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EVALUATION OF EMISSION REDUCTIONS
AND COST SAVINGS IN SECTIONAL
CONTROL AIR SEEDERS, DRILLS, AND
SOWING EQUIPMENT ACROSS THE
CANADIAN PRAIRIES

ON BEHALF OF

THE ALBERTA PULSE GROWERS
COMMISSION

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Alberta

Canada

Phase 2

Research Report

Evaluation of Emission Reductions and Cost Savings in Sectional Control Air Seeders, Drills, and Sowing Equipment across the Canadian Prairies

For:
Alberta Pulse Growers
Leduc, Alberta

Innovative Solutions
for Agriculture and Beyond

Phase 2

Research Report

Evaluation of Emission Reductions and Cost Savings in Sectional Control Air Seeders, Drills, and Sowing Equipment Across the Canadian Prairies

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Acknowledgement

Table of Contents

1.   Executive Summary

Sectional control technologies are widely available across the Canadian Prairies for modern-day sowing, seeding, and planting equipment. PAMI conducted in-field testing during the 2020 growing season to measure seeded overlap acres of different seeding equipment while also measuring the draft force of equipment that lifts the openers when encountering an overlap area.

Three different types of air seeder equipment were tested in-field to determine actual product overlap on both a pea and canola crop at a headland and around an obstacle. Based on the average measurements, it was found that there was an increased amount of overlap in the canola crop versus the pea crop when measured in the field, though the results varied between the headland and obstacle measurements. The following average overlap of the three tests normalized per foot of implement width for each crop were found:

- **Canola:**
  - Obstacle: 16.8 sqft of overlap/ft implement width
  - Headland: 21.0 sqft of overlap/ft implement width
- **Pea:**
  - Obstacle: 16.0 sqft of overlap/ft implement width
  - Headland: 14.4 sqft of overlap/ft implement width

When reviewing the overlap from the equipment monitor and comparing it to the field measurements, it was found that in most cases the monitor shows a substantially lower overlap amount when compared to what is actually measured in the field.

As can be expected, the implement and section size also influence the total overlap amount. Based on theoretical calculations (of the best-case scenario), it can be stated that typically the greater the implement size and/or the greater the obstacle diameter, the greater the overlap will be. By implementing sectional control technology, there is potential to drastically reduce total field overlap, which could reduce the total product required by producers, resulting in potential cost and environmental savings.

With technologies that lift openers, draft force testing was completed to measure the difference as sections were lifted from the ground. There was a noted reduction in draft force as the sections were lifted across the implement. Though these results were specific to the conditions present during testing and will vary under different conditions, they indicate that there are potential energy savings available from the use of this technology. The actual energy savings depends on multiple factors including soil properties, equipment specifics, product placement, field topography, to name a few.

Though the use of sectional control technology is a tool to help reduce overlap in the field, it is crucial to ensure proper equipment settings prior to seeding to help minimize in-field overlap.

2. Introduction

Overlap control is a crucial element in farm management when considering product (seed, fertilizer), fuel use, time management, and environmental impacts. Advancements in agricultural technology have provided producers with highly efficient equipment to help with on-farm management. With the implementation of global positioning systems (GPS) and auto-steer functions, producers are able to greatly improve efficiencies and better manage overlap while performing field operations. These advancements, along with sectional control technology, have been proven to reduce overlap, and in turn, input costs. Areas with overlapped product are typically found at headlands, around obstacles, associated with the "last pass" of a piece of equipment, or related to manual error. Focusing on overlap reduction in these areas could result in significant cost savings to producers as well as overall environmental benefits.

The approach to every field is unique in terms of obstacles, topography, equipment type, and operator preferences, making it difficult to use one formula across all field types when determining the benefits of using sectional control technology. Field variables, such as size, shape, number of obstacles, and obstacle shape and size will impact the total amount of field overlap.

Input management is a growing priority in agricultural production, and increasing productivity is key to maximizing profit. Historically, to increase productivity, wetlands have been drained, treelines removed, and the natural landscape has been disrupted to improve farming efficiencies. However, with advanced agricultural technologies, these areas can now be left undisturbed. The ability to retain wetlands and diverse natural areas while still managing a productive farming operation is an important stride toward sustainable agriculture.

There is a growing need to understand and implement sustainable farming practices during agricultural production, and new technology has been adapted by producers for modern-day sowing, seeding, and planting. Having a certain amount of overlap on fields is unavoidable; however, the goal is to reduce this amount. Implementing advanced technologies and ensuring proper equipment settings can drastically reduce field overlap on farm.

3.   Project Objectives

Phase Two of this project involved assessing cost savings and potential environmental effects by using sectional control technology. The aim of this project is to enhance the overall understanding of the savings that sectional control may provide.

Ground truthing of actual overlap measurements was conducted on three different pieces of equipment. These in-field measurements were then compared to the associated monitor data to compare the actual in-field overlap to what the equipment operator is seeing on the monitor. Theoretical overlap calculations were also reviewed to provide a better understanding of how certain variables affect the total overlap amount.

A load cell was used to measure the draft of an implement when sections of an implement lifted at previously seeded areas. The force plus the ground speed was used to calculate the power. The difference in power between the tests when the openers were lifted or lowered provides an indication of potential energy savings gained when using this technology.

To gain an understanding on potential cost savings, different overlap scenarios were reviewed, and calculations were completed based on the scenarios to display potential additional costs of overlap.

4. Project Description and Methods

In Phase Two of the project, the Prairie Agricultural Machinery Institute (PAMI) reviewed in-field overlap measurements and theoretical calculated overlap measurements for different equipment section widths used in sectional control. A load cell was used to determine draft measurements of an implement that lifted individual sections of the drill as it encountered previously seeded areas of the field.

4.1 Overlap Measurements

This following subsection details the in-field (actual), displayed, and theoretical measurements taken.

4.1.1 In-Field Actual Measurements

PAMI conducted field work in June 2020 with three different air seeders. To record any differences between small and large seed types, the measurements were repeated in both peas and canola and were taken after crop emergence so that the plants themselves could be visually used for measuring.

Overlap measurements for each row of an implement pass heading both towards and away from the headland were measured to determine the actual overlap area. One set of measurements was taken at a headland with the implement travelling at a 90° angle to the headland, and the second set of measurements was taken as the drill moved toward an obstacle (i.e., a slough, wetland, treeline, angle, etc.). Four measurements per headland were taken, and four sets of measurements per location were recorded to account for implement travel in both directions (i.e., toward the headland/obstacle and away from the headland/obstacle).

It must be noted that the look-ahead and look-behind/turn-on and turn-off times are set by the equipment operator and can vary greatly based on equipment type, product used, seeding speed, as well as other parameters. The settings represent the amount of time it takes to turn the sections on or off. The turn-on time refers to the amount of time the product takes to flow to the openers, and the turn-off time refers to the amount of time it takes to stop the product flow to the openers. **Figure 1** shows three examples outcomes with specific settings; however, actual in-field times will depend on specific equipment settings. Larger implements may also require extended time settings to account for the greater distance of travel as product moves through the distribution system. These manually adjusted settings from the equipment operator can make a substantial difference in terms of the amount of overlap in a field, so ensuring equipment is accurately set is essential to a productive operation.
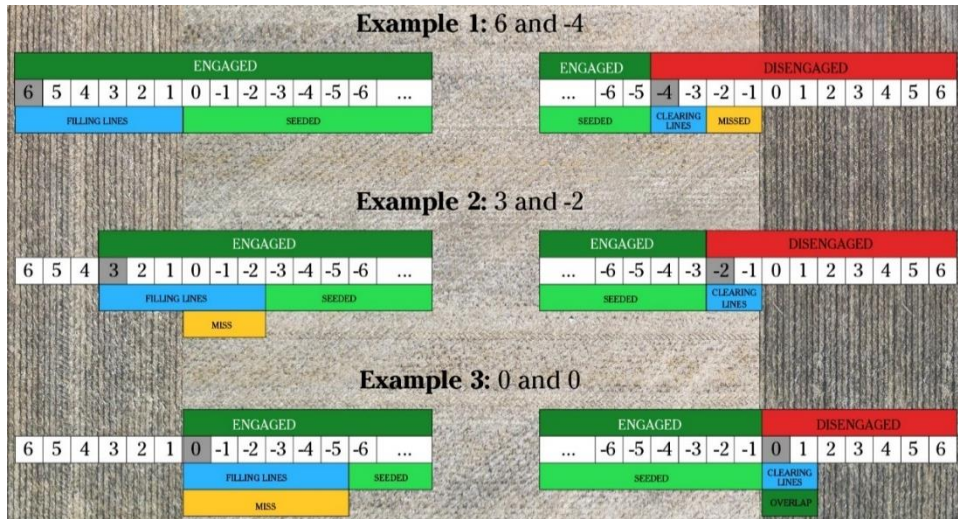
Figure 1. Look-ahead and look-behind time examples (Vaderstad North America, 2020).

4.1.2 Displayed Measurements

With advancements in agriculture technology, overlap measurements are often able to be seen directly on the equipment monitor. Data is recorded as the tasks are performed, and reports are created to give an overview of the operation. The in-field actual measurements were compared to task data that was pulled from the monitor and loaded into the analysis program, QGIS. This was possible with the data from two of the cooperators; however, the data was not available from the third.

Many of the reports provide totals for target rates, actual rates, total acres, time of operation, and more, depending on the system. The data displayed on the monitors provide equipment operators with a general idea of overlap percentage on specific fields. This tool can be used as a management aid, as it provides the operator the ability to see if and how much additional product is being used, which can then be managed accordingly. This data is also beneficial, as it can be saved for reference from year to year.

Although the displayed data is helpful, it may not be entirely accurate when referring to actual product overlap measurements. The metered product through the machine is assumed to be reasonably accurate; however, the time and distance it takes for the product to exit is not typically recognized, as well as the effects of the air fan speed on the seeder.

4.1.3 Theoretical Measurements

Theoretical overlap was calculated by accounting for overlap type, section size, and implement width. The computer-aided design (CAD) program, SolidWorks, was used to model various scenarios. The measurements were calculated to represent ideal field scenarios, meaning the overlap area accounted for the minimum amount of overlap with all of the ground being covered. Overlap depth in the field will differ depending on what

settings are used by the equipment operator, but for the purpose of modelling, best-case scenarios were used.

Previously, PAMI conducted a study of theoretical overlap by reviewing overlap in different field scenarios. These scenarios were based on implement size, field size, obstacle size and number, equipment overlap per pass, and last-pass overlap. The equipment overlap per pass refers to the last shank of an implement following the previous pass, which results in overlap. Information and calculations from this previous study were used to further demonstrate the theoretical overlap of different section/implement sizes in different scenarios for this project.

4.2 Load Cart Measurements

PAMI used a load cart to measure the draft force of the implement as specific sections were lifted in a predetermined sequence. The cart was connected between the tractor and implement, and a load cell was mounted internally to the cart indicated by the arrow in **Figure 2**. This load cell was used to measure the horizontal pull force (draft force) from the tractor to the implement, and it is designed so that vertical and side load forces do not influence these measurements. The data was recorded at a rate of 50 Hz while GPS location and speed were logged. The information was recorded with PAMI's SOMAT eDAQ data acquisition system.

