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PROJECT FINAL REPORT

Instructions:

- **Please note that making changes to the project without prior written consent from the funder(s) could constitute sufficient grounds for termination of funding.**
- This report must be a stand-alone report, *i.e.,* must be complete in and of itself. Scientific articles or other publications cannot be substituted for the report.
- A signed electronic copy of this report must be forwarded to the funders' representative on or before the due date, as per the investment agreement.
- A detailed, signed statement of revenues received and expenses incurred during the entire funding period of the project must be submitted along with this report, as per the investment agreement.
- For any questions regarding the preparation and submission of this report, please contact the funders' representative.

Section A: Project overview

1. **Project number:** 2013F121R
2. **Project title:** Assessing current soil test based fertilizer recommendations for direct seeding systems to optimize crop production and contribution margin
3. **Abbreviations:** Define ALL abbreviations used. B- Boron; C – Carbon; Ca – Calcium; CT – Conventional tillage; Cu – copper; DS - Direct seeding; ENR – Estimated nitrogen release; Fe- Iron; K – Potassium; Mg ha^{-1} – Mega gram per hectare; Mg – magnesium; Mn – Manganese; MWD – Mean weight diameter; N – Nitrogen; NO_3-N – Nitrate nitrogen; OM – Organic matter; P – Phosphorus; S - Sulphur; Zn – Zinc; NS – Not significant; ł - Significant at 10% probability; * - Significant at 5% probability; * - Significant at 1% probability; *** - Significant at 0.1% probability;
4. **Project start date:** (yyyy/mm/dd) **2013/04/01**
5. **Project completion date:** (yyyy/mm/dd) **2016/03/31**

6. Final report submission date: (yyyy/mm/dd) 2016/10/20	
7. Research and development team data	
a) Principal Investigator: (Requires personal data sheet (refer to Section 14) only if Principal Investigator has changed since last report.)	
Name	**Institution**
Kabal S. Gill	SARDA (Smoky Applied research & Demonstration Association)
b) Research team members (List all team members. For each new team member, *i.e.*, joined since the last report, include a personal data sheet. Additional rows may be added if necessary.)	
Name	**Institution**
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Section B: Non-technical summary (max 1 page)

Provide a summary of the project results which could be used by the funders for communication to industry stakeholders (*e.g.*, producers, processors, retailers, extension personnel, etc.) and/or the general public. This summary should give a brief background as to why the project was carried out, what were the principal outcomes and key messages, how these outcomes and key messages will advance the agriculture industry, how they will impact industry stakeholders and/or consumers, and what are the economic benefits for the industry. This summary should be in plain, non-scientific language.

The objectives were to assess the effects of different soil test based fertilizer rates and seeding systems on canola and cereals (wheat / barley) growth, production and soil properties; and communicate the information to the producers and others. Field trials were near Donnelly (NW7-77-20W5; GPS: 55°39'38.43"N, 117°6'10.64"W), southeast Peace Region, Alberta. From 2010 to 2015 (6 yrs), combinations of two seeding systems (DS – direct seeding and CT – conventional tillage) and four fertilizer rates (0, 60, 100 and 140% of the soil tests based recommendation) were repeated on the same plots using a canola – cereal (wheat in 2010 to 2012 and barley in 2013 and 2014) rotation. Each year, soil test results (0-6 and 6-12 inch depths) were used to calculate the nutrient (N, P, K, and S) amounts to be applied for each treatment.

There were no clear trends for seeding system effects on the residual NO_3-N, available P, extractable K, and sulphate S concentrations in the 0-6 inch soil. Increase in fertilizer rate increased (not always significant) the residual NO_3-N, available P, and sulphate S concentrations, after the years with below normal rain and crop yield. There was not a systematic build up of residual nutrients level from higher fertilizer rates with passage of years. These results can help producers to save on fertilizers after a low crop yield year.

When there was higher residual NO_3-N, available P and sulphate S levels after the crops at higher fertilizer rates, lower N, P and S fertilizer rates were recommended for some of those treatments. High yields in spite of lower fertilizer application in some of the higher fertilizer rate treatments indicated that the crops effectively used the residual nutrients.

The 2016 spring soil samples indicated increased stratification for some soil properties under with DS than CT at higher fertilizer rates. The OM, ENR and P concentrations showed a greater decline with increase in soil depth; whereas greater increase with soil depth was noticed for pH, Ca and Mg values. No change in stratification was noticed for the concentration of mobile nutrients like NO_3 and S.

More vigorous crops with 100% fertilizer caused faster soil moisture depletion than 0%. The aggregate stability results showed positive effects of reduction in tillage intensity and increase in fertilizer. The effect was larger for the seeding system than fertilizer rate. The length, surface area, volume and number of tips for canola and barley roots were increased with fertilizer application and were greater DS than CT system. The length, surface area and volume of barley roots were greater than canola while the number of tips were in a similar range for both crops.

The response of canola and wheat seed yields to fertilizer rate increase was curvilinear and indicated diminishing response to fertilization at higher fertilizer rates. Overall, a fertilizer rate near 100% of recommendation was appropriate to achieve their optimum yields. Unlike canola and wheat, the nature of barley yield response to fertilizer rate change did not show a consistent linear or curvilinear response and data indicated 100% to 140% fertilizer rates to be appropriate for optimum barley yield. Averaged across years, the seed yield was very slightly greater under DS than CT system (23 to 67 kg ha^{-1} yr^{-1}).

Compared to 0% fertilizer rate as reference (1), canola seed yield at 140% fertilizer rate was 1.35, 2.34, 3.00, 2.20 and 3.25 times in 2011, 2012, 2013, 2014 and 2015, respectively. Similarly, cereals seed yield at 140% was 1.05, 1.30, 1.26, 1.31, 1.18, and 1.43 times in 2010, 2011, 2012, 2013, 2014 and 2015, respectively. These relative yields showed that the percent seed yield response to fertilizer became larger with passage of years, indicating that repeated use of fertilizer on the same area widened the gap in productivity of fertilized and unfertilized plots. Apparently, some of the added fertilizers were being recycled in the soil for subsequent crops. This also suggests that fertilizer use efficiency based on application year data only is underestimated. Long term nutrient use efficiency can provide a better estimation.

Overall, residual nutrients measured by soil tests can assist producers to optimize fertilizer rates and save costs. Fertilizer additions improved soil water use, soil aggregation and root growth. Fertilizer effect on crop yield was enhanced with years of repeated use and some nutrients were recycled for subsequent crop via soil. No major differences were noticed between the seeding systems. Stratification of some soil properties needs more study.

Section C: Project details

1. **Background (max 1 page)**
   Describe the project background and include the relevant scientific and development work providing the impetus for the current project.

Background

High fertilizer prices make efficient use of nutrients extremely important for the bottom line in crop production. Agronomists consider soil test based fertilizer application a sustainable and economical technique to optimize crop production and profit margin while maintaining soil quality, and minimizing negative effects on environment. However, many farmers don't regularly use soil tests to decide their fertilizer application rates. The reasons given for this management decision range from doubts about its effectiveness to economics.

Effective soil test based fertilizer recommendations should consider both the current pool of available nutrients present at seeding and the potential supply of nutrients from soil during the growing season. In western Canada, soil testing laboratories generally base fertilizer recommendations on a single pre-plant soil test and estimate the contribution from soil during the growing season. Walley and Yates (2002) stated soil testing laboratories generally base N recommendations on a single pre-plant soil nitrate-N test and ignore or estimate the contribution from organic N, because of the difficulty in predicting nutrient mineralization from soil during the growing season. Also, recommendations for nutrient application have been primarily based on data sets collected from soils with a long-term history of low fertilizer usage under conventional tillage (CT) and crop rotations that included fallow. Nutrient release patterns are likely to differ substantially in modern agricultural systems, due to the shifts in long-term cropping history, nutrient application practices and tillage management (Grant et al 2002; Malhi et al. 2001).

Mineralization of nutrients from soil organic matter and crop residue is a microbial process, influenced greatly by environmental factors such as moisture and temperature (Goncalves and Carlyle 1994). Soil characteristics such as aeration, soil N concentration, soil organic C concentration, pH, soil texture and microbial biomass are also important (Walley and Yates 2002). Manure management, cropping history and other management factors, which influence the soil microclimate, crop residue return and distribution in the soil, soil organic matter content and N supply to the microbial biomass, also influence both actual amount and potential N mineralization (Zebarth et al. 2001). Therefore, rate and pattern of nutrient mineralization may vary substantially from location to location.

The supply of nutrients from soil to crop includes inorganic nutrients present in the soil at seeding time and those released from the soil for plant use during the growing season, minus nutrient immobilization and loss from the system (Malhi et al. 1992). The purpose of fertilizer management is to make up the difference between nutrients available to the crop and the amount required for optimum crop growth and yield. However, the supply of N from the soil varies greatly among fields and years (Zebarth et al. 2001).

Direct seeding (DS) management increases soil microbial N turn-over resulting in higher crop production and grain N uptake compared with CT (Soon et al. 2001). In a 9-yr study of continuous DS spring wheat, the N-supplying capacity of the soil was improved by a combination of fertilizing, reducing tillage and cropping more frequently (Campbell et al 1993). When available water is low, crop yield and N uptake can be higher under DS than CT (Halvorson et al. 2000; Soon and Arshad 2005). Grain yield and protein content can also be lower and the crop can be more responsive to N fertilization under DS than CT (Malhi et al. 2001). Compared to CT, the DS system did not change production costs or short-term economic returns. It had higher production potential due to moisture conservation, used less fuel, but it required more herbicides (Lafond et al. 1993). In a review of tillage effects on crop production, Lafond et al. 1996, found that reduced tillage systems generally did not influence crop establishment or improve crop yield, but they did slow down crop residue decomposition. In centre-east Alberta, DS generally improved grain and straw yields of barley due to greater water use efficiency in years with below normal precipitation (McAndrew et al. 1994).

Carter and Rennie (1985) found that crop recovery of ^{15}N fertilizer was significantly higher under shallow CT than DS in 2 of the 6 experiments while the converse was true in 1 experiment. Malhi and Nyborg (1991) observed that differences in ^{15}N recovery between the CT and DS were negligible for spring application whereas the ratio of plant to soil recovery from autumn application was greater under DS than CT. Haugen-Kozyra et al. (1993) found no differences between the DS and CT for ^{15}N recovery in barley plants and soil at various stages of crop growth in Alberta. Tillage systems had no consistent effect on growth, P concentration or uptake and seed yields of canola or wheat; and there was no tillage by P rate interactions (Grant et al. 2009).

The preceding review of research clearly indicates a need for the comparison of soil test based fertilizer recommendations under the CT and DS systems. Use of different fertilizer rates under the CT and DS systems would also demonstrate their relative performance under the 2 systems. Comparison of different fertilizer rates on same plots for a number of years under different seeding systems make this project unique from the earlier studies on soil test based fertilizer rates.

Local comparisons of crop yield and soil quality under different soil test based fertilizer rates, allow area producers to assess their effectiveness. The results are discussed with farmers through field tours, presentations, reports, articles, and media.

2. Objectives and deliverables (max 1 page)

State what the original objective(s) and expected deliverable(s) of the project were. Also describe any modifications to the objective(s) and deliverable(s) which occurred over the course of the project.

Objectives

1. To determine the effects of seeding systems on soil test based fertilizer rates for canola and cereals.

2. To study how soil test based fertilizer rates for optimum crop production and profit margin may change under different seeding systems when the same rate is used on a given area for a number of years.

3. To demonstrate seeding systems interaction with soil test based fertilizer rates for crop production and soil properties.

4. To measure the multi-year effects of different soil test based fertilizer rates seeding systems on crop production, contribution margin and soil properties.

5. To communicate the information on the optimum soil test based fertilizer rates under different seeding system to the producers and others.

In 2015, additional observations were done on root growth of canola and barley, nutrient availability using PRS probes and aggregates stability for the 0% and 100% fertilizer treatments under both the DS and CT systems.

3. Research design and methodology (max 4 pages)

Describe and summarise the project design, methodology and methods of laboratory/field and statistical analysis that were actually used to carry out the project. Please provide sufficient detail to determine the experimental and statistical validity of the work and give reference to relevant literature where appropriate. For ease of evaluation, please structure this section according to the objectives cited above.

Experimental

Trial location and treatments: The trials were located 4 miles south of Donnelly at the Gauthier farms (NW7-77-20W5; GPS: 55°39'38.43"N, 117°6'10.64"W) in the southeast Peace Region of Alberta. The site had been under direct seeding (DS) since 2002.

Two separate blocks were used for growing canola and a cereal (wheat or barley) each year, from 2010 to 2015. Combinations of two seeding systems (DS – direct seeding and CT – conventional tillage) and four fertilizer rates (0, 60, 100 and 140% of the soil tests based recommendation) were compared using a canola – cereal (wheat in 2010 to 2012 and barley in 2013 and 2014) rotation. The treatments were replicated four times using a split plot design, with the seeding system as main plots and fertilizer rates as sub plots. Six passes of the seed drill in each main plot are used to accommodate the 4 fertilizer rate (0%, 60%, 100%, & 140%) sub-plots plus a guard plot on each side.

From 2010 to 2015, the same seeding system and fertilizer rate were repeated in a given plot to demonstrate their effects of there fertilizer rates for 6 years. For each treatment (not for whole trial), soil test based fertilizer rate recommendations were considered for the N, P, K and S fertilization. Fertilizer application rates for the 60% and 140% treatments were calculated relative to the soil test based (100%) for that treatment. No fertilizer was applied to the 0% treatments for the 6 years.

In the DS system, herbicides were used as needed for weed management. In the CT system, fall and spring tillage operations were used for seedbed preparation. For in-crop weed management, similar herbicides were applied to all the plots of a crop. Fungicides and desiccants were used when required

Spring soil moisture and rain data during the growing season were collected from the nearest weather station at Ballater, AB (Table1).

Procedures: Soil samples were collected from each plot in the fall or spring (0-6 and 6-12 inch depths) and the soil test results were used to calculate the fertilizer recommendations and the amounts of nutrients to be applied. Combinations of seed placed 11-52-0, and side banded 46-0-0 + 0-0-60 + 20.5-0-0-24 fertilizers were used to supply the designated amounts of N, P, K and S.

2010 Procedures: The CT plots received fall and spring tillage operations. Mowed crop residue and glyphosate (360 g/ac) sprayed on May 7 for the DS plots. Seeding dates were May 11 for wheat (90 lb/ac Harvest), and May 12 for canola (Invigor 5440). Spectrum A (48 mL/ac) + Spectrum B (720 mL/ac) were sprayed on wheat plots (June 8). Due to uneven crop stand the canola plots were mowed in the vegetative growth stage and no data were collected. The harvest date for wheat was Sept. 18.

