529
Area of Non-Navigable Obstacles	1.90	0.527	1.68	0.595	1.90	0.527	1.81	0.554
Area of Navigable Obstacles	1.24	0.807	1.26	0.795	1.24	0.807	1.24	0.808
No. of Non-Navigable Obstacles	1.90	0.526	1.81	0.553	1.90	0.526	1.88	0.532
No. of Navigable Obstacles	1.46	0.684	1.47	0.679	1.46	0.684	1.45	0.690
Mean VIF	2.59		2.30		2.59		2.55	

The above table shows the results of VIF test of the regression models of corn, soybean, HRSW, and canola net seed cost savings. VIF tells us about how much the variance of a regression model is inflated. The more the Value of VIF, the more inflated the variance is, and the more multicollinearity the model suffers from (Robinson and Schumacker 2009). The general rule of thumb of VIF test is that mean VIF value over than 10 indicates an unacceptable level of multicollinearity of the model and needs further investigation (Belsley, Kuh, & Welsch, 1980). In this study, the mean VIF of all the four regression models of net chemical cost savings for corn, soybean, HRSW, and canola are 2.59, 2.30, 2.59, and 2.55 respectively which are far less than the acceptable limit of VIF value 10. Therefore, this small multicollinearity among the variables is acceptable and does not need further treatment.

4.8.2. General Model Fit

The net chemical cost savings obtained by adopting ASC in farming operations of all the four crops are calculated separately and are regressed on several field parameters. The number of observations for corn regression model is 105, which represent the sample 105 fields of North Dakota Prairie Pothole region where corn is grown. For the soybean regression model, 35 fields (5 counties) where soybean is not grown were skipped from the equation, and therefore, the number of observations dropped to 70. For canola, the number of observation is 98 since we dropped 7 fields where canola is not grown. HRSW is grown in all the counties considered under the span of this study, the number of observations is same (105) as corn.

The Root Mean Square Error (RMSE) tells us about the differences between the actual and predicted values of the observations. Therefore, the lower the RMSE, the lower the difference between the actual and predicted values of the observations, and thus the better the model fit. The regression equation of corn net chemical cost savings shows an RMSE of 185.81 which is less than the RMSE of soybean and HRSW regression model and less than the RMSE of the canola regression model. Hence the corn regression model has a better model fit than the soybean and the HRSW regression model and a worse model fit than the canola regression model. The R-square of this model is not very high. The R-square value of 0.2892 of this model denotes that the field parameters and dummy variables can explain only 28.92% of the variability in the dependent variable net savings. The F-statistic tells us that the model is significant at 99% confidence level. That is, the model has a good explanatory power.

The soybean regression model has a higher RMSE value than the RMSE of the corn and canola regression model and a lower RMSE value than the HRSW regression model. Therefore, difference between the actual and potential values of the observations is higher in the soybean regression model than that of the corn and canola regression model and the difference is lower than that in the HRSW regression model. Hence, the soybean regression model has a worse model fit than the corn and canola regression model and a better model fit than the HRSW regression model. The R-squared value of this model is lower than that of corn regression model but still, it is 0.2036, which is not very uncommon in the researches relating to social sciences and economics. The R-square means that the variables can explain 20.36% of the variability in the model. The value of F-statistic is 3.24 which is significant at 1% level of significance. It indicates that the soybean chemical cost savings regression model also has a very good explanatory power.

The RMSE of HRSW chemical cost savings regression model is the highest of all the regression models (290.34) which indicates that the model has a worse in-sample fit and higher error measures than the other three regression models. Furthermore, the R-square value of this model is even lower than that of the other two models discussed earlier and it is only 0.17 meaning that the independent variables can only explain 17% of the variability in the dependent variable of the model. The reason for this low R-square value is probably the high variability of the data. The significant F-statistic value of 3.21 (significant at 1%) indicates that including independent variables in the model gives a better result than the intercept only model.

In case of Canola seed regression model, The RMSE is very high (181.81). This RMSE is higher than that of the corn regression model and lower than that of the soybean and HRSW regression model. This fact indicates that the canola regression model can explain the observations better than the soybean and HRSW regression model but less than the corn regression model. The R-square value of this model is 0.2744 which indicates that the model explains only 27.44% of the variability of the response data.

We can observe from the above discussion that we can have a low R-square value from the four regression models, but we have a very small multicollinearity in the models as estimated by the low VIF values. A profound investigation into the regression results also reveals that the variances of the β values in the models are also very small. This small variance and a negligible level of multicollinearity tells us that the estimators in the model are unbiased. When the R-square is very high (close to 1), there will be a presence of multicollinearity in the model which makes the estimators biased (Pindyck and Rubinfeld). It is also noteworthy that previous study such as Luck et al (2010) found the R-square value to be 0.4682 for a five-section manually controlled sprayer and 0.5218 for a seven section automatically controlled sprayer when they estimated the percentage of overlap reduction due to the prayer. When predicting the percentage of overlap reduction due to ASC in a sprayer with 5, 7, and 9 sections controlled, researchers found the R-square value of 0.569, 0.647, and 0.593 respectively (Luck et al 2011). However, in this study, the regressions models are used not to predict the effect of field parameters on overlap reduction, but to estimate the effects of the field parameters on the net savings resulting from this overlap reduction. Therefore, the R-squares in this study are different from those of the previous studies.

4.8.3. Discussion Regarding the Sign and Magnitude of the Coefficients

The intercepts of the all the seed savings regression model are negative, and they are -191.7015, -158.7036, -225.9133, and -192.1332 for corn, soybean, HRSW, and canola respectively. The negative signs indicate that when all the field parameters are zero, the net savings go down and it reduces by $191.7015in case of corn, $158.7036 for soybean, $225.9133 for HRSW, and $192.1332 for Canola. This sounds rational because the field parameters can become zero only when the farmer chooses not to spray chemicals on the fields but spends money on an initial investment to install ASC in the 120-feet boom sprayer. In this case, there will be no cost savings, rather the farmer will incur additional cost to purchase ASC equipment. However, only the constant in the regression model for corn is significant at 10%, others are not significant even at 10% level of significance.

The coefficient of the variable “field area” is negative for corn, soybean, and canola regression models. The coefficients are -0.3668, -0.3761, and -0.2967 respectively for corn, soybean, and canola regression models respectively which indicates that with one hectare change in the field area, the net chemical cost savings for corn, soybean, and canola changes by $0.3668, $0.3761, and $0.2967 respectively. Other studies found that there is an inverse relationship between field area and the overlap area reduced by field size (Luck et al 2010, 2011, and Craig et al 2013). Finally, the coefficient of the variable “field area” in the HRSW regression model is 0.1507. However, we could not find the expected sign in this coefficient. The reason behind this is the high variability of the data set. When the field maps were selected, we tried to cover fields with all types of characteristics and selected some regular field, some irregular, some large fields, and some small fields, some with no obstacles inside them, some with numerous navigable and non-navigable obstacles so that we can estimate the impact of all the field parameters on the overlap reduction and net savings obtained from each field. This selection procedure was responsible for the high variability of the data set.

The second independent variable in this model is perimeter to area ratio, which is a measure of the irregularity of the shape of the field (Velandia et al, 2010). The coefficient is positive and significant at 10% for the regression models of the net chemical cost savings of three crops, corn, HRSW, and canola. The positive sign of this variable indicates that the higher the perimeter to area ratio, the higher the savings, and vice versa. This estimation is justified because the amount of net savings depends on the quantity of overlapping reduced in a field. According to Luck et al (2011), an irregularly shaped field incurs more overlapping area inside the field area than a regularly shaped field and this overlapping area can be reduced by adopting ASC. However, the coefficient associated with the variable “P/A ratio” in soybean regression model is not significant even at 10% level of significant. In corn regression model, the coefficient (1.7746) is a measure of the movement of net savings along with P/A ratio, which tells that one unit increase in the P/A ratio causes a $1.7746 increase in the net chemical cost savings of corn and vice versa. This increment is $1.5146, $2.7458, and $1.8769 in case of soybean, HRSW, and canola respectively.

The next field parameter is the area of non-navigable obstacles, the coefficient of which is -1.1360, -1.9203, -1.3665, and 0.1344 for corn, soybean, HRSW, and canola net cost savings regression models respectively. However, none of the coefficients are significant even at 10% level of significance. The negative coefficients of this variable may seem counterintuitive at the first glance. However, a critical investigation into the direction of this variable reveals that when there are a small number of larged sized non-navigable obstacles exist in the field, the sprayer must avoid less area and there is less overlapping, and thus savings will be less. The co-efficient suggests that one hectare change in the area of non-navigable obstacles in the field will cause \$1.1360 inverse change in net cost savings for spraying chemicals in corn fields, \$1.9203 inverse change in soybean chemical cost savings and \$1.3665in HRSW seed cost savings. However, we could not obtain expected sign in the canola chemical cost savings regression model. It is also noteworthy that the area of non-navigable obstacles has the least impact on the chemical cost savings of corn, and greatest impact on the chemical cost savings of soybean. Differences in per hectare chemical cost are the main reason behind this differences in impact.

The coefficients of the variable “area of navigable obstacles” are positive all the regression models which are 0.3310, 0.2251, 0.4795, and 0.3249 respectively for corn, soybean, HRSW, and canola respectively. The sign and magnitude of the coefficients indicate that change in the variable “area of navigable obstacles” and change in net chemical cost savings of the mentioned crops move in the same direction but at a different rate. That is, if the area of navigable obstacles increases by 1 hectare, the amount of net chemical cost saved for corn increases by \$0.3310, whereas the increase in net savings due to increase in the area of navigable obstacles are \$0.2251, 0.4795, and \$0.3249 for soybean, HRSW, and canola respectively. However, none of the variables is significant event at 10% confidence level. This is truly rational because navigable obstacles are those where the 120-feet boom sprayer can make parallel passes but is not supposed to plant seeds. In other words, ASC will allow the sprayer to pass through the navigable obstacles but will shut off the nozzles at the time of spraying chemicals. For this reason, the area of navigable obstacles (low-lands) was included while calculating the overlapping area of a field. As the area of navigable obstacles increases, the overlapping area that could be reduced using ASC also increases which, in turn, causes a rise in net savings. This is the reason behind the positive sign of the variable “area of navigable obstacles”.

The coefficients of the variable named “number of non- navigable obstacles” are positive for the regression model of all the four crops. The coefficient implies that an increase in the number of non-navigable obstacles such as trees, structures, non-agricultural lands and water lands raises the net seed cost savings for all the crops and vice versa. The coefficients associated with this variable are 7.1887, 7.8668, 10.8139, and 7.8797 respectively for corn, soybean, HRSW, and canola respectively. This relationship is logical if we take a closer look at the routing path of the sprayer around the non-navigable obstacles. In the presence of ASC, sprayer should take a turn when it approaches towards a non-navigable obstacle at the time of making parallel passel along the fields since ASC shuts off the nozzle when the machinery approaches an obstacle where the machine should not apply inputs. This creates overlap inside the field which can be reduced by adopting ASC. The more the number of obstacles, the more the number of turns the sprayer must take around the obstacles and thus the larger the area of overlapping. When we look at the calculation of field-wise total and percentage overlapping area (Table A1 in the appendix section) we see that fields with numerous non-navigable obstacles represent the more overlapping area in them. Since the cost savings obtained due to ASC are calculated by multiplying the area of overlap reduction with the input price of the crop, increased overlap area results in increased amount of cost savings. Therefore, as the number of overlap area increases, the net savings due to ASC also increases. From the coefficients associated with this variable, we can understand that one-unit change in the number of non-navigable obstacles changes the net cost savings obtained from corn, soybean, HRSW, and canola planting by $7.1887, $7.8668, $10.8139, and $7.8797 respectively. However, none of the coefficients are significant even at 90% confidence level.

The next variable is the number of navigable obstacles which shows a positive relationship with net savings for three of the four regression models by a positive co-efficient of 2.1514, 1.8287, 3.8513, and 2.7087 for corn, soybean, HRSW, and canola respectively. The positive coefficients of this variable denote that when the number of navigable obstacles, that is, the number of low-lands inside the field increases by one unit, the net chemical cost savings increase by $2.1514, $1.8287, $3.8513, and $2.7087 for soybean, HRSW, and canola respectively, and the opposite is also true. It is noteworthy that the net savings obtained from a field due to ASC increases along with the increase in low-lands, that is, navigable obstacles inside the field which we discussed in the previous paragraphs. As the number of navigable obstacles increases, the area of navigable obstacles also increases which, in turn, raises the net savings. As a result, we can see a positive coefficient for the variable "number of navigable obstacles".

It is interesting to note that, if we compare the impact of field parameters on net chemical cost savings obtained from installing ASC in a 120-feet sprayer with the impact of field parameters on seed cost savings which can be generated by installing ASC in a 60-feet planter, it can be observed that the impact of field parameters on net chemical cost savings is less than the impact of field parameters on net seed cost savings despite having more overlap reduction by installing ASC on the sprayer. The reason is that to calculate net savings, we not only consider the area of overlap, but also the cost of the inputs. Since the seed costs are greater than the chemical costs, changes in net seed costs savings due to field parameters were more drastic than the changes in net chemical cost savings.

It is noteworthy that we can only obtain one significant variable, P/A ratio, (at 10%) among all the field parameters to have an impact on the net chemical cost savings. This significance of the P/A ratio indicates that the field shape had the most significant impact on the net chemical cost savings. Some previous studies also supported that field shape, as measured by the P/A ration have the most profound impact on the overlap reduction due to ASC installation in a sprayer. Luck et al (2011) found that field shape had the greatest impact on the overlap reduction by an ASC-installed sprayer, and the significance of the P/A ratio was the highest in their study. Another study found that the net benefits generated from ASC are much greater for the irregularly shaped fields than the regular shaped fields (Smith et al 2013).

Nine regional dummies were added to the regression models of the four crops, corn, soybean, HRSW, and canola as intercept shifter into the regression models. These regional dummies are the ND budget regions which the sample fields and county belong to. The regional dummies were added to the regression equation to ascertain how the net savings vary across the regions. Since the input cost of chemicals is same for all the fields belonging to a region, it is necessary to estimate how the impact of field parameters on net savings differ among different regions. It is necessary to mention that, the North-Central budget region was omitted from all the four regression models to avoid collinearity. Also, for soybean regression model, South-West and North-West budget region were also omitted because soybean is not grown in these regions. For the same reason, South-Valley region was omitted for the regression model of canola chemical cost savings.

The highest positive coefficient can be seen for the regional dummy SE for three of the four regression models and the coefficients are 218.1942, 249.8523, and 272.3295 for corn, soybean, and HRSW respectively which indicates that the highest net chemical cost savings due to ASC can be obtained in the South-East region of ND budget region for corn, soybean, and HRSW. However, for canola regression model, we find the highest coefficient in the regional dummy SW, which denotes that the highest net chemical cost savings of canola can be found in the Southwest region and the field parameters have the highest impact on the variance in the dependent variable “net savings”. A negative coefficient can be found in the North-Valley region (denoted as NV in the regression) for each of the corn, HRSW, and canola regression models. These negative coefficients associated with the regional dummy NV denote that the net chemical cost savings will be the lowest in the North-Valley region for corn, HRSW, and canola. However, for soybean, we can find a positive coefficient value for the regional dummy, NV, though the coefficient is the lowest among the other regional dummies in soybean regression model. However, we did not get any significance any of the coefficients associated with the regional dummies of SE or NV in any of the regression models even at 10% level of significance. A higher positive coefficient of a regional dummy indicates the higher value of net savings in that region due to the changes in field parameters. For instance, in corn regression model, the regional dummy SW has higher positive coefficient value than NW, SC, SV, NE, EC, and NV and less than SE. Therefore, the changes in net savings are more in the Southwest region than the Northwest, South-Central, South-Valley, Northeast, East-Central, and North-Valley regions and less net chemical cost savings than in the Southeast region. For Soybean, the changes in net chemical cost savings due to changes in field parameters are more in the Northeast region than all other budget regions except for the Southeast region. This is the reason why we observe the highest positive coefficient in the variable SE (249.8523), and a higher positive coefficient in the variable Northeast region (162.1591) than in the other regions. The same phenomena are observed in the other two regressions for HRSW and canola.

4.9. Marginal Effects of Field Parameters on Net Chemical Cost Savings

The marginal effects of a unique field parameter on the net chemical cost savings generated from each field are determined by differentiating the regression equation with respect to that field parameter. More precisely, the marginal effect of field area on net chemical cost savings for corn is determined by,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = \frac{\partial}{\partial Area}(-191.7015) + \frac{\partial}{\partial Area}(-0.3668 Area) + \frac{\partial}{\partial Area}\left(1.7746 * \frac{Perimeter}{Area}\right) + \frac{\partial}{\partial Area}(\text{-1.1360*Area of Non-Navigable Obstacles}) + \frac{\partial}{\partial Area}(0.3310 * Area\ of\ Navigable\ Obstacles) + \frac{\partial}{\partial Area}(7.1887 * No. of\ Non-Navigable\ Obstacles) + \frac{\partial}{\partial area}(2.1514 * No. of\ Navigable\ Obstacles) \quad (4.10)$$

Therefore, the marginal effect of field area on corn net chemical cost savings becomes,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = -0.3668 - 1.7746 * Perimeter * Area^{-2} \quad (4.11)$$

Similarly, the marginal effect of field perimeter on net savings becomes,

$$\frac{\partial Net\ Savings}{\partial Field\ Perimeter} = \frac{1.7746}{Area} \quad (4.12)$$

Following the differentiation method in equation (1), the marginal effect of field area on soybean seed cost savings is,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = -0.3761 - 1.5146 * Perimeter * Area^{-2} \quad (4.13)$$

And the marginal effect of field perimeter on net soybean seed cost savings be,

$$\frac{\partial Net\ Savings}{\partial Field\ Perimeter} = \frac{1.5146}{Area} \quad (4.14)$$

The marginal effect of field area on net HRSW cost savings is given by,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = 0.1507 - 2.7458 * Perimeter * Area^{-2} \quad (4.15)$$

And the marginal effect of field perimeter on net HRSW Chemical cost savings be,

$$\frac{\partial Net\ Savings}{\partial Field\ Perimeter} = \frac{2.7458}{Area} \tag{4.16}$$

The marginal effect of field area on net canola Chemical cost savings is given by,

$$\frac{\partial Net\ Savings}{\partial Field\ Area} = -0.2967 - 1.6789 * Perimeter * Area^{-2} \tag{4.17}$$

And the marginal effect of field perimeter on net canola chemical cost savings is given by,

$$\frac{\partial Net\ Savings}{\partial Field\ Perimeter} = \frac{1.6789}{Area} \tag{4.18}$$

It is noteworthy that marginal effects of the other field parameters will be the coefficients associated with them. Since in the regression equation the only interactive variable is the P/A ratio which involves two field parameters, field area, and field perimeter, the marginal effects of these two parameters with net savings will be different from the coefficients associated with them. These marginal effects are calculated for each of the 105 sample corn fields and are averaged to find out a single effect. The averaged marginal effects of all the field parameters on the net savings of four crops are presented in the following table and are discussed in the following paragraphs:

Table 16. Average Marginal Effects of Field Parameters on Net Savings

Average Marginal Effects	Net Chemical Cost Savings			
	Corn	Soybean	HRSW	Canola
Field Area	-1.032	-0.954	-0.879	-0.954
Field Perimeter	0.009	0.008	0.015	0.009
Area of Non-Navigable Obstacles	-1.136	-1.920	-1.367	0.134
Area of Navigable Obstacles	0.331	0.225	0.479	0.325
No. of Non-Navigable Obstacles	7.189	7.867	10.814	7.879
No. of Navigable Obstacles	2.151	1.829	3.851	2.709

The marginal effects of field area on the net savings of the four crops denote that when the area of the field changes by 1 hectare, the net chemical cost savings inversely changes by \$1.0323, \$0.9536, \$0.8790, and \$0.9536 for corn, soybean, HRSW, and canola respectively. These marginal effects are quite different from the effects of the field area on the net savings which we obtained from the regression models. It is interesting to note that for HRSW regression model, we did not get the expected sign for the coefficient of the variable field area. Previous studies and researches tell us that field area has a negative impact on the net savings, that is, more savings can be generated due to ASC if the field area is small and vice versa. Therefore, there should be a negative coefficient along with the variable field area. In other words, the impact of field area on net savings should be negative which we could not achieve in HRSW regression. Rather, the variable showed a positive coefficient. However, when we calculated the marginal effect of field area on net savings we see that in case of all the four crops, we could achieve expected signs for the effect of field area on net savings which is commensurate with the findings of previous studies such as Luck et al (2010), Smith et al (2013) and Shockley et al (2012) which also found an inverse relationship between field area and net input cost savings due to ASC. The marginal impact of field perimeter on the sample 105 fields in our study is positive in all the regression models and the values are 0.0096, 0.0081, 0.0149, and 0.0098 respectively for corn, soybean, HRSW and canola which indicate that a 1-meter increase in field perimeter increases the net savings by \$0.0096, \$0.0081, \$0.0149, and \$0.0098 respectively for corn, soybean, HRSW and canola and the opposite is also true. In the regression analysis, we have already shown that the P/A ratio is the measure of the irregularity in the field shape and as the P/A ratio increases, the net savings generated from the fields also increases. The P/A ratio is obtained by dividing the perimeter of a field by its area. Since the numerator in the ratio is the perimeter of the field, therefore, the marginal impact of field parameter on the net savings should be positive. For the other field parameters, the marginal effects are the same as the coefficients of the variables as we obtained from the regression equations. Since we already discussed their impact, the discussion about the marginal effects of the variables other than the field area and field perimeter are skipped from this section.

The marginal effects of all the field parameters are shown by drawing Scatter plots taking the field parameters in the X-axis and the net savings of the fields on Y-axis. The scatter plots of each field parameter on the net seed cost savings of corn, soybean, HRSW, and canola are shown in the following figures:

4.9.1. Marginal Effects of Field Parameters on Net Chemical Cost Savings- Corn

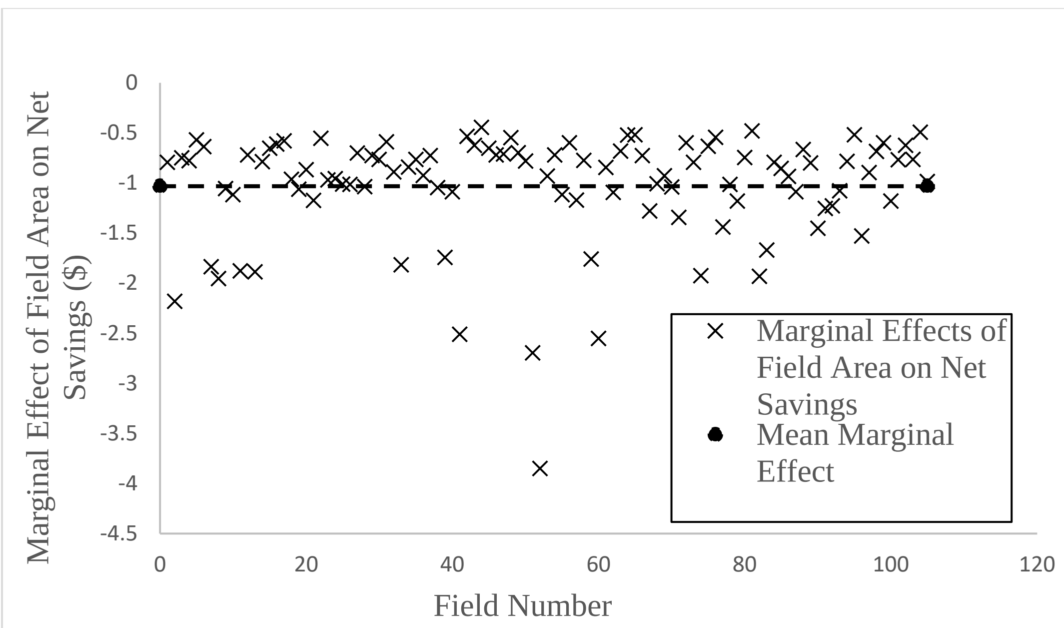

Figure 21. Scatter Plot of Marginal Effects of Field Area on Net Chemical Cost Savings (Corn)

The above scatter plot shows the field-wise marginal effect of field Area on net chemical cost savings of corn. The mean marginal effect is showed by a straight line which occurs at a point near -1. This line implies that when the field area increases by 1meter, the net seed cost savings of soybean decreases by $0.015 on an average, where the marginal effects vary between -4 to a point between -0.5 and 0 indicating that 1-meter increase in the field area reduces the net chemical cost savings of corn between value less than 50 cents to a value of about $4. Here, we can see that in most of the fields, the marginal changes in net savings due to the changes in field size cluster around the mean.