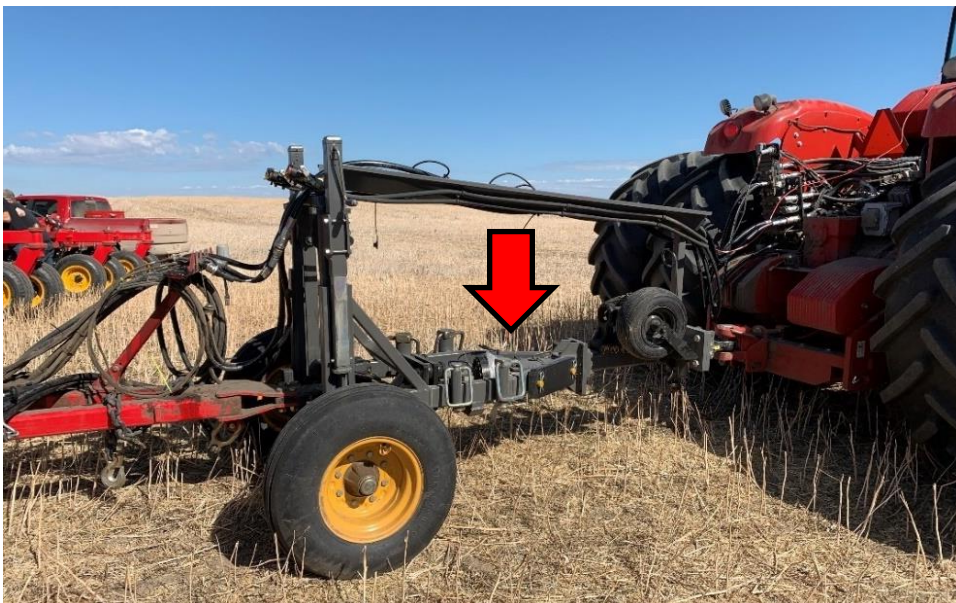**Figure 2.** Load cart attached between the tractor and implement.

The testing took place near Langbank, Saskatchewan, on September 10, 2020. The temperature at the time of seeding was 69.8°F with a west wind of 10.6 mph, gusting to 15.5 mph. An 84 ft Seed Hawk Vaderstad air drill with eight sections was tested at the site. A Versatile 500 tractor equipped with GPS guidance and an auto-steer system was

used to pull the implement (**Figure 3**). Inline side-band seed knives were used, and regular three-piece knives were used for fertilizer knives. The seed depth and fertilizer depths were set to 3/4 in. and 1 1/2 in., respectively. During the testing, no product was released to ensure consistency with equipment weight.

Figure 3. Versatile tractor and Seed Hawk Vaderstad implement and cart.

The testing areas were 72 ft long by 84 ft wide (the width of one implement pass). The area tested was determined by locating the flattest area of the field to attempt consistent elevation for the three replications. Each replication consisted of nine total treatment areas, each representing the different number of sections lowered in the ground. The testing design is displayed in **Figure 4**, with R1, R2, and R3 representing each of the three repetitions, and the following number (1 through 9) representing the treatment areas. Treatment 1 represents all eight sections down, Treatment 2 represents seven sections down, and Treatment 9 represents all sections lifted. In an effort to accurately produce similar field conditions throughout each test, the direction of equipment travel was east to west for all three repetitions.

R1-9	R1-8	R1-7	R1-6	R1-5	R1-4	R1-2	R1-2	R1-1
R2-9	R2-8	R2-7	R2-6	R2-5	R2-4	R2-3	R2-2	R2-1
R3-9	R3-8	R3-7	R3-6	R3-5	R3-4	R3-3	R3-2	R3-1

← ——— direction of testing

Figure 4. Draft measurement field test design.
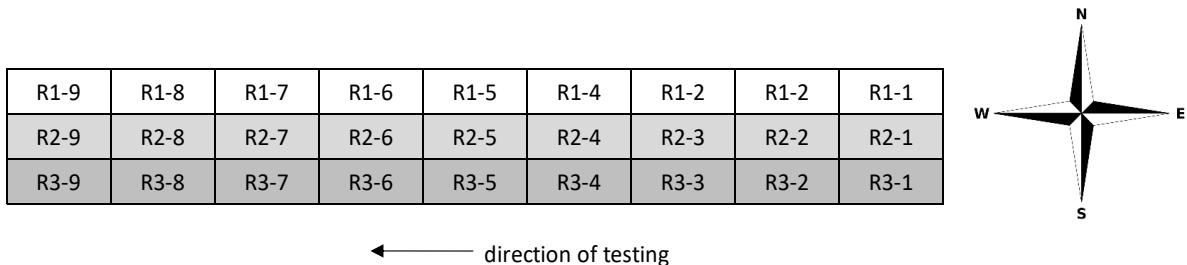
The sections were lifted in an alternating order, starting with all sections down then lifting one at a time until all were lifted. Lifting started with the furthest section on the left side of the toolbar (as if the implement is being seen from behind). After this section was lifted, the furthest section on the right side of the toolbar was lifted, and this pattern was

repeated until all sections were lifted (**Figure 5**). The lifting sequence was determined to minimize the offset of the implement catching and pulling (yaw) to the opposite side of that which was being lifted.
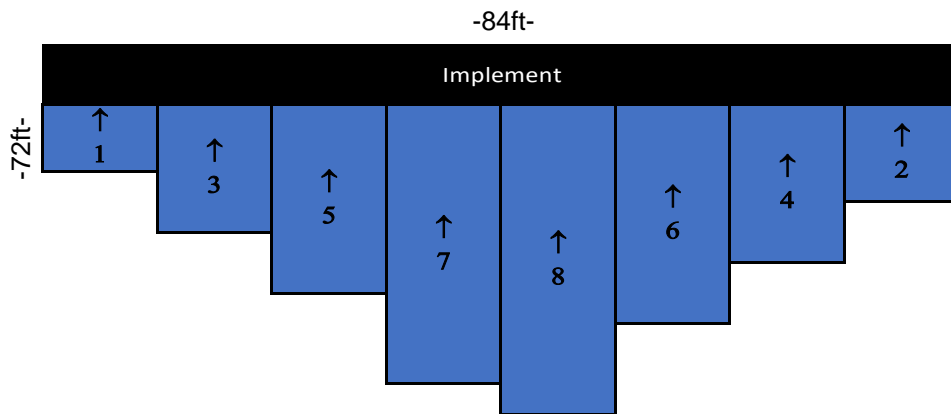

Figure 5. Section lift sequence of the implement.

Using technology that automatically lifts the implement or individual sections benefits the seed and product that has already been placed. Without lifting, the openers are dragged through the previously seeded area, which may result in a disrupted seed bed and hinder adequate plant growth.

5.   Results and Discussion

Core observations and findings are discussed in the following subsections.

5.1   Overlap Measurements

The overlap measurement analyses showed that the smaller the implement (or section size), the less overlap that occurred (assuming suitable equipment settings). Actual overlap measurements can vary greatly depending on section size, equipment settings, obstacle shape, and operator preferences.

5.1.1   In-Field Actual Measurements

The three pieces of equipment used for the in-field measurements included:

- A 60-ft implement with eight sections measuring 7.5-ft each, and a 10-in. row spacing.
- An 84-ft implement with eight sections measuring between 10-ft and 12-ft each, and a 12-in. row spacing.
- A 100-ft implement with ten sections measuring 10-ft each, and a 15-in. row spacing.

It was noted during the measurements that the canola crop was harder to distinguish when compared to the pea crop area due to a more scattered pattern of emergence. It is possible that the small canola seed exiting the openers created a more random pattern compared to the larger, heavier seed of the pea crop. **Figure 6** and **Figure 7** display examples of overlap of peas and canola, respectively.

Figure 6. Overlap of a pea crop.

Figure 7. Overlap of a canola crop.

The fields were examined post emergence to visually identify overlap location. The data was collected by measuring the distance from where the two passes crossed to where the overlap area ended (i.e., where plants were no longer seen). These measurements were taken in every row across the entire implement width, and a calculation was done to determine the entire area of actual overlap across the implement.

The overlap measurements varied greatly across each row of the toolbar and within the different field locations. **Table 1** displays the average of the two replications taken for each scenario. The results are displayed by overlap type (an obstacle or 90° angle to a headland), which direction the implement was travelling (heading toward or away from the headland), and by equipment and crop types. It must be noted that there was a large variance between the two replications of each measurement as well.

Table 1. In-field overlap measurements for one pass of each equipment type.

Overlap Type	Implement Direction	60-ft Implement (sqft) Overlap		84-ft Implement (sqft)		100-ft Implement Overlap (sqft)	
		Canola	Pea	Canola	Pea	Canola	Pea
Obstacle	From headland	835	1,094	1,784	1,826	2,396	1,116
	To headland	1,297	1,090	1,003	841	839	1,691
90° to Headland	From headland	1,346	541	1,851	1,283	1,909	646
	To headland	566	1,235	1,990	1,739	2,927	1,452

As determined by the measurements, no notable differences were found that could be directly related to equipment type. However, there was a noticeable difference in crop type observed in most scenarios, as canola overlap was found to be greater than pea overlap. Due to the nature of the small seed, pooling in the distribution system and

dispensing rate from the openers is likely greater with canola than that of peas. The fan speed would typically be less for smaller seeded crops than larger seeded crops, which would cause this pooling, resulting in the run-out.

For the measurements around an obstacle, in most cases more overlap was noticed in areas where the implement was travelling out of the headland and toward the field. Results were varied for the measurements taken 90° to the headland. A trend in the full data set was noted where more overlap was observed as the implement headed toward the headland; however, this could be due to equipment settings.

As the numbers in **Table 1** represent the overlap for each piece of equipment, the implement width must be considered when comparing the results. To further look at the results in comparable terms, they must be broken down into a per-foot basis to account for the different implement widths. The following (approximate) average overlap of the three tests per implement width for each crop were found to be as follows:

- **Canola:**
  - o Obstacle: 16.8 sqft overlap/ft implement width
  - o Headland: 21.0 sqft overlap/ft implement width
- **Pea:**
  - o Obstacle: 16.0 sqft overlap/ft implement width
  - o Headland: 14.4 sqft overlap/ft implement width

To show the theoretical overlap based on the actual field numbers for both peas and canola, these averages were related to a 160-ac field (**Table 2** and **Table 3**).

Table 2. Canola overlap of a 160ac field with two headland passes, based on above calculations.

	Canola Overlap (ac)			Canola Overlap (%)		
Calculated Implement Size	60 ft	80 ft	100 ft	60 ft	80 ft	100 ft
160ac	2.31	2.24	2.16	1.45	1.40	1.35
160ac + 10 interior obstacle passes	2.55	2.55	2.55	1.59	1.59	1.59
160ac + 20 interior obstacle passes	2.78	2.85	2.93	1.74	1.78	1.83
160ac + 30 interior obstacle passes	3.01	3.16	3.32	1.88	1.98	2.07
160ac + 40 interior obstacle passes	3.24	3.47	3.71	2.03	2.17	2.32
160ac + 50 interior obstacle passes	3.47	3.78	4.09	2.17	2.36	2.56

Table 3. Pea overlap of a 160ac field with two headland passes, based on above calculations.