2011 Procedures: Glyphosate (540 g/ac) sprayed on May 5 in DS plots. The CT plots received the fall and spring tillage operations. Seeded canola (9 lb/ac RR72-55) and wheat (90 lb/ac Harvest) on May 7. Sprayed canola with glyphosate (180 g/ac) on June 10 and wheat with Prestige A (180 mL/ac) + Prestige B (800 mL/ac) on June 11. Desiccated with glyphosate (702 g/ac) on Sept. 7 and Reglone on Sept. 9. Harvested both crops on Sept. 23.

2012 Procedures: Glyphosate (180 g/ac) was sprayed on May 9 in DS plots. The CT plots received the fall and spring tillage operations. Seeding occurred on May 12 for canola (6 lb/ac 5535CL) and May 18 for wheat(90 lb/ac Harvest). Canola received Imazamox: 70 % @ 8.2g/ac (Solo) + Tepraloxydim: 200 g/L @ 0.08 L/ac (Equinox) + Merge 5% v/v on

June 10; and wheat received Pyrasulfotole: 15 g/L; Fenoxaprop-p-ethyl: 48 g/L, Bromoxynil: 87.5 g/L @ 0.81 L/ac (Tundra) on June 10. Desiccated crops using glyphosate (540 g/ac) on Sept. 2 and 0.7 L/ac Reglone on Sept. 12. The harvest date was Sept. 15 for wheat and Sept. 19 for canola.

2013 Procedures: Applied 810 g/ac Glyphosate (Transorb) for DS plots only, May 13. The CT plots received the fall and spring tillage operations. Canola (8 lb/ac 73-15RR) was seeded May 15. Barley (120 lb/ac Ponoka) had to be reseeded on June 22, due to herbicide spray drift damage. Sprayed canola (810 g/ac Glyphosate (Transorb)) + Lontrel 360 (304 mL/ac) on June20*,* and barley with Curtail M (810 mL/ac) + Liquid Achieve (200 mL/ac) + Turbocharge (202.5 mL/ac) on July 18. The harvest date was Oct. 14 for barley and Sept. 14 for canola.

2014 Procedures: The CT plots received the previous fall and spring tillage operations. Applied 540 g/ac Glyphosate (Transorb) + 10 g/ac Heat, May 21 on DS plots. Canola (8 lb/ac L130) and barley (120 lb/ac Austensen) were seeded on May 21. Canola was sprayed with 180 g/ac glyphosate (Transorb) on June 12; 0.16 L/ac Proline 480 480 SC + 0.125% v/v (0.975L/ac) Agral 90 on July 9; and 1 L/ac Reglone + 150 ml/ac AgSurf on Aug. 22. Barley received 0.33L/ac Infinity + 0.2 L/ac Achieve SG + 0.2L/ac Turbocharge on June 12; and 0.16 L/ac Proline 480 SC + 0.125% v/v (0.975L/ac) Agral 90 on July 9. Harvest occurred on Sept. 3 for barley and Sept. 6 for canola.

2015 Procedures: The CT plots received the previous fall and spring tillage operations. Applied 540 g/ac Glyphosate (Transorb) on May 11 to DS plots. Seeded canola (9 lb/ac L152) and barley (136 lb/ac Austensen) on May 11. Canola received liberty (1.5 L/ac) on June 4 and 0.75 L/ac Reglone on Sept 17. Barley received Stellar A (400 mL/ac) + Stellar B (240 mL/ac) + Axial BIA (500 ml/ac) on June 9. Harvest occurred on Aug. 19 for barley and Sept. 28 for canola.

Soil moisture in 2013, 2014 and 2015: Soil moisture from the 0-10, 10-20, 20-30 and 30-40 cm depths was measured using a PR2 probe and specified fibreglass access tubes (2.5 cm diameter). These access tubes have water tight plugs at the bottom and plastic plugs are used to cover their tops between the periodic readings. The access tubes were installed in 2013 and left in place until end of 2015 season, for periodic measurements. Due to resource constraints only the replication 1 and 3 plots were monitored.

Before each measurement, the access tubes were cleaned using paper towel wrapped around a tool designed to fit the access tubes. This was followed by inserting the PR2 probe in access tubes to record 3 reading for each soil layer. After the first reading was recorded, the PR2 was rotated by 120^{o} for second reading, and followed by another 120^{o} rotation for third reading. An average of the 3 readings was used to represent the soil moisture around the access tube for each soil depth.

Nutrients availability using PRS probes in spring of 2015: Plant Root Simulator (PRS®) probes are ion exchange resin membranes held in plastic supports to measure ion supply *in situ,* with minimal disturbance. Anion probes (orange) have a positively-charged membrane to simultaneously attract and adsorb all negatively-charged anions, such as nitrate (NO_3^-), phosphate ($H_2PO_4^-$, HPO_4^{2-}), and sulphate (SO_4^{2-}). Cation probes (purple) have a negatively-charged membrane to simultaneously attract and adsorb all positively-charged cations, such as ammonium (NH_4^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}).

Prior to use, anion probes are saturated with HCO_3^- and cation probes are saturated with Na^+, to act as counter-ions that are easily desorbed, to allow ready absorption of soil ions. When buried, soil ions displace the counter-ions at a rate that depends on their activity and diffusion rate in soil solution. The quantity of soil ions adsorbed during a burial period is a function of all soil properties (physical, chemical, and biological) controlling nutrient availability in soil.

The PRS probes were installed into the soil by making a slot prior to insertion to avoid breaking the PRS probe on April 28. These were taken out of soil on May 11, adhering soil was removed, and then thoroughly washed with a scrub brush and deionized water. The probes were transported, in a cooler, to the lab for measurement of adsorbed nutrients.

Root measurements in 2015: A representative area was chosen in each plot to gently sample >5 plants plus surrounding soil from a row in the 0% and 100% fertilizer treatments under both DS and CT systems. Samples (both roots and shoots) were collected carefully using shovel, on June 17. To make sure that all roots were intact for scanning by the WinRHIZO imaging, the collected plants + adjoining soil were brought inside the work area. To remove any soil particles and debris sticking to the roots, each sample was soaked in water for few hours, followed by gently shaking under water and repeated rinsing. Then the aboveground part of he plants was cut so that all roots of a plant are still attached to the base. All the debris sticking to the roots was carefully picked using tweezers.

The roots of 5 selected plants were placed on the scanning surface and small amount of water added to allow spreading of roots with minimum overlaps. The roots were then scanned using the WinRHIZO imaging machine to estimate the length, surface area, projected area, volume and number of tips for the roots in different root size categories (0<0.5, 0.5<1.0, 1.0<1.5, 1.5<2.0, 2.0<2.5, 2.5<3.0, 3.0<3.5, 3.5<4.0, 4.0<4.5, >4.5 mm diameters). The data from different categories were used to calculate their total values.

The aboveground material of 5 plants and roots after scanning were dried to determine their dry weights. Their dry mass values were used to calculate the root mass/shoot mass ratio.

Soil aggregate analysis in fall 2015: Collected soil samples from the top 2 inch (5 cm) of 0% and 100% fertilizer rates under both the CT and DS plots using small spades. Soil moisture content was determined by drying a sub-sample at 110 °C. Gently broke the fresh soil sample and weighed 50 - 75 gm of greater than 8 mm aggregates. Assembled the 6 sieve set (4.0, 1.5, 1.0, 0.5, 0.25, 0.125 mm openings). For wet sieving, filled the containers for sieving aggregates so that water touches the bottom of top sieve (4.0 mm) sieve. Gently placed the soil sample on top of 4.0 mm sieve and allowed to soak for 10 minutes. Then gently added some extra water to make sure that the soil sample does not emerge out of water during the wet sieving. The sample was lowered and raised for 10 minutes, using a mechanical device.
Detached the sieve assembly and gently pulled out of water. Separated each sieve (six sieves for each sample), with minimum disturbance to the aggregates. Transferred aggregates from the given sieve in to the pre-weighed dish or beaker, making sure to wash all the soil on a given sieve with wash bottle into beaker/dish. Dried each set of sample in the oven at 100 °C and recorded the weight.

Mean weight diameter (MWD) was calculated from dry weights of soil in each of the 7 aggregates sizes shown in Table 7, as given below.

$$\text{MWD (mm)} = \sum \text{aggregate size (mm)} \times \text{fraction of total soil weight in that aggregate size.}$$

Soil Nutrients in May 2016: Soil samples from the 0-3, 3-6, 6-9 and 9-12 inch depths were collected from each plot in May 2016. Several soil properties measured to assess any changes in stratification resulting from 6 years of using different seeding systems and fertilizer rates on same plots.

4. Results, discussion and conclusions (max 8 pages)

Present the project results and discuss their implications. Discuss any variance between expected targets and those achieved. Highlight the innovative, unique nature of the new knowledge generated. Describe implications of this knowledge for the advancement of agricultural science. For ease of evaluation, please structure this section according to the objectives cited above.

NB: Tables, graphs, manuscripts, etc., may be included as appendices to this report.

Results and Discussion

Growing conditions

A combination of low spring soil moisture and much below normal rain during the June and July were considered to reduce the wheat seed yield and canola was damaged by frost and later mowed in 2010 (Table 1). In 2011, there was adequate soil moisture for above normal crop yields. There was adequate soil moisture for good growth of crops but higher than normal temperature during flowering and pollination periods of the crops and Aster Yellows adversely influenced the crop yield in 2012, especially for canola. The 2013 had higher than normal rain during June that caused flooding for few days, dry and hot weather during the flowering and grain filling periods and reseeding of barley in June. Despite these, adequate moisture supply in 2013 resulted in good crop yields. In 2014, the crop yields were considered to be lower than expected, due to very dry and relatively warmer weather in the crop growing season. Despite receiving only 50% of normal rain in 2015, the crop yields were good because it rained frequently in July and Aug.

Residual nutrients after canola and cereals in the 0-6 inch soil during 2010 to 2015

Nitrate N (NO_3-N): For the 2010 to 2015 data, there was no clear trend for seeding system effects on the residual NO_3-N concentration (Table 2). But higher fertilizer rates increased the residual NO_3-N concentration after the 2010, 2013 and 2014 crops of canola and after the 2010, 2013, 2014 and 2015 crops of cereal, with relatively larger effects after the drier years of 2010 and 2014. Maximum difference of 34.0 ppm between the 140% and 0% fertilizer was observed after the 2010 canola that was mowed. The 2011 and 2012 seasons had near normal moisture supply (Table 1), and there was no clear effect of fertilizer rate on residual NO_3-N concentration after either of the crops.

Available P: Like the residual NO_3-N concentration in the 0-6 inch soil, the residual available P concentration did not show a consistent effect of the seeding systems (Table 2). The increase (not always significant) in residual P concentration with increase in fertilizer rate was observed for all years of both canola and cereals crops, except after the 2011 canola crop. Averaged across the 6 years, the differences between the 140% and 0% fertilizer rates was 4.3 ppm after the canola and 4.4 ppm after the cereals, indicating no clear effect of the crop on residual P level.

Extractable K: The amount of residual K after crops did not show a consistent effect of the seeding systems or fertilizer rates (Table 3). Some exceptions were higher level under DS than CT after 2010 wheat, and tendency for increased level with fertilizer rate after 2011 and 2014 canola.

Sulphate S: No consistent effect of the seeding systems was observed on residual S level after either canola or cereals (Table 3). There was a trend for increase (not always significant) in residual S level at higher fertilizer rates, for 5 seasons after canola and for 2 seasons after barley. More often increase after canola than cereals was apparently due to the higher S fertilizer rate applied to canola (Table 13 & 14). The data also indicate some of the extra residual S after canola may have been used by the subsequent cereal crop.

The residual NO_3-N, P and S concentrations indicated that soil test was able to detect the differences resulting from higher fertilizer rates when present, i.e. after years with low crop yield. These results can help producers to save on fertilizers after a low crop yield year, which may be due to lack of moisture, uneven stand or other reasons. As a result of higher residual NO_3-N, available P and available S after the crops at higher fertilizer rates, there were lower N, P and S fertilizer rates recommended for some of those treatments (Table 10 & 11).

There was not a trend for differences between the 0% and other fertilizer rates from one year to another, indicating no systematic build up of residual nutrients resulting from higher fertilizer rates.

Available nutrient concentrations using PRS™ probes in 2015 spring

In addition to what was being done annually using traditional soil test methods, the PRS™ probes were used to assess the effects of 5 annual repetitions of the 0% and 100% fertilizer rates and 2 seeding systems at both North and South sites on the ability of soil to supply nutrients to plants.

Some of the available plant nutrients (NO_3, Fe, Mn and Cu) tended to show greater concentration with 100% than 0% fertilizer rate under both seeding systems at both the North and South sites (Table 4). Other nutrients (NH_4, Ca, Mg, K, P, Zn, B and S) did not show consistent effects of fertilizer application.

For both 0% and 100% fertilizer treatments, the concentration of NO_3 was greater (not significantly) under CT than DS while an opposite trend was shown by Zn concentration (Table 4). Other nutrients and elements did not show a consistent effect of the seeding systems.

The data from PRS™ probes supported the traditional soil test results.

Soil properties in May 2016

To assess the effects of repeating the same seeding system and fertilizer rates on same plots for 6 years, soil samples were collected from the 0-2-3, 3-6, 6-9, and 9-12 inch soil depths. The organic matter (OM), ENR, pH, NO_3, P, S, K, Ca and Mg results from different soil depths were compared to assess if seeding systems or fertilizer rates changed the stratification, i.e. change in depth wise distribution (Table 5, 6 & 7).

Organic matter (OM): Organic matter under DS was greater than CT in the 0-3 inch at both North and South sites, and tended to be greater than CT in the 3 -6 inch at South site (Table 5). Compared to 0% fertilizer rate, there was a tendency for higher OM at 60%, 100% and 140% in some of the 0-3 and 3-6 inch soil depths at both the North and South sites. The OM amount in deeper soil layers (6-9 and 9-12 inch) did not show consistent effects of seeding systems of fertilizer rates.

ENR: Estimated Nitrogen Release (ENR) showed a trend similar to the OM results (Table 5). Similarity of the OM and ENR results is expected as ENR value is calculated based on the OM content of soil in combination with weather conditions of the area.

pH: Soil pH did not show a consistent influence from seeding systems, except slightly lower (not significant) value in the 0-3 inch soil under DS than CT system (Table 5). Increase in fertilizer rate significantly reduced soil pH in the 0-3 inch at North and 0-3 and 3-6 inch soil at South site. The soil pH at both sites also showed tendency for decline (not significant) with increase in fertilizer rates for the 6-9 inch soil, while it did not show any influence of fertilizer rates for the 9-12 inch soil.