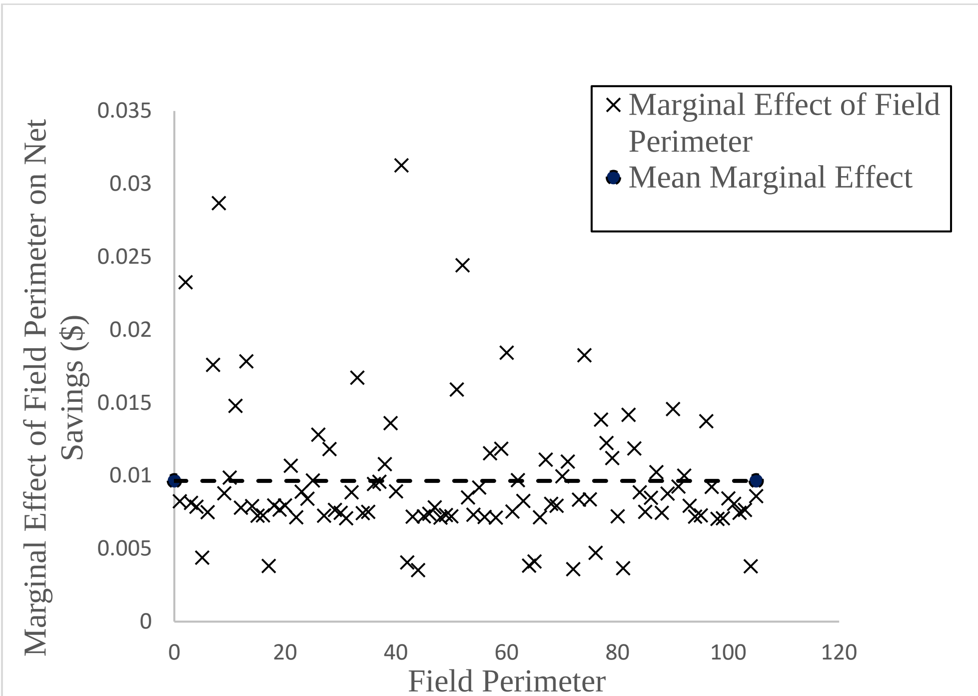

Figure 22. Scatter Plot of Marginal Effects of Field Perimeter on Net Chemical Cost Savings (Corn)

From the above scatter plot, we can see that there is a positive relationship between field perimeter and net chemical cost savings of corn. As the perimeter of a field increases by one meter, the net seed cost savings increases between 0 to 0.035 where most of the changes occur between the points 0 and 0.01. From the figure, it is evident that the mean marginal effect of field shape on net chemical cost savings of corn occurs at a point very close to 0.01. From table 16 we can see that the actual value of the mean change in net chemical cost savings of corn due to change in field shape is $0.009, which implies that when the field perimeter increases by 1 meter, the net seed cost savings goes upward by $0.009 or about 1 cent. The highest marginal change in net savings occurs at more than 0.031, which means that 1-meter change in field perimeter changes the net savings by maximum 3 cents. This highest change can be observed in field number 41 of Burleigh county. This field has a very small field area of only 56.76 ha and is highly irregular in shape as expressed by a high p/a ratio of 68.60.

4.9.2. Marginal Effects of Field Parameters on Net Chemical Cost Savings (Soybean)

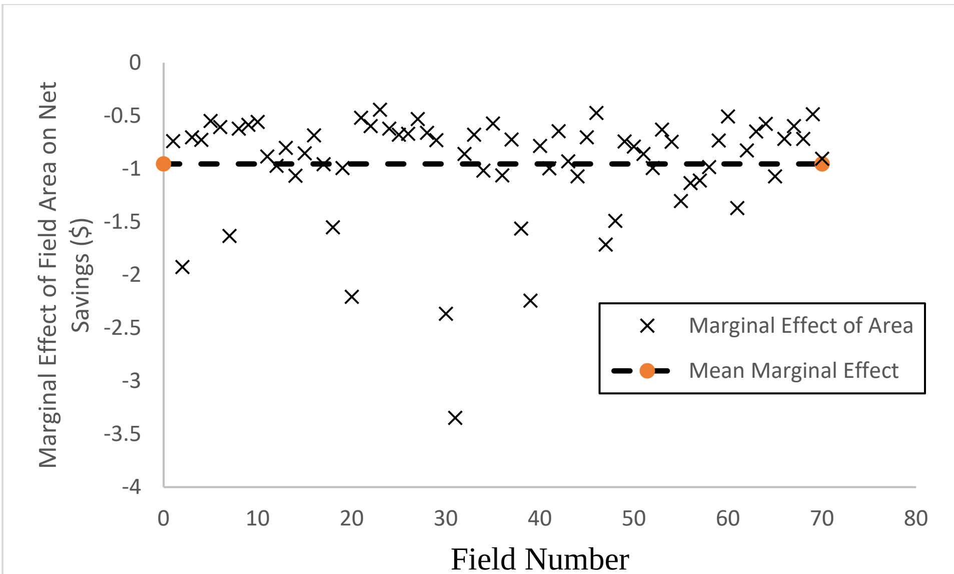

Figure 23. Scatter Plot of Marginal Effects of Field Area on Net Chemical Cost Savings (Soybean)

Field wise marginal effects of the field size on the soybean chemical cost savings are presented in the above scatter plot where the fields are presented in the X-axis and the marginal effects of field area on net savings are presented on Y-axis. From the above scatter plot we can see that field area has an inverse marginal effect on net soybean chemical cost savings, that is, when the field area increases by 1 hectare, the net chemical cost costs savings of soybean decrease by $0.95 or about $1 on an average. These changes in net chemical cost savings vary between -3.5 to 0. From the scatter plot we can see that most of the changes in net savings occur between -1 to -0.5, where the highest marginal effect is about -3.7, which occurs in a field between field number 31.

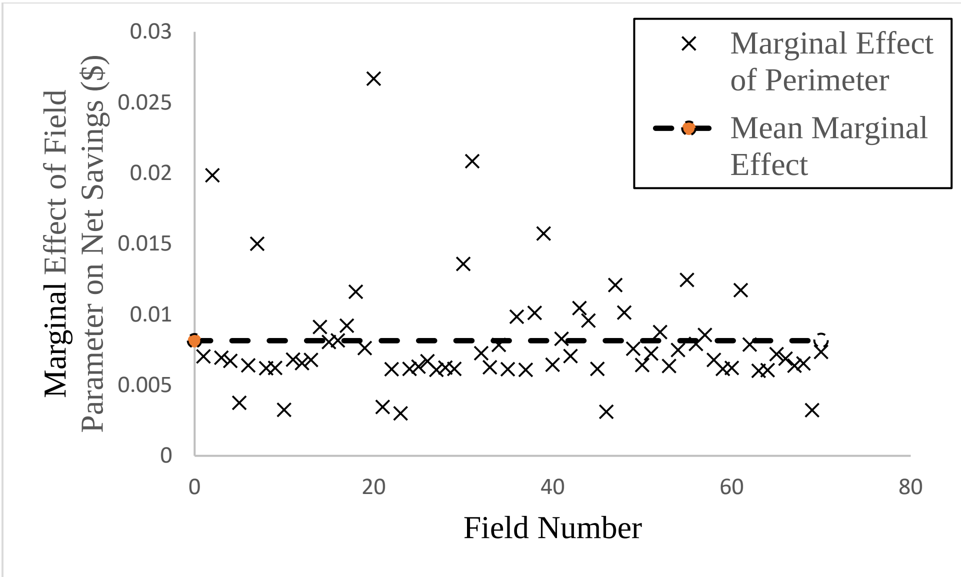

Figure 24. Scatter Plot of Marginal Effects of Field Perimeter on Net Chemical Cost Savings (Soybean)

The above scatter plot depicts a positive relationship between field perimeter and net chemical cost savings of soybean. We can see from figure 21 that as the perimeter of a field increases by one meter, the net seed cost savings increases between $0.002 to $0.018 where most of the changes occur around the mean, that is, a value between 0.004 to 0.006. From table 9 we know that this value is 0.0054 which means that a 1-meter change in the perimeter of the field changes the seed cost savings by $0.0054 and vice versa on average. The highest marginal change in net savings is 0.026 which could be seen in a field number 20 of Burleigh county.

4.9.3. Marginal Effects of Field Parameters on Net Chemical Cost Savings (HRSW)

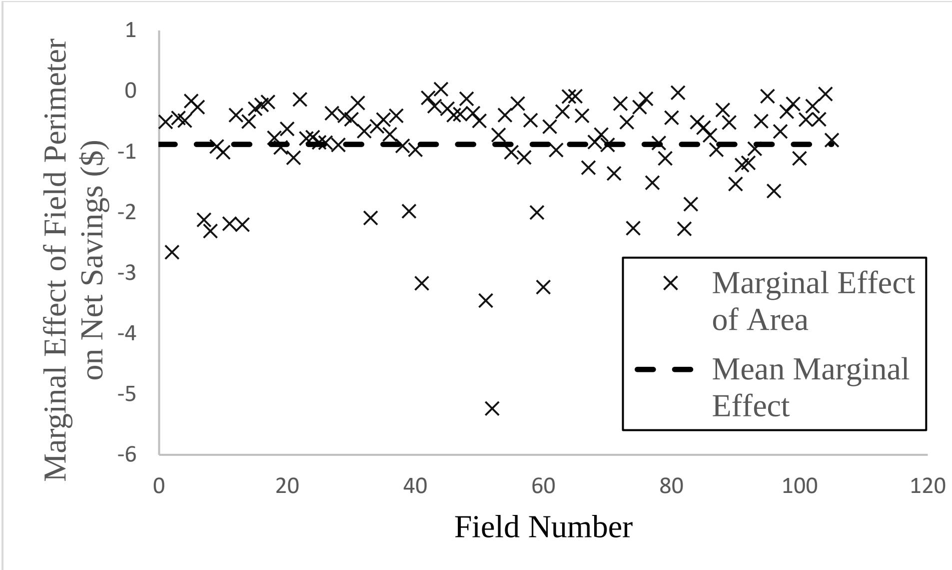

Figure 25. Scatter Plot of Marginal Effects of Field Area on Net Chemical Cost Savings (HRSW)

The field wise marginal effect of the field size (as measured by area in hectare) are presented in the above figure. From the scatter plot it is evident that on an average, with one hectare increase in the field area, net HRSW chemical cost savings decreases by a dollar value which falls between -5.5 and about 1. More specifically, with one hectare increase in the field area, the net HRSW chemical cost savings decreases by $0.88 on average (From table 16). We can also see from the scatter plot that for most of the fields, this decrease in net cost savings due to one hectare increase in field size is close to the mean. It is also observed that highest decrease in net savings due to one hectare increase in field size (a value close to -5.5) occurs in a field between field number 40 and 60, which means that field size within this interval in relatively low. It is also noteworthy that though we find some positive changes in net savings due to change in field size, which is contradictory to previous studies, the average marginal change in net savings due to change in field size is negative (-0.88), which is commensurate with the concept of negative relationship between change in field area and net savings as established in previous studies and the assumptions of this study.

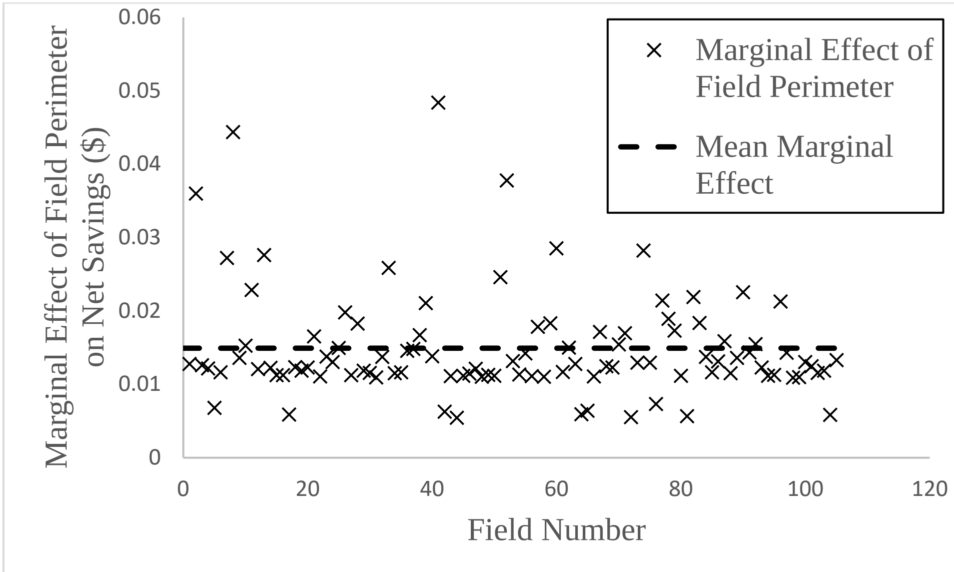

Figure 26. Scatter Plot of Marginal Effects of Field Perimeter on Net Chemical Cost Savings (HRSW)

The above scatter plot depicts a positive relationship between field perimeter and net chemical cost savings of HRSW. We can see from figure 23 that as the perimeter of a field increases by one meter, the net chemical cost savings increases between half a cent and about 5 cents where most of the changes occur around the mean, that is, about 1.5 cents. From table 16 we know that this value is 0.015 which means that a 1-meter increase in the perimeter of the field increases the chemical cost savings by 1.5 cents on average and vice versa.

4.9.4. Marginal Effects of Field Parameters on Net Chemical Cost Savings (Canola)

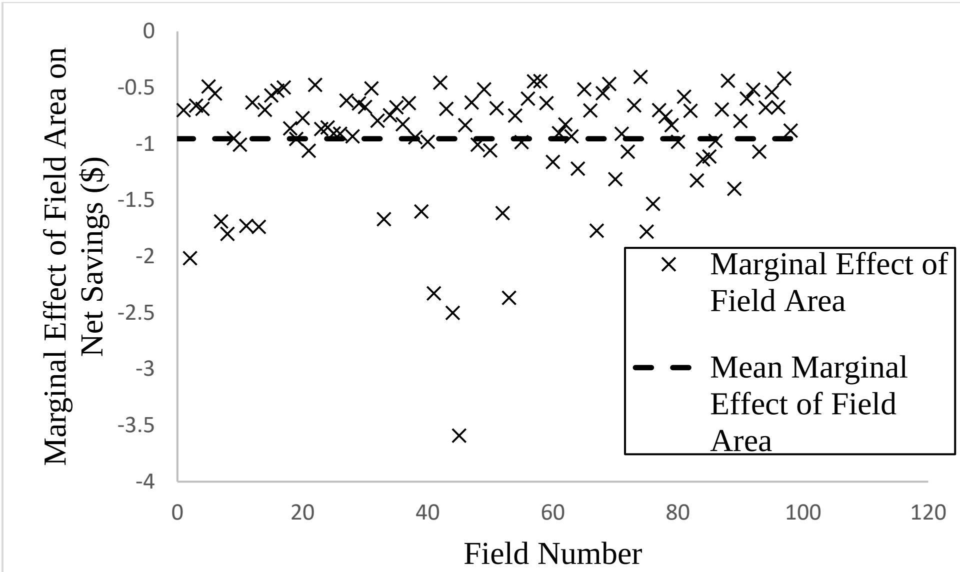

Figure 27. Scatter Plot of Marginal Effects of Field Area on Net Chemical Cost Savings (Canola)

The above figure represents the marginal effect of field size on net chemical cost savings of canola. Field number is represented in X-axis and marginal effect of field sizes on the Y-axis. From the figure, we see that the mean marginal effect occurs between -1 and -0.5. The mean marginal effect of field size on canola chemical cost savings is -0.95. The negative sign of the marginal effect of field size on net chemical cost savings of canola implies that there is an inverse relationship between field size and net chemical cost savings. The magnitude of the marginal effect indicates that when the field area increases by 1 hectare, the net chemical cost savings decrease by $0.95. In most of the fields, the net cost savings due to the unit change in field area are close to the mean value and fall between -1 to -0.5, where the highest marginal change occurs in a field with a high p/a ratio and small land area (field number 41) in Burleigh county.

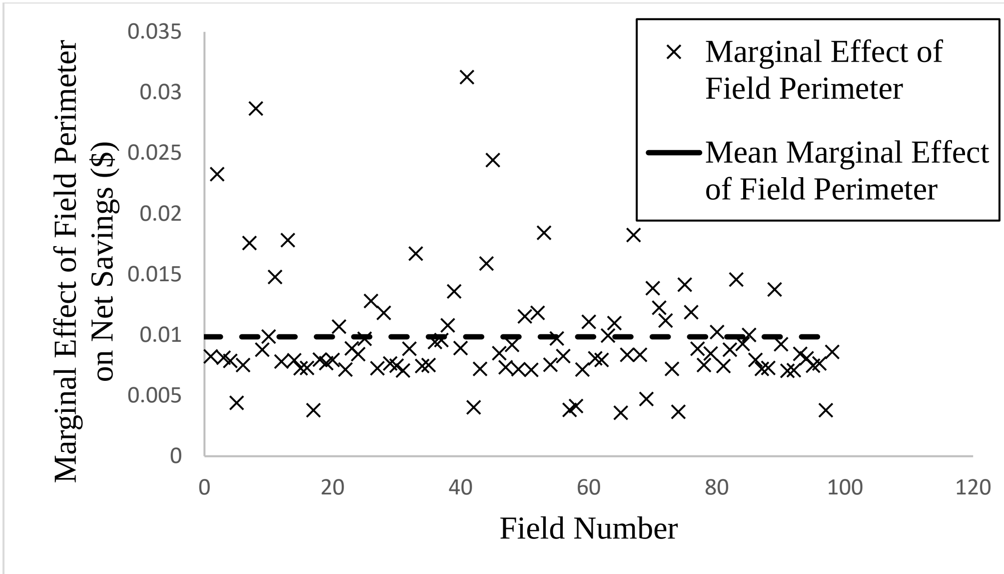

Figure 28. Scatter Plot of Marginal Effects of Field Perimeter on Net Chemical Cost Savings (Canola)

In figure 25, the positive figures in the Y-axis, that is, the values of the marginal effect of field perimeter on net chemical cost savings indicate that there is a positive relationship between the field perimeter and net chemical cost savings of canola. The mean marginal effect occurs at 0.01 which means that on an average, 1-meter increase in the field perimeter escalates the net chemical cost savings of canola by 1cent.

CHAPTER 5. CONCLUSION

5.1. General Discussion

In the previous studies, researchers focused on finding the reduction in the area and percentage of overlapping in the field due to adoption of ASC along with the existing machinery. The current study not only found the overlap area and percentage of overlap that can be reduced by adopting a 60 feet wide planter with 24 sections controlled automatically and a 120 feet wide boom sprayer with individual nozzle control, but also found out how much input costs a farm can save by adopting ASC. Additionally, this study successfully estimated the impact of the field parameters such as number and area of navigable and non-navigable obstacles inside the fields, field size and shape on the input cost savings and how the net savings of a farm due to ASC varies across the nine ND crop budget regions. A sensitivity analysis was also conducted to capture the effect of input price changes on the changes in net input cost savings. The current study is also unique in the sense that where the previous studies such as Shockley et al (2012), Smith et al (2013) and others considered the payback period as a decision-making tool to invest in ASC, this study promptly used the Net Present Value analysis to identify the input cost savings that investment in ASC can generate over its useful life.

In this study, a map-based model was developed in ArcGIS to simulate the routing path of a 60-foot planter and a 120-foot sprayer along the 105 field sample fields in 15 counties of the Prairie Pothole Region of North Dakota. Using the "calculate geometry" feature of ArcGIS, this study calculated the intersections and overlapping area that occurs inside the fields when the planter and the sprayer make parallel passes across the fields and takes turns along the headlands and around the non-navigable obstacles such as trees, structures, water bodies, and non-agricultural lands. Besides, for the first time, this study considered including the area of navigable obstacles (low-lands) while calculating the area where farmers tend to over apply seeds and chemicals. This is a rational approach because, in the presence of ASC, the planter and the sprayer are supposed to pass through the low-lands but will not apply seeds or chemical since ASC will shut the sections of the planter and the nozzles of the sprayer when it will approach the low-lands.

Following the above procedures, this study found that ASC can reduce overlap ranging from 3.25 ha to 95.58 ha depending on field size, shape, and the number and area of navigable and non-navigable obstacles that the field contains when the machine width is 60 feet, while an increased area of overlap reduction ranging from 6.68 to 177.57 ha can be observed as the machine width increased up to 120 feet. This relationship between the machine width and overlap reduction found in the current study is consistent with previous studies where the researchers found that ASC can generate more reduction in overlap when the machine width increases (Shockley et al, 2012). The percentage reduction in overlap area was found to be 2.73% to 25.73% for a 60-feet planter is used. For a 120-feet wide sprayer, the percentage reduction in overlap was found to be 4.18% to 45.37% which are different from what the other researches such as Luck et al (2010), Velandia et al (2010), and Jernigan et al (2011). The average overlap reduction was found to be 17.73 acres (8.44% of the total arable land) for the 60-feet wide planter, and 26.54 ha (12.89% of the total arable land) when the 120-feet sprayer is used. This reduction in overlap area can reduce the seed cost by \$0.86, \$0.34, -\$1.24, and \$0.20 per hectare on average for corn, soybean, HRSW, and canola respectively after deducting the cost of adopting ASC.