	Pea Overlap (ac)			Pea Overlap (%)		
Calculated Implement Size	60 ft	80 ft	100 ft	60 ft	80 ft	100 ft
160ac	1.59	1.54	1.48	0.99	0.96	0.93
160ac + 10 interior obstacle passes	1.81	1.83	1.85	1.13	1.14	1.16
160ac + 20 interior obstacle passes	2.03	2.13	2.22	1.27	1.33	1.39
160ac + 30 interior obstacle passes	2.25	2.42	2.59	1.41	1.51	1.62
160ac + 40 interior obstacle passes	2.47	2.71	2.96	1.55	1.70	1.85
160ac + 50 interior obstacle passes	2.69	3.01	3.32	1.68	1.88	2.08

5.1.2   Displayed Measurements

The task data from the equipment with the 60-ft and 80-ft implements was collected from the monitors and loaded into QGIS. The measurements shown on the monitor, and in the reports from the monitor, account for the time when the product was shut off from each section. Comparatively, the measurements done in the field accounted for the distance the product travelled in the ground and was distributed out of the machine, compared to the specific shut-off time logged in the monitor. **Figure 8** shows an example of overlap around a curve as well as straight toward a headland in the QGIS program, where the darker red area is where the overlap occurred, and the white spaces are where there were recorded "misses". When conducting the in-field work, it was noticed that the misses were rarely seen (as the areas had plants). This is an example of a situation where what is being displayed may not be an accurate representation of what is actually happening in the field.
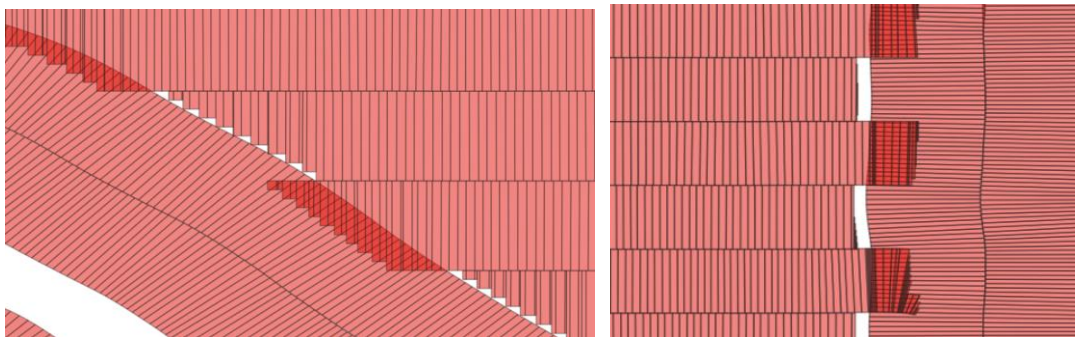

Figure 8. Overlap by section around a curve and at a headland, respectively.

A comparison was done between the overlap displayed and the actual area measured. The area measured in-field was cross referenced by GPS to the location in the QGIS program where the displayed measurements were located. This measurement was calculated in QGIS and compared to the actual measurement.

When comparing the actual measured area in the field to the QGIS measurement areas, it was apparent that the actual overlap area was higher than what the monitors displayed. The comparisons of these measured areas are shown in **Figure 9** and **Figure 10**. Measurements were taken to represent both directions of the implement at the headland: one set as it travelled into the headland and one set where it travelled away. These measurements represent overlap (in sqft) per one pass of the implement. The calculations indicated that the product was applied to a larger area than what was displayed on the monitor. Though the total amount of product recorded may be accurately displayed, the area of application may be inaccurate.
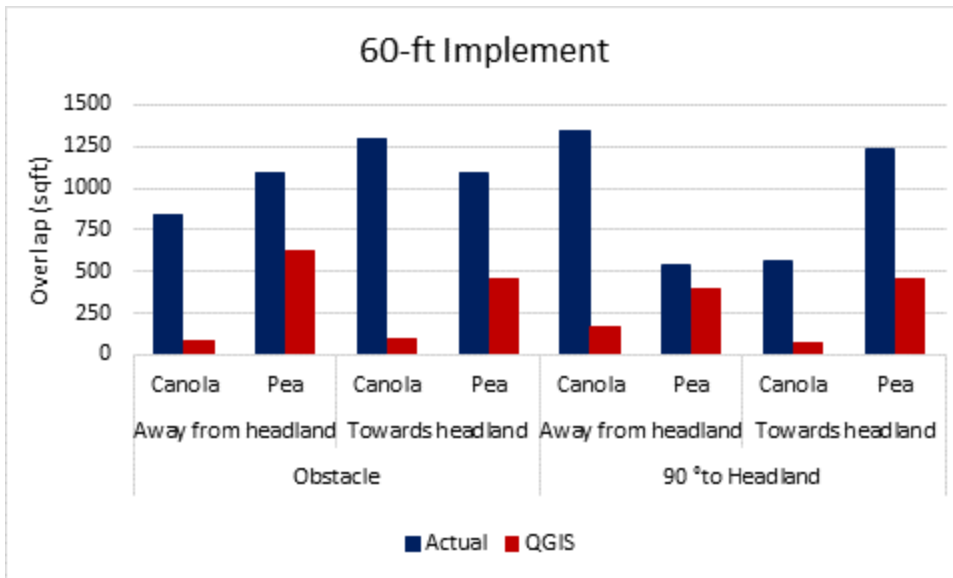
Figure 9. 60-ft implement actual overlap vs. displayed QGIS overlap.
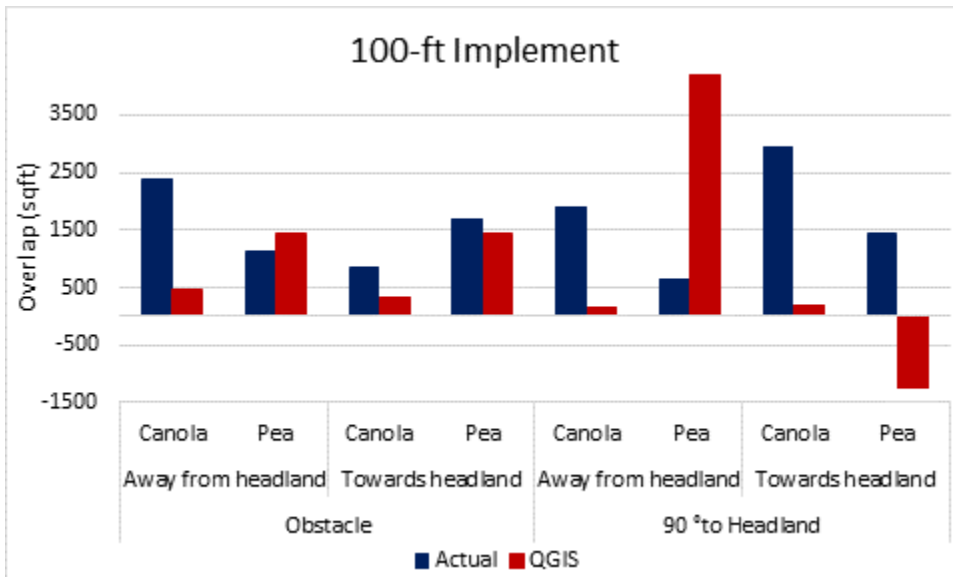
Figure 10. 100-ft implement actual overlap vs. displayed QGIS overlap.

A calculation was done to compare total overlap recorded in the field versus overlap recorded from the monitor (calculated on the QGIS program). As there was no monitor data from the third cooperator (with the 84-ft implement), these results were calculated in terms of overlap per foot of the average for the 60-ft and 100-ft equipment only. These represent overlap measurements in a 160-ac square field with different scenarios of additional interior obstacle passes and different implement widths (**Table 4** and **Table 5**). The results identified that there was a difference between what the monitor was showing and what was actually happening in- field (the actual field measurements were greater than what was being displayed on the monitor).

Table 4. Various overlap measurement representations in a 160-ac square canola field.

Field Size	Representative Implement Width (ft)	Monitor (ac)	Actual (ac)	Monitor (%)	Actual (%)
160 ac	60	0.20	2.21	0.13	1.38
	80	0.19	2.14	0.12	1.34
	100	0.19	2.06	0.12	1.29
160 ac + 10 interior obstacle passes	60	0.24	2.44	0.15	1.53
	80	0.24	2.45	0.15	1.53
	100	0.25	2.45	0.16	1.53
160 ac + 20 interior obstacle passes	60	0.28	2.68	0.17	1.67
	80	0.30	2.76	0.18	1.72
	100	0.31	2.84	0.20	1.78
160 ac + 30 interior obstacle passes	60	0.31	2.91	0.20	1.82
	80	0.35	3.07	0.22	1.92
	100	0.38	3.23	0.24	2.02
160 ac + 40 interior obstacle passes	60	0.35	3.15	0.22	1.97
	80	0.40	3.38	0.25	2.11
	100	0.44	3.62	0.27	2.26
16 0ac + 50 interior obstacle passes	60	0.39	3.38	0.24	2.11
	80	0.45	3.69	0.28	2.31
	100	0.50	4.01	0.31	2.51

Table 5. Various overlap measurement representations in a 160-ac square pea field.

Field Size	Representative Implement Width (ft)	Monitor (ac)	Actual (ac)	Monitor (%)	Actual (%)
160 ac	60	0.48	2.15	0.30	1.34
	80	0.46	2.08	0.29	1.30
	100	0.45	2.00	0.28	1.25
160 ac + 10 interior obstacle passes	60	0.57	2.38	0.35	1.49
	80	0.58	2.39	0.36	1.49
	100	0.60	2.40	0.37	1.50
160 ac + 20 interior obstacle passes	60	0.66	2.62	0.41	1.64
	80	0.70	2.71	0.44	1.69
	100	0.75	2.79	0.47	1.75
160 ac + 30 interior obstacle passes	60	0.75	2.86	0.47	1.79
	80	0.82	3.02	0.51	1.89
	100	0.90	3.19	0.56	1.99
160 ac + 40 interior obstacle passes	60	0.84	3.09	0.52	1.93
	80	0.94	3.34	0.59	2.09
	100	1.05	3.58	0.65	2.24
160 ac + 50 interior obstacle passes	60	0.93	3.33	0.58	2.08
	80	1.06	3.65	0.66	2.28
	100	1.20	3.98	0.75	2.49

From the calculations, it can be assumed that the actual overlap area in the field is typically greater than what is shown on the monitor. Depending on the field size and geometry and the number of obstacles in the field, overlap ranges from 1.3% to 2.5%. Determining actual overlap area in the field is a difficult measurement to accurately display, and the numbers shown on the monitor typically under-represent actual field overlap.

5.1.3 Theoretical Overlap Measurements

Field overlap can be broadly categorized into the following four scenarios:

- **Scenario 1** – Overlap around an obstacle.
- **Scenario 2** – Overlap measured at an angle to a headland.
- **Scenario 3** – Overlap created by the last pass in a field (i.e., where the last pass is not the exact width of the implement, overlap will occur).
- **Scenario 4*** – Overlap at 90° to a headland.

*The variance in Scenario 4 is mostly caused by the settings of the look-ahead/behind times or by manual shutoff when approaching the headland. The theoretical overlap of a sectional control system with a 90° should be zero.

Scenarios 1 and 2

CAD software was used to model two different scenarios: around an obstacle, and at a 45° angle to a headland. This modelling allowed for theoretical section widths to be compared to total overlap percentage. To maintain calculation consistency, the models were calculated as best-case scenarios, assuming no manual error or differences due to equipment settings. Measuring overlap at an obstacle varies greatly depending on size and shape of the obstacle. For modelling the obstacle scenario, a round obstacle with a diameter of 160 ft was chosen for analysis. Two implement passes were modelled with the obstacle scenario: one pass that would seed straight through the headland, and one pass that would seed up to the obstacle, stop, and change direction. The modelling of both overlap types with the associated calculated overlap areas can be found in **Appendix A**, along with the graphical assessment of both scenarios.

During the modelling, the area calculations revealed that by cutting the section width in half across an implement, the overlap area was cut approximately in half. For example, for overlap at a headland crossed at 45°, an implement with two 40-ft sections would result in about half the amount of overlap when compared to an 80-ft implement.