NO_3-N: There was no consistent effect of the seeding systems on NO_3 concentration (Table 6). Increase in fertilizer rate tended to increase (not significantly) the NO_3 concentration for all the sampled soil layers, which could be expected due to some of the residual NO_3 from applied fertilizer or enhanced mineralization from slightly higher OM level in fertilized plots. Increase in NO_3 concentration in deeper soil layers indicates potential for leaching, even though it is unlikely because the deeper soil has clayey texture with very slow drainage rate and plant roots can access the nutrients from the sampled soil layers.

P: The P concentration did not show a consistent effect of seeding systems within the sampled soil layers (Table 6). However, the differences between 0-3 inch and 9-12 inch soil depths were greater under the DS (15.5 ppm at North and 17.3 ppm at South) than under CT (13.8 ppm at North and 14.7 ppm at South) system, which indicate more stratification under DS than CT system.

Increases in fertilizer rate significantly increased P concentration in the 0-3 inch soil, tended to increase P concentration in the 3-6 inch soil, and had no consistent effect in the 6-9 and 9-12 inch soil. Thus, the extent of stratification was greater at higher fertilizer rates. For example, the differences in P concentration between the 0-3 and 9-12 inch soil layers were smaller at 0% fertilizer rate (6.1 ppm at North and 10.3 ppm at South) and larger at 140% fertilizer rate (21.8 ppm at North and 21.1 ppm at South). Increased stratification has implications for reduced P availability and crop yield in dry soils and increased P loss from surface soil during run off.

S: The S concentration was not influenced by seeding system while it increased or tended to increase with fertilizer rate increases (Table 6). The change in S concentration from fertilization was similar for all sampled soil layers, indication lack of fertilizer induced stratification. Like NO_3 concentration, increase in S concentration could be expected due to some of the residual S from applied fertilizer or enhanced mineralization from slightly higher OM level in fertilized plots.

K: Concentration of K did not any show influence of seeding systems or fertilizer rate changes when compared for the sampled soil layer or change from shallower to deeper soil layers (Table 7). Lack of noticeable change was probably due to relatively small amount of K applied as fertilizer compared to larger amount already present in soil.

Ca and Mg: Both Ca and Mg concentrations did not show significant influences of seeding system or fertilizer rates at either of the sites (Table 7). Like pH, however, their concentration tended to decline with increase in fertilizer rate. Increases in yield at higher fertilizer rates enhanced Ca and Mg uptake, as no Ca or Mg were applied, which may have also reduced soil pH. These results points to increased soil acidity and more need for liming at higher fertilizer rates.

Some of the measured soil properties indicated increase in stratification, change in their values with increase in soil depth, by reduction in tillage and increase in fertilizer rate. Properties like OM, ENR and P concentrations showed a relatively greater decline with soil depth under DS than CT system and at higher fertilizer rates. On the other hand, an opposite trend was indicated for pH, Ca and Mg values. No change in stratification for the concentration of mobile nutrients like NO_3 and S was noticed with either seeding systems or fertilizer rates.

Soil Moisture in 2013, 2014 and 2015

For both canola and barley under the DS system in 2013, 2014 and 2015, the data collected indicated a trend of less soil moisture in the 100% than 0% fertilizer treatment during several periods of the growing seasons (Fig. 1 to 8). Some exceptions were under barley for the 0-10 cm and 20-30 cm layers in 2013. Usually, the trend of relatively less soil moisture in 100% than 0% treatment started earlier in the shallower soil layers and later in the deeper soil layers.

More vigorous crops with 100% than 0% fertilizer treatment were considered responsible for the extra soil water depletion. It also indicates faster growth of plant roots to deeper soil and improved water use efficiency with fertilizer application.

Between April 28 and May 11 in 2015, the surface 2 inch (5cm) soil dried faster under CT than DS system (Table 8). Average across the 0% and 100% fertilizer rates, water depletion was 11.9% for CT compared to only 5.2% for DS at North site; and it was 12.5% for CT compared to 4.3% for DS at South site. Thus by May 11, the DS plots had 6.9% and 8.8% more soil moisture than CT plots at North and South site, respectively.

Aggregate stability for the to 2 inch (0-5 cm) soil

Stability of soil aggregates showed effects of both seeding systems and fertilizer rates (Table 9). The effect was larger for the seeding system than fertilizer rate. The mean weight diameter (MWD) of aggregates was greater under the DS than CT system, for both the 0% and 100% fertilizer rates at both the North and South sites. Averaged across fertilizer rates, the MWD was 1.07 and 1.18 mm greater under DS than CT system at the North and South sites, respectively. Main differences in MVD resulted from higher % of coarse (1.0 – 8.0 mm) and lower % of fine (<0.25 mm) aggregates under the DS than CT system. Improved aggregate stability with reduction in tillage intensity is supported by earlier results.

The differences in MWD between the 0% and 100% fertilizer rates were much smaller compared to the differences between seeding systems (Table 9). Averaged across seeding systems, the 100% fertilizer rate showed 0.24 and 0.42 mm greater MWD than 0% fertilizer rate at the North and South sites, respectively. Like seeding systems, the difference in MWD between the fertilizer rates were due to higher % of coarse and lower % of fine aggregates under the 100% than 0% fertilizer rate.

Overall, the aggregate stability results showed the positive effects of tillage intensity reduction and fertilizer addition. Increased aggregate stability and larger aggregates are considered a positive attribute of soil quality that may enhance crop production due to improved root growth, drainage and water movement in clayey soils.

Amount of nutrients recommended for the canola and cereals in 2010 to 2015

Canola: The amount of N recommended for the 2011, 2014 and 2015 canola was reduced with increase in fertilizer rate applied to the preceding cereal crop under both the CT and DS systems (Table 10). Compared to 0% rate, the N amount recommended for 140% rate was lower by 37 to 46 lb/ac under the CT and by 11 to 42 lb/ac under the DS system. These were the years following a dry cropping season with below normal cereal crop yield. There was no consistent effect of the seeding system on the amount of N recommended. The recommended N rate did not show systematic change with the passage of years, but rather reflected the changes in crop growing conditions and reduced crop yield in the preceding year.

In a given year, similar amounts of P, K and S were recommended for canola under the different seeding systems and fertilizer rates (Table 10). When different amounts were recommended, the changes were relatively small. Between the 140% and 0% fertilizer rates, the differences were 5 lb/ac for P_2O_5, 5 to 12.5 lb/ac S and none for K_2O. These data indicated much lower sensitivity of P, K and S recommendations than the N recommendations. Probably, large amounts of total P and K in soil compared to the amounts applied as fertilizer was responsible for smaller changes in recommendations.

Cereals: Similar to the recommendations for canola, there was a tendency for lower N recommendations for cereal crops in some years and similar P, K, and S recommendations with increases in fertilizer rates; and no effect of seeding systems (Table 11). Decreases in N recommended amounts at higher fertilizer rates were observed for the 2011, 2013, 2014 and 2015 under CT and for the 2011, 2014 and 2015 under DS. The differences between 140% and 0% fertilizer rate ranged from 12 to 66 lb/ac under CT and from 118 to 73 lb/ac under DS system.

Again like canola, the changes in N recommendations due to change in fertilizer rate did not show a systematic change with passage of years, but rather reflected the changes in crop growing conditions and level of crop yield in the preceding year.

Differences in the total amounts of nutrients recommended from 2010 to 2015 (6 years) between the 0% and 140% fertilizer rates under the 2 seeding systems are shown in Table 12. Lesser amounts recommended for 140% than 0% fertilizer treatment indicate a feedback mechanism for reducing fertilizer recommendations, resulting from added fertilizers. This implies that some of the added fertilizers are being recycled for subsequent crops, apparently via soil. This also suggest that fertilizer use efficiency based on application year data only is underestimated and multi-year estimate can provide a better estimation.

Nutrient amounts applied to the canola and cereals in 2010 to 2015

The amounts of nutrients applied were calculated based on the soil test based nutrient amount recommended for each treatment (average of all replications) and the designated % for that specific treatment. For example, 0% fertilizer treatment did not receive any fertilizer.

As expected, the nutrient amount applied increased with increase in % of fertilizer rate in most cases (Table 13 & 14). However, due to lower nutrient recommendations for some of the higher fertilizer rate treatments the applied nutrient amounts in a given year were not always in the exact 60%, 100% and 140% proportion. Actually for wheat under both CT and DS systems in 2011 and under CT system in 2015, less N was applied to 140% than to 100% treatments. Similarly under DS system in 2011, lesser N was applied to 100% than to 60% treatment.

Resulting from changes in nutrients applied based on soil test recommendations and designated % for the treatment, actual amounts applied were somewhat higher than the designated 60% treatment and somewhat lower than the designated 140% treatment (Table 15).

Canola yield and growth (2010 to 2015):

Canola yield: The effects of seeding system by fertilizer rate interactions on the canola seed yield were significant in 2012 and 2014 (Table 16). In 2012, the increase in canola yield was significant for each fertilizer rate increase under both seeding systems; and the total increase with change in fertilizer rate from 0% to 140% was greater under DS (2.16 Mg ha^{-1}) than CT (1.62 Mg ha^{-1}). In 2014, the significant yield improvement with increase in fertilizer rate occurred up to 100% rate under DS and only up to 60% under CT. In both years, the yield increase with change in fertilizer rate from 0% to 140% was greater under DS (2.16 and 1.18 Mg ha^{-1} in 2012 and 2014) than CT (1.62 and 0.82 Mg ha^{-1} in 2012 and 2014).

Averaged across the fertilizer rates, the canola yield response to seeding systems was not consistent (Table 16). Considering the 2011 to 2015 canola seed yield, overall advantage of 0.11 Mg ha^{-1} (0.022 Mg ha^{-1} per year) was observed from the DS over CT system.

Averaged for both seeding systems, the canola yield response to fertilization was significant and maximum yield was observed at the 140% fertilizer rate in all the 5 years (Table 16). Significant increase in canola yield was observed in all the 5 years when the fertilizer rate was increased from the 0% to 60%, in 2 years (2012 and 2014) when the fertilizer rate was increased from the 60% to 100%, and in 3 years (2012, 2013 and 2015) when the fertilizer rate was increased from the 100% to 140%. These data indicated diminishing canola response to fertilization at higher rates, as expected. Overall, a fertilizer rate near 100% of recommendation should be targeted to achieve optimum canola yield.

In general, change in fertilizer rate from 0% to 60% (60% change) produced greater increase in yield compared to fertilizer rate change from 60% to 140 % (80% change), as shown in Fig. 9 to 13. Averaged across seeding systems, during 2011 to 2015 the seed yield difference between the 0% and 60% rate (60% rate change) ranged from 0.75 to 1.97 Mg ha^{-1} (averaged 1.34 Mg ha^{-1} per year) while difference between the 60% and 140% rate (80% rate change) ranged from 0.23 to 0.93 Mg ha^{-1} (averaged 0.51 Mg ha^{-1} per year). Thus average increase in seed yield from 1% change in fertilizer rate translated in to 22.3 kg ha^{-1} for the 0% to 60% and 6.4 kg ha^{-1} for the 60% to 140%.

The difference in canola seed yield between the 140% and 0% fertilizer rates ranged from 1.00 Mg ha^{-1} in 2014 up to 2.85 Mg ha^{-1} in 2012, with an average of 1.85 Mg ha^{-1} per year and a total increase of 9.25 Mg ha^{-1} (Table 16). Compared to 0% fertilizer rate as a reference (1), canola seed yield at 140% was 1.35, 2.34, 3.00, 2.20 and 3.25 times in 2011, 2012, 2013, 2014 and 2015, respectively. These relative canola yields in different years showed that the canola seed yield response to fertilizer became larger with the passage of years. Apparently repeated use of fertilizer on same area widened the gap in canola productivity of fertilized and unfertilized plots.

Canola emergence and growth: Canola emergence was generally maximum at 0% fertilizer rate and tended to decline with increases in fertilizer rates, except that emergence under CT system in 2015 showed an increase with fertilizer rate and may be considered an anomaly (Table 17). The seeding system x fertilizer rate interaction was not significant in 2011, 2012, 2013 and 2014, while it was significant in 2015 due to unexpected trend of increased emergence at higher fertilizer rates under the CT system. Average effect of fertilization on emergence was significant in 2011 to 2014 and did not show a clear effect in 2015 (due to the unexpected trend under CT). Thus in general, fertilizer use can be considered to result in reduced emergence.

No consistent effect of seeding systems was observed on the canola emergence (Table 17) and plant height (Table 18) in different years.

The plant height of canola did not show significant seeding system x fertilizer rate interaction in 4 years (Table 18). In 2014, canola height was maximum at 140% and 60% fertilizer rates under the DS and CT systems, respectively.

The plant height showed significant response to fertilizer application in all the 5 years (Table 18). It was significantly increased with fertilizer rate up to only 60% in 4 years (2011, 2012, 2014 and 2015) and 100% in 2013.

Visually, the canola canopy usually had a lighter colour and delayed development in the 0% than in higher fertilizer rate treatments. Pictures from 2015, clearly shows delayed canola crop development in 0% than in fertilized treatments (Pictures 1 to 6).

Cereals yield and growth (2010 – 2015)

Wheat yield and growth in first 3 years (2010 – 2012): Interaction of seeding systems x fertilizer rate did not have significant effect on wheat yield in any of the 3 years (Table 19). Higher (not significantly) wheat yield in 2010 under CT than DS was observed at all fertilizer rates. Tilling the soil after using a DS system since 2002 may have resulted in the accelerated mineralization of nutrients from the crop residues and soil organic matter to improve nutrient availability to the crop in CT system. The effect of seeding systems on seed yield was significant in 2011 only, when higher yield was observed under the DS than CT system. Averaged for 3 years, the wheat yield was greater under DS than CT system, by 0.51 Mg ha^{-1} (0.17 Mg ha^{-1} per year).

Fertilization produced significant wheat yield increase in 2011 and 2012 (Table 19). Significant increase in wheat yield with fertilizer was observed up to 100% in 2011 and up to 60% in 2012. Maximum wheat yield occurred at 60% in 2010 (a dry year) and at 100% in 2011 and 2012 (near normal rain). Maximum yield benefit from fertilization (difference between the treatment with maximum yield and 0% treatment was much smaller (0.23 Mg ha^{-1}) in dry year of 2010, than in normal ran years of 2011 (1.22 Mg ha^{-1}) and 2012 (1.05 Mg ha^{-1}). The nature of wheat yield response to fertilization was curvilinear in all years under both seeding systems, except under DS in 2010 when fertilization produced relatively small wheat yield response (Fig. 14 to 16). Overall, the results indicate that fertilizer rate of 60% to 100% be targeted to achieve optimum wheat yields.