It should be noted that the net seed cost savings are the highest for corn. This finding is important to the farmers since according to Swenson, the highest return to management and labor can be obtained from corn production (NDSU Extension Service). Besides, ASC can reduce the chemical costs of corn, soybean, HRSW, and canola by -\$0.09/ha, \$0.03/ha, \$0.61/ha, and -\$0.02/ha on average after deducting the cost of investment. It is noteworthy that though the overlap reduction is more for the 120-feet sprayer, the 60-feet planter could generate more net savings for all the crops except HRSW. There are two reasons for this seemingly counterintuitive situation. Firstly, the prices of seeds and chemicals are multiplied with the reduction in overlap generated by the 60-feet planter and the 120-feet sprayer to calculate the savings in seed costs due to ASC. Since the seed costs of corn, soybean, and canola are less than the chemical costs of these crops, we see fewer cost savings for chemicals than the seed cost savings for these three crops. Secondly, the cost of investing in the planter and the sprayer was deducted from that amount of total savings to calculate the net savings. Since the cost of acquisition of the 120-feet sprayer is greater than that of the 60-feet planter, the net seed cost savings were greater than the chemical costs of corn, soybean, and canola. However, for HRSW, a different situation was observed. The seed cost saving for HRSW came negative, where the chemical cost savings per hectare was positive. This happened because the seed cost of HRSW is less than the chemical costs. These findings of this study establish a very important relationship between the cost of inputs and the benefits generated by ASC. When the prices of inputs are greater, the benefits or net cost savings due to ASC are also greater.

Besides calculating the total and net cost savings, the current study also focused on the net benefits generated by adopting ASC considering a crop-mix scenario. Considering a crop-mix scenario taking the input cost of all the four crops and their land-use weight together produces a different result for net seed and chemical cost savings as we obtained when the crops were considered individually. Results of this study show that when the crop-mix scenario was considered, net seed cost savings was negative (-\$0.19/ha). The reason of this negative savings for seed cost in a crop-mix scenario is that, the highly negative values of net seed cost savings of HRSW offset the positive net seed cost savings for the other three crops corn, soybean, and canola. These findings point out a potentially beneficial crop-mix for the farms in the North Dakota Prairie Pothole region. If the farmers consider a crop-mix of corn, soybean, and canola, the benefits generated from ASC will be higher since the net cost savings for all these three crops are positive. However, we found a positive net chemical cost savings of \$0.25/ha on an average when a crop-mix scenario is considered.

The total savings that were generated by installing ASC on a 60-foot planter and a 120-foot sprayer were further used as the present values of the investment for 8 years, that is, the useful life of the machine and the Net Present Values (NPV) of the investment in the ASC installation in both the 60-feet planter and a 120-feet sprayer were calculated for each of the 105 fields considering the discount factor as 8% (the opportunity cost of the investment). Results obtained from the NPV analysis show that farms in the ND Prairie Pothole Region will be benefitted by adopting ASC in farming operation since the average NPV that a farm can obtain in this region is \$1433.99 while investing in a 60-feet 24-row planter with ASC and \$1,463.91 while investing in a 120-feet boom sprayer with ASC. Therefore, findings from this study suggest that in the long run, ASC will prove beneficial in both seed and chemical application in the production of the four crops, corn, soybean, HRSW, and canola though in the initial stage the investment may not seem attractive for some crops (for instance, seed cost of HRSW, and chemical costs of corn and canola produced negative results while ASC adoption was considered).

A “what if” situation was considered by conducting a sensitivity analysis, where the changes in the net cost savings for all the four crops generated due to ASC were observed. This observation is important because according to Swenson (2013), the seed costs of corn and soybean are supposed to increase by 5-10%, while there will be a moderate change in the seed price of canola and the seed price of spring wheat is supposed to fall in near future. On the other hand, chemical costs of the crops are supposed to increase by and 20% due to the increased price of the herbicide such as glyphosate and phenoxy (Swenson, 2013). To capture these fluctuations in seed and chemical prices, the input prices were varied between +/-10%. Results from the sensitivity analysis showed that on an average, a 10% increase or decrease in seed price will increase or decrease the seed cost savings by $54.32 for corn, $44.59 for soybean, 10.53 for HRSW, and 40.25 for canola. In other words, a 10% increase or decrease in seed price will bring a change of 34.21% for corn, 121.26% for soybean, 3.77% for HRSW, and 153.67% for canola. The sensitivity analysis shows that farmers will be in an advantageous position by adopting ASC in crop production when the seed price increases since in this situation, farmers in the ND Prairie Pothole region will incur more net seed cost savings by reducing overlap area in the fields by adopting ASC. This analysis also shows that fluctuations in seed price will have the greatest impact on the net seed cost savings of canola, where we observe that a small 10% change in the seed price brings a 153.67% change in the net canola seed cost savings. The chemical price was also varied between +/- 10% to capture the chemical price changes effects on net chemical cost savings which can be obtained by installing ASC in a 120-feet boom sprayer with individual nozzle control. Results show that at existing price, farms do not expect to be in a profitable position by adopting ASC to spray chemicals in the fields since the net chemical cost savings show a negative figure for corn, soybean, and canola. This scenario changed when the chemical price increases by 10%, since the net savings show a positive value when the chemical price increase by 10%. This positive value in net cost savings due to a 10% increase in chemical price for corn, soybean, and canola implies that when the price of chemical increases, the cost savings that can be obtained due to ASC for these three crops can outweigh the cost of adopting the technology, and thus can bring substantial financial benefits for the farmers. For HRSW, we can see positive net savings, that is, chemical cost savings due to ASC greater than the investment cost. When the price of chemical falls by 10%, the net savings for HRSW still remains large enough to cover the investment cost of ASC and with a 10% increase in chemical price, this financial benefit of ASC to farms in the form of net savings increases by 143.66%. In a nutshell, the sensitivity analysis tells us that when the price of seeds and chemical increase, farms in the North Dakota Prairie Pothole Region can expect a substantial financial benefit in the form of seed and chemical cost savings. On the other hand, when the price of input falls, farms can still save some cost by the overlap reduction and by avoiding double application of inputs due to ASC, but that saving is too small to outweigh the huge cost of investing in ASC.

One unique approach that makes this study different from the previous studies is that, while other studies concentrated on finding the impact of field characteristics on overlap reduction and reduction in the application error of inputs in the field, this study directly estimates the impact of field parameters such as field size, shape, and the number and area of navigable and non-navigable obstacles inside the fields on net input cost savings that the farmers incur due to the adaption of ASC by developing and estimating an econometric model. Besides, this study also attempts to estimate the fixed effects imposed on the changes in net input cost savings by the difference in input price in 9 different budget regions of North Dakota. Results obtained from the empirical analysis suggest that when ASC installation on a 60-feet 24 sections-controlled planter is considered, field size has significant negative and field shape has a significant positive impact on net seed cost savings of corn and HRSW. However, for soybean and canola, the only field parameter that has a significant impact on net seed cost savings is the P/A ratio, which is a measure of the irregularity in field shape. On the other hand, when the impacts of field parameters on net chemical cost savings are considered, the only field parameter that has a significant impact on the net cost savings is the field shape. It is to be mentioned here that previous studies such as Luck et al (2011) and Craig et al (2013) found the impact of field shape to be greatest in reducing overlapping area inside the fields. Whereas, other studies such as Shockley et al (2012) and Velandia et al (2010) found the impact of both the field size and shape on the reduction in overlapping area to be significant. All these studies show that relationship between the field shape and reduction in overlap reduction due to ASC is positive, and the relationship between field size and reduction in overlap area is negative. This relationship indicates that farmers can obtain greater financial benefits in the form of input cost savings due to ASC in the fields which are small in size and more irregular in shape. This relationship is also established in our study. The only difference is that a new dimension to the relationship is added. Instead of considering the relationship between the field parameters and the reduction in overlapping area, our study attributed the field parameters to the net input cost savings and established a positive and significant relationship between field shape and net cost savings, and a negative relationship between field size and net input cost savings. This study also estimated that an increase in the number and area of navigable obstacles and the number of non-navigable obstacles inside the fields increase the net savings due ASC in those fields, where the area of non-navigable obstacles decreases the net cost savings. However, the impact of these variables on net savings is not significant. Therefore, we can say that among all the field parameters, field shape has a positive and significant impact on the net chemical cost savings, and for seed cost savings of corn and HRSW, the impact of both field size and field shape is significant.

5.2. Recommendations

Calculations of net seed and chemical cost savings presented in table A2 and A3 in the appendix section of this study show that, on an average, farms in the North Dakota Prairie Pothole Region can save \$2.60, \$2.20, \$0.50, and \$1.94 per hectare for corn, soybean, HRSW, and canola respectively. However, after deducting the cost of investing in the installation of ASC on a 60-feet planter, the average net seed cost savings amounted to \$0.86/ha for corn, \$0.34/ha for soybean, -\$1.24/ha for HRSW, and \$0.20/ha for canola. The positive net seed cost savings for corn, soybean, and canola indicates that farms in the North Dakota Prairied Pothole Region can expect financial benefits due to ASC since the seed cost savings generated by ASC for these three crops are substantial to cover the investment cost. Therefore, for corn, soybean, and canola seed plantation, farms can consider investing in installing ASC in a 60-feet 24-row crop planter. Whereas for HRSW, initially, it does not seem beneficial for the farms to invest in ASC while considering adoption of ASC in HRSW seed planting. However, the NPV analysis shows that ASC can generate positive cost savings for the farm if the machinery is used up to its whole useful life.

Farms will face a different decision-making scenario while planning to invest in the ASC installation in a 120-feet boom sprayer which is used to spray chemicals into the fields. Results suggest that though the farms can save some chemical costs for all the four crops due to the overlap reduction by adopting ASC, for corn and canola, this savings is not enough to outweigh the investment cost of installation of ASC. However, for soybean and HRSW, this chemical cost savings due to ASC is substantial to outweigh the cost of investing in ASC. Therefore, farmers in the Prairie Pothole Region should decide to invest in ASC while spraying chemical if they are considering a crop-mix scenario of soybean and HRSW. The seed cost savings proved to be more than the chemical cost savings though more overlapping area can be reduced by a 120-feet sprayer than a 60-feet planter since the seed costs for the crops are more than the chemical costs except for HRSW.

From the calculation of overlap reduction in the fields due to ASC installation in both the planter and the sprayer, we can see that field parameters have a profound impact on the cost savings generated from each field. Especially, field size and shape have the greatest impact among all. These impacts of field parameters were estimated by developing econometric models, results obtained from which show that field shape has the most significant positive impact on net input cost savings. The positive significant impact of field shape and negative significant impact of field area on corn and HRSW net seed cost savings show that farmers should consider field size and shape while taking a managerial decision regarding the adoption of ASC in corn and HRSW seed planting. When the field size is small and field shape is more irregular in shape, farms can expect to save a fairly enough seed cost if they decide to install ASC on a 60-feet wide planter. However, for seed cost savings of soybean and canola, the only significant impact we can see on the net seed cost savings is the field shape, or the perimeter to area ratio, which means that farms can expect higher cost savings for the more irregularly shaped fields rather than rectangular shaped fields. Therefore, farms that own numerous irregular shaped fields can be recommended to invest in ASC for a 60-feet planter. For the 120-feet boom sprayer, the impact of field shape is positive and significant for corn, HRSW, and canola. Therefore, farms can consider investing in ASC for spraying chemical in those fields which are irregular in shape. However, for soybean chemical cost savings, the impact of field shape is also positive, but it is not significant. Therefore, we cannot provide any recommendation for the farms regarding the adoption of ASC based on an insignificant impact of a field parameter. It is noteworthy that the number of observations for soybean regression is less than the regressions of the other three crops. Probably a significant impact of field shape on net chemical cost savings for soybean can be achieved by increasing the number of observations, that is, estimating the econometric model with more number of observations or field maps.

This study can be further extended in several directions. For instance, this study calculated the net cost savings due to ASC considering the crops individually and considering all the four crops together in the crop-mix scenario. But it should be noted that for some crops the net cost savings due to ASC is positive, and for some crops it is negative. Therefore, some studies can be conducted taking two or three crops generating a positive net seed cost savings in a crop-mix and see how the net savings due to ASC changes. For simulating the parallel passes of the 60-feet planter and the 120-feet sprayer, it is assumed that the planter or the sprayer moves either in the North-South or the East-West direction depending on the field shape. For example, in a field which is extended in a horizontal way, the ASC-installed machinery makes horizontal passes, and for a field which extends to a vertical way, the parallel passes of the planer and the sprayer are vertical. It can be observed by conducting a study that which routing path of the machinery reduces the overlapping area most.

This study is successful to calculate the overlap reduction and the dollar and percentage input cost savings for corn, soybean, HRSW, and canola in the selected 105 fields of the North Dakota Prairie Pothole region when ASC is installed in a 60-feet wide planter and a 120-feet wide boom sprayer. These findings are supposed to assist the farmers in the ND Prairie Pothole Region to take important investment decisions. The econometric model developed in this study succeeded to estimate the sign and magnitude of the impacts of field parameters such as field size and shape on net input cost savings due to ASC for the first time. This model will help farmers to make a field-wise comparison regarding the adoption of ASC in the production process.

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APPENDIX

Table A1. Field-Wise Total and Percentage Overlap Reduction

County	Field	Area	P/A Ratio	Area of Navigable Obstacles	Area of Non-Navigable Obstacles	No. of Navigable Obstacles	No. of Non-Navigable Obstacles	Reduction in Overlapping Area (ha)		Percentage Reduction in Overlapping (%)	
								60-Feet Planter	120-Feet Sprayer	60-Feet Planter	120-Feet Sprayer
Barnes	1.	215.21	51.71	11.51	0	2	0	21.12	30.63	9.82	14.23
Barnes	2.	76.30	78.04	0.65	4.64	2	2	9.59	11.64	12.56	15.26
Barnes	3.	218.13	47.19	6.45	6.17	1	6	15.42	31.73	7.07	14.55
Barnes	4.	225.39	52.42	9.28	0	6	0	11.42	29.95	5.06	13.29
Barnes	5.	404.22	46.42	0	6.43	0	6	26.77	47.44	6.62	11.74
Barnes	6.	236.33	35.88	1.69	0	2	0	9.71	17.45	4.10	7.39
Barnes	7.	100.89	83.61	1.29	5.79	1	1	10.81	15.53	10.72	15.39
Dicky	8.	153.92	69.70	6.29	0.82	1	0	15.25	19.84	9.91	12.89
Dicky	9.	248.98	57.10	17.30	0	2	0	28.23	33.47	11.34	13.44
Dicky	10.	149.93	117.60	9.43	0	36	0	18.88	26.13	12.60	17.43
Dicky	11.	96.28	118.65	1.09	0	1	0	8.87	12.71	9.21	13.20
Dicky	12.	235.33	63.25	37.87	0	1	0	45.87	177.57	19.49	75.45
Dicky	13.	182.96	74.95	11.95	0	3	2	21.90	23.83	11.97	13.02
Dicky	14.	214.71	38.33	0	1.95	0	0	7.95	14.41	3.70	6.71
Billings	15.	61.86	55.39	0	0	0	0	3.25	17.91	5.26	28.95
Billings	16.	201.89	78.43	1.49	0	1	0	11.66	11.66	5.77	5.77
Billings	17.	179.92	76.07	0	0.93	0	1	14.87	19.65	8.27	10.92
Billings	18.	120.07	102.28	0	0	0	0	11.20	54.47	9.33	45.37
Billings	19.	227.41	45.35	9.94	0	1	0	17.73	25.83	7.80	11.36
Billings	20.	99.50	85.28	0	0	0	0	9.21	12.21	9.25	12.27
Billings	21.	224.09	53.29	0	0	0	0	13.44	17.10	5.99	7.63
Bowman	22.	248.16	26.28	0	0	0	0	6.92	10.99	2.79	4.43
Bowman	23.	199.52	67.93	29.11	0	4	0	37.47	33.56	18.78	16.82

Table A1. Field-Wise Total and Percentage Overlap Reduction (Continued)

County	Field	Area	P/A Ratio	Area of Navigable Obstacles	Area of Non-Navigable Obstacles	No. of Navigable Obstacles	No. of Non-Navigable Obstacles	Reduction in Overlapping Area (ha)		Percentage Reduction in Overlapping (%)	
								60-Feet Planter	120-Feet Sprayer	60-Feet Planter	120-Feet Sprayer
Bowman	24.	210.89	70.01	0	2.66	0	2	15.40	23.63	7.30	11.20
Bowman	25.	183.44	66.57	0	0	0	0	11.63	19.13	6.34	10.43
Bowman	26.	138.62	50.59	0	0	0	0	8.23	10.35	5.94	7.46
Bowman	27.	244.42	46.06	0	0.73	0	1	10.05	15.41	4.11	6.30
Bowman	28.	150.14	56.80	0	0	0	0	8.02	14.83	5.34	9.87
Dunn	29.	161.76	88.98	0	0.76	0	2	15.07	21.81	9.32	13.48
Dunn	30.	495.18	64.78	72.50	10.02	1	11	95.58	94.95	19.30	19.18
Dunn	31.	212.39	51.24	0	0	0	0	12.71	20.94	5.98	9.86
Dunn	32.	97.23	85.35	0	0	0	0	9.99	9.78	10.28	10.06
Dunn	33.	212.02	31.95	0	2.70	0	1	9.32	15.47	4.40	7.29
Dunn	34.	376.07	37.90	0	11.07	0	9	18.59	30.05	4.94	7.99
Dunn	35.	128.11	77.48	0	2.46	0	3	12.48	20.32	9.74	15.86
Bottineu	36.	244.38	39.53	1.90	0	1	0	6.67	18.89	2.73	7.73
Bottineau	37.	243.95	33.59	3.54	0	2	0	10.14	16.23	4.16	6.65
Bottineau	38.	466.12	56.22	7.75	1.31	3	3	30.02	16.60	6.44	3.56
Bottineau	39.	222.66	74.86	33.66	0	12	0	43.63	54.59	19.59	24.52
Bottineau	40.	231.29	90.89	33.94	14.54	12	1	47.76	53.97	20.65	23.33
Bottineau	41.	223.14	62.85	14.72	0.19	16	1	22.32	31.77	10.00	14.24
Bottineau	42.	166.14	75.63	12.82	0.06	10	2	23.26	24.97	13.99	15.03
Burke	43.	231.84	47.25	7.18	1.48	3	4	18.84	23.13	8.13	9.98
Burke	44.	238.02	53.29	47.93	0	3	0	58.16	65.30	24.44	27.43
Burke	45.	250.55	31.48	3.43	0	4	0	11.56	19.69	4.61	7.86
Burke	46.	200.13	59.08	4.86	2.85	3	4	20.04	29.80	10.01	14.89
Burke	47.	106.12	86.67	3.25	0	3	0	11.04	13.75	10.40	12.96

Table A1. Field-Wise Total and Percentage Overlap Reduction (Continued)

County	Field	Area	P/A Ratio	Area of Navigable Obstacles	Area of Non-Navigable Obstacles	No. of Navigable Obstacles	No. of Non-Navigable Obstacles	Reduction in Overlapping Area (ha)		Percentage Reduction in Overlapping (%)	
								60-Feet Planter	120-Feet Sprayer	60-Feet Planter	120-Feet Sprayer
Burke	48.	238.70	63.87	7.90	1.65	7	8	22.21	29.52	9.30	12.36
Burke	49.	236.09	53.21	3.79	0	7	0	16.26	24.87	6.89	10.53
Divide	50.	463.18	40.79	6.33	0	1	0	22.79	33.22	4.92	7.17
Divide	51.	429.90	36.84	22.31	0.43	6	1	35.69	49.89	8.30	11.60
Divide	52.	248.14	50.46	21.49	4.52	4	1	32.32	40.61	13.03	16.37
Divide	53.	160.03	82.29	4.58	0	2	0	15.35	20.84	9.59	13.02
Divide	54.	220.07	79.51	0	5.13	0	8	20.97	32.45	9.53	14.75
Divide	55.	223.28	70.50	2.08	0	5	0	17.37	29.09	7.78	13.03
Divide	56.	178.13	67.53	0	0	0	0	11.57	25.09	6.50	14.08
Burleigh	57.	188.26	59.21	0	9.76	0	8	19.28	26.86	10.24	14.27
Burleigh	58.	185.35	37.74	0	0.96	0	1	8.82	14.96	4.76	8.07
Burleigh	59.	164.54	63.16	2.00	1.63	2	1	12.65	19.35	7.69	11.76
Burleigh	60.	130.46	101.32	0.42	6.68	1	4	14.15	18.87	10.84	14.46
Burleigh	61.	198.81	80.90	0	4.80	0	11	24.38	46.37	12.26	23.33
Burleigh	62.	56.76	68.60	3.56	0	1	0	7.36	10.93	12.97	19.26
Burleigh	63.	438.58	41.68	11.33	9.88	2	3	24.11	42.61	5.50	9.71
Cass	64.	246.88	35.85	0	0	0	0	9.72	18.33	3.94	7.42
Cass	65.	502.50	22.10	0	12.80	0	5	17.34	28.07	3.45	5.59
Cass	66.	246.23	39.65	5.63	0	1	0	9.14	16.18	3.71	6.57
Cass	67.	239.80	47.76	12.47	1.45	1	1	21.54	26.62	8.98	11.10
Cass	68.	226.37	43.76	0	11.66	0	2	12.18	19.78	5.38	8.74
Cass	69.	248.92	25.30	0	6.75	0	4	8.20	17.11	3.30	6.88
Cass	70.	242.81	45.51	0.71	7.58	1	3	11.93	17.64	4.91	7.27
Cavalier	71.	245.94	57.43	52.62	0.15	3	2	63.26	68.49	25.72	27.85

Table A1. Field-Wise Total and Percentage Overlap Reduction (Continued)

County	Field	Area	P/A Ratio	Area of Navigable Obstacles	Area of Non-Navigable Obstacles	No. of Navigable Obstacles	No. of Non-Navigable Obstacles	Reduction in Overlapping Area (ha)		Percentage Reduction in Overlapping (%)	
								60-Feet Planter	120-Feet Sprayer	60-Feet Planter	120-Feet Sprayer
Cavalier	72.	111.64	146.59	0	11.42	0	5	17.05	20.28	15.28	18.17
Cavalier	73.	72.65	142.58	0	10.72	0	4	7.13	13.19	9.81	18.15
Cavalier	74.	208.56	66.53	0	0	0	0	13.14	23.52	6.30	11.28
Cavalier	75.	241.95	48.40	0	4.47	0	3	12.41	20.64	5.13	8.53
Cavalier	76.	193.05	81.52	2.26	0	1	0	18.31	28.46	9.48	14.74
Cavalier	77.	247.16	32.27	0	0.16	0	2	9.77	15.77	3.95	6.38
Eddy	78.	144.95	53.04	0	0	1	0	4.95	6.68	3.41	4.61
Eddy	79.	158.43	72.75	0	12.10	2	3	14.12	20.82	8.91	13.14
Eddy	80.	246.28	52.87	0.41	0.24	36	2	31.12	37.82	12.64	15.36
Eddy	81.	485.87	31.44	0	7.69	1	2	16.64	32.67	3.42	6.72
Eddy	82.	125.31	110.58	0	0	1	0	13.28	14.29	10.60	11.40
Eddy	83.	149.52	109.91	0	0.37	3	1	16.68	17.99	11.16	12.04
Eddy	84.	200.20	48.19	0	0	0	0	11.33	17.28	5.66	8.63
Foster	85.	235.69	64.63	7.15	5.18	1	4	15.31	23.61	6.49	10.02
Foster	86.	209.35	66.91	0	17.17	6	2	15.01	26.50	7.17	12.66
Foster	87.	173.18	70.52	5.13	0.23	4	3	15.27	17.71	8.82	10.23
Foster	88.	238.33	40.11	0	1.27	2	2	10.98	19.13	4.61	8.03
Foster	89.	202.08	49.28	0	0	0	0	9.23	17.19	4.57	8.51
Foster	90.	121.75	74.60	0.27	0.57	5	1	10.63	13.94	8.73	11.45
Foster	91.	191.50	95.76	0	0.35	0	2	19.42	28.61	10.14	14.94
Griggs	92.	177.34	86.05	0.44	5.86	0	2	16.50	26.59	9.31	14.99
Griggs	93.	223.53	89.85	9.13	10.64	1	8	34.26	51.57	15.33	23.07
Griggs	94.	246.52	58.16	8.90	4.56	0	4	21.81	30.84	8.85	12.51
Griggs	95.	243.46	20.74	0	3.46	0	3	14.95	21.98	6.14	9.03
Griggs	96.	129.13	84.67	0.80	2.37	0	1	8.88	19.83	6.88	15.36