PAMI previously did a study of mechanical overlap in riparian areas. This study reviewed different field and obstacle sizes and how the overlap area differed with implement width. These equations were used to present the theoretical measurements displayed in **Table 6**. The section/implement size was chosen in intervals to represent smaller sections of 8 ft and 10 ft as well as larger widths up to what would be considered a large implement of 100 ft. The modelling used in this study assumed that 50% of the

implement width overlapped into the headlands, and 60% of the implement width overlapped around the obstacles, as overlap is unavoidable in these scenarios. These numbers do vary, however, but were used as a baseline. It must be noted that the section/implement widths chosen fit in a square 160 ac field; therefore, no "last pass" overlap was accounted for. A more detailed chart can be found in **Appendix B**.

Table 6. Section/Implement size vs. theoretical overlap on a 160-ac square field.

| Section /implement size (ft) | Theoretical overlap for a 160-ac field (no obstacles) (%) | 160-ac field | | | |
		plus 10-50 ft diameter obstacles (%)	plus 10-100 ft diameter obstacles (%)	plus 10-200 ft diameter obstacles (%)	plus 10-400 ft diameter obstacles (%)
8	0.60	0.73	0.85	1.10	1.81
10	0.75	0.92	1.06	1.39	2.27
15	1.13	1.40	1.61	2.10	3.43
20	1.50	1.89	2.18	2.82	4.61
40	2.98	3.97	4.55	5.84	9.45
60	4.44	6.24	7.12	9.07	14.53
80	5.88	8.71	9.88	12.50	19.84
100	7.29	11.38	12.84	16.13	25.39

As displayed, the larger diameter obstacles theoretically have a substantially higher overlap amount than the smaller obstacles. The study by Gregg, Lung, & Leduc, 2008, also determined that an increased number of obstacles resulted in increased overlap as well as a large increase if the obstacles are located around the perimeter.

Figure 11 and **Figure 12** display overlap percentage versus implement width, and obstacle diameter versus theoretical overlap using calculations from the previous PAMI study. **Figure 11** represents a 160-ac field plus 10 100-ft diameter obstacles, resulting in increased overlap with increased implement width. **Figure 12** represents overlap that is reduced with fewer large obstacles, versus multiple small obstacles. The results of the study concluded that the variables having the most impact on overlap were implement width, obstacle diameter, the number of obstacles, and field size (Gregg et al, 2008).
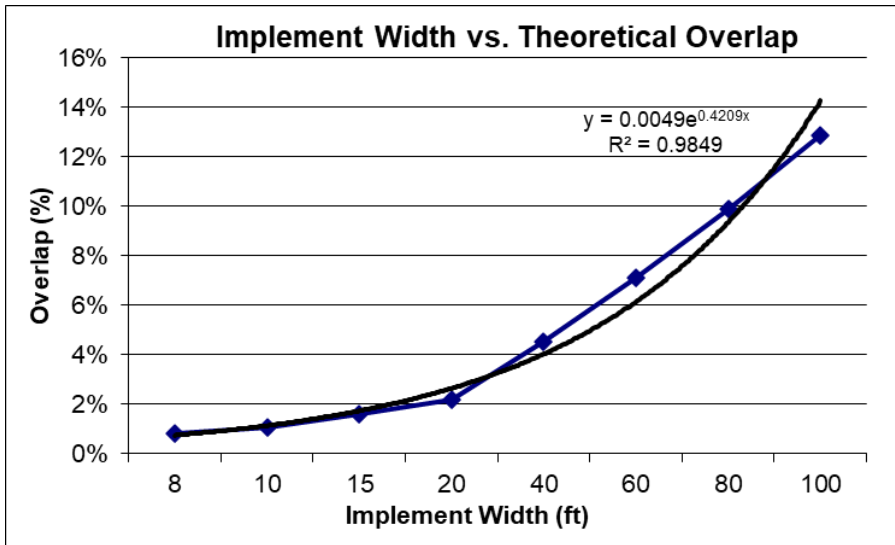
Figure 11. Implement width vs. theoretical overlap (Gregg, Lung, & Leduc, 2008).

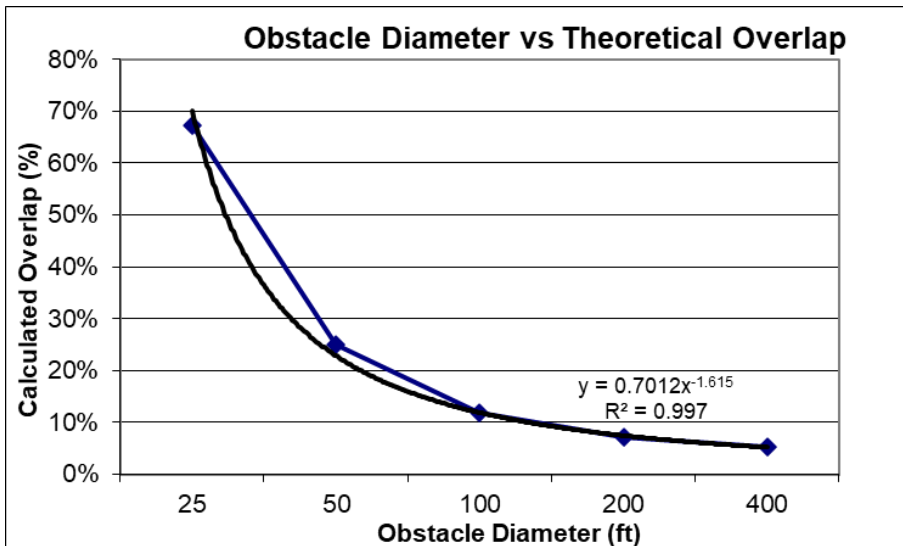**Figure 12.** Obstacle diameter versus theoretical overlap (Gregg, Lung, & Leduc, 2008).

Scenario 3

Overlap caused by the last pass of the equipment on the field varies with equipment size and whether sectional control is being used. A theoretical calculation was done, assuming the field is square, and there is no additional overlap on headlands (**Table 7**). The applicator widths were chosen at random.

Table 7. Last pass overlap calculations for various implement sizes of a 160-ac field with two headlands.

Field Size (ac)	Implement size (ft)	Number of passes	Last pass overlap (ft)	Total Overlap (ac)	Total Overlap (%)
160	34	73.65	11.9	0.68	0.43
160	44	56.00	44	0.00	0.00
160	54	44.89	5.94	0.33	0.21
160	64	37.25	48	2.63	1.64
160	74	31.68	23.68	1.27	0.80
160	84	27.43	47.88	2.53	1.58
160	94	24.09	85.54	4.45	2.78
160	104	21.38	64.48	3.29	2.06

5.2　Load Cart Data

The load cart data was supported by further field tests, including soil moisture and texture and compaction tests to relate the draft measurements to the field conditions of the site tested.

5.2.1　Soil Conditions

A soil cone penetrometer was used to obtain the soil compaction reading. For each of the nine test areas, three replications of the test were performed (27 test iterations). Compaction measurements were taken at depths of 1 in. and 2 in. The first measurement represented the penetrometer reading at the base level of 1 in., and the second represented the penetrometer reading at the 2 in. point. **Figure 13** displays the compaction results for each repetition at both depths. The readings are displayed in pounds per square inch (psi).
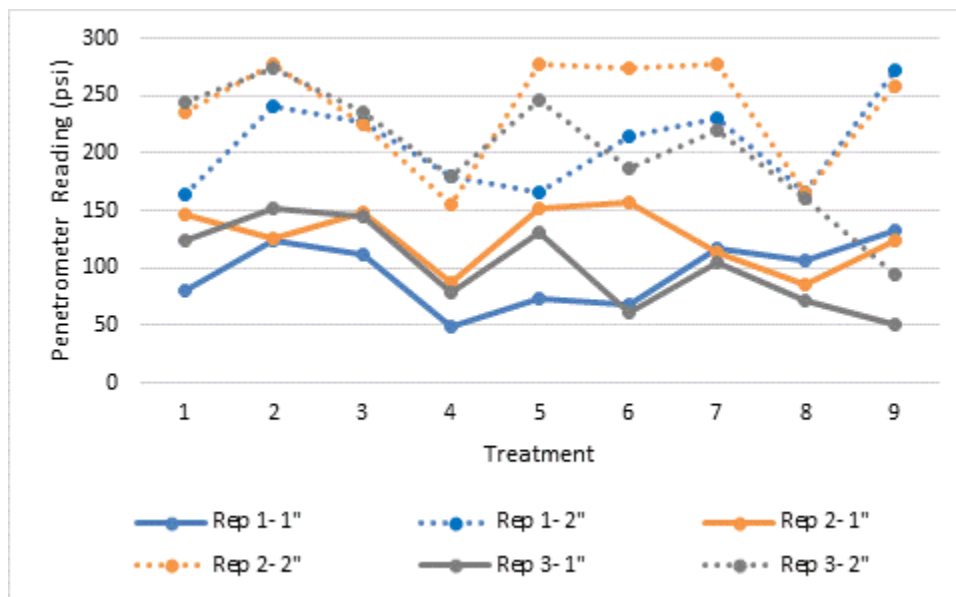

Figure 13. Soil penetrometer readings.

Soil cores were taken in each of the 27 locations at depths of 0 to 6 in. Three cores were taken per location and combined into one composite sample to get an average representation of the sample area. From these samples, soil moisture tests were conducted as well as soil texture tests. **Table 8** shows the soil moisture by dry basis for each of the sample areas. As displayed, there was a slight increase in soil moisture from treatments one to nine.

Table 8. Soil moisture (in percentage) of each treatment, dry basis.

	1	2	3	4	5	6	7	8	9
Rep 1	15.85	16.98	15.99	14.31	15.24	21.88	20.35	26.61	26.91
Rep 2	16.11	17.46	17.70	19.78	19.78	23.74	25.80	24.30	20.07
Rep 3	16.94	20.65	19.48	18.54	16.15	22.27	24.06	22.04	26.46
Average	**16.30**	**18.36**	**17.72**	**17.54**	**17.06**	**22.63**	**23.40**	**24.32**	**24.48**

The soil texture analysis was conducted by a third-party company. This analysis classified the textural class by percentage of sand, silt, and clay. As soil texture changes, the soil properties change, which affects bulk density, surface area, and pore volume. This directly relates to the water-holding capacity of the soil (soils with larger pores [sand] have a higher infiltration rate than those with smaller pores [clay]). Soil particles are classified into the following sizes:

- Clay: <0.002 mm
- Silt: 0.05-0.002 mm
- Sand: 2.00-0.05 mm

A study by Collins & Fowler, 1995, found a significant difference in draft force by soil texture, with the highest being in heavy clay soil and the lowest being in a sandy loam soil (a 24% difference). The lab results for the samples concluded that the tested soils were mostly in the loam category, with exceptions of R1-3 and R1-2 classified as a sandy loam. **Figure 14** shows approximately where the soil texture results fit in the soil texture triangle. The in-depth results of the soil texture results can be found in **Appendix C**.
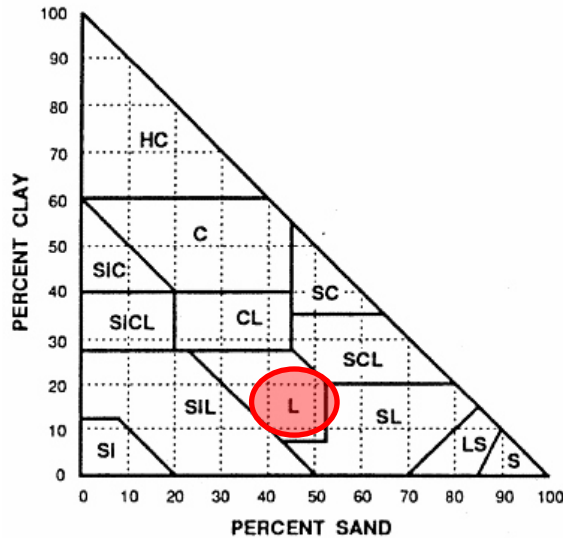
Figure 14. Soil texture triangle with test field results (Agriculture and Agri-Food Canada, 2009).