A general trend of increasing wheat yields with higher fertilizer rates, in spite of fertilizer N application being low in the 60% and 100% treatments and nearly zero in the 140% treatment in 2011 (Table 19), indicated that the wheat crop effectively used the residual NO_3-N after the 2010 mowed canola.

Wheat emergence did not show significant response to seeding system and fertilizer rate or their interaction (Table 19). For example, wheat population was somewhat greater under CT than DS system in 2010, and under DS than CT system in 2011 and 2012. Similarly, the mean wheat population at different fertilizer rates was highest at 0% in 2010, 100% in 2011 and 60% in 2012.

Similar to the wheat emergence, the wheat plant height also did not show significant response to seeding system and fertilizer rates or their interaction, except that the wheat plants in 2010 were shorter in 0% than in other fertilizer rate treatments (Table 19).

Barley growth and yield in second 3 years (2013 – 2015): Like wheat, the barley yield response to seeding system x fertilizer interaction was not significant in any year (Table 20). Main effect of seeding system was significant in 2014 and 2015, but without a consistent trend. Across 3 years, the DS system produced 0.19 Mg ha^{-1} (0.063 Mg ha^{-1} per year) higher yield than CT system.

Significant response of barley yield to fertilization was observed in all the 3 years (Table 20). Barley yield differences between 0% and 60% fertilizer rate were significant for each year, while between 60% and 100% fertilizer rates were not significant in any year. The 140 % fertilizer rate produced significantly greater barley yield than both the 60% and 100% rates in 2013 and 2015, while the increase was not significant in 2014. Maximum barley seed yield was produced with 140% fertilizer rate in all the 3 years, with benefit of 1.44, 0.91 and 1.07 Mg ha^{-1} in 2013, 2014 and 2015, respectively. Thus the total benefit of 3.42 Mg ha^{-1} (1.14 Mg ha^{-1} per annum) was observed from 140% over the 0% fertilizer rate. Unlike canola and wheat, the nature of barley yield response to fertilizer rate change was not consistently linear or curvilinear (Fig. 17 to 19). The data indicated 100% to 140% fertilizer rates to be appropriate for optimum barley yield.

The seeding system by fertilizer interaction was significant for barley emergence in 2015, when barley population in response to fertilizer rate increase tended to increase under DS and decline under CT (Table 21). Barley population was significantly greater under CT than DS system in 2014 and 2015, while differences between the 2 seeding systems were relatively small in 2013. These results indicate better barley emergence under CT than DS, but that advantage was related to barley yield in only 2015.

The barley plant height also did not show significant response to seeding system and fertilizer rate interaction (Table 20). But average barley height was greater under DS than CT in both 2014 and 2015. Barley plant height in 2014 and 2015 did not show a consistent response to fertilization.

Like canola, generally the response of cereals to fertilization tended to increase with the passage of years. Compared to 0% fertilizer rate as 100%, seed yield at 140% fertilizer rate was 1.05, 1.30, 1.26, 1.31, 1.18, and 1.43 times in 2010, 2011, 2012, 2013, 2014 and 2015, respectively. Again, repeated use of fertilizer on same area widened the gap in productivity of fertilized and unfertilized plots.

Canola and barley roots in 2105

Canola root length was increased with fertilizer application under both the CT and DS seeding systems (Table 21). This increase was observed for all root sizes (from <0.5 to >4.5 mm diameters). Also, somewhat greater proportion of thinner roots was observed in 0% than in 100% fertilizer rates under both the seeding systems. For example, the <0.5 mm roots comprised 87 to 93% of total length in 0% rate relative to 84 to 87% % of total length in 100% fertilizer rate.

The actual differences between the 0% and 100% rates were greater for the finer canola roots and declined with increase diameter of roots, because most of the total root length was comprised of finer roots. The differences between 0% and 100%, for example, were 190 cm under CT and 70 cm under DS for the <0.5 mm roots, with differences between thicker roots being much smaller (ranged 0.83 to 18.4 cm under CT and 1.79 to 24.5 cm under DS).

Unlike the actual differences, the relative increase in canola root length from fertilization was smaller for the finer roots and larger for the thicker roots. For example, compared to 0% rate as reference (1), the relative root length under the 100% fertilizer rate was 1.75 times under CT and 1.22 times under DS for the <0.5 mm roots, and it gradually increased to 34.6 times under CT and 40.6 times under DS for the 3.0 – 3.5 mm diameter roots.

The trends for surface area, projected surface area and volume of canola roots were similar to the root length results (Table 21).

Almost all of the canola root tips were in the <0.5 mm size, which represented 95 to 99% of the total number of tips (Table 21). This could be expected, because tips of roots are the newest grown parts of roots. Like preceding root measurements, the number of canola root tips was greater for 100% than 0% fertilizer rate under both seeding systems.

Barley root data presented very similar response to fertilization as the canola roots, for both the seeding systems and fertilizer rates (Table 22).

For both the canola and barley roots, generally the length, surface area, projected area, volume and number of tips were greater under DS than CT systems, for both the 0% and 100% fertilizer rates (Table 21 & 22). Some exceptions were noticed for greater root length of barley under CT than DS for the <0.5, 2.5-3.0, and 3.5-4.0 mm diameter roots in 0% and the 3.5-4.0 and 4.0-4.5 mm diameter roots in 100% fertilizer rate.

Comparison of canola and barley root results showed the length, surface area, projected area and volume of barley roots were greater than canola while the number of tips were in the similar range for both crops (Table 23).

Like other root data, 100% fertilizer rate had greater root mass than 0% rate for both canola and barley (Table 24). However, the differences in 0% and 100% fertilizer rates were many times more for canola than for barley. For example, the 100% rate had 5.42 times (under CT) and 7.35 times (under DS) greater root mas than 0% fertilizer rate for canola. Corresponding values for barley were 1.02 times and 1.13 times.

Similar to root mass, the canola shoot mass was greater under 100% than 0% fertilizer rate (Table 24). But the barley root mass did not show a consistent effect of fertilizer rate.

The root mass / shoot mass ratio was lower for the 100% than 0% fertilizer rate, except for barley under CT, indicating that fertilizer rate had generally more pronounced effect on the root than shoot mass in the early crop growth period.

The seeding system did not have a consistent effect on root or shoot masses of both crops for either the 0% or 100% fertilizer rates. The root / shoot mass ratio was lower under DS than CT for canola while it did not show consistent effects of seeding system for barley.

Acknowledgements

The following organizations are thankfully acknowledged for providing funds for the project.

- Alberta Canola Producers Commission funded major portion of the costs in 2013, 2014 and 2015.
- Alberta Barley Commission provided $1,000 per year for the 2013, 2014 and 2015.
- Portions of the Agricultural Opportunity Fund (AOF), AAF, Government of Alberta funds were used for the project in all the six years.
- Portions of the Municipal districts of Smoky River, Big lakes, Greenview and Northern Sunrise funds were used for the project in all the six years.

5. Literature cited

Provide complete reference information for all literature cited throughout the report.

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6. Project team (max ½ page)

Describe the contribution of each member of the R&D team to the functioning of the project. Also describe any changes to the team which occurred over the course of the project.

Kabal S. Gill coordinated all steps of the project, i.e. funding, preparation for the field work, field activities, field observations, sample collection, sample processing, laboratory analyses, and data management. He also did the data analyses, interpretation, writing reports and extension presentations.

7. Benefits to the industry (max 1 page; respond to sections *a)* and *b)* separately)

a) Describe the impact of the project results on the Alberta or western Canadian agriculture and food industry (results achieved and potential short-term, medium-term and long-term outcomes).

- This project has addressed the concerns about use of soil tests for fertilizers applications in the southeast Peace Region.
- Comparisons of soil tests under both direct seeding and conventional tillage systems in the present study were different than most of the previous studies.
- Use of different fertilizer rates and seeding systems on same area for 6 years showed how repeated use of fertilizers can enhance the effects of fertilizer use with the passage of time.
- Using soil tests to determine the fertilizer rates for target crop production levels could optimize fertilizer rates and minimize environment effects as well as improve yield and profit.
- Assessment of soil tests for both direct seeding systems and conventional tillage systems showed that the soil tests were effective under both seeding systems.
- Awareness about the benefits of using soil tests has been created amongst the producers and others using annual reports, newsletters, presentations, field days, web sites and newspaper articles.
- This information will help producers of canola and cereal crops to optimize their crop production and contribution margins at their farms under both the direct seeding systems and conventional tillage systems.
- Producers will optimize the input costs, minimize environmental effects and improve soil quality.
- Project has created local information on the comparison of different fertilizer rates under direct seeding systems and conventional tillage systems to optimize seed yield and profit margin.
- This project highlighted the importance of using soil tests for optimum crop production and economic sustainability.

b) Quantify the potential economic impact of the project results (*e.g.,* cost-benefit analysis, potential size of market, improvement in efficiency, etc.).

  - Benefits of using soil tests to apply fertilizer under direct seeding systems and conventional tillage systems have been documented.
  - It has been shown that the degree of benefits from fertilization vary from one year to another.
  - Project addressed the issues of increasing input costs and economic sustainability of crop production in the southeast Peace Region.
  - The same principles would likely apply to other areas in western Canada.
  - It provided an opportunity to demonstrate better versus poor agronomic practices.
  - Sustainable cropping systems and improved yields would be the long-term outcome of this project.
  - Optimization of inputs and other benefits could also reduce the ecological cost of manufacturing, transporting and applying inputs.
  - Based on a nominal $10 per acre benefit from reduced input costs and increased production on 5% of seeded acres in the Peace region, the annual benefits for farmers could add up to $1.25 million.
  - For $33,000 funding from the Consortium, the estimated benefit on canola and other crops is about 3,788% per annum.
  - It is suggested that public policies need to encourage adoption of economically and environmentally sustainable crop production practices.

8. **Contribution to training of highly qualified personnel (max ½ page)**
   Specify the number of highly qualified personnel (*e.g.*, students, post-doctoral fellows, technicians, research associates, etc.) who were trained over the course of the project.

- During the 2010 to 2015 trial years, 3 technicians were trained in collection of soil samples, laying out the plots, applications of agronomic practices plus collection and management of data.
- Several summer students were trained on numerous tasks to undertake the different activities mentioned above.
- In 2015, 2 agrologists were trained in collection of soil samples, laying out the plots, applications of agronomic practices plus collection and management of data.

9. **Knowledge transfer/technology transfer/commercialisation (max 1 page)**
   Describe how the project results were communicated to the scientific community, to industry stakeholders, and to the general public. Please ensure that you include descriptive information, such as the date, location, etc. Organise according to the following categories as applicable:
   a) Scientific publications (*e.g.*, scientific journals); attach copies of any publications as an appendix to this final report
   b) Industry-oriented publications (*e.g.*, agribusiness trade press, popular press, etc.); attach copies of any publications as an appendix to this final report
   c) Scientific presentations (*e.g.*, posters, talks, seminars, workshops, etc.); attach copies of any presentations as an appendix to this final report
   d) Industry-oriented presentations (*e.g.*, posters, talks, seminars, workshops, etc.); attach copies of any presentations as an appendix to this final report
   e) Media activities (*e.g.*, radio, television, internet, etc.)
   f) Any commercialisation activities or patents
   N.B.: Any publications and/or presentations should acknowledge the contribution of each of the funders of the project, as per the investment agreement.

- Each year, the trial maps and related information were made available at the site entrance for self-guided tours by the farmers and others during the July to September period. Numerous farmers, and several industry, extension and research professionals have mentioned using self-guided tours.
- Each year, the results were presented at the AGM of the Big Meadows Soil Conservation Society, ASB's of the four municipalities supporting SARDA, and AGM of SARDA.
- Each year, abstract and full a report of the project were published in the annual project reports of SARDA. These were mailed to SARDA members, funding agencies and government and industry professionals collaborating with SARDA.
- Each year, abstract of the project report was published in an issue of the Back Forty newsletter of SARDA, bulk mailed to about 3000 producers and emailed to about 450 professionals/ farmers.
- In 2010 and 2012, SARDA organized an open house at the trial site in July. It was well attended by the farmers and others.
- In 2011, the trial was showcased to the Alberta Soils Tour, a group of about 75 professionals across Alberta.
- In 2012, SARDA presented the trial to the Provincial Agriculture Service Board participants, numbering about 300.
- Results were presented at the November 2013 ACPC regional meeting in Falher.
- Results were presented at the November 2013 ABC and APG regional meeting in Falher.
- In 2014, results were presented at producer meetings at 5 different locations in the southeast Peace region.
- In 2015, SARDA organized a tour of the trials that was attended by 25 producers and industry professionals.

- Results were presented at the “SARDA AGM, Feb. 25, 2016, Falher” to SARDA members, other farmers and professionals.

Section D: Project resources

1. **Provide a detailed listing of all cash revenues to the project and expenditures of project cash funds in a separate document certified by the organisation’s accountant or other senior executive officer, as per the investment agreement.** Revenues should be identified by funder, if applicable. Expenditures should be classified into the following categories: personnel; travel; capital assets; supplies; communication, dissemination and linkage (CDL); and overhead (if applicable).
2. **Provide a justification of project expenditures and discuss any major variance (*i.e.*, ± 10%) from the budget approved by the funder(s).**
3. **Resources:**
   Provide a list of all external cash and in-kind resources which were contributed to the project.

   NOTE: The allocation of resources given the following Table refers to 2013 to 2015 period (3 years). The report also covers the 2010 to 2012 years (3 years), when the project was funded from SARDA resources.

Total resources contributed to the project		
Source	**Amount**	**Percentage of total project cost**
Agriculture Funding Consortium	28,000	66%
Other government sources: Cash	9,600	23%
Other government sources: In-kind		%
Industry: Cash	3,000	7%
Industry: In-kind	1,800	4%
Total Project Cost		**100%**

External resources (additional rows may be added if necessary)		
Government sources		
Name (no abbreviations unless stated in Section A3)	Amount cash	Amount in-kind
Industry sources		
Name (no abbreviations unless stated in Section A3)	Amount cash	Amount in-kind
Supplemental funding from ACPC in 2015	5,000	

Section E: Research Team Signatures and Authorised Representative's Approval

The Principal Investigator and an authorised representative from the Principal Investigator's organisation of employment MUST sign this form.

Research team members and an authorised representative from their organisation(s) of employment MUST also sign this form.

By signing as an authorised representative of the Principal Investigator's employing organisation and/or the research team member's(s') employing organisation(s), the undersigned hereby acknowledge submission of the information contained in this final report to the funder(s).

Principal Investigator

Principal Investigator	
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Section F: Suggested reviewers for the final report

Provide the names and contact information of four potential reviewers for this final report. The suggested reviewers should not be current collaborators. The Agriculture Funding Consortium reserves the right to choose other reviewers. Under *Section 34* of the *Freedom of Information and Protection Act (FOIP)* reviewers must be aware that their information is being collected and used for the purpose of the external review.