Table A1. Field-Wise Total and Percentage Overlap Reduction (Continued)

County	Field	Area	P/A Ratio	Area of Navigable Obstacles	Area of Non-Navigable Obstacles	No. of Navigable Obstacles	No. of Non-Navigable Obstacles	Reduction in Overlapping Area (ha)		Percentage Reduction in Overlapping (%)	
								60-Feet Planter	120-Feet Sprayer	60-Feet Planter	120-Feet Sprayer
Griggs	97.	192.23	57.21	0	0	0	0	11.82	14.87	6.15	7.73
Griggs	98.	251.87	45.08	7.68	5.17	0	3	16.74	23.41	6.64	9.29
Grand-Forks	99.	250.31	32.80	0.76	0	0	0	8.31	10.47	3.32	4.18
Grand-Forks	100.	210.44	96.63	0	1.64	0	3	17.16	26.76	8.16	12.72
Grand-Forks	101.	219.99	49.71	1.87	0	2	0	11.59	17.09	5.27	7.77
Grand-Forks	102.	237.74	34.65	0	7.55	0	2	8.44	14.99	3.55	6.30
Grand-Forks	103.	231.53	52.05	0	0	0	0	10.48	16.41	4.53	7.09
Grand-Forks	104.	468.82	33.85	0	0	0	0	19.62	31.62	4.18	6.75
Grand-Forks	105.	206.22	71.92	0	5.34	0	1	13.07	25.33	6.34	12.28
Average								17.73	26.97	8.44	13.27

Table A2. Field-Wise Seed Costs Savings of Corn, Soybean, HRSW, and Canola

County	Field	Total Seed Cost Savings ($/ha)				Cost of ASC	Net Seed Cost Savings ($/ha)				% Net Seed Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Barnes	1.	796.16	562.09	130.88	470.19	393.66	402.50	168.43	-262.78	76.53	4.96	2.94	-19.71	1.60
Barnes	2.	361.26	255.05	59.39	213.35	139.57	221.70	115.49	-80.18	73.79	7.71	5.69	-16.96	4.34
Barnes	3.	581.29	410.39	95.56	343.29	399.00	182.28	11.38	-303.45	-55.72	2.22	0.20	-22.45	-1.15
Barnes	4.	430.22	303.74	70.73	254.08	412.30	17.93	-108.56	-341.57	-158.22	0.21	-1.81	-24.46	-3.15
Barnes	5.	1009.02	712.37	165.88	595.90	739.41	269.61	-27.04	-573.53	-143.51	1.77	-0.25	-22.90	-1.60
Barnes	6.	365.86	258.30	60.15	216.07	432.31	-66.45	-174.01	-372.17	-216.25	-0.74	-2.77	-25.42	-4.11
Barnes	7.	407.44	287.66	66.98	240.62	184.55	222.90	103.11	-117.57	56.08	5.86	3.84	-18.81	2.50
Dicky	8.	574.81	405.82	94.49	339.47	274.21	300.59	131.60	-179.72	65.25	5.18	3.21	-18.85	1.90
Dicky	9.	1064.11	751.26	174.93	628.43	443.57	620.54	307.69	-268.64	184.86	6.61	4.64	-17.41	3.34
Dicky	10.	711.68	502.45	116.99	420.30	267.10	444.58	235.35	-150.10	153.20	7.86	5.90	-16.16	4.59
Dicky	11.	334.21	235.96	54.94	197.38	171.52	162.69	64.43	-116.58	25.85	4.48	2.52	-19.54	1.21
Dicky	12.	1728.88	1220.60	284.22	1021.03	419.26	1309.62	801.34	-135.04	601.77	14.77	12.80	-9.26	11.49
Dicky	13.	825.42	582.75	135.69	487.47	325.95	499.47	256.80	-190.25	161.52	7.24	5.28	-16.78	3.97
Dicky	14.	299.58	211.50	49.25	176.92	382.52	-82.94	-171.02	-333.27	-205.60	-1.02	-2.99	-25.05	-4.30

Table A2. Field-Wise Seed Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Seed Cost Savings ($/ha)				Cost of ASC	Net Seed Cost Savings ($/ha)				% Net Seed Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Billings	15.	80.26	---	17.29	72.42	73.67	6.59	---	-56.38	-1.25	0.43	---	-17.15	-0.09
Billings	16.	287.55	---	61.94	259.48	240.42	47.13	---	-178.48	19.06	0.95	---	-16.64	0.42
Billings	17.	366.82	---	79.02	331.01	214.26	152.56	---	-135.24	116.75	3.44	---	-14.15	2.92
Billings	18.	276.25	---	59.51	249.29	142.99	133.27	---	-83.48	106.30	4.50	---	-13.08	3.98
Billings	19.	437.38	---	94.22	394.69	270.82	166.57	---	-176.60	123.87	2.97	---	-14.61	2.45
Billings	20.	227.08	---	48.92	204.92	118.50	108.59	---	-69.58	86.42	4.42	---	-13.16	3.90
Billings	21.	331.38	---	71.39	299.03	266.86	64.52	---	-195.47	32.17	1.17	---	-16.42	0.65
Bowman	22.	170.69	---	36.77	154.01	345.95	-175.29	---	-309.19	-191.95	-2.86	---	-23.45	-3.48
Bowman	23.	924.13	---	199.08	833.91	278.15	645.97	---	-79.08	555.76	13.13	---	-7.46	12.51
Bowman	24.	379.95	---	81.85	342.86	294.00	85.95	---	-212.15	48.86	1.65	---	-18.93	1.04
Bowman	25.	286.93	---	61.81	258.92	255.73	31.20	---	-193.92	3.19	0.69	---	-19.90	0.08
Bowman	26.	203.02	---	43.73	183.20	193.25	9.76	---	-149.52	-10.05	0.29	---	-20.30	-0.33
Bowman	27.	247.99	---	53.42	223.78	340.75	-92.76	---	-287.33	-116.97	-1.54	---	-22.12	-2.15
Bowman	28.	197.74	---	42.60	178.43	209.32	-11.58	---	-166.72	-30.88	-0.31	---	-20.90	-0.92

Table A2. Field-Wise Seed Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Seed Cost Savings ($/ha)				Cost of ASC	Net Seed Cost Savings ($/ha)				% Net Seed Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Dunn	29.	371.71	---	80.08	335.43	246.92	124.79	---	-166.84	88.51	3.13	---	-19.41	2.46
Dunn	30.	2357.61	---	507.88	2127.46	755.86	1601.75	---	-247.98	1371.60	13.11	---	-9.42	12.44
Dunn	31.	313.48	---	67.53	282.88	324.20	-10.71	---	-256.66	-41.32	-0.20	---	-22.74	-0.87
Dunn	32.	246.51	---	53.10	222.44	148.41	98.09	---	-95.31	74.03	4.09	---	-18.44	3.42
Dunn	33.	229.88	---	49.52	207.44	323.64	-93.76	---	-274.12	-116.20	-1.79	---	-24.33	-2.46
Dunn	34.	458.41	---	98.75	413.66	574.04	-115.63	---	-475.29	-160.38	-1.25	---	-23.79	-1.92
Dunn	35.	307.87	---	66.32	277.81	195.56	112.31	---	-129.23	82.26	3.55	---	-18.98	2.88
Bottineau	36.	201.16	177.57	40.19	148.54	458.56	-257.41	-280.99	-418.38	-310.02	-3.49	-4.32	-28.43	-5.70
Bottineau	37.	305.65	269.82	61.06	225.70	457.75	-152.09	-187.93	-396.68	-232.04	-2.07	-2.90	-27.00	-4.27
Bottineau	38.	904.71	798.65	180.74	668.07	874.64	30.08	-75.99	-693.89	-206.57	0.21	-0.61	-24.72	-1.99
Bottineau	39.	1315.07	1160.89	262.72	971.09	417.80	897.27	743.10	-155.07	553.29	13.37	12.54	-11.57	11.16
Bottineau	40.	1439.63	1270.85	287.61	1063.07	433.99	1005.63	836.85	-146.39	629.07	14.42	13.60	-10.51	12.22
Bottineau	41.	672.83	593.95	134.42	496.84	418.71	254.13	175.24	-284.29	78.13	3.78	2.95	-21.16	1.57
Bottineau	42.	700.99	618.81	140.04	517.63	311.76	389.24	307.05	-171.71	205.88	7.77	6.95	-17.16	5.57

Table A2. Field-Wise Seed Costs Savings of Corn, Soybean, HRSW, and Canola (continued)

County	Field	Total Seed Cost Savings ($/ha)				Cost of ASC	Net Seed Cost Savings ($/ha)				% Net Seed Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Burke	43.	464.74	---	100.12	419.37	402.79	61.95	---	-302.67	16.58	1.08	---	-24.57	0.32
Burke	44.	1434.58	---	309.04	1294.53	413.52	1021.06	---	-104.48	881.02	17.39	---	-8.26	16.63
Burke	45.	285.09	---	61.41	257.26	435.29	-150.20	---	-373.87	-178.03	-2.43	---	-28.08	-3.19
Burke	46.	494.29	---	106.48	446.04	347.69	146.60	---	-241.21	98.34	2.97	---	-22.68	2.21
Burke	47.	272.28	---	58.66	245.70	184.37	87.91	---	-125.71	61.33	3.36	---	-22.29	2.60
Burke	48.	547.78	---	118.00	494.31	414.71	133.08	---	-296.70	79.60	2.26	---	-23.39	1.50
Burke	49.	401.00	---	86.39	361.86	410.16	-9.16	---	-323.78	-48.30	-0.16	---	-25.81	-0.92
Divide	50.	562.12	---	121.09	507.25	795.30	-233.17	---	-674.20	-288.05	-2.04	---	-27.39	-2.79
Divide	51.	880.37	---	189.65	794.43	738.16	142.21	---	-548.51	56.26	1.34	---	-24.01	0.59
Divide	52.	797.27	---	171.75	719.44	426.07	371.20	---	-254.32	293.37	6.06	---	-19.29	5.31
Divide	53.	378.69	---	81.58	341.72	274.78	103.91	---	-193.20	66.94	2.63	---	-22.72	1.88
Divide	54.	517.15	---	111.41	466.67	377.87	139.29	---	-266.46	88.80	2.57	---	-22.79	1.81
Divide	55.	428.53	---	92.32	386.70	383.38	45.15	---	-291.07	3.32	0.82	---	-24.53	0.07
Divide	56.	285.50	---	61.50	257.63	305.85	-20.35	---	-244.35	-48.23	-0.46	---	-25.82	-1.22

Table A2. Field-Wise Seed Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Seed Cost Savings ($/ha)				Cost of ASC	Net Seed Cost Savings ($/ha)				% Net Seed Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Burleigh	57.	599.64	513.03	116.11	429.15	399.98	199.67	113.06	-283.87	29.18	3.41	2.26	-25.04	0.70
Burleigh	58.	274.42	234.78	53.13	196.39	393.79	-119.37	-159.00	-340.65	-197.39	-2.07	-3.22	-30.52	-4.78
Burleigh	59.	393.29	336.48	76.15	281.47	349.58	43.70	-13.10	-273.43	-68.12	0.85	-0.30	-27.60	-1.86
Burleigh	60.	439.92	376.38	85.18	314.84	277.16	162.76	99.22	-191.98	37.68	4.01	2.86	-24.44	1.30
Burleigh	61.	758.09	648.60	146.78	542.55	422.38	335.71	226.22	-275.59	120.17	5.43	4.28	-23.02	2.72
Burleigh	62.	228.89	195.83	44.32	163.81	120.59	108.30	75.24	-76.27	43.22	6.14	4.98	-22.31	3.42
Burleigh	63.	749.82	641.52	145.18	536.63	931.79	-181.97	-290.28	-786.61	-395.16	-1.33	-2.49	-29.78	-4.05
Cass	64.	366.15	227.05	68.80	---	442.17	-76.02	-215.12	-373.37	---	-0.82	-3.73	-21.35	---
Cass	65.	653.47	405.22	122.79	---	899.98	-246.51	-494.76	-777.19	---	-1.30	-4.21	-21.84	---
Cass	66.	344.33	213.52	64.70	---	440.99	-96.67	-227.48	-376.29	---	-1.04	-3.95	-21.58	---
Cass	67.	811.68	503.32	152.52	---	429.49	382.19	73.83	-276.97	---	4.23	1.32	-16.31	---
Cass	68.	458.94	284.59	86.24	---	405.43	53.52	-120.84	-319.19	---	0.63	-2.28	-19.91	---
Cass	69.	309.12	191.69	58.09	---	445.82	-136.70	-254.13	-387.73	---	-1.46	-4.37	-21.99	---
Cass	70.	449.50	278.73	84.46	---	434.88	14.61	-156.15	-350.42	---	0.16	-2.75	-20.38	---

Table A2. Field-Wise Seed Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Seed Cost Savings ($/ha)				Cost of ASC	Net Seed Cost Savings ($/ha)				% Net Seed Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Cavalier	71.	2069.38	1683.30	391.96	1408.09	401.39	1667.99	1281.92	-9.43	1006.70	20.73	19.59	-0.62	18.39
Cavalier	72.	557.86	453.78	105.66	379.59	182.21	375.65	271.58	-76.54	197.38	10.29	9.14	-11.07	7.94
Cavalier	73.	233.10	189.62	44.15	158.61	118.57	114.54	71.05	-74.41	40.05	4.82	3.68	-16.53	2.48
Cavalier	74.	429.90	349.70	81.43	292.52	340.37	89.53	9.32	-258.95	-47.85	1.31	0.17	-20.04	-1.03
Cavalier	75.	405.95	330.22	76.89	276.23	394.88	11.08	-64.66	-317.98	-118.65	0.14	-1.00	-21.21	-2.20
Cavalier	76.	598.93	487.19	113.44	407.53	315.06	283.87	172.13	-201.61	92.48	4.50	3.35	-16.86	2.15
Cavalier	77.	319.70	260.06	60.55	217.54	403.38	-83.68	-143.32	-342.82	-185.84	-1.03	-2.18	-22.39	-3.38
Eddy	78.	167.17	131.68	30.66	110.15	254.11	-86.93	-122.42	-223.44	-143.95	-1.78	-3.17	-24.88	-4.46
Eddy	79.	476.95	375.70	87.48	314.27	277.74	199.21	97.96	-190.26	36.53	3.72	2.32	-19.38	1.04
Eddy	80.	1051.24	828.07	192.82	692.68	431.75	619.49	396.32	-238.94	260.93	7.45	6.05	-15.66	4.76
Eddy	81.	561.94	442.64	103.07	370.27	851.78	-289.84	-409.14	-748.71	-481.51	-1.77	-3.16	-24.87	-4.45
Eddy	82.	448.57	353.34	82.28	295.57	219.67	228.89	133.67	-137.40	75.90	5.41	4.01	-17.70	2.72
Eddy	83.	563.49	443.87	103.35	371.29	262.13	301.36	181.74	-158.77	109.17	5.97	4.57	-17.14	3.28
Eddy	84.	382.85	301.57	70.22	252.27	350.98	31.87	-49.41	-280.76	-98.71	0.47	-0.93	-22.63	-2.26

Table A2. Field-Wise Seed Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Seed Cost Savings ($/ha)				Cost of ASC	Net Seed Cost Savings ($/ha)				% Net Seed Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Foster	85.	517.09	407.31	94.84	340.72	413.15	103.94	-5.84	-318.30	-72.43	1.31	-0.09	-21.80	-1.38
Foster	86.	506.95	399.33	92.98	334.04	366.97	139.97	32.35	-273.99	-32.94	1.98	0.58	-21.12	-0.71
Foster	87.	515.89	406.37	94.62	339.93	303.58	212.32	102.80	-208.95	36.36	3.63	2.23	-19.47	0.94
Foster	88.	370.84	292.12	68.02	244.36	417.78	-46.93	-125.66	-349.76	-173.42	-0.58	-1.98	-23.69	-3.27
Foster	89.	311.92	245.70	57.21	205.53	354.23	-42.31	-108.53	-297.02	-148.70	-0.62	-2.02	-23.72	-3.31
Foster	90.	359.12	282.88	65.87	236.63	213.41	145.71	69.47	-147.54	23.22	3.54	2.14	-19.56	0.86
Foster	91.	656.04	516.76	120.33	432.27	335.69	320.34	181.07	-215.36	96.58	4.95	3.55	-18.15	2.27
Griggs	92.	557.48	439.13	102.25	367.33	344.07	213.41	95.06	-241.81	23.27	3.56	2.01	-22.01	0.59
Griggs	93.	1157.19	911.53	212.25	762.50	433.68	723.52	477.86	-221.42	328.82	9.58	8.03	-15.99	6.61
Griggs	94.	736.66	580.27	135.12	485.40	478.29	258.37	101.98	-343.17	7.11	3.10	1.55	-22.47	0.13
Griggs	95.	505.05	397.83	92.64	332.78	472.35	32.70	-74.52	-379.71	-139.56	0.40	-1.15	-25.17	-2.58
Griggs	96.	299.89	236.22	55.01	197.60	250.53	49.36	-14.30	-195.52	-52.93	1.13	-0.42	-24.44	-1.84
Griggs	97.	399.22	314.47	73.22	263.05	372.95	26.27	-58.48	-299.73	-109.90	0.40	-1.14	-25.17	-2.57
Griggs	98.	565.32	445.31	103.69	372.50	488.66	76.66	-43.35	-384.97	-116.16	0.90	-0.65	-24.67	-2.07

Table A2. Field-Wise Seed Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Seed Cost Savings ($)				Cost of ASC	Net Seed Cost Savings ($)				% Net Seed Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
GrandForks	99.	280.60	193.80	58.83	184.89	526.63	-246.03	-332.83	-467.80	-341.74	-2.91	-5.70	-26.39	-6.13
GrandForks	100.	579.70	400.38	121.54	381.98	442.74	136.96	-42.36	-321.20	-60.76	1.93	-0.86	-21.55	-1.30
GrandForks	101.	391.38	270.31	82.05	257.89	462.86	-71.48	-192.55	-380.81	-204.97	-0.96	-3.75	-24.44	-4.19
GrandForks	102.	284.95	196.81	59.74	187.76	500.19	-215.23	-303.38	-440.44	-312.43	-2.68	-5.47	-26.16	-5.90
GrandForks	103.	353.99	244.49	74.22	233.25	487.13	-133.13	-242.63	-412.91	-253.87	-1.70	-4.49	-25.18	-4.93
GrandForks	104.	662.60	457.64	138.92	436.60	986.35	-323.75	-528.71	-847.43	-549.75	-2.04	-4.83	-25.52	-5.27
GrandForks	105.	441.40	304.86	92.54	290.85	433.87	7.53	-129.01	-341.33	-143.03	0.11	-2.68	-23.37	-3.12
Average		543.23	445.94	105.29	402.46		158.81	36.77	-279.13	26.28	2.74	1.19	-20.65	0.88

Table A3. Field-Wise Chemical Costs Savings of Corn, Soybean, HRSW, and Canola

County	Field	Total Chemical Cost Savings ($/ha)				Cost of ASC	Net Chemical Cost Savings ($/ha)				% Net Chemical Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Barnes	1.	309.91	347.10	483.46	278.92	291.10	18.81	56.00	192.36	-12.18	0.86	2.30	5.66	-0.62
Barnes	2.	117.81	131.95	183.78	106.03	103.20	14.61	28.74	80.58	2.83	1.89	3.32	6.69	0.41
Barnes	3.	321.04	359.57	500.82	288.94	295.05	25.99	64.51	205.77	-6.12	1.18	2.61	5.98	-0.31
Barnes	4.	302.99	339.36	472.67	272.70	304.88	-1.88	34.48	167.80	-32.18	-0.08	1.35	4.72	-1.57
Barnes	5.	479.99	537.59	748.78	431.99	546.77	-66.78	-9.18	202.01	-114.78	-1.63	-0.20	3.17	-3.12
Barnes	6.	176.58	197.77	275.47	158.92	319.68	-143.10	-121.91	-44.21	-160.75	-5.98	-4.55	-1.19	-7.47
Barnes	7.	157.11	175.97	245.10	141.40	136.47	20.65	39.50	108.63	4.94	2.02	3.46	6.82	0.54
Dicky	8.	200.74	224.83	313.16	180.67	204.45	-3.71	20.38	108.70	-23.79	-0.24	1.19	4.47	-1.70
Dicky	9.	338.62	379.26	528.25	304.76	330.73	7.90	48.53	197.53	-25.97	0.31	1.72	5.03	-1.15
Dicky	10.	264.32	296.03	412.33	237.88	199.15	65.17	96.89	213.18	38.74	4.30	5.70	9.01	2.84
Dicky	11.	128.61	144.04	200.62	115.75	127.89	0.72	16.15	72.74	-12.14	0.07	1.48	4.79	-1.39
Dicky	12.	1796.50	2012.08	2802.5	1616.85	312.60	1483.90	1699.48	2489.94	1304.25	62.32	63.73	67.04	60.87
Dicky	13.	241.05	269.98	376.03	216.95	243.03	-1.98	26.95	133.01	-26.08	-0.11	1.30	4.61	-1.57
Dicky	14.	145.74	163.23	227.35	131.17	285.21	-139.47	-121.98	-57.85	-154.04	-6.42	-5.01	-1.71	-7.88

Table A3. Field-Wise Chemical Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Chemical Cost Savings ($/ha)				Cost of ASC	Net Chemical Cost Savings ($/ha)				% Net Chemical Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Billings	15.	144.97	---	218.90	163.09	36.25	108.72	---	182.65	126.84	21.71	---	24.16	22.52
Billings	16.	94.36	---	142.48	106.15	118.30	-23.94	---	24.18	-12.15	-1.47	---	0.98	-0.66
Billings	17.	159.03	---	240.13	178.91	105.43	53.60	---	134.71	73.48	3.68	---	6.13	4.49
Billings	18.	440.88	---	665.73	495.99	70.36	370.52	---	595.37	425.63	38.12	---	40.57	38.93
Billings	19.	209.08	---	315.71	235.22	133.25	75.83	---	182.46	101.96	4.12	---	6.56	4.92
Billings	20.	98.80	---	149.19	111.15	58.30	40.50	---	90.89	52.85	5.03	---	7.47	5.83
Billings	21.	138.39	---	208.98	155.69	131.31	7.09	---	77.67	24.39	0.39	---	2.84	1.20
Bowman	22.	89.01	---	134.40	100.13	210.49	-121.48	---	-76.08	-110.35	-6.05	---	-2.51	-4.88
Bowman	23.	271.62	---	410.15	305.57	169.24	102.38	---	240.91	136.34	6.34	---	9.88	7.50
Bowman	24.	191.25	---	288.78	215.15	178.88	12.37	---	109.90	36.27	0.72	---	4.26	1.89
Bowman	25.	154.79	---	233.74	174.14	155.59	-0.80	---	78.14	18.55	-0.05	---	3.49	1.11
Bowman	26.	83.73	---	126.44	94.20	117.58	-33.85	---	8.86	-23.38	-3.02	---	0.52	-1.85
Bowman	27.	124.70	---	188.30	140.29	207.32	-82.62	---	-19.02	-67.03	-4.18	---	-0.64	-3.01