5.2.2   Draft Measurements

The speed of the equipment was targeted at 5 mph for each test, resembling typical field speed, though as it was manually controlled, it may not have been completely consistent. The actual measured average speed during each repetition varied from the 5-mph target by less than 0.2 mph, resulting in an estimated error in draft force of less than 5% due to the speed differences. Draft force, GPS location, and speed were logged during the test. The test area chosen was the flattest area of land available; however, it should be noted that there was a slight difference in elevation.

The average draft force was calculated by taking the average of the force values recorded over the length of the treatments through each repetition. The power requirements for each treatment were calculated using the following equation, with draft force in pounds and speed in miles per hour.

$$Average\ Power = \frac{Average\ Draft\ Force\ x\ Speed}{375}$$

The draft load was calculated for each treatment for all three of the repetitions. The data included in these calculations was selected to represent information at steady state. This included eliminating data points from the analysis that potentially represented the transition times of the lifted sections. The average draft force for each test can be seen in **Table 9** along with the average speed per test.

Table 9. Average draft force and speed for each treatment.

Treatment	Rep 1			Rep 2			Rep 3		
	Average Draft Force (lb)	Average speed (mph)	Average Draft Load (hp)	Average Draft Force (lb)	Average speed (mph)	Average Draft Load (hp)	Average Draft Force (lb)	Average speed (mph)	Average Draft Load (hp)
1 (all down)	14,964	4.89	195	14,688	5.12	201	13,946	5.05	188
2	13,629	4.81	175	16,405	5.13	224	13,695	5.04	184
3	15,122	4.78	193	10,789	5.19	149	13,508	5.08	183
4	13,398	4.87	174	11,526	5.15	158	12,287	5.10	167
5	10,118	4.90	132	11,856	5.14	163	12,198	4.97	162
6	91,77	4.95	121	10,746	5.14	147	10,307	5.08	140
7	7,297	4.96	97	9,715	5.13	133	9,998	5.10	136
8	5,474	4.96	72	8,364	5.17	115	7,452	5.19	103
9 (all up)	5,170	4.95	68	8,280	5.28	117	5,751	5.15	79

An ANOVA analysis (Analysis of Means) with a 95% confidence interval was used to analyze the draft measurements to determine any significant differences in the means of the tests. A Tukey Pairwise Comparison test indicated that there was a significant difference in draft force noted throughout the tests (**Table 10**).

Table 10. Tukey Pairwise Comparisons at a 95% confidence level.

Treatment	Total Count	Mean (Draft Load, lbs.)	SE Mean	StDev	Coefficient of Variance (%)	Grouping			
1 (all down)	3	14,532	304	526	3.62	A			
2	3	14,577	915	1,584	10.87	A			
3	3	13,140	1,264	2,190	16.67	A	B		
4	3	12,404	543	941	7.59	A	B	C	
5	3	11,391	644	1,116	9.79	A	B	C	
6	3	10,077	467	809	8.03		B	C	D
7	3	9,003	857	1,484	16.49			C	D
8	3	7,097	853	1,477	20.82				D
9 (all up)	3	6,400	955	1,654	25.84				D

Means that do not share a letter are significantly different.

There was a trend noted where the average draft measurements declined as the sections across the toolbar were lifted. There was, however, a slight increase in Treatment 2. This could be related to an unknown increase in draft that occurred in Rep 2, which is reflected in the mean of the treatments. Each repetition was recorded using a GoPro video device. Reviewing the playback of Rep 2, there is an instance where the implement deviated slightly from its steady state, which likely caused the

increase in draft load. **Figure 15** displays the average draft load of the three reps relative to the percentage of the implement lifted.
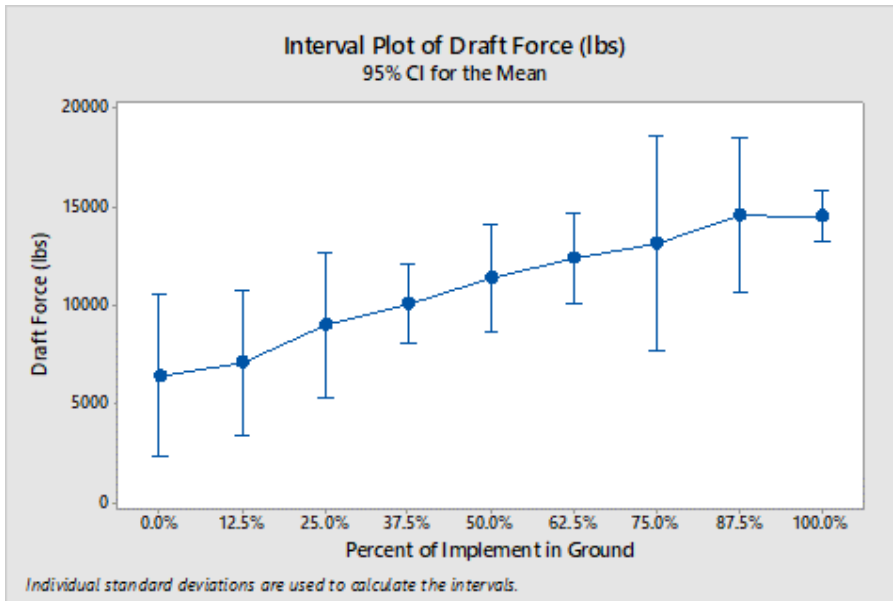

Figure 15. Interval plot of draft force by percentage of implement lifted.

As the sections of the implement were lifted in the alternating pattern previously defined, there was a trend noted about the yaw balance across the toolbar. When the first section was lifted, the toolbar was off balance but regained that balance when the second section was lifted. This balance refers to an equal number of sections lifted/lowered on either side of the toolbar. This factor may be reflected in the draft measurements. **Figure 16** displays the average draft measurements the three replications, including the trendline, across all treatments.
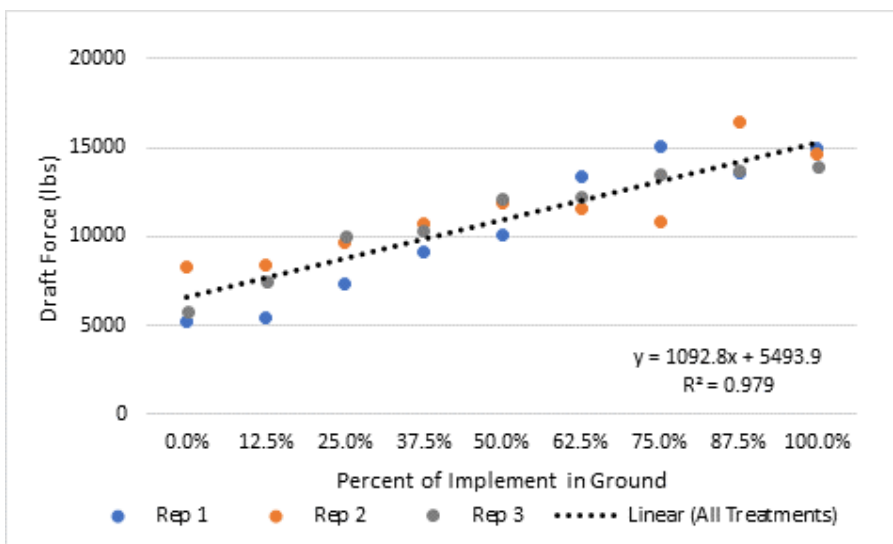

Figure 16. Draft force by percentage of implement lifted.

Draft measurements differ greatly with equipment type, size, and speed as well as soil properties, field topography, and many other variables. The results presented in this report represent one set of measurements with one piece of equipment in one field condition. This study showed that there is a direct correlation between the amount of implement in the ground versus the amount lifted out of the ground. There is the potential for future study in this area to further investigate the draft with an unbalanced toolbar. As energy management is becoming more important in agriculture, introducing technologies that reduce draft can directly benefit the producer.

6. Agronomic and Environmental Effects

The following section defines the agronomic and environmental effects of sectional control technology.

6.1 Agronomic Effects

Overlapped seeding/planting practices can lead to undesirable effects on a crop. Many crop types are sensitive to plant populations and respond negatively to overapplied fertilizer. This can result in crop lodging, which creates management problems for these areas as well as difficulty during the busy harvest season.

Overapplied fertilizer has potential to harm the soil and create undesirable growing conditions for plants. Many fertilizers have high salt levels, which can impact crop growth as well as negatively effect soil microorganisms. Ammonium fertilizers, in particular, can cause soils to become more acidic over time, creating adverse conditions for plant growth. Fertilizer toxicity or "burn", typically caused by nitrogen, has the potential to severely damage seed and seedlings.

Using technology to assist in seeding is a huge benefit to farmers. The implementation of GPS guidance systems reduces manual stress on the equipment operator. Sectional control technology provides the opportunity for better field management, as it allows the operator to selectively manage smaller sections rather than the entire implement width. With growing equipment sizes, proper management and equipment settings are essential to running a productive and efficient operation (e.g., a reduction in input costs for seed, fertilizer, and herbicides). By using larger equipment, fewer passes are needed in field, resulting in improved time efficiencies and better on-farm management practices.

6.2 Environmental Effects

Product overlap can also have negative environmental effects. Irregular fields increase this risk by creating more obstacles to avoid, resulting in higher overlap percentages.

Nitrogen losses from excess fertilizer applications can potentially harm the environment. Nitrogen losses can occur in three main ways: nitrate leaching, denitrification, and volatilization (Clark, 2014). Nitrate (NO_3^-) is extremely soluble, allowing it to readily leach through the soil. As the water moves both downward and laterally through the soil, the nitrate is carried with it and absorbed into the soil profile. This nutrient-enriched water can then leach from the desired area and contaminate both groundwater and above-surface waterbodies. Denitrification occurs in waterlogged soils (absent of oxygen) results in dinitrogen gas (N_2) being released into the atmosphere. This process converts $NO3^-$ into N_2 which then reacts with the ozone and contributes to air pollution (Bernhard, 2010). Volatilization losses are losses caused from the conversion of

ammonium (NH_4^+) to ammonia gas (NH_3). **Table 11** outlines the breakdown of the nitrogen cycle processes.

Table 11. Nitrogen cycle processes (Johnson, Albrecht, Ketterings, Beckman, & Stockin, 2005).

Nitrogen Process	Formula								
Fixation	N_2 **nitrogen gas**	→	NH_3 **ammonia**	→	R-NH_2 **organic N**				
Mineralization	R-NH_2 **organic N**	→	NH_3 **ammonia**	→	NH_4^+ **ammonium**				
Nitrification	NH_4^+ **ammonium**	→	NO_2^- **nitrite**	→	NO_3^- **nitrate**				
Denitrification	NO_3^- **nitrate**	→	NO_2^- **nitrite**	→	NO **nitric oxide**	→	N_2O **nitrous oxide**	→	N_2 **dinitrogen gas**
Volatilization	$\overset{O}{\overset{\|}{H_2N\text{-}C\text{-}NH_2}}$ **urea**	→	NH_4^+ **ammonium**	→	NH_3 **ammonia**				
Immobilization	NH_4^+ and/or NO_3^- **ammonium /** **nitrate**	→	R-NH_2 **organic N**						

There are known benefits to improving nitrogen efficiency, such as cost reductions when less fertilizer is used; savings on fossil fuel use, and therefore, a reduction in CO_2 emissions, as producing nitrogen is energy intensive; and fewer nitrates, ammonia, and other nitrogen contaminants entering the environment (Government of Canada, 2020). The 4R Nutrient Stewardship concept is widely used in the industry to promote sustainable and productive farming practices. The 4Rs of fertilizer use are right rate, right source, right time, and right place (The Fertilizer Institute, 2017). Following this best management practice minimizes risk and allows for the best use of crop nutrition.