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Appendices

Figure 1 to 8: Soil moisture (%vol/vol) data are for the 0% and 100% fertilizer rates under the DS system in the 0-10 (5), 10-20 (15), 20-30 (25), and 30-40 (35) cm soil depths.

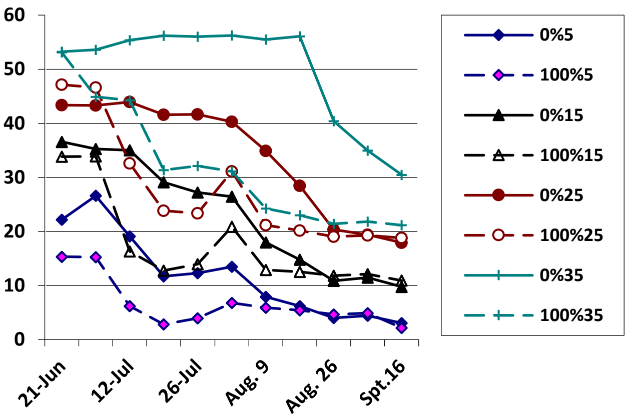

Figure 1. Soil moisture (% vol/vol): North Canola 2013.

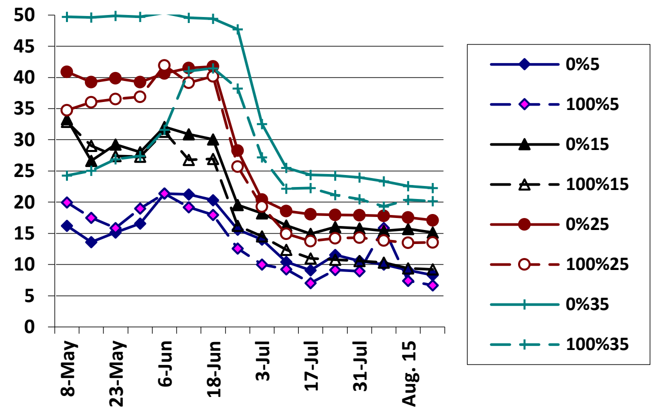

Figure 4. Soil moisture (% vol/vol): North Barley 2014

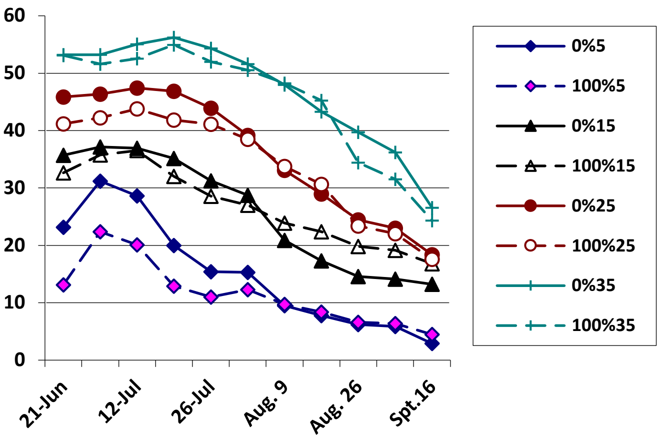

Figure 2. Soil moisture (% vol/vol): South Barley 2013.

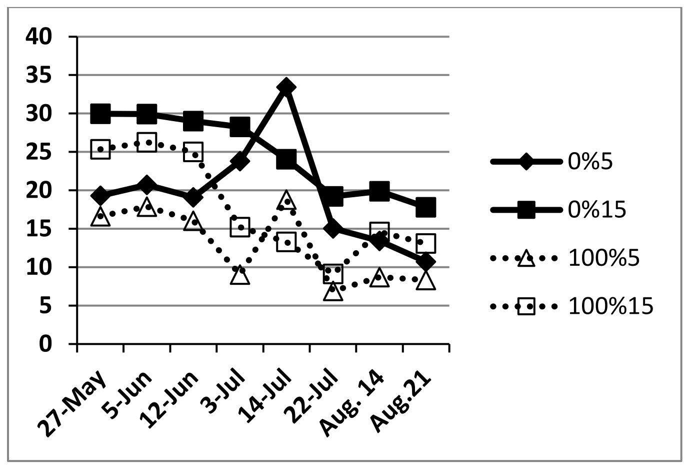

Figure 5. Soil moisture (% vol/vol: North Canola 2015

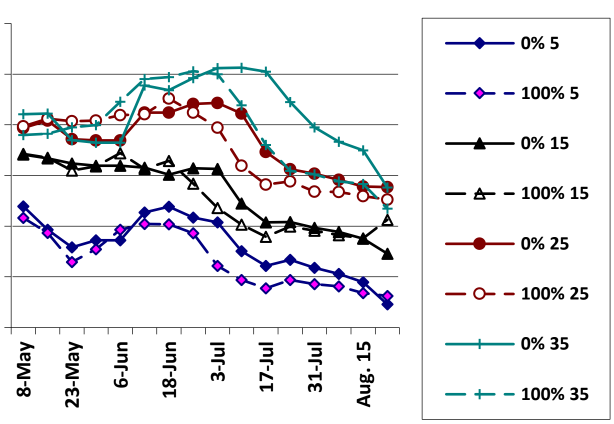

Figure 3. Soil moisture (% vol/vol): South Canola 2014.

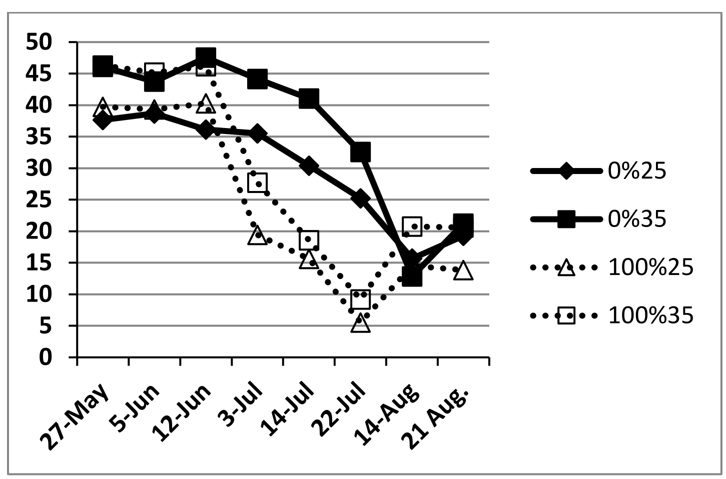

Figure 6. Soil moisture (% vol/vol): North Canola 2015

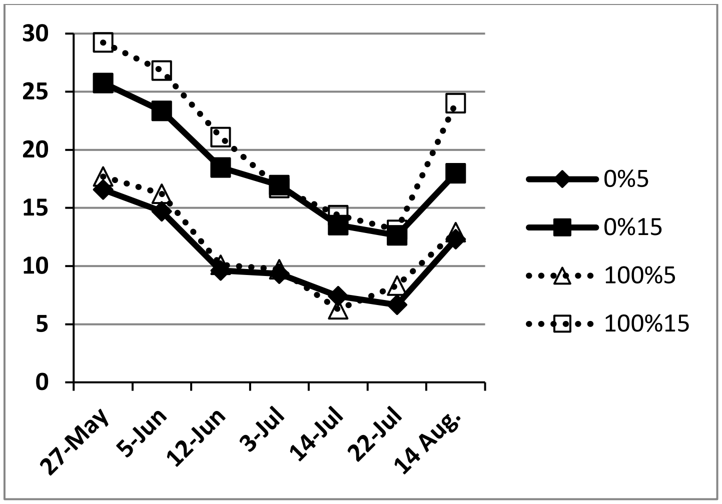

Figure 7. Soil moisture (% vol/vol): South Barley 2015

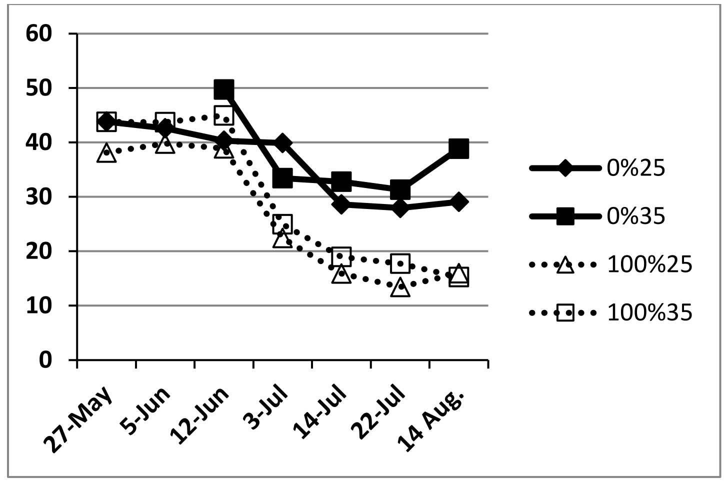

Figure 8. Soil moisture (% vol/vol): South Barley 2015

Figure 9 to 19. Yield of canola and cereals (Mg ha^{-1}) for the 0%, 60%, 100% and 140% fertilizer rates under the direct seeding (DS) and conventional tillage (CT) systems in different years.

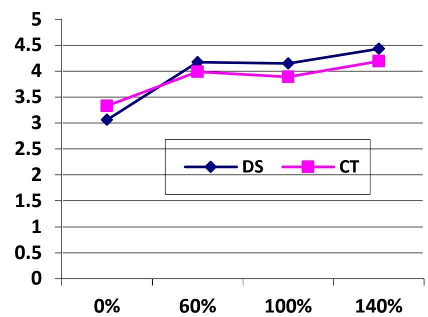

Figure 9. Canola yield in 2011 (north)

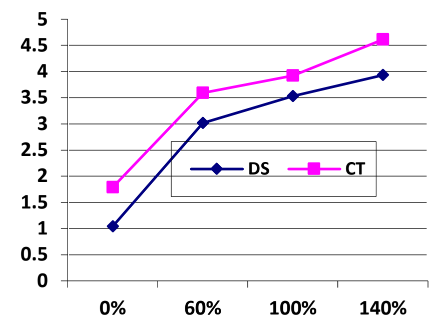

Figure 11. Canola yield (Mg ha^{-1}) in 2013 (north)

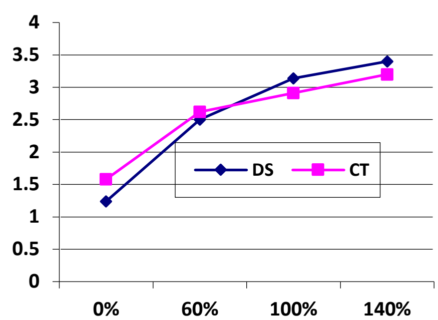

Figure 10. Canola yield (Mg ha^{-1}) in 2012 (south)

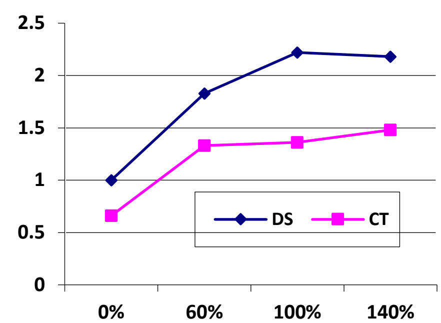

Figure 12. Canola yield (Mg ha^{-1}) in 2014 (south)

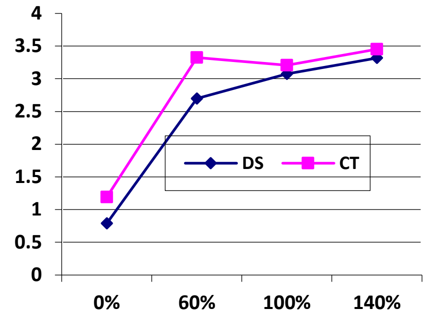

Figure 13. Canola yield (Mg ha^{-1}) in 2015 (north)

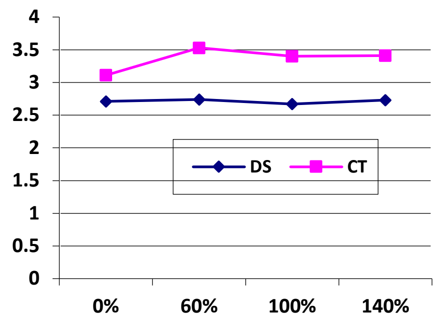

Figure 14. Wheat yield in 2010 (north)

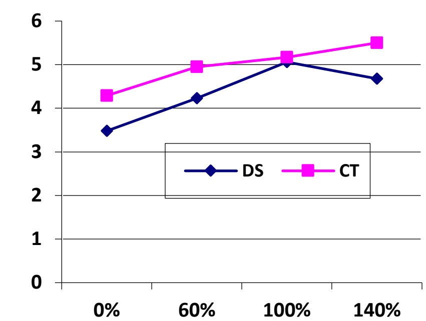

Figure 15. Wheat yield in 2011 (south)

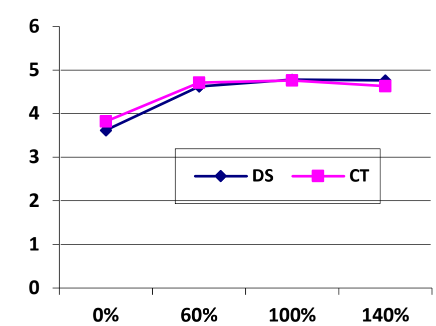

Figure 16. Wheat yield (Mg ha^{-1}) in 2012 (north)

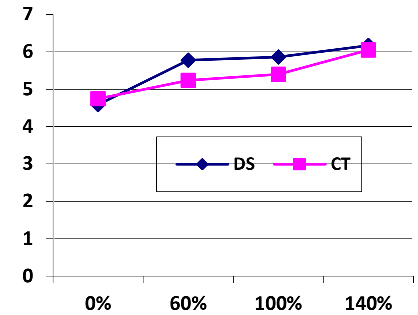

Figure 17. Barley yield (Mg ha^{-1}) in 2013 (south)

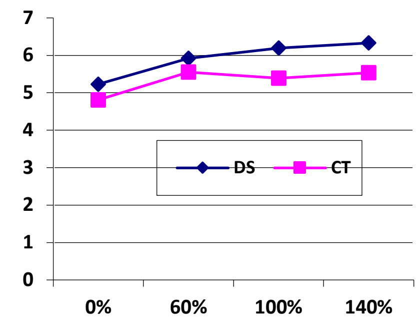

Figure 18. Barley yield (Mg ha^{-1}) in 2014 (north)

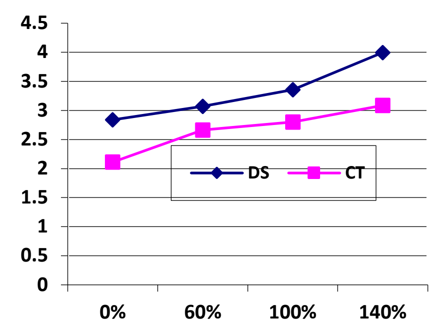

Figure 19. Barley yield (Mg ha^{-1}) in 2015 (south)

Picture 1 to 6: Canola plots to show differences in crop development for fertilized and unfertilized treatments.