Table A3. Field-Wise Chemical Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Chemical Cost Savings ($/ha)				Cost of ASC	Net Chemical Cost Savings ($/ha)				% Net Chemical Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Bowman	28.	119.99	---	181.20	134.99	127.35	-7.35	---	53.85	7.65	-0.61	---	2.93	0.56
Dunn	29.	176.51	---	266.53	198.57	163.73	12.77	---	102.79	34.84	0.98	---	5.20	2.37
Dunn	30.	768.53	---	1160.4	864.59	501.21	267.31	---	659.26	363.38	6.67	---	10.89	8.06
Dunn	31.	169.47	---	255.89	190.65	214.98	-45.51	---	40.92	-24.33	-2.65	---	1.58	-1.26
Dunn	32.	79.14	---	119.51	89.04	98.41	-19.27	---	21.09	-9.38	-2.45	---	1.78	-1.06
Dunn	33.	125.17	---	189.01	140.82	214.61	-89.44	---	-25.60	-73.79	-5.21	---	-0.99	-3.82
Dunn	34.	243.26	---	367.32	273.66	380.65	-137.39	---	-13.33	-106.99	-4.51	---	-0.29	-3.12
Dunn	35.	164.43	---	248.29	184.98	129.67	34.75	---	118.61	55.31	3.35	---	7.58	4.74
Bottineau	36.	152.91	152.91	269.13	172.03	353.35	-200.44	-200.44	-84.22	-181.32	-10.13	-10.13	-2.42	-8.15
Bottineau	37.	131.33	131.33	231.15	147.75	352.72	-221.39	-221.39	-121.57	-204.97	-11.21	-11.21	-3.50	-9.23
Bottineau	38.	134.36	134.36	236.47	151.15	673.96	-539.60	-539.60	-437.49	-522.80	-14.30	-14.30	-6.59	-12.32
Bottineau	39.	441.88	441.88	777.70	497.11	321.94	119.94	119.94	455.76	175.17	6.66	6.66	14.37	8.64
Bottineau	40.	436.79	436.79	768.75	491.39	334.42	102.37	102.37	434.33	156.97	5.47	5.47	13.18	7.45

Table A3. Field-Wise Chemical Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Chemical Cost Savings ($/ha)				Cost of ASC	Net Chemical Cost Savings ($/ha)				% Net Chemical Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Bottineau	41.	257.11	257.11	452.52	289.25	322.64	-65.52	-65.52	129.88	-33.39	-3.63	-3.63	4.09	-1.64
Bottineau	42.	202.08	202.08	355.66	227.34	240.23	-38.15	-38.15	115.44	-12.89	-2.84	-2.84	4.88	-0.85
Burke	43.	187.20	---	282.67	210.60	295.26	-108.06	---	-12.59	-84.66	-5.76	---	-0.44	-4.01
Burke	44.	528.51	---	798.04	594.57	303.13	225.38	---	494.92	291.44	11.70	---	17.01	13.45
Burke	45.	159.37	---	240.65	179.29	319.08	-159.71	---	-78.44	-139.79	-7.88	---	-2.56	-6.13
Burke	46.	241.23	---	364.26	271.39	254.87	-13.64	---	109.39	16.51	-0.84	---	4.47	0.91
Burke	47.	111.31	---	168.07	125.22	135.15	-23.84	---	32.92	-9.93	-2.78	---	2.54	-1.03
Burke	48.	238.89	---	360.72	268.75	303.99	-65.11	---	56.72	-35.25	-3.37	---	1.94	-1.62
Burke	49.	201.30	---	303.96	226.46	300.67	-99.37	---	3.29	-74.21	-5.20	---	0.11	-3.45
Divide	50.	268.84	---	405.94	454.24	578.23	-309.39	---	-172.28	-275.79	-8.25	---	-3.04	-6.54
Divide	51.	403.77	---	609.70	369.76	536.69	-132.92	---	73.01	-82.44	-3.82	---	1.39	-2.11
Divide	52.	328.68	---	496.30	189.72	309.78	18.90	---	186.53	59.98	0.94	---	6.15	2.65
Divide	53.	168.64	---	254.64	295.51	199.78	-31.15	---	54.86	-10.07	-2.40	---	2.80	-0.69

Table A3. Field-Wise Chemical Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Chemical Cost Savings ($/ha)				Cost of ASC	Net Chemical Cost Savings ($/ha)				% Net Chemical Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Divide	54.	262.68	---	396.64	264.88	274.73	-12.05	---	121.91	20.78	-0.68	---	4.53	1.04
Divide	55.	235.45	---	355.53	228.43	278.74	-43.29	---	76.79	-13.86	-2.40	---	2.81	-0.68
Divide	56.	203.05	---	306.60	198.57	222.37	-19.33	---	84.23	6.05	-1.34	---	3.87	0.37
Burleigh	57.	217.43	260.91	371.80	244.61	248.23	-30.81	12.68	123.57	-3.63	-2.02	0.69	4.74	-0.21
Burleigh	58.	121.11	145.34	207.10	136.25	244.39	-123.28	-99.06	-37.29	-108.14	-8.22	-5.50	-1.45	-6.41
Burleigh	59.	156.61	187.93	267.81	176.19	216.96	-60.35	-29.02	50.85	-40.77	-4.53	-1.82	2.23	-2.72
Burleigh	60.	152.71	183.26	261.13	171.80	172.01	-19.30	11.25	89.13	-0.21	-1.83	0.89	4.94	-0.02
Burleigh	61.	375.34	450.40	641.82	422.25	262.14	113.20	188.27	379.69	160.11	7.03	9.75	13.80	8.84
Burleigh	62.	88.47	106.16	151.28	99.53	74.84	13.63	31.32	76.44	24.69	2.30	5.68	9.73	4.78
Burleigh	63.	344.86	413.83	589.70	387.96	578.29	-233.43	-164.46	11.41	-190.33	-6.58	-3.86	0.18	-4.77
Cass	64.	185.42	267.00	289.25	---	330.84	-145.42	-63.83	-41.584	---	-5.82	-1.77	-1.07	---
Cass	65.	284.01	408.98	443.06	---	673.38	-389.36	-264.40	-230.31	---	-7.66	-3.61	-2.90	---
Cass	66.	163.71	235.74	255.39	---	329.96	-166.25	-94.22	-74.57	---	-6.67	-2.63	-1.92	---

Table A3. Field-Wise Chemical Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Chemical Cost Savings ($/ha)				Cost of ASC	Net Chemical Cost Savings ($/ha)				% Net Chemical Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Cass	67.	269.27	387.75	420.06	---	321.35	-52.08	66.40	98.71	---	-2.15	1.90	2.61	---
Cass	68.	200.09	288.13	312.14	---	303.35	-103.26	-15.22	8.79	---	-4.51	-0.46	0.25	---
Cass	69.	173.14	249.32	270.09	---	333.57	-160.43	-84.25	-63.47	---	-6.37	-2.32	-1.62	---
Cass	70.	178.47	257.00	278.42	---	325.39	-146.91	-68.38	-46.97	---	-5.98	-1.93	-1.23	---
Cavalier	71.	637.49	720.64	1080.9	623.63	281.18	356.31	439.46	799.78	342.45	15.56	16.98	20.60	15.29
Cavalier	72.	188.79	213.42	320.13	184.69	127.64	61.16	85.78	192.49	57.05	5.89	7.30	10.92	5.61
Cavalier	73.	122.75	138.76	208.14	120.08	83.06	39.69	55.71	125.09	37.03	5.87	7.29	10.91	5.60
Cavalier	74.	218.90	247.45	371.18	214.14	238.44	-19.54	9.017	132.74	-24.29	-1.01	0.41	4.03	-1.28
Cavalier	75.	192.15	217.21	325.82	187.97	276.62	-84.47	-59.41	49.20	-88.65	-3.75	-2.33	1.29	-4.02
Cavalier	76.	264.89	299.44	449.16	259.13	220.70	44.19	78.74	228.46	38.43	2.46	3.88	7.50	2.19
Cavalier	77.	146.76	165.91	248.86	143.57	282.57	-135.81	-116.67	-33.71	-138.99	-5.90	-4.49	-0.86	-6.18
Eddy	78.	62.19	70.30	105.45	60.84	187.43	-125.24	-117.13	-81.98	-126.59	-9.28	-7.68	-3.58	-9.59
Eddy	79.	193.79	219.07	328.60	189.58	204.86	-11.07	14.21	123.74	-15.28	-0.75	0.85	4.95	-1.06

Table A3. Field-Wise Chemical Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Chemical Cost Savings ($/ha)				Cost of ASC	Net Chemical Cost Savings ($/ha)				% Net Chemical Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Eddy	80.	352.05	397.97	596.95	344.40	318.46	33.59	79.51	278.50	25.94	1.47	3.07	7.16	1.16
Eddy	81.	304.07	343.74	515.60	297.46	628.27	-324.19	-284.53	-112.66	-330.80	-7.17	-5.57	-1.47	-7.48
Eddy	82.	133.01	150.36	225.53	130.12	162.03	-29.02	-11.67	63.50	-31.91	-2.49	-0.89	3.21	-2.80
Eddy	83.	167.51	189.36	284.04	163.87	193.34	-25.83	-3.98	90.69	-29.48	-1.86	-0.25	3.84	-2.16
Eddy	84.	160.80	181.78	272.67	157.31	258.88	-98.07	-77.10	13.79	-101.57	-5.26	-3.66	0.44	-5.57
Foster	85.	219.76	248.43	372.64	214.99	304.76	-85.00	-56.34	67.88	-89.78	-3.87	-2.27	1.82	-4.18
Foster	86.	246.62	278.79	418.18	241.26	270.70	-24.08	8.08	147.48	-29.45	-1.24	0.37	4.46	-1.54
Foster	87.	164.82	186.32	279.48	161.24	223.94	-59.11	-37.61	55.55	-62.70	-3.67	-2.06	2.03	-3.98
Foster	88.	178.06	201.29	301.94	174.19	308.18	-130.11	-106.89	-6.24	-133.98	-5.87	-4.26	-0.17	-6.17
Foster	89.	160.03	180.90	271.35	156.55	261.30	-101.27	-80.40	10.05	-104.75	-5.38	-3.78	0.32	-5.69
Foster	90.	129.80	146.72	220.09	126.97	157.43	-27.63	-10.70	62.66	-30.45	-2.44	-0.84	3.26	-2.75
Foster	91.	266.27	301.01	451.51	260.49	247.63	18.65	53.38	203.88	12.86	1.05	2.65	6.75	0.74
Griggs	92.	247.54	279.83	419.74	242.16	229.31	18.23	50.52	190.43	12.85	1.10	2.71	6.80	0.80

Table A3. Field-Wise Chemical Costs Savings of Corn, Soybean, HRSW, and Canola (Continued)

County	Field	Total Chemical Cost Savings ($/ha)				Cost of ASC	Net Chemical Cost Savings ($/ha)				% Net Chemical Cost Savings			
		Corn	Soybean	HRSW	Canola		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola
Griggs	93.	479.99	542.59	813.89	469.55	289.04	190.95	253.56	524.86	180.52	9.18	10.78	14.88	8.87
Griggs	94.	287.02	324.45	486.68	280.78	318.77	-31.76	5.68	167.91	-37.99	-1.38	0.22	4.32	-1.69
Griggs	95.	204.61	231.29	346.94	200.16	314.81	-110.20	-83.51	32.13	-114.65	-4.86	-3.26	0.84	-5.17
Griggs	96.	184.57	208.64	312.96	180.56	166.97	17.60	41.67	145.99	13.58	1.46	3.07	7.16	1.16
Griggs	97.	138.36	156.41	234.61	135.35	248.56	-110.20	-92.15	-13.95	-113.21	-6.16	-4.56	-0.46	-6.47
Griggs	98.	217.90	246.33	369.49	213.17	325.68	-107.78	-79.36	43.81	-112.52	-4.60	-2.99	1.10	-4.91
GrandForks	99.	97.45	144.06	165.24	95.33	432.49	-335.04	-288.43	-267.25	-337.16	-14.38	-8.37	-6.76	-14.79
GrandForks	100.	249.08	368.21	422.36	243.67	363.60	-114.51	4.62	58.77	-119.93	-5.85	0.16	1.77	-6.26
GrandForks	101.	159.03	235.10	269.67	155.58	380.12	-221.08	-145.02	-110.45	-224.54	-10.80	-4.79	-3.18	-11.21
GrandForks	102.	139.48	206.19	236.51	136.45	410.77	-271.29	-204.58	-174.26	-274.32	-12.26	-6.25	-4.64	-12.67
GrandForks	103.	152.74	225.78	258.99	149.42	400.05	-247.31	-174.26	-141.06	-250.63	-11.48	-5.47	-3.86	-11.89
GrandForks	104.	294.35	435.12	499.11	287.95	810.02	-515.68	-374.90	-310.91	-522.07	-11.82	-5.81	-4.20	-12.23
GrandForks	105.	235.79	348.56	399.82	230.66	356.31	-120.52	-7.75	43.50	-125.65	-6.28	-0.27	1.34	-6.69
Average		236.50	288.98	380.57	245.56		-38.10	-10.99	105.97	-21.94	-0.96	0.33	4.32	-0.20

Table A4. Field-Wise Seed Costs Savings Considering a Rotation/Crop Mix Scenario

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Barnes	1.	402.50	168.43	-262.78	76.53	0.341	0.5403	0.1183	0.0001	137.37	91.00	-31.09	0.008	197.30
Barnes	2.	221.70	115.49	-80.18	73.79	0.341	0.5403	0.1183	0.0001	75.67	62.40	-9.48	0.007	128.59
Barnes	3.	182.28	11.38	-303.45	-55.72	0.341	0.5403	0.1183	0.0001	62.21	6.19	-35.90	-0.006	32.46
Barnes	4.	17.93	-108.56	-341.57	-158.22	0.341	0.5403	0.1183	0.0001	6.12	-58.65	-40.41	-0.02	-92.96
Barnes	5.	269.61	-27.04	-573.53	-143.51	0.341	0.5403	0.1183	0.0001	92.02	-14.61	-67.85	-0.01	9.55
Barnes	6.	-66.45	-174.01	-372.17	-216.25	0.341	0.5403	0.1183	0.0001	-22.68	-94.02	-44.03	-0.02	-160.75
Barnes	7.	222.90	103.11	-117.57	56.08	0.341	0.5403	0.1183	0.0001	76.07	55.71	-13.91	0.006	117.88
Dicky	8.	300.59	131.60	-179.72	65.25	0.341	0.5403	0.1183	0.0001	102.59	71.10	-21.26	0.007	152.44
Dicky	9.	620.54	307.69	-268.64	184.86	0.341	0.5403	0.1183	0.0001	211.78	166.25	-31.78	0.019	346.28
Dicky	10.	444.58	235.35	-150.10	153.20	0.341	0.5403	0.1183	0.0001	151.74	127.16	-17.76	0.015	261.16
Dicky	11.	162.69	64.43	-116.58	25.85	0.341	0.5403	0.1183	0.0001	55.53	34.81	-13.79	0.003	76.55
Dicky	12.	1309.62	801.34	-135.04	601.77	0.341	0.5403	0.1183	0.0001	446.98	432.96	-15.98	0.06	864.02
Dicky	13.	499.47	256.80	-190.25	161.52	0.341	0.5403	0.1183	0.0001	170.47	138.75	-22.51	0.02	286.73
Dicky	14.	-82.94	-171.02	-333.27	-205.60	0.341	0.5403	0.1183	0.0001	-28.31	-92.40	-39.43	-0.02	-160.16
Billings	15.	6.59	---	-56.38	-1.25	0.155	---	0.7555	0.0678	1.02	---	-42.60	-0.08	-41.66

Table A4. Field-Wise Seed Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Billings	16.	47.13	---	-178.48	19.06	0.155	---	0.7555	0.0678	7.30	---	-134.84	1.29	-126.24
Billings	17.	152.56	---	-135.24	116.75	0.155	---	0.7555	0.0678	23.65	---	-102.17	7.92	-70.61
Billings	18.	133.27	---	-83.48	106.30	0.155	---	0.7555	0.0678	20.66	---	-63.07	7.21	-35.20
Billings	19.	166.57	---	-176.60	123.87	0.155	---	0.7555	0.0678	25.82	---	-133.42	8.40	-99.20
Billings	20.	108.59	---	-69.58	86.42	0.155	---	0.7555	0.0678	16.83	---	-52.57	5.86	-29.87
Billings	21.	64.52	---	-195.47	32.17	0.155	---	0.7555	0.0678	10.00	---	-147.68	2.18	-135.50
Bowman	22.	-175.29	---	-309.19	-191.95	0.155	---	0.7555	0.0678	-27.17	---	-233.59	-13.01	-273.78
Bowman	23.	645.97	---	-79.08	555.76	0.155	---	0.7555	0.0678	100.13	---	-59.74	37.68	78.06
Bowman	24.	85.95	---	-212.15	48.86	0.155	---	0.7555	0.0678	13.32	---	-160.28	3.31	-143.65
Bowman	25.	31.20	---	-193.92	3.19	0.155	---	0.7555	0.0678	4.84	---	-146.51	0.22	-141.45
Bowman	26.	9.76	---	-149.52	-10.05	0.155	---	0.7555	0.0678	1.51	---	-112.96	-0.68	-112.13
Bowman	27.	-92.76	---	-287.33	-116.97	0.155	---	0.7555	0.0678	-14.38	---	-217.07	-7.93	-239.38

Table A4. Field-Wise Seed Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Bowman	28.	-11.58	---	-166.72	-30.88	0.155	---	0.7555	0.0678	-1.79	---	-125.96	-2.09	-129.84
Dunn	29.	124.79	---	-166.84	88.51	0.155	---	0.7555	0.0678	19.34	---	-126.05	6.00	-100.71
Dunn	30.	1601.75	---	-247.98	1371.60	0.155	---	0.7555	0.0678	248.27	---	-187.35	92.99	153.92
Dunn	31.	-10.71	---	-256.66	-41.32	0.155	---	0.7555	0.0678	-1.66	---	-193.91	-2.80	-198.37
Dunn	32.	98.09	---	-95.31	74.03	0.155	---	0.7555	0.0678	15.20	---	-72.01	5.02	-51.78
Dunn	33.	-93.76	---	-274.12	-116.20	0.155	---	0.7555	0.0678	-14.53	---	-207.10	-7.88	-229.51
Dunn	34.	-115.63	---	-475.29	-160.38	0.155	---	0.7555	0.0678	-17.92	---	-359.08	-10.87	-387.88
Dunn	35.	112.31	---	-129.23	82.26	0.155	---	0.7555	0.0678	17.41	---	-97.64	5.58	-74.65
Bottineau	36.	-257.41	-280.99	-418.38	-310.02	0.095	0.3211	0.437	0.1465	-24.56	-90.23	-182.83	-45.42	-343.03
Bottineau	37.	-152.09	-187.93	-396.68	-232.04	0.095	0.3211	0.437	0.1465	-14.51	-60.34	-173.35	-33.99	-282.20
Bottineau	38.	30.08	-75.99	-693.89	-206.57	0.095	0.3211	0.437	0.1465	2.87	-24.40	-303.23	-30.26	-355.03
Bottineau	39.	897.27	743.10	-155.07	553.29	0.095	0.3211	0.437	0.1465	85.60	238.61	-67.77	81.06	337.50

Table A4. Field-Wise Seed Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Bottineau	40.	1005.63	836.85	-146.39	629.07	0.095	0.3211	0.437	0.1465	95.94	268.71	-63.97	92.16	392.84
Bottineau	41.	254.13	175.24	-284.29	78.13	0.095	0.3211	0.437	0.1465	24.24	56.27	-124.23	11.45	-32.27
Bottineau	42.	389.24	307.05	-171.71	205.88	0.095	0.3211	0.437	0.1465	37.13	98.59	-75.04	30.16	90.85
Burke	43.	61.95	---	-302.67	16.58	0.022	---	0.5979	0.3111	1.34	---	-180.97	5.16	-174.47
Burke	44.	1021.06	---	-104.48	881.02	0.022	---	0.5979	0.3111	22.05	---	-62.47	274.08	233.67
Burke	45.	-150.20	---	-373.87	-178.03	0.022	---	0.5979	0.3111	-3.24	---	-223.54	-55.39	-282.17
Burke	46.	146.60	---	-241.21	98.34	0.022	---	0.5979	0.3111	3.17	---	-144.22	30.59	-110.46
Burke	47.	87.91	---	-125.71	61.33	0.022	---	0.5979	0.3111	1.90	---	-75.16	19.08	-54.19
Burke	48.	133.08	---	-296.70	79.60	0.022	---	0.5979	0.3111	2.87	---	-177.40	24.76	-149.76
Burke	49.	-9.16	---	-323.78	-48.30	0.022	---	0.5979	0.3111	-0.20	---	-193.59	-15.03	-208.81
Divide	50.	-233.17	---	-674.20	-288.05	0.022	---	0.5979	0.3111	-5.04	---	-403.11	-89.61	-497.76
Divide	51.	142.21	---	-548.51	56.26	0.022	---	0.5979	0.3111	3.07	---	-327.96	17.50	-307.38

Table A4. Field-Wise Seed Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Divide	52.	371.20	---	-254.32	293.37	0.022	---	0.5979	0.3111	8.02	---	-152.06	91.27	-52.77
Divide	53.	103.91	---	-193.20	66.94	0.022	---	0.5979	0.3111	2.24	---	-115.52	20.82	-92.45
Divide	54.	139.29	---	-266.46	88.80	0.022	---	0.5979	0.3111	3.01	---	-159.32	27.63	-128.68
Divide	55.	45.15	---	-291.07	3.32	0.022	---	0.5979	0.3111	0.98	---	-174.03	1.03	-172.02
Divide	56.	-20.35	---	-244.35	-48.23	0.022	---	0.5979	0.3111	-0.44	---	-146.10	-15.00	-161.54
Burleigh	57.	199.67	113.06	-283.87	29.18	0.23	0.3629	0.38	0.0271	45.92	41.03	-107.87	0.79	-20.13
Burleigh	58.	-119.37	-159.00	-340.65	-197.39	0.23	0.3629	0.38	0.0271	-27.45	-57.70	-129.45	-5.35	-219.95
Burleigh	59.	43.70	-13.10	-273.43	-68.12	0.23	0.3629	0.38	0.0271	10.05	-4.75	-103.90	-1.85	-100.45
Burleigh	60.	162.76	99.22	-191.98	37.68	0.23	0.3629	0.38	0.0271	37.44	36.01	-72.95	1.02	1.51
Burleigh	61.	335.71	226.22	-275.59	120.17	0.23	0.3629	0.38	0.0271	77.21	82.09	-104.73	3.26	57.84
Burleigh	62.	108.30	75.24	-76.27	43.22	0.23	0.3629	0.38	0.0271	24.91	27.30	-28.98	1.17	24.40
Burleigh	63.	-181.97	-290.28	-786.61	-395.16	0.23	0.3629	0.38	0.0271	-41.85	-105.34	-298.91	-10.71	-456.82