Advancements in agricultural technology have paved the way for greater efficiency and more productive and sustainable operations. Aside from sectional control, some notable advancements include

- a more efficient use of fertilizer, resulting in reduced fertilizer needs and costs,
- no-till farming, which aids in the reduction of carbon emissions,
- more diverse crop rotations to support soil health, and
- reducing the practice of summer fallowing, which has been shown to support overall soil health.

Overlap increases when equipment needs to navigate around obstacles, such as sloughs and wetlands. These areas are typically considered to be undesirable areas to receive seed and fertilizer (i.e., low production zones). Wetlands play a significant role in ecosystem health by providing a habitat for a large number of species, filtering chemicals, and storing soil carbon, to name a few. However, wetlands are often drained

for a number of reasons in agricultural areas. One of which is to create a more desirable, easy equipment path for navigation around the area. By using more advanced agricultural equipment and technology, such as GPS and sectional control, wetland disruption can be more readily avoided and, in many cases, left intact.

A decreased draft load can also be related to fuel and emission savings. The difference in power requirements when the openers are lifted can provide an indication of potential energy savings. Fuel use is difficult to accurately measure on farm. However, in general terms, having a higher horsepower will result in higher fuel use (Natural Resources Canada, 2014). As total horsepower declines while lifting implement sections, the potential for fuel savings exists when using this technology.

7. Potential Cost Savings

When overlap is decreased on farm, there is an opportunity to realize potential cost savings, mostly in the form of reduced inputs.

The cost calculations in **Table 12** were taken from the Saskatchewan 2020 Crop Planning Guide (Saskatchewan Ministry of Agriculture, 2020). The associated costs used for these calculations include general field inputs for a variety of crop types in three soil zones. These include the average cost of seed, fertilizer, and machinery fuel and repair. Actual costs will vary depending on seed variety, fertilizer type, equipment specifics, and other factors. A spreadsheet with greater detail is available for download from the Saskatchewan Ministry of Agriculture input specifics and can be found at https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/farm-business-management/crop-planning-guide-and-crop-planner.

Table 12. Cost of overlap by crop type and soil zone.

| Crop Type	Soil Zone	Seed/ac	Seed Treatment/ac	Nitrogen/ac	Phosphorous, Sulfur + other fertilizer /ac	Machinery Fuel/ac	Machinery Repair/ac	Total/ac	Total for 160ac	160ac field- additional costs				
										2% Overlap	5% Overlap	10% Overlap	15% Overlap	20% Overlap
Canola	brown	$66.19	$9.00	$51.81	$31.86	$13.05	$8.57	$180.48	$28,876.80	$577.54	$1,443.84	$2,887.68	$4,331.52	$5,775.36
	dark brown	$66.19	$9.00	$53.32	$32.76	$16.31	$9.66	$187.24	$29,958.40	$599.17	$1,497.92	$2,995.84	$4,493.76	$5,991.68
	black	$66.19	$9.00	$57.35	$35.16	$20.39	$10.94	$199.03	$31,844.80	$636.90	$1,592.24	$3,184.48	$4,776.72	$6,368.96
Spring Wheat	brown	$19.78	$7.87	$32.19	$11.30	$12.32	$8.57	$92.03	$14,724.80	$294.50	$736.24	$1,472.48	$2,208.72	$2,944.96
	dark brown	$21.85	$8.69	$47.29	$17.63	$15.40	$9.66	$120.52	$19,283.20	$385.66	$964.16	$1,928.32	$2,892.48	$3,856.64
	black	$24.84	$9.88	$53.83	$18.98	$19.25	$10.94	$137.72	$22,035.20	$440.70	$1,101.76	$2,203.52	$3,305.28	$4,407.04
Durum*	brown	$27.30	$9.60	$43.76	$15.37	$12.32	$8.57	$116.92	$18,707.20	$374.14	$935.36	$1,870.72	$2,806.08	$3,741.44
	dark brown	$30.16	$10.61	$50.30	$17.63	$15.40	$9.66	$133.76	$21,401.60	$428.03	$1,070.08	$2,140.16	$3,210.24	$4,280.32
Barley (malt)	brown	$23.32	$9.70	$34.71	$13.56	$12.32	$8.57	$102.18	$16,348.80	$326.98	$817.44	$1,634.88	$2,452.32	$3,269.76
	dark brown	$25.52	$10.61	$37.22	$14.46	$15.40	$9.66	$112.87	$18,059.20	$361.18	$902.96	$1,805.92	$2,708.88	$3,611.84
	black	$29.04	$12.07	$40.75	$15.82	$19.25	$10.94	$127.87	$20,459.20	$409.18	$1,022.96	$2,045.92	$3,068.88	$4,091.84
Oats	brown	$21.12	$8.05	$27.16	$9.94	$12.32	$8.57	$87.16	$13,945.60	$278.91	$697.28	$1,394.56	$2,091.84	$2,789.12
	dark brown	$26.40	$8.87	$35.72	$13.11	$15.40	$9.66	$109.16	$17,465.60	$349.31	$873.28	$1,746.56	$2,619.84	$3,493.12
	black	$31.69	$10.06	$47.79	$14.92	$19.25	$10.94	$134.65	$21,544.00	$430.88	$1,077.20	$2,154.40	$3,231.60	$4,308.80
Lentils (lg green)	brown	$34.13	$13.01	$2.02	$8.59	$13.77	$8.57	$80.09	$12,814.40	$256.29	$640.72	$1,281.44	$1,922.16	$2,562.88
	dark brown	$34.13	$13.01	$2.23	$9.49	$17.21	$9.66	$85.73	$13,716.80	$274.34	$685.84	$1,371.68	$2,057.52	$2,743.36
	black	$34.13	$13.01	$2.13	$9.04	$21.52	$10.94	$90.77	$14,523.20	$290.46	$726.16	$1,452.32	$2,178.48	$2,904.64
Peas (green)	brown	$36.99	$10.88	$3.51	$14.92	$13.77	$8.57	$88.64	$14,182.56	$283.65	$709.13	$1,418.26	$2,127.38	$2,836.51
	dark brown	$42.12	$12.39	$4.15	$17.63	$17.21	$9.66	$103.16	$16,505.60	$330.11	$825.28	$1,650.56	$2,475.84	$3,301.12
	black	$47.52	$13.98	$4.68	$19.89	$21.52	$10.94	$118.53	$18,964.80	$379.30	$948.24	$1,896.48	$2,844.72	$3,792.96

*no data available for durum in the black soil zone

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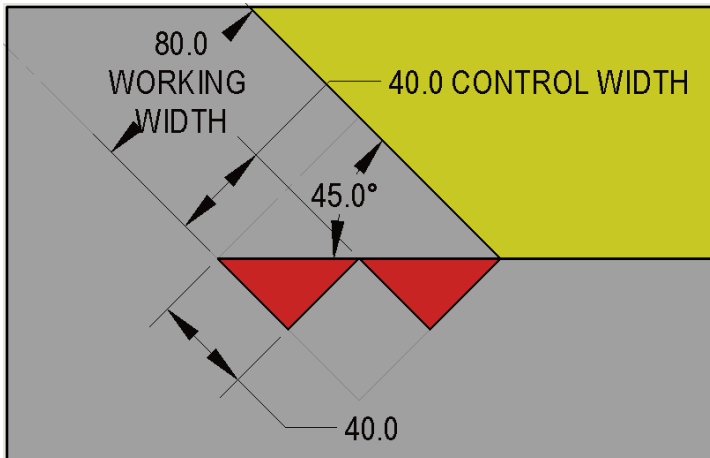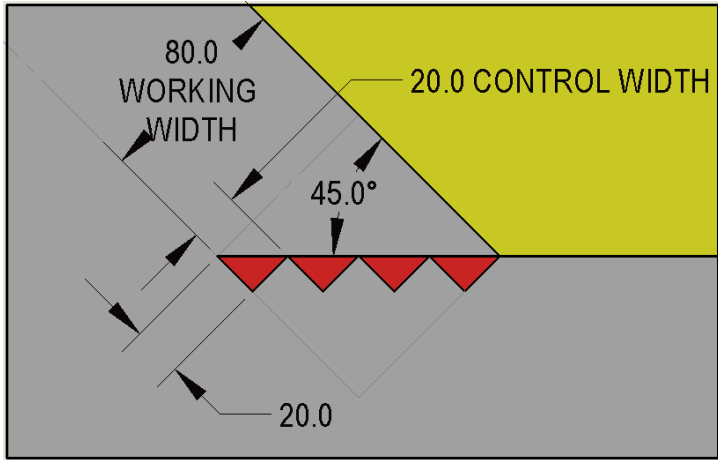
Appendix A

SolidWorks Overlap Diagrams

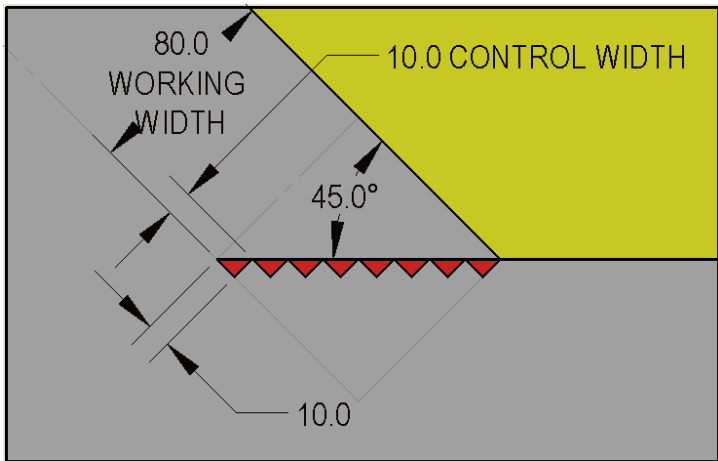45° angle of an 80 ft implement
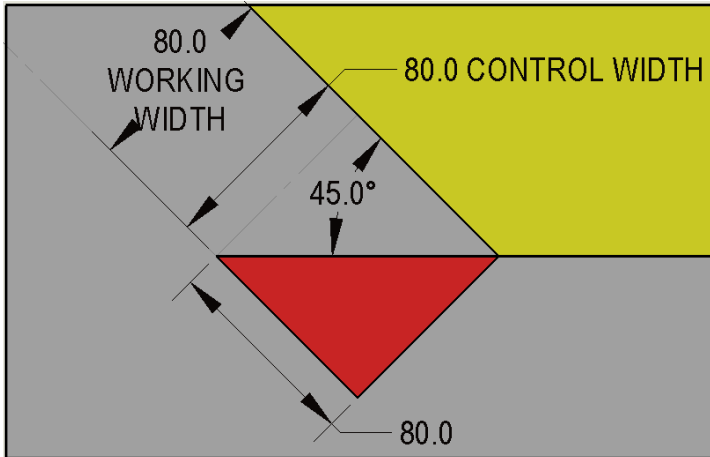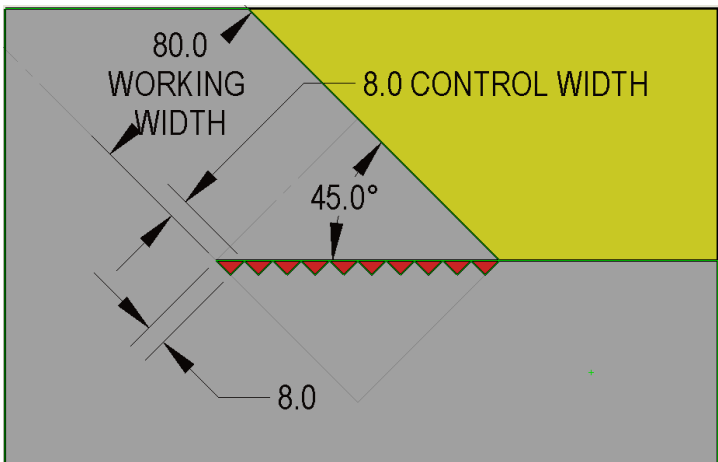