Picture 1. Fertilized (left) vs. Unfertilized (right)

Picture 2. Fertilized (left) vs. Unfertilized (right)

Picture 3. Fertilized (left) vs. Unfertilized (right)

Picture 4. Fertilized (left) vs. Unfertilized (right)

Picture 5. Unfertilized (left) vs. Fertilized (right)

Picture 5. Unfertilized (left) vs. Fertilized (right)

Table 1. Spring soil moisture (SSM) and monthly rain (mm) during crop growing seasons. Percent of normal for each year are given in brackets.

	2010	2011	2012	2013	2014	2015
SSM	15.0	34.6	37.5	60.0	60.4	50.0
	(20)	(47)	(50)	(81)	(81)	(68)
May	65.8	30.9	49.8	19.6	21.1	19
	(160)	(75)	(121)	(48)	(51)	(46)
June	17.5	182.8	90.8	101.8	58.1	34
	(24)	(246)	(122)	(1367)	(78)	(46)
July	19.8	123.2	77.0	65.4	30.4	29
	(29)	(178)	(111)	(94)	(43)	(42)
Aug.	54.0	34.6	76.8	13.6	2.6	44
	(97)	(62)	(138)	(24)	(05)	(86)
Total rain	172	406	332	260	173	177
	(55)	(129)	(105)	(83)	(55)	(56)

Table 2. Nitrate-N (NO_3-N) and available P concentrations (ppm) in the 0-6 cm soil depth after harvest of canola or cereal (wheat from 2010 to 2012 and barley from 2013 to 2015) crop in different years.

Treat	2010	2011	2012	2013	2014	2015	2010	2011	2012	2013	2014	2015
	NO_3-N After Canola						**NO_3-N After Cereal**					
Mean DS	39.1	6.4	13.0	6.5	22.2	10.6	33.8	5.9	8.4	4.6	8.8	17.8
Mean CT	34.6	5.9	15.0	5.5	27.8	9.4	32.8	6.8	9.1	8.5	19.1	21.2
LSD A	*44.9*	*2.2*	*4.5*	*1.1*	*6.0*	*3.08*	*33.7*	*5.6*	*6.7*	*13.5*	*11.0*	*6.76*
Signi.	*NS*	*NS*	*NS*	*ł*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Mean 0%	24.3	6.3	11.5	5.3	10.2	10.1	21.0	3.3	10.3	3.5	7.5	16.4
Mean 60%	27.5	7.0	17.3	4.	22.0	7.2	33.3	7.3	8.8	4.3	10.5	17.4
Mean100%	39.5	5.0	12.3	5.5	29.0	10.2	37.8	7.0	8.8	5.8	14.0	21.1
Mean140%	56.3	6.3	15.0	9.3	38.8	12.6	41.0	6.5	7.3	12.8	24.3	22.7
LSD B[1]	*7.2*	*2.2*	4.5	1.2	*7.2*	*5.73*	*11.3*	*1.4*	3.6	2.2	*5.5*	*7.37*
Signi.	***	*NS*	*NS*	**	**	*NS*	†	*NS*	*NS*	*	**	*NS*
	Available P After Canola						**Available P After Cereal**					
Mean DS	12.6	11.6	15.8	11.4	15.6	18.2	13.5	18.6	14.6	10.8	10.9	17.1
Mean CT	17.4	16.4	15.4	12.1	13.5	16.8	13.1	17.3	11.8	11.5	13.6	15.8
LSD A[1]	*2.2*	*3.7*	*1.9*	*3.7*	*3.0*	*6.65*	*2.8*	*2.6*	*4.8*	*4.5*	*4.0*	*5.18*
Signi.	*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Mean 0%	14.3	13.8	13.0	9.5	10.5	14.4	12.8	15.3	12.5	9.0	9.5	12.6
Mean 60%	13.8	16.3	14.3	11.8	12.8	15.0	12.8	15.0	13.3	10.5	13.8	15.2
Mean100%	12.3	13.5	17.5	13.5	16.2	20.2	14.0	19.8	12.8	11.3	10.8	18.8
Mean140%	19.8	12.5	17.5	12.3	18.8	20.4	13.8	21.8	14.3	13.8	15.0	19.2
LSD B[1]	*5.5*	*4.1*	*2.0*	*2.7*	*4.2*	*9.84*	*3.0*	*5.3*	*6.7*	*2.1*	*3.2*	*4.87*
Signi.	*	*NS*	*	*	*	*NS*	*NS*	*	*NS*	**	*	*

Table 3. Extractable potassium (K) and SO_4-S concentrations (ppm) in the 0-6 cm soil depth after harvest of canola or cereal (wheat from 2010 to 2012 and barley from 2013 to 2015) crop in different years.

Treat	2010	2011	2012	2013	2014	2015	2010	2011	2012	2013	2014	2015
	Etractable K After Canola						**Etractable K After Cereals**					
Mean DS	95	148	123	171	103	134	147	102	175	106	128	103
Mean CT	86	146	122	177	99	133	131	198	159	107	126	93
LSD A[1]	*23.6*	*113.4*	*121.3*	*148.2*	*25.0*	*45.7*	*12.4*	*19.1*	*18.0*	*15.9*	*6.3*	*16.2*
Signi.	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*	*NS*	*NS*	*NS*	*NS*	*NS*
Mean 0%	94	139	116	180	97	130	138	94	170	106	133	98
Mean 60%	87	148	126	168	92	129	140	103	151	104	130	92
Mean100%	86	150	128	177	107	140	137	105	179	108	124	104
Mean140%	*96*	*153*	*121*	*171*	*108*	*135*	*140*	*99*	*170*	*109*	*127*	*100*
LSD B[1]	*5.2*	*14.4*	*14.0*	*10.6*	*15.3*	*31.3*	*24.7*	*10.6*	*21.6*	*18.6*	*8.1*	*14.5*
Signi.	*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
	S After Canola						**S After Cereals**					
Mean DS	14.8	17.1	16.8	15.9	19.8	16.6	11.6	11.4	12.3	10.1	13.4	15.4
Mean CT	13.5	18.1	16.9	16.1	21.0	13.4	12.0	12.3	13.3	13.5	15.0	14.8
LSD A[1]	*9.0*	*2.1*	*30.3*	*15.7*	*4.2*	*8.56*	*3.4*	*1.1*	*2.1*	*4.5*	*3.2*	*4.37*
Signi.	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	†	*NS*	*NS*		*NS*
Mean 0%	10.8	15.8	13.5	12.3	16.2	14.0	11.5	11.5	12.	9.5	12.5	13.6
Mean 60%	15.5	16.8	15.8	16.5	19.0	17.4	11.8	12.3	13.0	10.8	15.8	13.2
Mean100%	13.3	19.8	19.8	18.0	22.0	14.4	12.0	11.5	13.3	13.8	14.0	16.7
Mean140%	17.0	18.3	18.3	17.3	24.2	14.6	12.0	12.0	12.5	13.3	14.5	17.0
LSD B[1]	*3.6*	*3.3*	*3.8*	*2.9*	*4.6*	*10.8*	*0.8*	*1.3*	*2.6*	*1.6*	*3.9*	*3.7*
Signi.	ł	*NS*	*NS*	*	*	*NS*	*NS*	*NS*	*NS*	***	*NS*	*

Table 4. Concentration (micro grams/10cm^2/14 days) of nutrients measured using PRS probes for the 0% and 100% fertilizer treatments in conventional tillage (CT) and direct seeding (DS) systems, measured for the April 28 to May 11 period in 2015.

Treat.		NO_3-N	NH_4-N	Ca	Mg	K	P	Fe	Mn	Cu	Zn	B	S
						North (Barley 2014)							
CT0%	**Mean**	**125**	**1.80**	**1446**	**467**	**45.8**	**1.60**	**11.8**	**1.71**	**0.09**	**1.64**	**0.49**	**82**
	SD	*48*	*0.27*	*282*	*110*	*24.9*	*0.80*	*8.5*	*1.35*	*0.12*	*1.88*	*0.27*	*21*
CT100%	**Mean**	**218**	**2.06**	**1528**	**462**	**56.7**	**1.96**	**23.1**	**7.19**	**0.22**	**1.58**	**0.38**	**94**
	SD	*70*	*0.36*	*261*	*103*	*34.1*	*0.73*	*11.4*	*2.10*	*0.10*	*1.59*	*0.18*	*25*
DS0%	**Mean**	**74**	**2.76**	**1618**	**485**	**55.7**	**2.30**	**6.8**	**0.84**	**0.04**	**1.96**	**0.26**	**81**
	SD	*23*	*0.99*	*436*	*131*	*14.2*	*1.20*	*2.4*	*0.42*	*0.05*	*1.40*	*0.11*	*18*
DS100%	**Mean**	**157**	**1.92**	**1553**	**425**	**52.6**	**2.99**	**16.4**	**7.93**	**0.35**	**1.67**	**0.39**	**92**
	SD	42	0.75	372	66	12.6	0.57	12.7	5.93	0.50	0.82	0.25	21
						South (Canola 2014)							
CT0%	**Mean**	**188**	**3.21**	**1360**	**554**	**21.6**	**1.59**	**17.6**	**3.75**	**0.13**	**1.10**	**0.28**	**73**
	SD	*38*	*0.83*	*192*	*118*	*3.9*	*0.42*	*6.4*	*2.16*	*0.08*	*0.61*	*0.25*	*9.0*
CT100%	**Mean**	**249**	**3.25**	**1134**	**437**	**29.4**	**1.99**	**34.4**	**23.27**	**0.29**	**1.45**	**0.50**	**94**
	SD	*157*	*2.18*	*639*	*216*	*18.4*	*1.21*	*27.3*	*18.54*	*0.21*	*0.81*	*0.31*	*61.7*
DS0%	**Mean**	**147**	**2.44**	**1184**	**479**	**38.0**	**1.92**	**14.8**	**3.16**	**0.09**	**1.11**	**0.36**	**95**
	SD	*41*	*0.82*	*248*	*94*	*13.4*	*0.53*	*6.2*	*2.29*	*0.14*	*0.39*	*0.17*	*30*
DS100%	**Mean**	**211**	**3.24**	**1450**	**575**	**53.6**	**1.61**	**22.3**	**11.21**	**0.29**	**1.90**	**0.24**	**121**
	SD	*57*	*0.85*	*292*	*138*	*31.7*	*0.29*	*10.1*	*5.72*	*0.28*	*0.95*	*0.11*	*26*

Table 5. Organic matter, pH and ENR for the 0-3, 3-6, 6-9 and 9-12 inch soil depths in May 2016.

	North					South			
Treat	**0-3”**	**3-6”**	**6-9”**	**9-12”**		**0-3”**	**3-6”**	**6-9”**	**9-12”**
				Organic matter (OM%)					
Mean DS	4.56	3.51	2.61	2.54		4.52	3.88	2.46	2.43
Mean CT	3.73	3.49	2.51	2.42		4.07	3.50	2.58	2.43
LSD A	*0.712*	*0.143*	*0.379*	*0.459*		*0.36*	*0.50*	*1.279*	*0.935*
Signi.	*x*	*NS*	*NS*	*NS*		*x*	*ł*	*NS*	*NS*
Mean 0%	3.90	3.50	2.51	2.58		4.15	3.60	2.08	2.49
Mean 60%	4.30	3.28	2.61	2.46		4.40	3.78	2.73	2.31
Mean100%	4.09	3.63	2.50	2.39		4.51	3.74	2.64	2.36
Mean140%	4.30	3.61	2.61	2.49		4.11	3.65	2.63	2.56
LSD B	*0.505*	*0.417*	*0.333*	*0.413*		*0.322*	*0.37*	1.188	0.328
Signi.	*NS*	*NS*	*NS*	*NS*		*x*	*NS*	*NS*	*NS*
				ENR (lb/season)					
Mean DS	58.0	47.1	38.1	35.6		57.8	50.8	40.2	36.3a
Mean CT	49.4	46.9	36.8	36.2		52.7	47.0	37.8	36.3
LSD A[1]	3.22	1.43	3.41	3.22		4.15	5.00	4.45	9.35
Signi. [1]	*x*	*NS*	*NS*	*NS*		*x*	*ł*	*NS*	*NS*
Mean 0%	51.1	47	37.1	38.7		53.9	48.0	40	36.9
Mean 60%	55.3	44.8	37.7	35.4		56.3	49.8	39.3	35.1
Mean100%	53.0	48.3	37	32.6		57.8	49.4	38.4	35.6
Mean140%	55.4	48.1	38.1	36.9		53.3	48.5	38.3	37.6
LSD B	*5.24*	*4.17*	*3.37*	*5.06*		*3.41*	*3.7*	5.33	3.28
Signi.	*NS*	*NS*	*NS*	*NS*		*x*	*NS*	*NS*	*NS*
				pH (water)					
Mean DS	5.86	6.25	6.78	7.08		5.68	6.0	6.34	6.58
Mean CT	6.09	6.27	6.81	7.13		5.65	5.96	6.44	6.68
LSD A	0.489	0.235	0.193	0.198		0.462	0.604	0.915	0.833
Signi.	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Mean 0%	6.35	6.3	6.83	7.06		5.99	6.11	6.61	6.70
Mean 60%	6.06	6.2	6.81	7.04		5.61	6.05	6.28	6.68
Mean100%	5.84	6.34	6.88	7.21		5.61	5.96	6.54	6.53
Mean140%	5.66	6.2	6.65	7.11		5.45	5.79	6.15	6.63
LSD B	*0.24*	*0.267*	*0.462*	*0.468*		*0.213*	*0.239*	0.516	0.526
Signi.	*****	*NS*	*NS*	*NS*		*x*	*x*	*NS*	*NS*

Table 6. Nitrate-N (NO_3), phosphorus (P), and sulphur (S) concentrations for the 0-3, 3-6, 6-9 and 9-12 inch soil depths on May 2016.