Table A4. Field-Wise Seed Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Cass	64.	-76.02	-215.12	-373.37	---	0.355	0.5178	0.1268	---	-27.02	-111.39	-47.34	---	-185.75
Cass	65.	-246.51	-494.76	-777.19	---	0.355	0.5178	0.1268	---	-87.61	-256.19	-98.55	---	-442.35
Cass	66.	-96.67	-227.48	-376.29	---	0.355	0.5178	0.1268	---	-34.35	-117.79	-47.71	---	-199.86
Cass	67.	382.19	73.83	-276.97	---	0.355	0.5178	0.1268	---	135.83	38.23	-35.12	---	138.94
Cass	68.	53.52	-120.84	-319.19	---	0.355	0.5178	0.1268	---	19.02	-62.57	-40.47	---	-84.02
Cass	69.	-136.70	-254.13	-387.73	---	0.355	0.5178	0.1268	---	-48.58	-131.59	-49.16	---	-229.33
Cass	70.	14.61	-156.15	-350.42	---	0.355	0.5178	0.1268	---	5.19	-80.85	-44.43	---	-120.09
Cavalier	71.	1667.99	1281.92	-9.43	1006.70	0.064	0.3056	0.3984	0.2321	106.42	391.75	-3.76	233.66	728.07
Cavalier	72.	375.65	271.58	-76.54	197.38	0.064	0.3056	0.3984	0.2321	23.97	82.99	-30.49	45.81	122.25
Cavalier	73.	114.54	71.05	-74.41	40.05	0.064	0.3056	0.3984	0.2321	7.31	21.71	-29.65	9.30	8.67
Cavalier	74.	89.53	9.32	-258.95	-47.85	0.064	0.3056	0.3984	0.2321	5.71	2.85	-103.16	-11.11	-105.71
Cavalier	75.	11.08	-64.66	-317.98	-118.65	0.064	0.3056	0.3984	0.2321	0.71	-19.76	-126.68	-27.54	-173.28

Table A4. Field-Wise Seed Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Cavalier	76.	283.87	172.13	-201.61	92.48	0.064	0.3056	0.3984	0.2321	18.11	52.60	-80.32	21.46	11.85
Cavalier	77.	-83.68	-143.32	-342.82	-185.84	0.064	0.3056	0.3984	0.2321	-5.34	-43.80	-136.58	-43.13	-228.85
Eddy	78.	-86.93	-122.42	-223.44	-143.95	0.225	0.5289	0.2412	0.0047	-19.58	-64.75	-53.89	-0.68	-138.90
Eddy	79.	199.21	97.96	-190.26	36.53	0.225	0.5289	0.2412	0.0047	44.86	51.81	-45.89	0.17	50.95
Eddy	80.	619.49	396.32	-238.94	260.93	0.225	0.5289	0.2412	0.0047	139.51	209.61	-57.63	1.23	292.72
Eddy	81.	-289.84	-409.14	-748.71	-481.51	0.225	0.5289	0.2412	0.0047	-65.27	-216.39	-180.59	-2.26	-464.52
Eddy	82.	228.89	133.67	-137.40	75.90	0.225	0.5289	0.2412	0.0047	51.55	70.70	-33.14	0.36	89.46
Eddy	83.	301.36	181.74	-158.77	109.17	0.225	0.5289	0.2412	0.0047	67.87	96.12	-38.30	0.51	126.21
Eddy	84.	31.87	-49.41	-280.76	-98.71	0.225	0.5289	0.2412	0.0047	7.18	-26.13	-67.72	-0.46	-87.14
Foster	85.	103.94	-5.84	-318.30	-72.43	0.225	0.5289	0.2412	0.0047	23.41	-3.09	-76.78	-0.34	-56.79
Foster	86.	139.97	32.35	-273.99	-32.94	0.225	0.5289	0.2412	0.0047	31.52	17.11	-66.09	-0.15	-17.61
Foster	87.	212.32	102.80	-208.95	36.36	0.225	0.5289	0.2412	0.0047	47.81	54.37	-50.40	0.17	51.96

Table A4. Field-Wise Seed Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Foster	88.	-46.93	-125.66	-349.76	-173.42	0.225	0.5289	0.2412	0.0047	-10.57	-66.46	-84.36	-0.82	-162.21
Foster	89.	-42.31	-108.53	-297.02	-148.70	0.225	0.5289	0.2412	0.0047	-9.53	-57.40	-71.64	-0.70	-139.27
Foster	90.	145.71	69.47	-147.54	23.22	0.225	0.5289	0.2412	0.0047	32.81	36.74	-35.59	0.11	34.08
Foster	91.	320.34	181.07	-215.36	96.58	0.225	0.5289	0.2412	0.0047	72.14	95.77	-51.95	0.45	116.42
Griggs	92.	213.41	95.06	-241.81	23.27	0.225	0.5289	0.2412	0.0047	48.06	50.28	-58.33	0.11	40.12
Griggs	93.	723.52	477.86	-221.42	328.82	0.225	0.5289	0.2412	0.0047	162.94	252.74	-53.41	1.55	363.81
Griggs	94.	258.37	101.98	-343.17	7.11	0.225	0.5289	0.2412	0.0047	58.18	53.94	-82.77	0.03	29.38
Griggs	95.	32.70	-74.52	-379.71	-139.56	0.225	0.5289	0.2412	0.0047	7.36	-39.41	-91.59	-0.66	-124.29
Griggs	96.	49.36	-14.30	-195.52	-52.93	0.225	0.5289	0.2412	0.0047	11.12	-7.57	-47.16	-0.25	-43.86
Griggs	97.	26.27	-58.48	-299.73	-109.90	0.225	0.5289	0.2412	0.0047	5.92	-30.93	-72.29	-0.52	-97.82
Griggs	98.	76.66	-43.35	-384.97	-116.16	0.225	0.5289	0.2412	0.0047	17.26	-22.93	-92.86	-0.55	-99.07
GrandForks	99.	-246.03	-332.83	-467.80	-341.74	0.225	0.4001	0.4098	0.0266	-40.23	-133.17	-191.71	-9.09	-374.19

Table A4. Field-Wise Seed Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
GrandForks	100.	136.96	-42.36	-321.20	-60.76	0.225	0.4001	0.4098	0.0266	22.39	-16.95	-131.63	-1.62	-127.80
GrandForks	101.	-71.48	-192.55	-380.81	-204.97	0.225	0.4001	0.4098	0.0266	-11.69	-77.04	-156.05	-5.45	-250.23
GrandForks	102.	-215.23	-303.38	-440.44	-312.43	0.225	0.4001	0.4098	0.0266	-35.19	-121.38	-180.49	-8.31	-345.38
GrandForks	103.	-133.13	-242.63	-412.91	-253.87	0.225	0.4001	0.4098	0.0266	-21.77	-97.08	-169.21	-6.75	-294.81
GrandForks	104.	-323.75	-528.71	-847.43	-549.75	0.225	0.4001	0.4098	0.0266	-52.93	-211.54	-347.28	-14.62	-626.37
GrandForks	105	7.53	-129.01	-341.33	-143.03	0.225	0.4001	0.4098	0.0266	1.23	-51.62	-139.88	-3.80	-194.07
Average										29.18	8.99	-108.15	7.09	-62.88

Table A5. Field-Wise Chemical Costs Savings Considering a Rotation/Crop Mix Scenario

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Barnes	1.	18.81	56.00	192.36	-12.18	0.341	0.5403	0.1183	0.0001	6.42	30.26	22.76	-0.001	59.43
Barnes	2.	14.61	28.74	80.58	2.83	0.341	0.5403	0.1183	0.0001	4.99	15.53	9.53	0.0002	30.05
Barnes	3.	25.99	64.51	205.77	-6.12	0.341	0.5403	0.1183	0.0001	8.87	34.86	24.34	-0.0006	68.07
Barnes	4.	-1.88	34.48	167.80	-32.18	0.341	0.5403	0.1183	0.0001	-0.64	18.63	19.85	-0.003	37.83
Barnes	5.	-66.78	-9.18	202.01	-114.78	0.341	0.5403	0.1183	0.0001	-22.79	-4.96	23.90	-0.011	-3.87
Barnes	6.	-143.10	-121.91	-44.21	-160.75	0.341	0.5403	0.1183	0.0001	-48.84	-65.87	-5.23	-0.016	-119.95
Barnes	7.	20.65	39.50	108.63	4.94	0.341	0.5403	0.1183	0.0001	7.05	21.34	12.85	0.0004	41.24
Dicky	8.	-3.71	20.38	108.70	-23.79	0.341	0.5403	0.1183	0.0001	-1.27	11.01	12.86	-0.002	22.60
Dicky	9.	7.90	48.53	197.53	-25.97	0.341	0.5403	0.1183	0.0001	2.70	26.22	23.37	-0.003	52.28
Dicky	10.	65.17	96.89	213.18	38.74	0.341	0.5403	0.1183	0.0001	22.24	52.35	25.22	0.004	99.81
Dicky	11.	0.72	16.15	72.74	-12.14	0.341	0.5403	0.1183	0.0001	0.24	8.73	8.60	-0.001	17.57
Dicky	12.	1483.90	1699.48	2489.94	1304.25	0.341	0.5403	0.1183	0.0001	506.45	918.22	294.56	0.13	1719.37

Table A5. Field-Wise Chemical Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Dicky	13.	-1.98	26.95	133.01	-26.08	0.341	0.5403	0.1183	0.0001	-0.67	14.56	15.74	-0.003	29.62
Dicky	14.	-139.47	-121.98	-57.85	-154.04	0.341	0.5403	0.1183	0.0001	-47.60	-65.91	-6.84	-0.015	-120.37
Billings	15.	108.72	---	182.65	126.84	0.155	---	0.7555	0.0678	16.85	0	137.99	8.60	163.44
Billings	16.	-23.94	---	24.18	-12.15	0.155	---	0.7555	0.0678	-3.71	0	18.27	-0.82	13.73
Billings	17.	53.60	---	134.71	73.48	0.155	---	0.7555	0.0678	8.31	0	101.77	4.98	115.06
Billings	18.	370.52	---	595.37	425.63	0.155	---	0.7555	0.0678	57.43	0	449.80	28.86	536.09
Billings	19.	75.83	---	182.46	101.96	0.155	---	0.7555	0.0678	11.75	0	137.85	6.91	156.52
Billings	20.	40.50	---	90.89	52.85	0.155	---	0.7555	0.0678	6.28	0	68.67	3.58	78.53
Billings	21.	7.09	---	77.67	24.39	0.155	---	0.7555	0.0678	1.10	0	58.68	1.65	61.43
Bowman	22.	-121.48	---	-76.08	-110.35	0.155	---	0.7555	0.0678	-18.83	0	-57.48	-7.48	-83.79
Bowman	23.	102.38	---	240.91	136.34	0.155	---	0.7555	0.0678	15.87	0	182.01	9.24	207.12
Bowman	24.	12.37	---	109.90	36.27	0.155	---	0.7555	0.0678	1.92	0	83.03	2.46	87.41

Table A5. Field-Wise Chemical Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Bowman	25.	-0.80	---	78.14	18.55	0.155	---	0.7555	0.0678	-0.12	0	59.04	1.26	60.17
Bowman	26.	-33.85	---	8.86	-23.38	0.155	---	0.7555	0.0678	-5.25	0	6.69	-1.59	-0.14
Bowman	27.	-82.62	---	-19.02	-67.03	0.155	---	0.7555	0.0678	-12.81	0	-14.37	-4.54	-31.72
Bowman	28.	-7.35	---	53.85	7.65	0.155	---	0.7555	0.0678	-1.14	0	40.68	0.52	40.06
Dunn	29.	12.77	---	102.79	34.84	0.155	---	0.7555	0.0678	41.43	0	77.66	2.36	82.00
Dunn	30.	267.31	---	659.26	363.38	0.155	---	0.7555	0.0678	-7.05	0	498.07	24.64	564.14
Dunn	31.	-45.51	---	40.92	-24.33	0.155	---	0.7555	0.0678	-2.99	0	30.92	-1.65	22.21
Dunn	32.	-19.27	---	21.09	-9.38	0.155	---	0.7555	0.0678	-13.86	0	15.94	-0.64	12.31
Dunn	33.	-89.44	---	-25.60	-73.79	0.155	---	0.7555	0.0678	-21.30	0	-19.34	-5.00	-38.20
Dunn	34.	-137.39	---	-13.33	-106.99	0.155	---	0.7555	0.0678	5.39	0	-10.07	-7.25	-38.62
Dunn	35.	34.75	---	118.61	55.31	0.155	---	0.7555	0.0678	-28.20	0	89.61	3.75	98.75
Bottineau	36.	-200.44	-200.44	-84.22	-181.32	0.095	0.3211	0.437	0.1465	-19.12	-64.36	-36.81	-26.56	-146.85

Table A5. Field-Wise Chemical Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Bottineau	37.	-221.39	-221.39	-121.57	-204.97	0.095	0.3211	0.437	0.1465	-21.12	-71.09	-53.13	-30.03	-175.36
Bottineau	38.	-539.60	-539.60	-437.49	-522.80	0.095	0.3211	0.437	0.1465	-51.48	-173.27	-191.18	-76.59	-492.52
Bottineau	39.	119.94	119.94	455.76	175.17	0.095	0.3211	0.437	0.1465	11.44	38.51	199.17	25.66	274.79
Bottineau	40.	102.37	102.37	434.33	156.97	0.095	0.3211	0.437	0.1465	9.77	32.87	189.80	22.99	255.44
Bottineau	41.	-65.52	-65.52	129.88	-33.39	0.095	0.3211	0.437	0.1465	-6.25	-21.04	56.76	-4.89	24.58
Bottineau	42.	-38.15	-38.15	115.44	-12.89	0.095	0.3211	0.437	0.1465	-3.64	-12.25	50.45	-1.89	32.67
Burke	43.	-108.06	---	-12.59	-84.66	0.022	---	0.5979	0.3111	-2.33	0	-7.53	-26.34	-36.20
Burke	44.	225.38	---	494.92	291.44	0.022	---	0.5979	0.3111	4.87	0	295.91	90.67	391.45
Burke	45.	-159.71	---	-78.44	-139.79	0.022	---	0.5979	0.3111	-3.45	0	-46.90	-43.49	-93.84
Burke	46.	-13.64	---	109.39	16.51	0.022	---	0.5979	0.3111	-0.29	0	65.40	5.14	70.25
Burke	47.	-23.84	---	32.92	-9.93	0.022	---	0.5979	0.3111	-0.52	0	19.68	-3.09	16.08
Burke	48.	-65.11	---	56.72	-35.25	0.022	---	0.5979	0.3111	-1.41	0	33.91	-10.97	21.54

Table A5. Field-Wise Chemical Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Burke	49.	-99.37	---	3.29	-74.21	0.022	---	0.5979	0.3111	-2.15	0	1.97	-23.09	-23.27
Divide	50.	-309.39	---	-172.28	-275.79	0.022	---	0.5979	0.3111	-6.68	0	-103.01	-85.78	-195.49
Divide	51.	-132.92	---	73.01	-82.44	0.022	---	0.5979	0.3111	-2.87	0	43.65	-25.65	15.13
Divide	52.	18.90	---	186.53	59.98	0.022	---	0.5979	0.3111	0.41	0	111.52	18.66	130.59
Divide	53.	-31.15	---	54.86	-10.07	0.022	---	0.5979	0.3111	-0.67	0	32.80	-3.13	28.99
Divide	54.	-12.05	---	121.91	20.78	0.022	---	0.5979	0.3111	-0.26	0	72.89	6.46	79.09
Divide	55.	-43.29	---	76.79	-13.86	0.022	---	0.5979	0.3111	-0.94	0	45.91	-4.31	40.66
Divide	56.	-19.33	---	84.23	6.05	0.022	---	0.5979	0.3111	-0.42	0	50.36	1.88	51.83
Burleigh	57.	-30.81	12.68	123.57	-3.63	0.23	0.3629	0.38	0.0271	-7.09	4.60	46.96	-0.09	44.37
Burleigh	58.	-123.28	-99.06	-37.29	-108.14	0.23	0.3629	0.38	0.0271	-28.35	-35.95	-14.17	-2.93	-81.40
Burleigh	59.	-60.35	-29.02	50.85	-40.77	0.23	0.3629	0.38	0.0271	-13.88	-10.53	19.32	-1.10	-6.19
Burleigh	60.	-19.30	11.25	89.13	-0.21	0.23	0.3629	0.38	0.0271	-4.44	4.08	33.87	-0.006	33.51

Table A5. Field-Wise Chemical Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Burleigh	61.	113.20	188.27	379.69	160.11	0.23	0.3629	0.38	0.0271	26.04	68.32	144.28	4.34	242.98
Burleigh	62.	13.63	31.32	76.44	24.69	0.23	0.3629	0.38	0.0271	3.13	11.37	29.05	0.67	44.22
Burleigh	63.	-233.43	-164.46	11.41	-190.33	0.23	0.3629	0.38	0.0271	-53.69	-59.68	4.34	-5.16	-114.19
Cass	64.	-145.42	-63.83	-41.584	---	0.355	0.5178	0.1268	---	-51.68	-33.05	-5.27	---	-90.01
Cass	65.	-389.36	-264.40	-230.31	---	0.355	0.5178	0.1268	---	-138.38	-136.90	-29.20	---	-304.49
Cass	66.	-166.25	-94.22	-74.57	---	0.355	0.5178	0.1268	---	-59.09	-48.79	-9.46	---	-117.33
Cass	67.	-52.08	66.40	98.71	---	0.355	0.5178	0.1268	---	-18.51	34.38	12.52	---	28.39
Cass	68.	-103.26	-15.22	8.79	---	0.355	0.5178	0.1268	---	-36.70	-7.88	1.12	---	-43.46
Cass	69.	-160.43	-84.25	-63.47	---	0.355	0.5178	0.1268	---	-57.02	-43.62	-8.05	---	-108.69
Cass	70.	-146.91	-68.38	-46.97	---	0.355	0.5178	0.1268	---	-52.21	-35.41	-5.96	---	-93.58
Cavalier	71.	356.31	439.46	799.78	342.45	0.064	0.3056	0.3984	0.2321	22.73	134.29	318.63	79.48	555.14
Cavalier	72.	61.16	85.78	192.49	57.05	0.064	0.3056	0.3984	0.2321	3.90	26.22	76.69	13.24	120.05

Table A5. Field-Wise Chemical Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Cavalier	73.	39.69	55.71	125.09	37.03	0.064	0.3056	0.3984	0.2321	2.53	17.02	49.83	8.59	77.98
Cavalier	74.	-19.54	9.017	132.74	-24.29	0.064	0.3056	0.3984	0.2321	-1.25	2.76	52.89	-5.64	48.76
Cavalier	75.	-84.47	-59.41	49.20	-88.65	0.064	0.3056	0.3984	0.2321	-5.39	-18.15	19.60	-20.57	-24.52
Cavalier	76.	44.19	78.74	228.46	38.43	0.064	0.3056	0.3984	0.2321	2.82	24.06	91.02	8.92	126.82
Cavalier	77.	-135.81	-116.67	-33.71	-138.99	0.064	0.3056	0.3984	0.2321	-8.66	-35.65	-13.43	-32.26	-90.01
Eddy	78.	-125.24	-117.13	-81.98	-126.59	0.225	0.5289	0.2412	0.0047	-28.20	-61.95	-19.77	-0.59	-110.52
Eddy	79.	-11.07	14.21	123.74	-15.28	0.225	0.5289	0.2412	0.0047	-2.49	7.51	29.85	-0.07	34.79
Eddy	80.	33.59	79.51	278.50	25.94	0.225	0.5289	0.2412	0.0047	7.57	42.05	67.17	0.12	116.91
Eddy	81.	-324.19	-284.53	-112.66	-330.80	0.225	0.5289	0.2412	0.0047	-73.00	-150.49	-27.17	-1.55	-252.23
Eddy	82.	-29.02	-11.67	63.50	-31.91	0.225	0.5289	0.2412	0.0047	-6.54	-6.17	15.32	-0.15	2.46
Eddy	83.	-25.83	-3.98	90.69	-29.48	0.225	0.5289	0.2412	0.0047	-5.82	-2.11	21.88	-0.14	13.81
Eddy	84.	-98.07	-77.10	13.79	-101.57	0.225	0.5289	0.2412	0.0047	-22.09	-40.78	3.33	-0.48	-60.02

Table A5. Field-Wise Chemical Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Foster	85.	-85.00	-56.34	67.88	-89.78	0.225	0.5289	0.2412	0.0047	-19.14	-29.80	16.37	-0.42	-32.99
Foster	86.	-24.08	8.08	147.48	-29.45	0.225	0.5289	0.2412	0.0047	-5.42	4.28	35.57	-0.14	34.29
Foster	87.	-59.11	-37.61	55.55	-62.70	0.225	0.5289	0.2412	0.0047	-13.31	-19.89	13.40	-0.29	-20.10
Foster	88.	-130.11	-106.89	-6.24	-133.98	0.225	0.5289	0.2412	0.0047	-29.30	-56.53	-1.51	-0.63	-87.97
Foster	89.	-101.27	-80.40	10.05	-104.75	0.225	0.5289	0.2412	0.0047	-22.81	-42.52	2.42	-0.49	-63.40
Foster	90.	-27.63	-10.70	62.66	-30.45	0.225	0.5289	0.2412	0.0047	-6.22	-5.66	15.11	-0.14	3.09
Foster	91.	18.65	53.38	203.88	12.86	0.225	0.5289	0.2412	0.0047	4.20	28.23	49.18	0.06	81.67
Griggs	92.	18.23	50.52	190.43	12.85	0.225	0.5289	0.2412	0.0047	4.10	26.72	45.93	0.06	76.81
Griggs	93.	190.95	253.56	524.86	180.52	0.225	0.5289	0.2412	0.0047	43.00	134.11	126.60	0.85	304.55
Griggs	94.	-31.76	5.68	167.91	-37.99	0.225	0.5289	0.2412	0.0047	-7.15	3.00	40.50	-0.18	36.17
Griggs	95.	-110.20	-83.51	32.13	-114.65	0.225	0.5289	0.2412	0.0047	-24.82	-44.17	7.75	-0.54	-61.78
Griggs	96.	17.60	41.67	145.99	13.58	0.225	0.5289	0.2412	0.0047	3.96	22.04	35.21	0.06	61.28

Table A5. Field-Wise Chemical Costs Savings Considering a Rotation/Crop Mix Scenario (Continued)