- 1- 80 ft section
- **3200 sqft overlap**
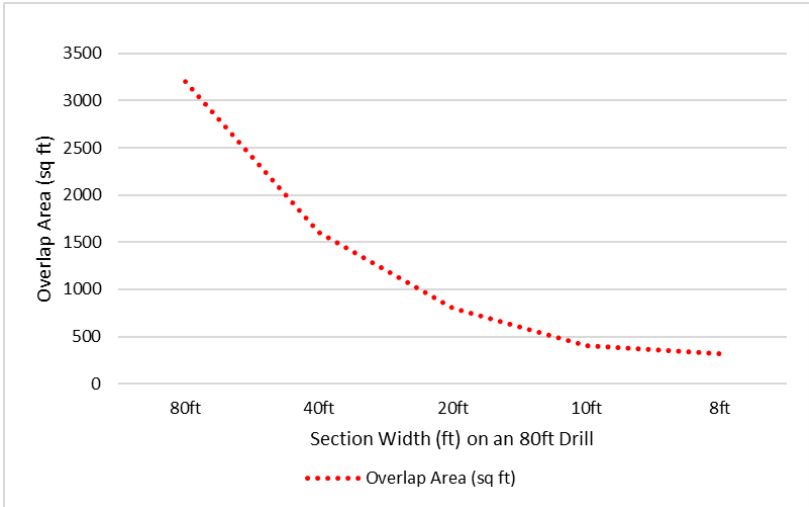

- 2- 40 ft sections
- **1600 sqft overlap**

- 4- 20 ft sections
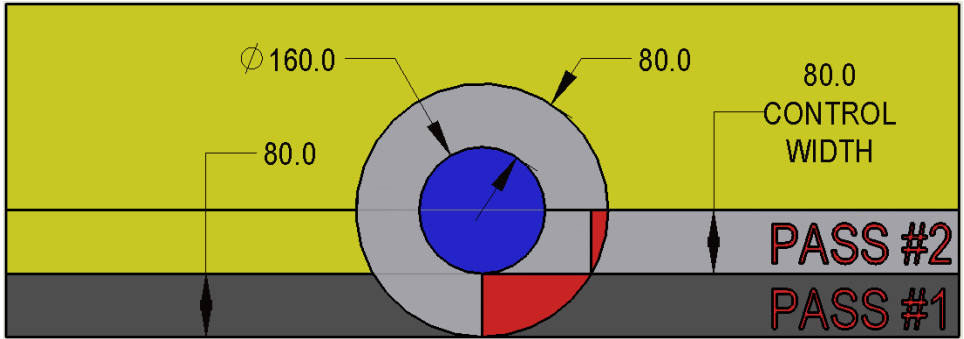- **800 sqft overlap**

- 8- 10 ft sections
- **400 sqft overlap**

- 10- 8 ft sections
- **320 sqft overlap**

Obstacle (160 ft diameter)

- Pass #1, 1- 80 ft section = **7862 sqft overlap**
- Pass #2, 1- 80 ft section = **1159 sqft overlap**
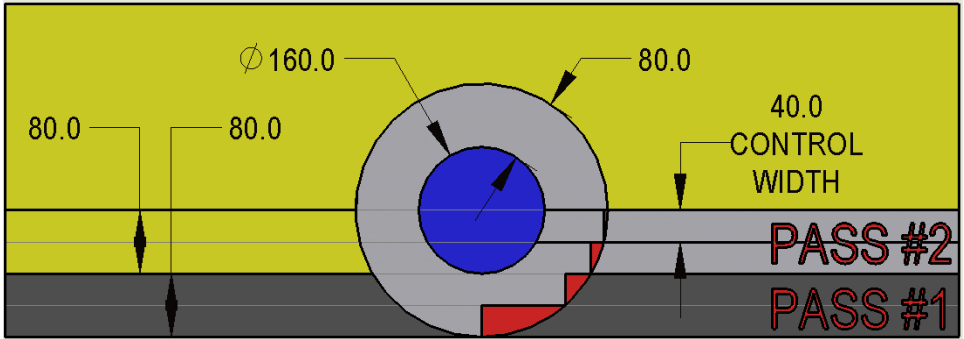
- Pass #1, 2- 40 ft sections = **3628 sqft overlap**
- Pass #2, 2- 40 ft sections = **506 sqft overlap**
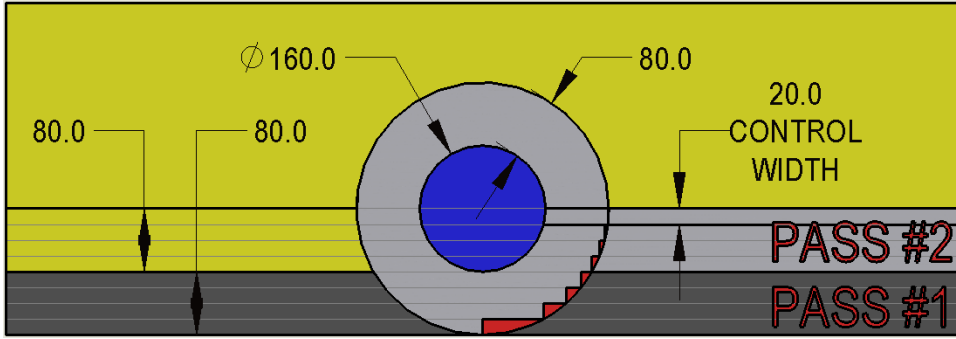
- Pass #1, 4- 20 ft sections = **1698 sqft overlap**
- Pass #2, 4- 20 ft sections = **234 sqft overlap**

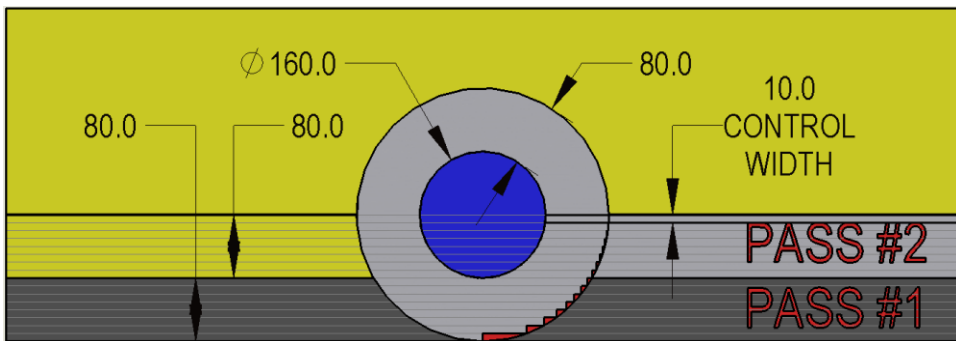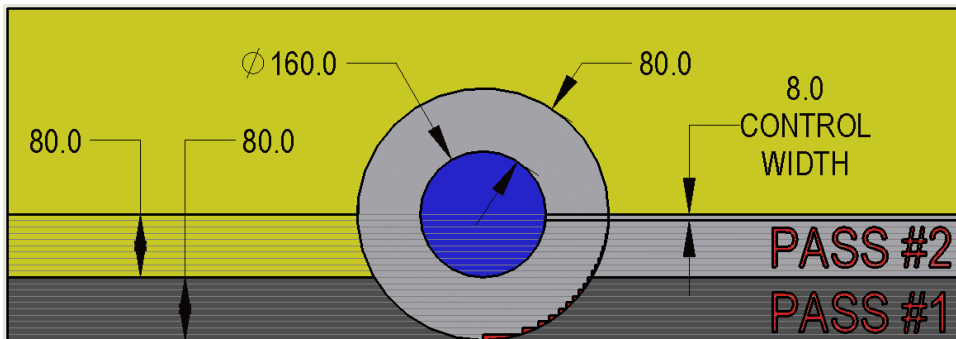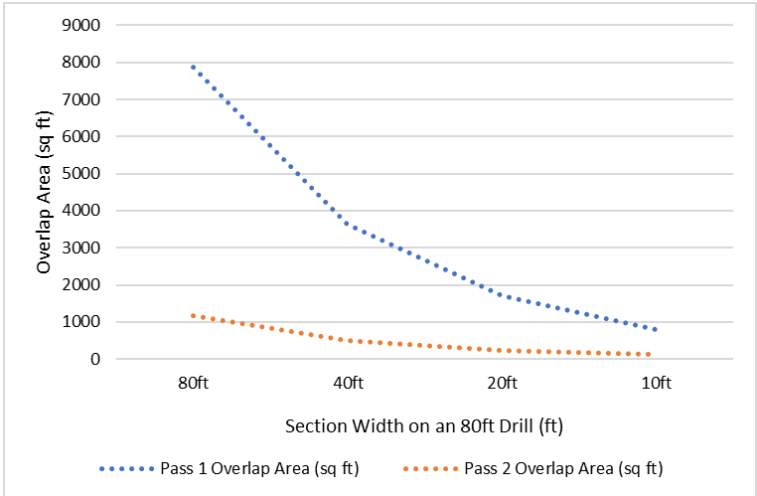- Pass #1, 8- 10 ft sections = **806 sqft overlap**
- Pass #2, 8- 10 ft sections = **112 sqft overlap**

- Pass #1, 10- 8 ft sections = **635 sqft overlap**
- Pass #2, 10- 8 ft sections = **89 sqft overlap**

Section Width on an 80ft Drill (ft)

••••• Pass 1 Overlap Area (sq ft)   ••••• Pass 2 Overlap Area (sq ft)

Appendix B

Raw Data for Overlap Calculations (Gregg, Lung, & Leduc, 2008)