	North				South			
Treat	0-3”	3-6”	6-9”	9-12”	0-3”	3-6”	6-9”	9-12”
				NO_3-N (ppm)				
Mean DS	12.9	8.4	7.1	7.0	20.3	15.4	8.3	7.7
Mean CT	8.6	10.1	5.1	5.4	24.0	18.4	12.6	10.6
LSD A	*4.92*	*1.24*	*6.47*	*6.96*	*8.09*	*5.43*	*6.18*	*8.18*
Signi.	*	*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Mean 0%	9.4	10.8	6.0	6.0	19.9	13.9	8.1	5.4
Mean 60%	7.9	6.4	5.9	6.9	20	14.9	8.1	5.8
Mean100%	12.6	7.8	5.3	4.6	23.8	18.4	11.6	12.8
Mean140%	13.1	12.1	7.3	7.4	24.9	20.5	13.9	12.8
LSD B	*6.03*	*5.43*	*5.72*	*5.25*	*8.45*	*6.29*	*10.72*	*8.12*
Signi.	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
				P (ppm)				
Mean DS	22.6	13.8	9.3	6.7	21.9	12.3	6.4	4.6
Mean CT	21.6	11.9	12.2	7.8	20.5	11.1	6.8	5.8
LSD A	*9.32*	*3.98*	*3.69*	*8.04*	*6.39*	*3.96*	*3.32*	*1.4*
Signi	*NS*	*NS*	*	*NS*	*NS*	*NS*	*NS*	*ł*
Mean 0%	15.9	12.8	10.8	9.8	15.3	10.0	6.5	5.0
Mean 60%	18.1	11.8	11.1	7.3	19.5	11.0	6.6	4.9
Mean100%	26.8	13.5	10.4	6.1	23.9	13.8	7.5	5.6
Mean140%	27.6	13.3	10.6	5.8	26.3	12.1	5.9	5.2
LSD B	*9.65*	*10.02*	*11.38*	*8.46*	*5.55*	*4.19*	*1.7*	*2.08*
Signi.	*	*NS*	*NS*	*NS*	*	*NS*	*NS*	*NS*
				S (ppm)				
Mean DS	14.1	19.1	14	16.8	16.1	14.7	13.9	12.6
Mean CT	13.8	13.4	17	11.4	16.0	13.5	14.1	13.8
LSD A	*2.54*	*14.59*	*14.9*	*10.93*	*4.7*	*4.04*	*5.90*	*3.5*
Signi.	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Mean 0%	12.6	15.5	11.5	10.9	15.4	11.8	11.5	10.1
Mean 60%	12.9	21.9	13.5	17.9	13.5	12.8	12.5	12.1
Mean100%	14.9	13.9	13.4	15.0	18.1	15.3	16.1	14.3
Mean140%	15.4	13.8	23.6	12.6	17.3	16.6	16.0	16.3
LSD B	*4.72*	*16.93*	*15.71*	*9.66*	*4.0*	*3.38*	*4.00*	*2.24*
Signi.	*NS*	*NS*	*NS*	*NS*	*NS*	*	*ł*	***

Table 7. Potassium (K), calcium (Ca) and magnesium (Mg) concentrations for 0-3, 3-6, 6-9 and 9-12 inch soil depths in May 2016.

	North				South			
Treat	0-3"	3-6"	6-9"	9-12"	0-3"	3-6"	6-9"	9-12"
				K (ppm)				
Mean DS	176.2	90.8	93.4	116.4	134.9	71.2	77.2	84.7
Mean CT	170.3	96.1	85.9	107.0	119.3	67.6	78.6	87.7
LSD A	*79.47*	*11.95*	*16.72*	*21.62*	*14.19*	*18.27*	*23.66*	*20.69*
Signi.	*NS*	*NS*	*NS*	*NS*	*	*NS*	*NS*	*NS*
Mean 0%	166.3	93.0	86.5	122.8	126.0	69.9	81.9	87.3
Mean 60%	167.5	91.1	94.1	104.9	115.9	67.7	72.6	81.4
Mean100%	181.9	97.4	84.0	112.8	138.0	70.9	79.9	90.5
Mean140%	177.4	92.4	94.0	106.4	128.5	69.1	77.3	85.6
LSD B	*36.62*	*26.03*	*14.14*	*48.73*	*20.18*	*8.84*	*12.79*	*11.76*
Signi.	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
				Ca (ppm)				
Mean DS	1467	1542	1582	1646	1430	1439	1491	1512
Mean CT	1493	1555	1560	1701	1438	1338	1491	1555
LSD A	*219.7*	*198.7*	*84.3*	*336.0*	*430.3*	*478.1*	*482.9*	*107.4*
Signi.	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Mean 0%	1603.8	1578	1521	1546	1488	1400	1675	1599
Mean 60%	1516.3	1538	1579	1719	1375	1402	1385	1466
Mean100%	1416.3	1545	1501	1705	1480	1375	1501	1579
Mean140%	1383.8	1535	1684	1724	1392.5	1376	1404	1490
LSD B	*168.49*	*149.3*	*247.4*	*279.2*	*89.79*	*139.8*	*271.7*	*175.0*
Signi.	*	*NS*	*NS*	*NS*	*	*NS*	*NS*	*NS*
				Mg (ppm)				
Mean DS	395	541.6	799	1043	507.8	592	922	1232
Mean CT	477	547.2	800	1023	556.3	612	982	1291
LSD A	*139.05*	*121.15*	*163.6*	*180.6*	*221.7*	*353.6*	*607.0*	*355.4*
Signi.	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Mean 0%	512.5	606	828	1002	580	628	989	1276
Mean 60%	441.3	537	810	1000	525	621	903	1254
Mean100%	404.4	538	736	1057	506	565	954	1289
Mean140%	386.3	497	823	1073	518	596	963	1226
LSD B	*73.25*	*285.1*	*451.4*	*372.9*	*64.9*	*100.2*	*183.1*	*180.5*
Signi.	**	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

Table 8. Soil moisture (%vol) in the top 5 cm soil for the 0% and 100% fertilizer treatments in conventional tillage (CT) and direct seeding (DS) systems, measured in spring of 2015

			North				South			
Treat			Apr. 28	May 1	May 8	May 11	Apr. 28	May 1	May 8	May 11
CT0%	**Mean**		**32.95**	**24.91**	**27.11**	**19.85**	**29.55**	**18.73**	**18.45**	**15.85**
		SD	*2.57*	*2.21*	*3.75*	*4.27*	*1.66*	*2.55*	*1.23*	*2.51*
CT100%	**Mean**		**28.21**	**23.25**	**21.85**	**17.5**	**27.81**	**20.88**	**19.15**	**16.49**
		SD	*2.67*	*1.96*	*2.15*	*3.70*	*1.71*	*2.46*	*2.60*	*1.38*
DS0%	**Mean**		**29.32**	**24.99**	**23.46**	**24.42**	**29.55**	**25.19**	**22.28**	**24.08**
		SD	*4.27*	*1.45*	*2.47*	*2.45*	*1.66*	*2.54*	*1.01*	*1.98*
DS100%	**Mean**		**32.41**	**28.51**	**27.145**	**26.81**	**29.03**	**29.36**	**24.24**	**25.94**
		SD	*1.47*	*3.56*	*4.53*	*2.45*	*0.79*	*2.19*	*2.47*	*2.57*

Table 9. Mean weight diameter (MWD, mm) of soil aggregates and their percentages (%) in different size (mm) classes for the 0% and 100% fertilizer treatments in conventional tillage (CT) and direct seeding (DS) systems in October 2015.

			By classes & Diameter (mm)			By diameter sizes (mm)						
		MWD	Coarse 1.0-8.0	Med. 0.25-1.0	Fine <0.25	4.0 -8.0	1.5 -4.0	1.0 -1.5	0.5 -1.0	0.25 -0.5	0.125 -0.25	< 0.125
Treat		mm	%	%	%	%	%	%	%	%	%	%
					North (Canola)							
CT0%	**Mean**	**2.75**	**65.2**	**11.4**	**23.4**	**34.3**	**13.6**	**17.3**	**8.5**	**2.9**	**3.0**	**20.3**
	SD	*0.70*	*8.4*	*5.7*	*6.5*	*14.3*	*6.4*	*9.8*	*5.6*	*1.3*	*2.0*	*6.6*
CT100%	**Mean**	**3.07**	**66.8**	**16.9**	**16.3**	**40.4**	**15.3**	**11.0**	**8.6**	**8.3**	**5.9**	**10.4**
	SD	1.38	19.6	10.0	10.1	25.8	4.6	4.3	4.9	6.4	4.1	7.3
DS0%	**Mean**	**3.89**	**75.3**	**12.9**	**11.8**	**57.3**	**10.0**	**8.07**	**7.8**	**5.1**	**2.4**	**9.4**
	SD	0.32	5.53	4.81	2.91	7.83	7.33	3.45	1.86	3.39	0.83	2.33
DS100%	**Mean**	**4.05**	**78.0**	**11.6**	**10.4**	**41.8**	**20.6**	**15.6**	**7.6**	**4.0**	**2.8**	**7.7**
	SD	0.25	7.2	1.4	6.6	4.8	10.4	9.7	1.5	1.3	11.3	5.1
					South (Barley)							
CT0%	**Mean**	**2.54**	**53.6**	**14.9**	**31.5**	**33.7**	**10.4**	**9.5**	**7.5**	**7.4**	**5.2**	**26.4**
	SD	0.31	5.2	3.8	7.8	*5.5*	*2.3*	*1.3*	*1.8*	*2.8*	*2.2*	*7.2*
CT100%	**Mean**	**2.72**	**54.4**	**11.0**	**34.5**	**38.0**	**9.8**	**6.7**	**6.7**	**4.3**	**4.0**	**30.5**
	SD	0.14	2.1	6.9	8.6	*5.4*	*4.5*	*2.7*	*3.8*	*3.4*	*2.3*	*10.6*
DS0%	**Mean**	**3.48**	**70.2**	**13.4**	**16.5**	**49.0**	**11.8**	**9.4**	**7.9**	**5.4**	**2.8**	**13.7**
	SD	0.60	6.5	2.0	6.4	*13.5*	*8.4*	*4.1*	*3.1*	*1.6*	*1.0*	*7.1*
DS100%	**Mean**	**4.15**	**79.7**	**9.8**	**10.5**	**61.6**	**10.2**	**7.8**	**5.9**	**3.9**	**2.5**	**8.0**
	SD	0.44	5.3	5.1	3.1	*9.3*	*2.6*	*2.8*	*2.8*	*2.4*	*1.1*	*3.4*

Table 10. Amount (lb/ac) of nutrients recommended for canola (45 bu/ac) in different treatments

		CT				DS			
Nutrient	Year	0%	60%	100%	140%	0%	60%	100%	140%
N	2010	90	90	90	90	90	90	90	90
	2011	93	52	62	55	89	70	52	47
	2012	128	120	122	121	132	122	120	126
	2013	121	117	112	121	121	122	120	122
	2014	138	134	121	101	137	136	137	126
	2015	116	113	103	70	134	132	119	106
	Total	**686**	**626**	**610**	**558**	**703**	**672**	**638**	**617**
P_2O_5	2010	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	2011	40.0	37.5	40.0	42.5	42.5	42.5	37.5	37.5
	2012	37.5	37.5	35.0	32.5	37.5	40.0	30.0	32.5
	2013	45.0	42.5	45.0	40.0	45.0	40.0	45.0	37.5
	2014	45.0	45.0	45.0	42.5	45.0	52.5	45.0	37.5
	2015	45.0	42.5	45.0	42.5	45.0	45.0	45.0	45.0
	Total	**252**	**245**	**250**	**240**	**255**	**260**	**242**	**230**
K_2O	2010	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	2011	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	2012	20.0	20.0	20.0	22.5	22.5	20.0	20.0	20.0
	2013	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	2014	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	2015	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	Total	**140**	**410**	**410**	**142**	**142**	**140**	**140**	**140**
S	2010	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
	2011	40.0	40.0	37.5	40.0	40.0	40.0	40.	37.5
	2012	37.5	36.0	37.5	40.0	40.0	40.0	40.0	40.0
	2013	40.0	37.5	40.0	32.5	37.5	40.0	42.5	32.5
	2014	40.0	35.0	30.0	27.5	45.0	35.0	32.5	35.0
	2015	27.5	17.5	25.0	30.0	25.0	22.5	20.0	17.5
	Total	**225**	**206**	**210**	**210**	**228**	**218**	**215**	**202**

Table 11. Amount (lb/ac) of nutrients recommended for cereals (60 bu/ac wheat in 2010, 2011 and 2012; 90 bu/ac barley in 2013, 2014 and 2015) in different treatments.

		CT				DS			
Nutrient	Year	0%	60%	100%	140%	0%	60%	100%	140%
N	2010	90	90	90	90	90	90	90	90
	2011	66	60	40	0	54	56	12	8
	2012	120	121	124	122	119	120	122	119
	2013	108	112	88	88	98	98	80	100
	2014	146	148	144	134	142	145	140	124
	2015	130	92	84	68	134	126	101	61
	Total	**660**	**623**	**570**	**502**	**637**	**635**	**545**	**502**
P_2O_5	2010	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
	2011	30.0	27.5	32.5	17.5	30.0	35.0	35.0	32.5
	2012	30.0	22.5	30.0	30.0	35.0	35.0	35.0	35.0
	2013	37.5	37.5	37.5	40.0	37.5	25.0	32.5	30.0
	2014	52.5	50.0	52.5	52.0	52.5	50.0	50.0	50.0
	2015	55.0	55.0	47.5	47.5	55.0	50.0	45.0	42.5
	Total	**240**	**228**	**235**	**222**	**245**	**230**	**232**	**225**
K_2O	2010	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	2011	25.0	45.0	45.0	20.0	17.5	27.5	27.5	17.5
	2012	15.0	16.0	15.0	15.0	15.0	15.0	15.0	15.0
	2013	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	2014	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	2015	25.0	57.5	30.0	25.0	50.0	40.0	30.0	17.5
	Total	**110**	**164**	**135**	**105**	**128**	**128**	**118**	**95**
S	2010	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	2011	5.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0
	2012	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2013	37.5	42.5	35.0	35.0	30.0	30.0	30.0	35.0
	2014	40.0	32.5	32.5	30.0	37.5	30.0	30.0	30.0
	2015	27.5	22.5	17.5	20.0	27.5	25.0	20.0	15.0
	Total	**120**	**108**	**95**	**95**	**108**	**95**	**90**	**90**

Table 12. Total of the differences in recommended fertilizer nutrients (lb /ac) for 6 years (2010 to 2015), between the 0% and 140% fertilizer rates (0% minus 140%), using data from Table 10 and 11.