County	Field	Net Savings				Land Use Weight				Weighted Net Savings				Total Weighted Net Savings
		Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	Corn	Soybean	HRSW	Canola	
Griggs	97.	-110.20	-92.15	-13.95	-113.21	0.225	0.5289	0.2412	0.0047	-24.82	-48.74	-3.36	-0.53	-77.45
Griggs	98.	-107.78	-79.36	43.81	-112.52	0.225	0.5289	0.2412	0.0047	-24.27	-41.97	10.57	-0.53	-56.21
GrandForks	99.	-335.04	-288.43	-267.25	-337.16	0.225	0.4001	0.4098	0.0266	-54.78	-115.40	-109.52	-8.97	-288.67
GrandForks	100.	-114.51	4.62	58.77	-119.93	0.225	0.4001	0.4098	0.0266	-18.72	1.85	24.08	-3.19	4.02
GrandForks	101.	-221.08	-145.02	-110.45	-224.54	0.225	0.4001	0.4098	0.0266	-36.15	-58.02	-45.26	-5.97	-145.40
GrandForks	102.	-271.29	-204.58	-174.26	-274.32	0.225	0.4001	0.4098	0.0266	-44.36	-81.85	-71.41	-7.30	-204.92
GrandForks	103.	-247.31	-174.26	-141.06	-250.63	0.225	0.4001	0.4098	0.0266	-40.44	-69.72	-57.81	-6.67	-174.63
GrandForks	104.	-515.68	-374.90	-310.91	-522.07	0.225	0.4001	0.4098	0.0266	-84.31	-149.99	-127.41	-13.89	-375.61
GrandForks	105	-120.52	-7.75	43.50	-125.65	0.225	0.4001	0.4098	0.0266	-19.71	-3.10	17.83	-3.34	-8.32
Average										-5.76	-1.46	39.98	-1.26	31.50

Table A6. Discounted NPV Table for the Total Savings Obtained by ASC

Budget Region	County	Field	Initial Investment (Cost of ASC) ($)		Discount Factor	NPV of Savings ($)	
			Planter	Sprayer		Planter	Sprayer
South-East	Barnes	1.	393.66	291.10	0.08	3,002.36	1,723.28
South-East	Barnes	2.	139.57	103.20	0.08	1,401.40	662.54
South-East	Barnes	3.	399.00	295.05	0.08	2,080.47	1,791.67
South-East	Barnes	4.	412.30	304.88	0.08	1,422.82	1,664.56
South-East	Barnes	5.	739.41	546.77	0.08	3,564.59	2,573.09
South-East	Barnes	6.	432.31	319.68	0.08	1,128.26	828.08
South-East	Barnes	7.	184.55	136.47	0.08	1,553.40	884.75
South-East	Dicky	8.	274.21	204.45	0.08	2,177.63	1,100.34
South-East	Dicky	9.	443.57	330.73	0.08	4,095.39	1,870.28
South-East	Dicky	10.	267.10	199.15	0.08	2,768.58	1,518.87
South-East	Dicky	11.	171.52	127.89	0.08	1,254.06	708.03
South-East	Dicky	12.	419.26	312.60	0.08	6,955.30	11,364.41
South-East	Dicky	13.	325.95	243.03	0.08	3,194.87	1,323.77
South-East	Dicky	14.	382.52	285.21	0.08	895.33	662.08

Table A6. Discounted NPV Table for the Total Savings Obtained by ASC (Continued)

Budget Region	County	Field	Initial Investment (Cost of ASC) ($)		Discount Factor	NPV of Savings ($)	
			Planter	Sprayer		Planter	Sprayer
South-West	Billings	15.	73.67	36.25	0.08	101.10	1,106.79
South-West	Billings	16.	240.42	118.30	0.08	385.74	625.68
South-West	Billings	17.	214.26	105.43	0.08	584.53	1,148.48
South-West	Billings	18.	142.99	70.36	0.08	458.58	3,405.90
South-West	Billings	19.	270.82	133.25	0.08	681.63	1,515.33
South-West	Billings	20.	118.50	58.30	0.08	376.00	720.74
South-West	Billings	21.	266.86	131.31	0.08	454.76	959.91
South-West	Bowman	22.	345.95	210.49	0.08	25.69	491.32
South-West	Bowman	23.	278.15	169.24	0.08	1,734.22	1,972.45
South-West	Bowman	24.	294.00	178.88	0.08	533.37	1,329.07
South-West	Bowman	25.	255.73	155.59	0.08	369.09	1,064.92
South-West	Bowman	26.	193.25	117.58	0.08	248.83	542.64
South-West	Bowman	27.	340.75	207.32	0.08	199.27	775.92
South-West	Bowman	28.	209.32	127.35	0.08	221.28	818.83

Table A6. Discounted NPV Table for the Total Savings Obtained by ASC (Continued)

Budget Region	County	Field	Initial Investment (Cost of ASC) ($)		Discount Factor	NPV of Savings ($)	
			Planter	Sprayer		Planter	Sprayer
South-West	Dunn	29.	246.92	163.73	0.08	562.52	1,228.01
South-West	Dunn	30.	755.86	501.21	0.08	4,378.06	5,558.51
South-West	Dunn	31.	324.20	214.98	0.08	358.44	1,121.25
South-West	Dunn	32.	148.41	98.41	0.08	388.38	525.63
South-West	Dunn	33.	323.64	214.61	0.08	176.96	772.36
South-West	Dunn	34.	574.04	380.65	0.08	424.19	1,537.39
South-West	Dunn	35.	195.56	129.67	0.08	474.86	1,166.83
North-Central	Bottineau	36.	458.56	353.35	0.08	205.36	833.32
North-Central	Bottineau	37.	457.75	352.72	0.08	551.06	666.48
North-Central	Bottineau	38.	874.64	673.96	0.08	2,111.38	368.73
North-Central	Bottineau	39.	417.80	321.94	0.08	3,922.62	3,107.22
North-Central	Bottineau	40.	433.99	334.42	0.08	4,317.51	3,055.27
North-Central	Bottineau	41.	418.71	322.64	0.08	1,801.98	1,672.67
North-Central	Bottineau	42.	311.76	240.23	0.08	2,001.88	1,328.01

Table A6. Discounted NPV Table for the Total Savings Obtained by ASC (Continued)

Budget Region	County	Field	Initial Investment (Cost of ASC) ($)		Discount Factor	NPV of Savings ($)	
			Planter	Sprayer		Planter	Sprayer
North West	Burke	43.	402.79	295.26	0.08	748.63	1,075.72
North West	Burke	44.	413.52	303.13	0.08	3,140.73	3,567.44
North West	Burke	45.	435.29	319.08	0.08	271.03	848.08
North West	Burke	46.	347.69	254.87	0.08	876.93	1,511.82
North West	Burke	47.	184.37	135.15	0.08	490.23	680.02
North West	Burke	48.	414.71	303.99	0.08	942.46	1,445.52
North West	Burke	49.	410.16	300.67	0.08	583.35	1,173.54
North West	Divide	50.	795.30	578.23	0.08	597.39	1,390.63
North West	Divide	51.	738.16	536.69	0.08	1,443.00	2,420.38
North West	Divide	52.	426.07	309.78	0.08	1,549.22	2,097.33
North West	Divide	53.	274.78	199.78	0.08	663.44	1,035.25
North West	Divide	54.	377.87	274.73	0.08	903.41	1,649.00
North West	Divide	55.	383.38	278.74	0.08	678.34	1,445.60
North West	Divide	56.	305.85	222.37	0.08	401.49	1,264.67

Table A6. Discounted NPV Table for the Total Savings Obtained by ASC (Continued)

Budget Region	County	Field	Initial Investment (Cost of ASC) ($)		Discount Factor	NPV of Savings ($)	
			Planter	Sprayer		Planter	Sprayer
South-Central	Burleigh	57.	399.98	248.23	0.08	1,782.87	1,433.27
South-Central	Burleigh	58.	393.79	244.39	0.08	605.16	692.25
South-Central	Burleigh	59.	349.58	216.96	0.08	1,082.07	994.22
South-Central	Burleigh	60.	277.16	172.01	0.08	1,324.26	1,009.02
South-Central	Burleigh	61.	422.38	262.14	0.08	2,337.26	2,640.57
South-Central	Burleigh	62.	120.59	74.84	0.08	712.63	609.36
South-Central	Burleigh	63.	931.79	578.29	0.08	1,797.72	2,088.70
South Valley	Cass	64.	442.17	330.84	0.08	1,031.38	1,053.11
South Valley	Cass	65.	899.98	673.38	0.08	1,729.88	1,446.50
South Valley	Cass	66.	440.99	329.96	0.08	944.75	891.97
South Valley	Cass	67.	429.49	321.35	0.08	2,837.07	1,688.46
South Valley	Cass	68.	405.43	303.35	0.08	1,441.57	1,190.11
South Valley	Cass	69.	445.82	333.57	0.08	798.22	958.72
South Valley	Cass	70.	434.88	325.39	0.08	1,374.10	1,006.73

Table A6. Discounted NPV Table for the Total Savings Obtained by ASC (Continued)

Budget Region	County	Field	Initial Investment (Cost of ASC) ($)		Discount Factor	NPV of Savings ($)	
			Planter	Sprayer		Planter	Sprayer
North-East	Cavalier	71.	401.39	281.18	0.08	6,088.97	4,524.70
North-East	Cavalier	72.	182.21	127.64	0.08	1,567.45	1,295.65
North-East	Cavalier	73.	118.57	83.06	0.08	612.54	842.34
North-East	Cavalier	74.	340.37	238.44	0.08	1,007.96	1,411.82
North-East	Cavalier	75.	394.88	276.62	0.08	878.35	1,171.95
North-East	Cavalier	76.	315.06	220.70	0.08	1,563.41	1,776.25
North-East	Cavalier	77.	403.38	282.57	0.08	599.33	823.85
East-Central	Eddy	78.	254.11	187.43	0.08	407.95	1,100.34
East-Central	Eddy	79.	277.74	204.86	0.08	1,611.15	1,870.28
East-Central	Eddy	80.	431.75	318.46	0.08	3,731.52	1,518.87
East-Central	Eddy	81.	851.78	628.27	0.08	1,373.68	708.03
East-Central	Eddy	82.	219.67	162.03	0.08	1,556.81	11,364.41
East-Central	Eddy	83.	262.13	193.34	0.08	1,969.48	1,323.77
East-Central	Eddy	84.	350.98	258.88	0.08	1,165.22	662.08

Table A6. Discounted NPV Table for the Total Savings Obtained by ASC (Continued)

Budget Region	County	Field	Initial Investment (Cost of ASC) ($)		Discount Factor	NPV of Savings ($)	
			Planter	Sprayer		Planter	Sprayer
East-Central	Foster	85.	413.15	304.76	0.08	1,634.68	1,390.63
East-Central	Foster	86.	366.97	270.70	0.08	1,640.70	2,420.38
East-Central	Foster	87.	303.58	223.94	0.08	1,739.53	2,097.33
East-Central	Foster	88.	417.78	308.18	0.08	1,050.88	1,035.25
East-Central	Foster	89.	354.23	261.30	0.08	881.08	1,649.00
East-Central	Foster	90.	213.41	157.43	0.08	1,208.83	1,445.60
East-Central	Foster	91.	335.69	247.63	0.08	2,262.43	1,264.67
East-Central	Griggs	92.	344.07	229.31	0.08	1,863.73	1,228.01
East-Central	Griggs	93.	433.68	289.04	0.08	4,149.19	5,558.51
East-Central	Griggs	94.	478.29	318.77	0.08	2,439.12	1,121.25
East-Central	Griggs	95.	472.35	314.81	0.08	1,527.80	525.63
East-Central	Griggs	96.	250.53	166.97	0.08	937.13	772.36
East-Central	Griggs	97.	372.95	248.56	0.08	1,208.10	1,537.39
East-Central	Griggs	98.	488.66	325.68	0.08	1,750.20	1,166.83

Table A6. Discounted NPV Table for the Total Savings Obtained by ASC (Continued)

Budget Region	County	Field	Initial Investment (Cost of ASC) ($)		Discount Factor	NPV of Savings ($)	
			Planter	Sprayer		Planter	Sprayer
North Valley	GrandForks	99.	526.63	432.49	0.08	349.42	254.52
North Valley	GrandForks	100.	442.74	363.60	0.08	1,367.11	1,172.35
North Valley	GrandForks	101.	462.86	380.12	0.08	759.03	2,183.47
North Valley	GrandForks	102.	500.19	410.77	0.08	389.45	1,532.71
North Valley	GrandForks	103.	487.13	400.05	0.08	618.06	783.22
North Valley	GrandForks	104.	986.35	810.02	0.08	1,082.32	997.10
North Valley	GrandForks	105	433.87	356.31	0.08	944.20	883.90
Average						1433.99	1463.91

Table A7. Sensitivity Analysis-Net Seed Costs Savings by Varying the Seed Cost Between +/-10%

County	Field	Changes in Corn Seed Cost Savings			Changes in Soybean Seed Cost Savings			Changes in HRSW Seed Cost Savings			Changes in Canola Seed Cost Savings		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Barnes	1.	322.88	402.50	482.11	112.22	168.42	224.64	-275.87	-262.78	-249.69	29.51	76.53	123.55
Barnes	2.	185.57	221.70	257.82	89.98	115.49	140.99	-86.12	-80.18	-74.24	52.45	73.79	95.12
Barnes	3.	124.15	182.28	240.41	-29.66	11.38	52.42	-313.01	-303.45	-293.89	-90.05	-55.72	-21.39
Barnes	4.	-25.10	17.93	60.95	-138.93	-108.56	-78.18	-348.64	-341.57	-334.50	-183.63	-158.22	-132.81
Barnes	5.	168.71	269.61	370.52	-98.27	-27.04	44.20	-590.12	-573.53	-556.95	-203.10	-143.51	-83.92
Barnes	6.	-103.04	-66.45	-29.87	-199.84	-174.01	-148.18	-378.18	-372.17	-366.15	-237.85	-216.25	-194.64
Barnes	7.	182.15	222.89	263.64	74.34	103.11	131.87	-124.27	-117.57	-110.87	32.01	56.08	80.14
Dicky	8.	243.11	300.59	358.07	91.02	131.60	172.18	-189.17	-179.72	-170.27	31.31	65.25	99.20
Dicky	9.	514.13	620.54	726.95	232.57	307.69	382.82	-286.13	-268.64	-251.14	122.02	184.86	247.71
Dicky	10.	373.42	444.58	515.75	185.11	235.35	285.60	-161.80	-150.10	-138.40	111.17	153.20	195.23
Dicky	11.	129.27	162.69	196.11	40.84	64.43	88.03	-122.08	-116.58	-111.09	6.11	25.85	45.59
Dicky	12.	1136.74	1309.63	1482.52	679.28	801.34	923.40	-163.46	-135.04	-106.62	499.67	601.77	703.88
Dicky	13.	416.93	499.47	582.01	198.52	256.80	315.07	-203.82	-190.25	-176.68	112.77	161.52	210.27
Dicky	14.	-112.90	-82.94	-52.99	-192.16	-171.02	-149.86	-338.20	-333.27	-328.35	-223.29	-205.60	-187.91
Billings	15.	-1.44	6.59	14.61	---	---	---	-58.11	-56.38	-54.65	-8.49	-1.25	5.99
Billings	16.	18.37	47.13	75.88	---	---	---	-184.67	-178.48	-172.28	-6.89	19.06	45.00
Billings	17.	115.88	152.56	189.24	---	---	---	-143.14	-135.24	-127.34	83.65	116.75	149.85
Billings	18.	105.64	133.27	160.89	---	---	---	-89.43	-83.48	-77.53	81.37	106.30	131.23
Billings	19.	122.83	166.57	210.30	---	---	---	-186.02	-176.60	-167.17	84.40	123.87	163.34
Billings	20.	85.88	108.59	131.30	---	---	---	-74.47	-69.58	-64.68	65.93	86.42	106.91
Billings	21.	31.38	64.52	97.66	---	---	---	-202.61	-195.47	-188.34	2.27	32.17	62.08
Bowman	22.	-192.35	-175.29	-158.22	---	---	---	-312.87	-309.19	-305.51	-207.35	-191.95	-176.55
Bowman	23.	553.56	645.97	738.38	---	---	---	-98.99	-79.08	-59.17	472.37	555.76	639.15
Bowman	24.	47.95	85.95	123.94	---	---	---	-220.34	-212.15	-203.97	14.57	48.86	83.14
Bowman	25.	2.51	31.20	59.90	---	---	---	-200.10	-193.92	-187.74	-22.70	3.19	29.08
Bowman	26.	-10.54	9.76	30.07	---	---	---	-153.89	-149.52	-145.14	-28.37	-10.05	8.26
Bowman	27.	-117.56	-92.76	-67.96	---	---	---	-292.67	-287.33	-281.98	-139.35	-116.97	-94.59
Bowman	28.	-31.35	-11.58	8.20	---	---	---	-170.98	-166.72	-162.46	-48.73	-30.88	-13.04
Dunn	29.	87.62	124.79	161.97	---	---	---	-174.85	-166.84	-158.84	54.96	88.51	122.05
Dunn	30.	1365.99	1601.75	1837.52	---	---	---	-298.76	-247.98	-197.19	1158.86	1371.60	1584.34
Dunn	31.	-42.06	-10.71	20.64	---	---	---	-263.42	-256.66	-249.91	-69.60	-41.32	-13.03

Table A7. Sensitivity Analysis-Net Seed Costs Savings by Varying the Seed Cost Between +/-10% (Continued)

County	Field	Changes in Corn Seed Cost Savings			Changes in Soybean Seed Cost Savings			Changes in HRSW Seed Cost Savings			Changes in Canola Seed Cost Savings		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Dunn	32.	73.44	98.09	122.74	---	---	---	-100.62	-95.31	-90.00	51.78	74.03	96.27
Dunn	33.	-116.74	-93.76	-70.77	---	---	---	-279.07	-274.12	-269.17	-136.94	-116.20	-95.45
Dunn	34.	-161.47	-115.63	-69.79	---	---	---	-485.16	-475.29	-465.41	-201.75	-160.38	-119.01
Dunn	35.	81.53	112.31	143.10	---	---	---	-135.87	-129.23	-122.60	54.48	82.26	110.04
Bottineau	36.	-277.52	-257.41	-237.29	-298.75	-280.99	-263.23	-422.39	-418.38	-414.36	-324.88	-310.02	-295.17
Bottineau	37.	-182.66	-152.09	-121.53	-214.91	-187.93	-160.95	-402.79	-396.68	-390.58	-254.61	-232.04	-209.47
Bottineau	38.	-60.39	30.08	120.55	-155.86	-75.99	3.87	-711.97	-693.89	-675.82	-273.38	-206.57	-139.76
Bottineau	39.	765.77	897.27	1028.78	627.01	743.10	859.19	-181.35	-155.07	-128.80	456.18	553.29	650.40
Bottineau	40.	861.67	1005.63	1149.60	709.77	836.85	963.94	-175.15	-146.39	-117.63	522.76	629.07	735.38
Bottineau	41.	186.84	254.13	321.41	115.85	175.24	234.64	-297.73	-284.29	-270.85	28.45	78.13	127.82
Bottineau	42.	319.14	389.24	459.34	245.17	307.05	368.93	-185.72	-171.71	-157.71	154.12	205.88	257.64
Burke	43.	15.48	61.95	108.43	---	---	---	-312.68	-302.67	-292.66	-25.35	16.58	58.52
Burke	44.	877.60	1021.06	1164.52	---	---	---	-135.38	-104.48	-73.57	751.56	881.02	1010.47
Burke	45.	-178.71	-150.20	-121.69	---	---	---	-380.01	-373.87	-367.73	-203.76	-178.03	-152.31
Burke	46.	97.17	146.60	196.02	---	---	---	-251.86	-241.21	-230.56	53.74	98.34	142.95
Burke	47.	60.68	87.91	115.14	---	---	---	-131.58	-125.71	-119.85	36.7	61.33	85.90
Burke	48.	78.30	133.08	187.85	---	---	---	-308.50	-296.70	-284.90	30.17	79.60	129.03
Burke	49.	-49.26	-9.16	30.94	---	---	---	-332.42	-323.78	-315.14	-84.49	-48.30	-12.12
Divide	50.	-289.39	-233.17	-176.96	---	---	---	-686.31	-674.20	-662.09	-338.77	-288.05	-237.32
Divide	51.	54.17	142.21	230.24	---	---	---	-567.48	-548.51	-529.55	-23.18	56.26	135.71
Divide	52.	291.47	371.20	450.93	---	---	---	-271.50	-254.32	-237.15	221.43	293.37	365.32
Divide	53.	66.04	103.91	141.78	---	---	---	-201.36	-193.20	-185.05	32.77	66.94	101.11
Divide	54.	87.57	139.29	191.00	---	---	---	-277.60	-266.46	-255.32	42.14	88.80	135.47
Divide	55.	2.30	45.15	88.00	---	---	---	-300.30	-291.07	-281.84	-35.35	3.32	41.99
Divide	56.	-48.90	-20.35	8.20	---	---	---	-250.50	-244.35	-238.20	-73.99	-48.23	-22.46
Burleigh	57.	139.70	199.67	259.63	61.75	113.06	164.36	-295.48	-283.87	-272.26	-13.74	29.18	72.09
Burleigh	58.	-146.81	-119.37	-91.93	-182.48	-159.00	-135.53	-345.97	-340.65	-335.34	-217.03	-197.39	-177.75
Burleigh	59.	4.38	43.70	83.03	-46.75	-13.10	20.55	-281.05	-273.43	-265.82	-96.26	-68.12	-39.97
Burleigh	60.	118.77	162.76	206.75	61.58	99.22	136.86	-200.50	-191.98	-183.46	6.20	37.68	69.17
Burleigh	61.	259.90	335.71	411.52	161.36	226.22	291.08	-290.27	-275.59	-260.91	65.92	120.17	174.43
Burleigh	62.	85.41	108.30	131.19	55.66	75.24	94.82	-80.70	-76.27	-71.84	26.84	43.22	59.60

Table A7. Sensitivity Analysis-Net Seed Costs Savings by Varying the Seed Cost Between +/-10% (Continued)