Overlap Calulations

	Field Dimensions			Obstacles (Circular)				Farmable	Applicator	Exterior Field Overlap				Obstacle Overlap				Total	Total
	Width	Length	Area	Number	Diameter	Area		Area	Width	Perimeter	Overlap (50%)			Perimeter	Overlap (60%)			Overlap	Overlap
	(ft)	(ft)	(Acres)		(ft)	(ft^2)	(Acres)	(Acres)	(ft)	(ft)	(ft^2)	(Acres)	%	(ft)	(ft^2)	(Acres)	%	(Acres)	%
Square Field	2640	2640	160	0	100	7853.98	0.18	160.00	8	10528	42112	0.97	0.60%	339.29	0	0.00	0.00%	**0.97**	**0.60%**
	2640	2640	160	0	100	7853.98	0.18	160.00	10	10520	52600	1.21	0.75%	345.58	0	0.00	0.00%	**1.21**	**0.75%**
	2640	2640	160	0	100	7853.98	0.18	160.00	15	10500	78750	1.81	1.13%	361.28	0	0.00	0.00%	**1.81**	**1.13%**
	2640	2640	160	0	100	7853.98	0.18	160.00	20	10480	104800	2.41	1.50%	376.99	0	0.00	0.00%	**2.41**	**1.50%**
	2640	2640	160	0	100	7853.98	0.18	160.00	40	10400	208000	4.78	2.98%	439.82	0	0.00	0.00%	**4.78**	**2.98%**
	2640	2640	160	0	100	7853.98	0.18	160.00	60	10320	309600	7.11	4.44%	502.65	0	0.00	0.00%	**7.11**	**4.44%**
	2640	2640	160	0	100	7853.98	0.18	160.00	80	10240	409600	9.40	5.88%	565.49	0	0.00	0.00%	**9.40**	**5.88%**
	2640	2640	160	0	100	7853.98	0.18	160.00	100	10160	508000	11.66	7.29%	628.32	0	0.00	0.00%	**11.66**	**7.29%**
Obstacles +10	2640	2640	160	20	100	7853.98	0.18	156.39	80	10240	409600	9.40	6.01%	565.49	542867	12.46	7.97%	**21.87**	**13.98%**
Obstacles -10	2640	2640	160	0	100	7853.98	0.18	160.00	80	10240	409600	9.40	5.88%	565.49	0	0.00	0.00%	**9.40**	**5.88%**
Obstacles = 50ft	2640	2640	160	10	50	1963.50	0.05	159.55	80	10240	409600	9.40	5.89%	408.41	196035	4.50	2.82%	**13.90**	**8.71%**
Obstacles = 100ft	2640	2640	160	10	100	7853.98	0.18	158.20	80	10240	409600	9.40	5.94%	565.49	271434	6.23	3.94%	**15.63**	**9.88%**
Obstacles = 200ft	2640	2640	160	10	200	31415.93	0.72	152.79	80	10240	409600	9.40	6.15%	879.65	422230	9.69	6.34%	**19.10**	**12.50%**
Obstacles = 400 ft	2640	2640	160	10	400	125663.71	2.88	131.15	80	10240	409600	9.40	7.17%	1507.96	723823	16.62	12.67%	**26.02**	**19.84%**
	2640	2640	160	10	100	7853.98	0.18	158.20	8	10528	42112	0.97	0.61%	339.29	16286	0.37	0.24%	**1.34**	**0.85%**
	2640	2640	160	10	100	7853.98	0.18	158.20	10	10520	52600	1.21	0.76%	345.58	20734.5	0.48	0.30%	**1.68**	**1.06%**
	2640	2640	160	10	100	7853.98	0.18	158.20	15	10500	78750	1.81	1.14%	361.28	32515.5	0.75	0.47%	**2.55**	**1.61%**
	2640	2640	160	10	100	7853.98	0.18	158.20	20	10480	104800	2.41	1.52%	376.99	45238.9	1.04	0.66%	**3.44**	**2.18%**
	2640	2640	160	10	100	7853.98	0.18	158.20	40	10400	208000	4.78	3.02%	439.82	105558	2.42	1.53%	**7.20**	**4.55%**
	2640	2640	160	10	100	7853.98	0.18	158.20	60	10320	309600	7.11	4.49%	502.65	180956	4.15	2.63%	**11.26**	**7.12%**
	2640	2640	160	10	100	7853.98	0.18	158.20	80	10240	409600	9.40	5.94%	565.49	271434	6.23	3.94%	**15.63**	**9.88%**
	2640	2640	160	10	100	7853.98	0.18	158.20	100	10160	508000	11.66	7.37%	628.32	376991	8.65	5.47%	**20.32**	**12.84%**
Field Acres = 160	2640	2640	160	10	100	7853.98	0.18	158.20	80	10240	409600	9.40	5.94%	565.49	271434	6.23	3.94%	**15.63**	**9.88%**
Field Acres = 320	2640	5280	320	10	100	7853.98	0.18	318.20	80	15520	620800	14.25	4.48%	565.49	271434	6.23	1.96%	**20.48**	**6.44%**
Field Acres = 640	5280	5280	640	10	100	7853.98	0.18	638.20	80	20800	832000	19.10	2.99%	565.49	271434	6.23	0.98%	**25.33**	**3.97%**
Field Acres =160 & Obstacles= 10	2640	2640	160	10	100	7853.98	0.18	158.20	80	10240	409600	9.40	5.94%	565.49	271434	6.23	3.94%	**15.63**	**9.88%**
Field Acres = 320 & Obstacles= 20	2640	5280	320	20	100	7853.98	0.18	316.39	80	15520	620800	14.25	4.50%	565.49	542867	12.46	3.94%	**26.71**	**8.44%**
Field Acres = 640 & Obstacles= 40	5280	5280	640	40	100	7853.98	0.18	632.79	80	20800	832000	19.10	3.02%	565.49	1085734	24.93	3.94%	**44.03**	**6.96%**

Appendix C

Soil Texture Analysis Results

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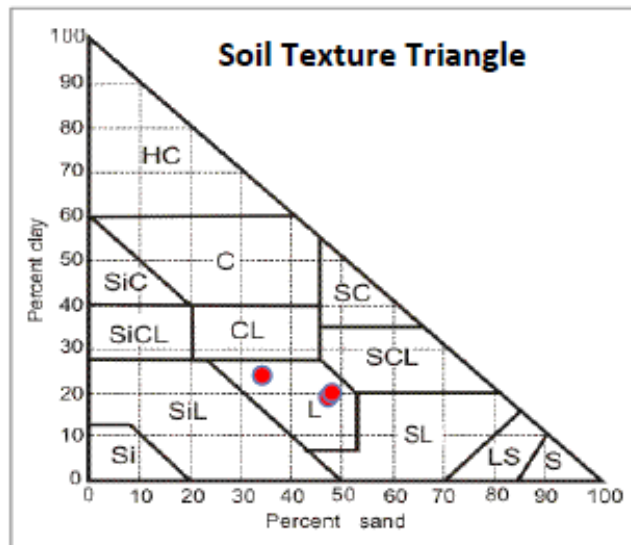|					Project :			3510 6th Ave North

Report #: 90463
Report Date: 2020-09-22
Received: 2020-09-18
Completed: 2020-09-22
Test Done: ST

Project :

PO:

3510 6th Ave North
Lethbridge, AB T1H 5C3
403-328-1133
www.downtoearthlabs.com
info@downtoearthlabs.com

		Sample ID:	200918K019	200918K020	200918K021	200918K022	200918K023
		Cust. Sample ID:	R1-1	R1-2	R1-3	R1-4	R1-5
Analyte	**Units**	**Limit**					
Sand	%	0.1	48.1	48.1	52.1	52.1	48.1
Silt	%	0.1	33.1	32.1	28.1	32.1	32.1
Clay	%	0.1	18.8	19.8	19.8	15.8	19.8
Soil Texture	-	1	Loam	Loam	Sandy Loam	Sandy Loam	Loam

C-1
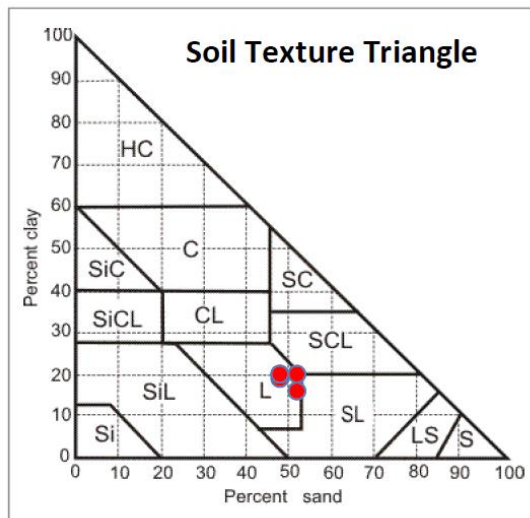
Down To Earth Labs Inc.
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Report #: 90463	Project :	3510 6th Ave North
Report Date: 2020-09-22		Lethbridge, AB T1H 5C3
Received: 2020-09-18		403-328-1133
Completed: 2020-09-22	PO:	www.downtoearthlabs.com
Test Done: ST		info@downtoearthlabs.com

			Sample ID:	200918K024	200918K025	200918K026	200918K027
		Cust. Sample ID:		R1-6	R1-7	R1-8	R1-9
Analyte	Units	Limit					
Sand	%	0.1		47.2	48.0	34.1	34.2
Silt	%	0.1		34.0	32.2	42.1	41.9
Clay	%	0.1		18.8	19.8	23.8	23.8
Soil Texture	-	1		Loam	Loam	Loam	Loam

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		Sample ID:	200918K028	200918K029	200918K030	200918K031	200918K032
	Cust.	Sample ID:	R2-1	R2-2	R2-3	R2-4	R2-5
Analyte	Units	Limit					
Sand	%	0.1	50.2	50.2	50.2	50.2	40.2
Silt	%	0.1	28.0	32.9	33.9	31.9	38.9
Clay	%	0.1	21.8	16.8	15.8	17.8	20.8
Soil Texture	-	1	Loam	Loam	Loam	Loam	Loam

Soil Texture Triangle

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Report #: 90464			Project :			3510 6th Ave North
Report Date: 2020-09-22						Lethbridge, AB T1H 5C3
Received: 2020-09-18						403-328-1133
Completed: 2020-09-22			PO:			www.downtoearthlabs.com
Test Done: ST						info@downtoearthlabs.com

		Sample ID:	200918K033	200918K034	200918K035	200918K036
		Cust. Sample ID:	R2-6	R2-7	R2-8	R2-9
Analyte	Units	Limit				
Sand	%	0.1	40.2	34.2	36.2	46.4
Silt	%	0.1	37.9	43.9	42.9	33.8
Clay	%	0.1	21.8	21.8	20.8	19.8
Soil Texture	-	1	Loam	Loam	Loam	Loam

Soil Texture Triangle

Raygan Boyce - Chemist

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Analyte	Units	Sample ID: Cust. Sample ID: Limit	200918K037 R3-1	200918K038 R3-2	200918K039 R3-3	200918K040 R3-4	200918K041 R3-5
Sand	%	0.1	44.4	47.2	46.2	48.2	47.3
Silt	%	0.1	32.8	34.9	35.9	33.9	32.8
Clay	%	0.1	22.8	17.8	17.8	17.8	19.8
Soil Texture	-	1	Loam	Loam	Loam	Loam	Loam

Soil Texture Triangle

Down To Earth Labs Inc.
The Science of Higher Yields

			Report #: 90465	Project :	
			Report Date: 2020-09-22		
			Received: 2020-09-18		
			Completed: 2020-09-22	PO:	
			Test Done: ST		

Analyte	Units	Cust. Sample ID: Limit	Sample ID: 200918K042 R3-6	200918K043 R3-7	200918K044 R3-8	200918K045 R3-9
Sand	%	0.1	35.1	35.1	40.1	30.1
Silt	%	0.1	43.1	44.1	38.1	46.1
Clay	%	0.1	21.8	20.8	21.8	23.8
Soil Texture	-	1	Loam	Loam	Loam	Loam

Soil Texture Triangle
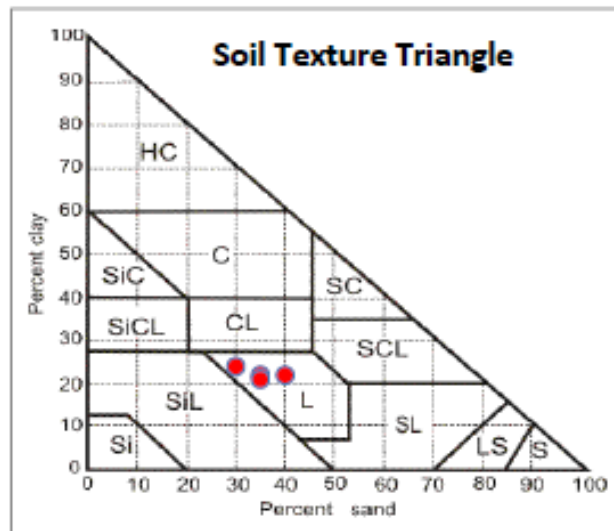
Raygan Boyce - Chemist

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