County	Field	Changes in Corn Seed Cost Savings			Changes in Soybean Seed Cost Savings			Changes in HRSW Seed Cost Savings			Changes in Canola Seed Cost Savings		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Burleigh	63.	-256.96	-181.97	-106.99	-354.43	-290.28	-226.12	-801.13	-786.61	-772.09	-448.83	-395.16	-341.50
Cass	64.	-112.63	-76.02	-39.41	-237.82	-215.12	-192.41	-380.25	-373.37	-366.48	---	---	---
Cass	65.	-311.86	-246.51	-181.16	-535.29	-494.76	-454.24	-789.47	-777.19	-764.91	---	---	---
Cass	66.	-131.10	-96.67	-62.23	-248.83	-227.48	-206.12	-382.76	-376.29	-369.82	---	---	---
Cass	67.	301.02	382.19	463.36	23.50	73.83	124.17	-292.22	-276.97	-261.71	---	---	---
Cass	68.	7.62	53.52	99.41	-149.29	-120.84	-92.38	-327.81	-319.19	-310.56	---	---	---
Cass	69.	-167.61	-136.70	-105.79	-273.30	-254.13	-234.96	-393.54	-387.73	-381.92	---	---	---
Cass	70.	-30.34	14.61	59.56	-184.02	-156.15	-128.28	-358.87	-350.41	-341.97	---	---	---
Cavalier	71.	1461.05	1667.99	1874.93	1113.5	1281.92	1450.25	-48.62	-9.43	29.77	865.89	1006.70	1147.51
Cavalier	72.	319.87	375.65	431.44	226.20	271.58	316.95	-87.11	-76.54	-65.98	159.42	197.38	235.34
Cavalier	73.	91.23	114.54	137.85	52.09	71.05	90.01	-78.83	-74.41	-69.99	24.19	40.05	55.91
Cavalier	74.	46.54	89.53	132.52	-25.65	9.32	44.29	-267.09	-258.95	-250.80	-77.10	-47.85	-18.60
Cavalier	75.	-29.52	11.08	51.67	-97.68	-64.66	-31.64	-325.67	-317.98	-310.30	-146.27	-118.65	-91.03
Cavalier	76.	223.98	283.87	343.76	123.41	172.13	220.85	-212.96	-201.61	-190.27	51.72	92.48	133.2
Cavalier	77.	-115.65	-83.68	-51.71	-169.33	-143.32	-117.31	-348.88	-342.82	-336.77	-207.59	-185.84	-164.09
Eddy	78.	-103.65	-86.93	-70.22	-135.59	-122.42	-109.26	-226.51	-223.44	-220.38	-154.97	-143.95	-132.94
Eddy	79.	151.52	199.21	246.91	60.39	97.96	135.53	-199.01	-190.26	-181.51	5.10	36.53	67.96
Eddy	80.	514.36	619.49	724.61	313.51	396.32	479.13	-258.22	-238.94	-219.65	191.66	260.93	330.20
Eddy	81.	-346.04	-289.84	-233.65	-453.40	-409.14	-364.88	-759.02	-748.71	-738.41	-518.54	-481.51	-444.48
Eddy	82.	184.04	228.89	273.75	98.33	133.67	169.00	-145.63	-137.40	-129.17	46.34	75.90	105.45
Eddy	83.	245.01	301.36	357.71	137.35	181.74	226.12	-169.11	-158.77	-148.44	72.04	109.17	146.30
Eddy	84.	-6.41	31.87	70.15	-79.56	-49.41	-19.25	-287.78	-280.76	-273.73	-123.94	-98.71	-73.49
Foster	85.	52.23	103.94	155.65	-46.57	-5.84	34.90	-327.79	-318.30	-308.82	-106.50	-72.43	-38.36
Foster	86.	89.28	139.97	190.67	-7.58	32.35	72.28	-283.29	-273.99	-264.69	-66.34	-32.94	0.47
Foster	87.	160.73	212.32	263.91	62.16	102.80	143.44	-218.41	-208.95	-199.49	2.36	36.36	70.35
Foster	88.	-84.02	-46.93	-9.85	-154.87	-125.66	-96.45	-356.56	-349.76	-342.95	-197.86	-173.42	-148.98
Foster	89.	-73.50	-42.31	-11.12	-133.10	-108.53	-83.96	-302.74	-297.01	-291.29	-169.25	-148.70	-128.14
Foster	90.	109.80	145.71	181.62	41.18	69.47	97.76	-154.13	-147.54	-140.96	-0.44	23.22	46.88
Foster	91.	254.74	320.34	385.95	129.40	181.07	232.75	-227.39	-215.36	-203.33	53.36	96.58	139.81
Griggs	92.	157.66	213.41	269.16	51.15	95.06	138.98	-252.04	-241.81	-231.59	-13.47	23.27	60.00
Griggs	93.	607.80	723.52	839.24	386.70	477.86	569.01	-242.65	-221.42	-200.20	252.57	328.82	405.07

Table A7. Sensitivity Analysis-Net Seed Costs Savings by Varying the Seed Cost Between +/-10% (Continued)

County	Field	Changes in Corn Seed Cost Savings			Changes in Soybean Seed Cost Savings			Changes in HRSW Seed Cost Savings			Changes in Canola Seed Cost Savings		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Griggs	94.	184.70	258.37	332.03	43.95	101.98	160.01	-356.69	-343.17	-329.66	-41.43	7.11	55.65
Griggs	95.	-17.80	32.70	83.20	-114.30	-74.52	-34.73	-388.97	-379.71	-370.45	-172.84	-139.56	-106.28
Griggs	96.	19.37	49.36	79.35	-37.93	-14.30	9.32	-201.02	-195.52	-190.02	-72.69	-52.93	-33.17
Griggs	97.	-13.65	26.27	66.19	-89.93	-58.48	-27.03	-307.05	-299.73	-292.40	-136.20	-109.90	-83.59
Griggs	98.	20.13	76.66	133.19	-87.89	-43.35	1.18	-395.34	-384.97	-374.60	-153.41	-116.16	-78.91
GrandForks	99.	-274.09	-246.03	-217.97	-352.21	-332.83	-313.45	-473.69	-467.80	-461.92	-360.23	-341.74	-323.25
GrandForks	100.	78.99	136.96	194.93	-82.40	-42.36	-2.32	-333.36	-321.20	-309.05	-98.96	-60.76	-22.57
GrandForks	101.	-110.62	-71.48	-32.34	-219.58	-192.55	-165.52	-389.01	-380.81	-372.60	-230.76	-204.97	-179.18
GrandForks	102.	-243.73	-215.23	-186.74	-323.06	-303.38	-283.70	-446.42	-440.44	-434.47	-331.20	-312.43	-293.65
GrandForks	103.	-168.53	-133.13	-97.73	-267.08	-242.63	-218.19	-420.33	-412.91	-405.49	-277.20	-253.87	-230.55
GrandForks	104.	-390.01	-323.75	-257.49	-574.48	-528.71	-482.95	-861.32	-847.43	-833.54	-593.41	-549.75	-506.09
GrandForks	105	-36.61	7.53	51.67	-159.50	-129.01	-98.53	-350.58	-341.33	-332.08	-172.11	-143.03	-113.94

Table A8. Sensitivity Analysis-Net Chemical Costs Savings by Varying the Chemical Cost Between +/-10%

County	Field	Changes in Corn Chemical Cost Savings ($)			Changes in Soybean Chemical Cost Savings ($)			Changes in HRSW Chemical Cost Savings ($)			Changes in Canola Chemical Cost Savings ($)		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Barnes	1.	-12.18	18.81	142.78	21.29	56.00	194.84	144.02	192.36	385.75	-40.07	-12.18	99.39
Barnes	2.	2.83	14.61	61.73	15.55	28.74	81.52	62.20	80.58	154.09	-7.78	2.83	45.24
Barnes	3.	-6.12	25.99	154.40	28.56	64.51	208.34	155.69	205.77	406.10	-35.01	-6.12	109.46
Barnes	4.	-32.18	-1.88	119.32	0.54	34.48	170.22	120.53	167.80	356.87	-59.45	-32.18	76.90
Barnes	5.	-114.78	-66.78	125.22	-62.94	-9.18	205.85	127.14	202.01	501.53	-157.98	-114.78	58.02
Barnes	6.	-160.75	-143.10	-72.46	-141.68	-121.91	-42.80	-71.76	-44.21	65.98	-176.65	-160.75	-97.18
Barnes	7.	4.94	20.65	83.49	21.90	39.50	109.89	84.12	108.63	206.67	-9.20	4.94	61.50
Dicky	8.	-23.79	-3.71	76.58	-2.11	20.38	110.31	77.39	108.70	233.96	-41.85	-23.79	48.48
Dicky	9.	-25.97	7.90	143.35	10.61	48.53	200.23	144.70	197.53	408.83	-56.44	-25.97	95.94
Dicky	10.	38.74	65.17	170.89	67.28	96.89	215.30	171.95	213.18	378.12	14.95	38.74	133.89
Dicky	11.	-12.14	0.72	52.16	1.75	16.15	73.76	52.67	72.74	152.99	-23.72	-12.14	34.15
Dicky	12.	1304.25	1483.90	2202.50	1498.2	1699.47	2504.31	2209.68	2489.9	3610.95	1142.56	1304.25	1950.99
Dicky	13.	-26.08	-1.98	94.44	-0.05	26.95	134.94	95.41	133.01	283.43	-47.78	-26.08	60.70
Dicky	14.	-154.04	-139.47	-81.17	-138.30	-121.98	-56.69	-80.59	-57.85	33.09	-167.16	-154.04	-101.58

Table A8. Sensitivity Analysis-Net Chemical Costs Savings by Varying the Chemical Cost Between +/-10% (Continued)

County	Field	Changes in Corn Chemical Cost Savings ($)			Changes in Soybean Chemical Cost Savings ($)			Changes in HRSW Chemical Cost Savings ($)			Changes in Canola Chemical Cost Savings ($)		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Billings	15.	94.22	108.72	166.70	0	0	0	160.76	182.65	270.21	110.53	126.84	192.07
Billings	16.	-33.38	-23.94	13.80	0	0	0	9.93	24.18	81.17	-22.76	-12.15	30.31
Billings	17.	37.70	53.60	117.21	0	0	0	110.69	134.71	230.76	55.59	73.48	145.04
Billings	18.	326.43	370.52	546.87	0	0	0	528.80	595.37	861.66	376.03	425.63	624.03
Billings	19.	54.92	75.83	159.46	0	0	0	150.89	182.46	308.75	78.44	101.96	196.05
Billings	20.	30.62	40.50	80.02	0	0	0	75.97	90.89	150.56	41.73	52.85	97.31
Billings	21.	-6.75	7.09	62.44	0	0	0	56.77	77.67	161.26	8.82	24.39	86.66
Bowman	22.	-130.38	-121.48	-85.88	0	0	0	-89.53	-76.08	-22.32	-120.37	-110.35	-70.30
Bowman	23.	75.22	102.38	211.03	0	0	0	199.90	240.91	404.97	105.78	136.34	258.57
Bowman	24.	-6.76	12.37	88.87	0	0	0	81.03	109.90	225.42	14.76	36.27	122.33
Bowman	25.	-16.28	-0.80	61.12	0	0	0	54.77	78.14	171.64	1.13	18.55	88.21
Bowman	26.	-42.22	-33.85	-0.35	0	0	0	-3.79	8.86	59.43	-32.80	-23.38	14.30
Bowman	27.	-95.09	-82.62	-32.74	0	0	0	-37.85	-19.02	56.30	-81.06	-67.03	-10.92
Bowman	28.	-19.35	-7.35	40.65	0	0	0	35.73	53.85	126.33	-5.85	7.65	61.65

Table A8. Sensitivity Analysis-Net Chemical Costs Savings by Varying the Chemical Cost Between +/-10% (Continued)

County	Field	Changes in Corn Chemical Cost Savings ($)			Changes in Soybean Chemical Cost Savings ($)			Changes in HRSW Chemical Cost Savings ($)			Changes in Canola Chemical Cost Savings ($)		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Dunn	29.	-4.88	12.77	83.38	0	0	0	76.14	102.79	209.41	14.98	34.84	114.27
Dunn	30.	190.46	267.31	574.72	0	0	0	543.21	659.26	1123.45	276.92	363.38	709.22
Dunn	31.	-62.46	-45.51	22.28	0	0	0	15.33	40.92	143.28	-43.39	-24.33	51.94
Dunn	32.	-27.18	-19.27	12.39	0	0	0	9.14	21.09	68.90	-18.28	-9.38	26.24
Dunn	33.	-101.95	-89.44	-39.37	0	0	0	-44.50	-25.60	50.01	-87.87	-73.79	-17.46
Dunn	34.	-161.72	-137.39	-40.09	0	0	0	-50.06	-13.33	133.59	-134.35	-106.99	2.48
Dunn	35.	18.31	34.75	100.53	0	0	0	93.79	118.61	217.93	36.81	55.31	129.30
Bottineau	36.	-215.73	-200.44	-139.27	-215.73	-200.44	-139.27	-111.13	-84.22	23.43	-198.52	-181.32	-112.51
Bottineau	37.	-234.52	-221.39	-168.85	-234.52	-221.39	-168.85	-144.69	-121.57	-29.12	-219.75	-204.97	-145.87
Bottineau	38.	-553.04	-539.60	-485.86	-553.04	-539.60	-485.86	-461.13	-437.49	-342.90	-537.92	-522.80	-462.34
Bottineau	39.	75.75	119.94	296.69	75.75	119.94	296.69	377.99	455.76	766.84	125.46	175.17	374.02
Bottineau	40.	58.69	102.37	277.09	58.69	102.37	277.09	357.46	434.33	741.83	107.83	156.97	353.53
Bottineau	41.	-91.24	-65.52	37.32	-91.24	-65.52	37.32	84.63	129.88	310.89	-62.31	-33.39	82.31
Bottineau	42.	-58.35	-38.15	42.69	-58.35	-38.15	42.69	79.87	115.43	257.70	-35.62	-12.89	78.05

Table A8. Sensitivity Analysis-Net Chemical Costs Savings by Varying the Chemical Cost Between +/-10% (Continued)

County	Field	Changes in Corn Chemical Cost Savings ($)			Changes in Soybean Chemical Cost Savings ($)			Changes in HRSW Chemical Cost Savings ($)			Changes in Canola Chemical Cost Savings ($)		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Burke	43.	-126.78	-108.06	-33.18	0	0	0	-40.86	-12.59	100.48	-105.72	-84.66	-0.42
Burke	44.	172.53	225.38	436.78	0	0	0	415.11	494.92	814.13	231.99	291.44	529.27
Burke	45.	-175.65	-159.71	-95.97	0	0	0	-102.50	-78.44	17.82	-157.72	-139.79	-68.08
Burke	46.	-37.76	-13.64	82.85	0	0	0	72.96	109.39	255.09	-10.63	16.51	125.07
Burke	47.	-34.98	-23.84	20.68	0	0	0	16.11	32.92	100.15	-22.45	-9.93	40.16
Burke	48.	-88.99	-65.11	30.44	0	0	0	20.65	56.72	201.01	-62.12	-35.25	72.25
Burke	49.	-119.50	-99.37	-18.85	0	0	0	-27.11	3.29	124.87	-96.86	-74.21	16.37
Divide	50.	-336.27	-309.39	-201.86	0	0	0	-212.88	-172.28	-9.91	-306.03	-275.79	-154.81
Divide	51.	-173.29	-132.92	28.59	0	0	0	12.04	73.01	316.89	-127.87	-82.44	99.25
Divide	52.	-13.97	18.90	150.37	0	0	0	136.90	186.53	385.05	23.01	59.98	207.89
Divide	53.	-48.01	-31.15	36.31	0	0	0	29.40	54.86	156.72	-29.04	-10.07	65.82
Divide	54.	-38.32	-12.05	93.02	0	0	0	82.25	121.91	280.57	-8.77	20.78	138.98
Divide	55.	-66.84	-43.29	50.89	0	0	0	41.23	76.79	218.99	-40.35	-13.86	92.09
Divide	56.	-39.63	-19.33	61.89	0	0	0	53.57	84.23	206.87	-16.79	6.05	97.43

Table A8. Sensitivity Analysis-Net Chemical Costs Savings by Varying the Chemical Cost Between +/-10% (Continued)

County	Field	Changes in Corn Chemical Cost Savings ($)			Changes in Soybean Chemical Cost Savings ($)			Changes in HRSW Chemical Cost Savings ($)			Changes in Canola Chemical Cost Savings ($)		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Burleigh	57.	-52.55	-30.81	56.17	-13.41	12.68	117.04	86.39	123.57	272.29	-28.09	-3.63	94.21
Burleigh	58.	-135.39	-123.28	-74.83	-113.59	-99.06	-40.92	-57.99	-37.29	45.55	-121.77	-108.14	-53.64
Burleigh	59.	-76.01	-60.35	2.30	-47.82	-29.02	46.15	24.07	50.85	157.97	-58.39	-40.77	29.71
Burleigh	60.	-34.57	-19.30	41.79	-7.08	11.25	84.55	63.01	89.13	193.58	-17.39	-0.21	68.51
Burleigh	61.	75.66	113.20	263.33	143.22	188.27	368.43	315.50	379.69	636.42	117.89	160.11	329.02
Burleigh	62.	4.78	13.63	49.02	20.71	31.32	73.79	61.31	76.44	136.96	14.73	24.69	64.50
Burleigh	63.	-267.92	-233.43	-95.49	-205.85	-164.46	1.07	-47.56	11.41	247.30	-229.12	-190.33	-35.14
Cass	64.	-163.96	-145.42	-71.25	-90.53	-63.83	42.97	-70.51	-41.58	74.12	0	0	0
Cass	65.	-417.76	-389.36	-275.76	-305.29	-264.40	-100.80	-274.62	-230.31	-53.09	0	0	0
Cass	66.	-182.62	-166.25	-100.77	-117.79	-94.22	0.08	-100.11	-74.57	27.58	0	0	0
Cass	67.	-79.01	-52.08	55.63	27.62	66.40	221.50	56.70	98.71	266.73	0	0	0
Cass	68.	-123.27	-103.26	-23.22	-44.03	-15.22	100.03	-22.42	8.79	133.65	0	0	0
Cass	69.	-177.74	-160.43	-91.18	-109.18	-84.25	15.48	-90.48	-63.47	44.56	0	0	0
Cass	70.	-164.76	-146.91	-75.53	-94.08	-68.38	34.42	-74.81	-46.97	64.40	0	0	0

Table A8. Sensitivity Analysis-Net Chemical Costs Savings by Varying the Chemical Cost Between +/-10% (Continued)

County	Field	Changes in Corn Chemical Cost Savings ($)			Changes in Soybean Chemical Cost Savings ($)			Changes in HRSW Chemical Cost Savings ($)			Changes in Canola Chemical Cost Savings ($)		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Cavalier	71.	292.56	356.31	611.30	367.39	439.46	727.71	691.68	799.78	1232.16	280.09	342.45	591.90
Cavalier	72.	42.27	61.16	136.67	64.44	85.78	171.15	160.48	192.49	320.54	38.58	57.05	130.93
Cavalier	73.	27.42	39.69	88.80	41.83	55.71	111.21	104.27	125.09	208.34	25.02	37.03	85.06
Cavalier	74.	-41.43	-19.54	68.02	-15.73	9.02	107.99	95.63	132.74	281.22	-45.71	-24.29	61.36
Cavalier	75.	-103.68	-84.47	-7.61	-81.13	-59.41	27.48	16.62	49.20	179.53	-107.44	-88.65	-13.46
Cavalier	76.	17.70	44.19	150.14	48.79	78.74	198.51	183.54	228.46	408.12	12.52	38.43	142.08
Cavalier	77.	-150.48	-135.81	-77.10	-133.25	-116.67	-50.30	-58.60	-33.71	65.83	-153.36	-138.99	-81.57
Eddy	78.	-131.46	-125.24	-100.36	-124.15	-117.13	-89.01	-92.52	-81.98	-39.80	-132.67	-126.59	-102.26
Eddy	79.	-30.45	-11.07	66.44	-7.70	14.21	101.83	90.88	123.74	255.18	-34.24	-15.28	60.55
Eddy	80.	-1.61	33.59	174.41	39.72	79.51	238.70	218.80	278.50	517.28	-8.50	25.94	163.70
Eddy	81.	-354.60	-324.19	-202.56	-318.90	-284.53	-147.04	-164.22	-112.66	93.58	-360.55	-330.80	-211.82
Eddy	82.	-42.32	-29.02	24.18	-26.71	-11.67	48.47	40.95	63.50	153.72	-44.93	-31.91	20.13
Eddy	83.	-42.58	-25.83	41.17	-22.92	-3.98	71.76	62.29	90.69	204.31	-45.86	-29.48	36.07
Eddy	84.	-114.15	-98.07	-33.75	-95.28	-77.10	-4.39	-13.48	13.79	122.85	-117.30	-101.57	-38.65

Table A8. Sensitivity Analysis-Net Chemical Costs Savings by Varying the Chemical Cost Between +/-10% (Continued)

County	Field	Changes in Corn Chemical Cost Savings ($)			Changes in Soybean Chemical Cost Savings ($)			Changes in HRSW Chemical Cost Savings ($)			Changes in Canola Chemical Cost Savings ($)		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
Foster	85.	-106.98	-85.00	2.90	-81.18	-56.34	43.04	30.61	67.88	216.94	-111.28	-89.78	-3.78
Foster	86.	-48.75	-24.08	74.56	-19.79	8.08	119.60	105.66	147.48	314.75	-53.57	-29.45	67.06
Foster	87.	-75.59	-59.11	6.82	-56.25	-37.61	36.92	27.60	55.55	167.34	-78.82	-62.70	1.80
Foster	88.	-147.92	-130.11	-58.89	-127.01	-106.89	-26.37	-36.44	-6.24	114.53	-151.40	-133.98	-64.31
Foster	89.	-117.28	-101.27	-37.26	-98.49	-80.40	-8.04	-17.09	10.05	118.59	-120.41	-104.75	-42.13
Foster	90.	-40.61	-27.63	24.29	-25.37	-10.70	47.99	40.65	62.66	150.70	-43.15	-30.45	20.36
Foster	91.	-7.98	18.65	125.16	23.28	53.38	173.78	158.73	203.88	384.49	-13.19	12.86	117.05
Griggs	92.	-6.53	18.23	117.24	22.53	50.52	162.45	148.45	190.43	358.33	-11.37	12.85	109.71
Griggs	93.	142.95	190.95	382.95	199.30	253.56	470.60	443.47	524.86	850.41	133.56	180.52	368.34
Griggs	94.	-60.46	-31.76	83.05	-26.76	5.68	135.46	119.24	167.91	362.58	-66.07	-37.99	74.32
Griggs	95.	-130.66	-110.20	-28.36	-106.64	-83.51	9.00	-2.56	32.13	170.91	-134.67	-114.65	-34.59
Griggs	96.	-0.86	17.60	91.42	20.81	41.67	125.13	114.70	145.99	271.18	-4.47	13.58	85.81
Griggs	97.	-124.04	-110.20	-54.86	-107.79	-92.15	-29.59	-37.41	-13.95	79.90	-126.74	-113.21	-59.07
Griggs	98.	-129.57	-107.78	-20.62	-103.99	-79.36	19.17	6.86	43.81	191.60	-133.83	-112.52	-27.25

Table A8. Sensitivity Analysis-Net Chemical Costs Savings by Varying the Chemical Cost Between +/-10% (Continued)

County	Field	Changes in Corn Chemical Cost Savings ($)			Changes in Soybean Chemical Cost Savings ($)			Changes in HRSW Chemical Cost Savings ($)			Changes in Canola Chemical Cost Savings ($)		
		Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha	Savings at 10% Lower Seed Cost/ha	Savings at Base cost	Savings at 10% Higher Seed Cost/ha
GrandForks	100.	-139.42	-114.51	-14.88	-32.20	4.62	151.90	16.53	58.77	227.71	-144.29	-119.93	-22.46
GrandForks	101.	-236.99	-221.08	-157.47	-168.53	-145.02	-50.98	-137.42	-110.45	-2.58	-240.10	-224.54	-162.31
GrandForks	102.	-285.24	-271.29	-215.50	-225.20	-204.58	-122.11	-197.91	-174.26	-79.65	-287.97	-274.32	-219.74
GrandForks	103.	-262.58	-247.31	-186.21	-196.84	-174.26	-83.95	-166.96	-141.06	-37.46	-265.57	-250.63	-190.86
GrandForks	104.	-545.11	-515.68	-397.94	-418.41	-374.90	-200.85	-360.82	-310.91	-111.27	-550.87	-522.07	-406.89
GrandForks	105	-144.10	-120.52	-26.21	-42.61	-7.75	131.67	3.52	43.50	203.43	-148.71	-125.65	-33.38