	Canola		**Cereals**	
	CT	DS	CT	DS
N	128	86	158	135
P_2O_5	12	25	18	20
K_2O	-2	2	5	33
S	15	26	25	18

Table 13. Amount (lb/ac) of nutrients applied to canola for different treatments

Nutrient	Year	CT 0%	CT 60%	CT 100%	CT 140%	DS 0%	DS 60%	DS 100%	DS 140%
N	2010	0	54	90	126	0	54	90	126
	2011	0	32	63	77	0	42	52	66
	2012	0	72	122	169	0	74	120	176
	2013	0	70	112	169	0	74	120	172
	2014	0	80	121	141	0	81	138	177
	2015	0	68	103	99	0	79	119	149
	Total	**0**	**62.7**	**101.8**	**130.2**	**0**	**67.3**	**106.5**	**144.3**
	Percent	**0**	**62**	**100**	**128**	**0**	**63**	**100**	**135**
P_2O_5	2010	0	24.0	40.0	56.0	0	24.0	40.0	56.0
	2011	0	22.5	40.0	59.5	0	25.5	37.5	52.5
	2012	0	22.6	35.0	45.5	0	24.0	30.0	45.5
	2013	0	25.5	45.0	56.0	0	24.0	45.0	52.5
	2014	0	27.0	45.0	59.5	0	31.5	45.0	52.5
	2015	0	25.5	45.0	59.5	0	27.0	45.0	63.0
	Total	**0**	**24.5**	**41.7**	**56.0**	**0**	**26.0**	**40.4**	**53.7**
	Percent	**0**	**59**	**100**	**134**	**0**	**64**	**100**	**133**
K_2O	2010	0	24.0	40.0	56.0	0	24.0	40.0	56.0
	2011	0	12.0	20.0	28.0	0	12.0	20.0	28.0
	2012	0	12.0	20.0	31.5	0	12.0	20.0	28.0
	2013	0	20.0	20.0	20.0	0	20.0	20.0	20.0
	2014	0	12.0	20.0	28.0	0	12.0	20.0	28.0
	2015	0	12	20	28	0	12	20	28
	Total	**0**	**15.3**	**23.3**	**31.9**	**0**	**15.3**	**23.3**	**31.3**
	Percent	**0**	**66**	**100**	**137**	**0**	**66**	**100**	**134**
S	2010	0	24.0	40.0	56.0	0	24.0	40.0	56.0
	2011	0	24.0	37.5	56.0	0	24.0	40.0	52.5
	2012	0	21.0	37.5	56.0	0	24.0	40.0	56.0
	2013	0	40.0	40.0	40.0	0	40.0	40.0	40.0
	2014	0	21.0	30.0	38.5	0	21.0	32.5	49.0
	2015	0	10.5	25.0	42.0	0	13.5	20.0	24.5
	Total	**0**	**23.4**	**35.0**	**48.1**	**0**	**24.4**	**35.4**	**46.3**
	Percent	**0**	**67**	**100**	**137**	**0**	**69**	**100**	**131**

Table 14. Amount (lb/ac) of nutrients applied to cereals (wheat in 2010, 2011 and 2012; barley in 2013, 2014 and 2-15) for different treatments. Percent of nutrient amount applied relative to 100% is presented below mean for that treatment.

Nutrient	Year	CT 0%	CT 60%	CT 100%	CT 140%	DS 0%	DS 60%	DS 100%	DS 140%
N	2010	0	54	90	126	0	54	90	126
	2011	0	36	40.0	5	0	34	12	10
	2012	0	73	124	171	0	72	122	167
	2013	0	67	90	122	0	59	80	140
	2014	0	89	144	187	0	88	140	173
	2015	0	56	84	96	0	80	101	85
	Mean	**0**	**62.5**	**95.3**	**117.8**	**0**	**64.5**	**90.8**	**116.8**
	Percent	**0**	**66**	**100**	**124**	**0**	**71**	**100**	**129**
P_2O_5	2010	0	21.0	35.0	49.0	0	21.0	35.0	49.0
	2011	0	16.5	32.5	24.5	0	21.0	35.0	45.5
	2012	0	13.5	30.0	42.0	0	21.0	35.0	49.0
	2013	0	22.5	37.5	56.0	0	15.0	32.5	42.0
	2014	0	30.0	52.5	73.5	0	30.0	50.0	70.0
	2015	0	33.0	47.5	66.5	0	30.0	45.0	59.5
	Mean	**0**	**23.0**	**39.2**	**51.9**	**0**	**23.0**	**38.8**	**52.5**
	Percent	**0**	**59**	**100**	**132**	**0**	**59**	**100**	**135**
K_2O	2010	0	9.0	15.0	21.0	0	9.0	15.0	21.0
	2011	0	27.0	45.0	28.0	0	16.5	27.5	24.5
	2012	0	9.6	15.0	21.0	0	9.0	15.0	21.0
	2013	0	9.0	15.0	21.0	0	9.0	15.0	21.0
	2014	0	9.0	15.0	21.0	0	9.0	15.0	21.0
	2015	0	34.5	30.0	35.0	0	30.0	40.0	24.5
	Mean	**0**	**16.4**	**22.5**	**24.5**	**0**	**13.8**	**21.2**	**22.2**
	Percent	**0**	**73**	**100**	**109**	**0**	**62**	**100**	**105**
S	2010	0	6.0	10.0	14.0	0	6.0	10.0	14.0
	2011	0	0.0	0.0	0.0	0	0.0	0.0	0.0
	2012	0	0.0	0.0	0.0	0	0.0	0.0	0.0
	2013	0	12.8	17.5	24.5	0	9.0	15.0	24.5
	2014	0	9.8	16.3	21.0	0	9.0	15.0	21.0
	2015	0	13.5	17.5	28.0	0	16.5	25.0	21.0
	Mean	**0**	**7.0**	**10.2**	**14.6**	**0**	**6.8**	**10.8**	**13.4**
	Percent	**0**	**69**	**100**	**143**	**0**	**62**	**100**	**124**

Table 15. Six years average for the percentage of applied nutrients for the 60% and 140% fertilizer treatments, compared to the 100% treatments for canola and cereals under 2 seeding systems, using data from Table 13 and 14.

	Canola		**Cereals**	
Nutrient	CT	DS	CT	DS
	60% Fertilizer rate treatments			
N	62	63	66	71
P_2O_5	59	64	59	59
K_2O	66	66	73	62
S	67	69	69	62
	140%% Fertilizer rate treatments			
N	128	135	124	129
P_2O_5	134	133	132	135
K_2O	137	134	109	105
S	137	131	143	124

Table 16. Canola seed yield (Mg ha^{-1}) in 2011 to 2015.

Treat	2011	2012	2013	2014	2015
DS0%	3.06	1.24	1.04	1.00	0.88
DS60%	4.17	2.50	3.02	1.83	2.70
DS100%	4.15	3.14	3.53	2.22	3.07
DS140%	4.43	3.40	3.93	2.18	3.32
CT0%	3.33	1.58	1.79	0.66	1.19
CT60%	3.99	2.62	3.59	1.33	3.33
CT100%	3.89	2.91	3.92	1.36	3.21
CT140%	4.19	3.20	4.61	1.48	3.45
LSD AxB[1]	*0.44*	*0.252*	*0.649*	*0.234*	*0.484*
Signi.	*NS*	****	*NS*	***	*NS*
Mean DS	3.95	2.58	2.88	1.81	2.79
Mean CT	3.85	2.57	3.48	1.21	2.49
LSD A[1]	*0.260*	*0.280*	*0.69*	*0.352*	*1.54*
Signi	*NS*	*NS*	*†*	***	*NS*
Mean 0%	3.19	1.41	1.42	0.83	1.04
Mean 60%	4.08	2.56	3.34	1.58	3.01
Mean100%	4.02	3.02	3.73	1.79	3.14
Mean140%	4.31	3.30	4.27	1.83	3.39
LSD B[1]	*0.31*	*0.178*	*0.46*	*0.166*	*0.341*
Signi	****	*****	*****	****	*****

Table 17. Canola emergence (plants m^{-2}) in 2011 to 2015.

Treat	**2011**	**2012**	**2013**	**2014**	**2015**
DS0%	77	86	134	83	111
DS60%	64	60	98	87	93
DS100%	32	64	68	80	81
DS140%	25	73	60	60	89
CT0%	86	97	187	118	36
CT60%	57	61	125	81	42
CT100%	57	69	109	78	57
CT140%	54	61	53	93	67
LSD AxB[1]	*51.0*	*24.0*	*38.9*	*30.4*	*27.9*
Signi	*NS*	*NS*	*NS*	*NS*	*
Mean DS	64	70	90	92	93
Mean CT	50	72	119	78	51
LSD A[1]	*7.1*	*26.0*	*61.3*	*15.2*	*10.3*
Signi	***	*NS*	*NS*	*NS*	***
Mean 0%	81	91	160	100	74
Mean 60%	61	60	112	84	68
Mean100%	45	66	89	79	69
Mean140%	39	67	57	77	78
LSD B[1]	*36.1*	*17.0*	*27.5*	*21.5*	*19.7*
Signi	*	**	***	*	*NS*

Table 18. Canola plant height (cm) in 2011 to 2015.

Treat	2011	2012	2013	2014	2015
DS0%	97	84	70	78	69
DS60%	113	99	93	88	85
DS100%	111	104	103	88	89
DS140%	109	103.7	99	92	87
CT0%	102	83	92	69	66
CT60%	108	96	101	83	88
CT100%	117	99	110	69	83
CT140%	114	100	108	72	84
LSD AxB	*7.0*	*7.2*	*11.1*	*7.6*	*7.5*
Signi	*NS*	*NS*	*NS*	*	*NS2*
Mean DS	108	98	91	86	80
Mean CT	110	94	103	73	82
LSD A	*6.9*	*7.2*	*9.9*	*4.7*	*18.1*
Signi	*NS*	*NS*	*	**	*NS*
Mean 0%	99	83	81	74	67
Mean 60%	110	98	97	85	86
Mean100%	114	102	107	79	86
Mean140%	112	102	104	82	85
LSD B	*5.0*	*5.07*	*7.9*	*7.6*	*5.3*
Signi	**	***	***	*	***

Table 19. . Wheat seed yield (Mg ha^{-1}), emergence (plants m-2) and plant height (cm) in 2010 to 2012.

	Seed yield			**Emergence**			**Plant height**		
Treat	2010	2011	2012	2010	2011	2012	2010	2011	2012
DS0%	2.71	4.29	4.62	164	168	226	76	85	82
DS60%	2.74	4.95	4.62	172	156	204	76	85	91
DS100%	2.67	5.17	4.78	174	185	207	76	85	91
DS140%	2.73	5.50	4.76	146	173	197	75	86	90
CT0%	3.11	3.48	3.82	184	135	192	78	83	83
CT60%	3.53	4.23	4.71	161	159	220	79	83	91
CT100%	3.40	5.06	4.76	154	178	212	79	85	93
CT140%	3.41	4.68	4.63	169	145	172	80	83	89.9
LSD AxB	*0.37*	*0.510*	*0.359*	*53.8*	*36.7*	*3.6*	*2.7*	*3.5*	*3.04*
Signi	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Mean DS	2.71	4.98	4.45	164	155	208	76	85	89
Mean CT	3.36	4.37	4.44	167	170	199	79	83	89
LSD A	*1.27*	*0.412*	*0.798*	*80.1*	*40.0*	*4.6*	*7.9*	*1.9*	*6.23*
Signi	*NS*	*	*NS*	*NS*	*NS*	*NS*	*NS*	†	*NS*
Mean 0%	2.91	3.89	3.72	174	152	209	77	83	82
Mean 60%	3.14	4.56	4.67	166	157	212	78	84	91
Mean100%	3.04	5.11	4.77	164	181	210	78	85	92
Mean140%	3.07	5.09	4.70	158	159	185	77	84	90
LSD B	*0.26*	*0.367*	*0.254*	*28.1*	*56.6*	*2.5*	*1.9*	*2.5*	*2.15*
Signi	*NS*	**	***	*NS*	*NS*	*NS*	*NS*	*NS*	***

Table 20. . Barley seed yield (Mg ha^{-1}), emergence (plants m-2) and plant height (cm) in 2013 to 2015.

	Seed yield			Emergence			Plant height	
Treat	2013	2014	2015	2013	2014	2015	2014	2015
DS0%	4.59	5.23	2.84	178	252	178	61	49
DS60%	5.78	5.92	3.07	194	244	184	63	42
DS100%	5.86	6.19	3.56	198	244	191	59	45
DS140%	6.17	6.33	4.00	177	226	189	57	39
CT0%	4.74	4.81	2.11	154	200	157	55	39
CT60%	5.23	5.55	2.68	187	219	159	54	37
CT100%	5.40	5.39	2.80	193	195	104	52	41
CT140%	6.05	5.53	3.09	204	195	104	50	45
LSD AxB	*0.617*	*0.668*	*0.460*	*49.6*	*36.0*	*38.7*	*9.1*	*3.6*
Signi	*NS*	*NS*	*NS*	*NS*	*NS*	*	*NS*	*NS5.7*
Mean DS	5.60	5.92	2.67	187	202	131	60	45
Mean CT	5.36	5.32	3.32	184	242	185	53	39
LSD A	*0.72*	*0.287*	*0.350*	*37.8*	*23.5*	*25.0*	*6.6*	*4.2*
Signi	NS	**	*	*NS*	*	**	*	*
Mean 0%	4.67	5.02	2.47	166	226	168	58	44
Mean 60%	5.51	5.73	2.87	191	231	171	58	40
Mean100%	5.63	5.79	3.08	195	220	147	56	43
Mean140%	6.11	5.93	3.54	190	211	146	54	42
LSD B	*0.44*	*0.472*	*0.326*	*35.1*	*25.4*	*27.3*	*6.4*	*2.6*
Signi	***	**	***	*NS*	*NS*	*NS*	*NS*	*

Table 21. Canola (for 5 plants) roots length, surface area, projected area, volume, and number of tips for various diameter (mm) values in different treatments on June 15, 2015.

Treat		Total (cm)	0< 0.5	0.5< 1.0	1.0< 1.5	1.5< 2.0	2.0< 2.5	2.5< 3.0	3.0< 3.5	3.5< 4.0	4.0< 4.50	> 4.5
						Length (cm)						
CT 0%	Mean	320	278	28.4	6.79	3.48	1.45	0.16	0.13	0.00	0.04	0.38
	SD	*179*	*165*	*11.3*	*3.47*	*3.14*	*2.04*	*0.20*	*0.26*	*0.00*	*0.08*	*0.76*
CT 100%	Mean	560	468	46.9	13.77	8.95	7.30	5.54	4.07	1.79	0.87	2.09
	SD	*136*	*128*	*13.7*	*3.04*	*1.80*	*0.88*	*2.61*	*2.68*	*1.34*	*0.83*	*1.69*
DS 0%	Mean	552	511	27.9	8.23	3.13	0.93	0.08	0.02	0.00	0.00	0.00
	SD	*319*	*313*	*13.4*	*0.75*	*1.92*	*0.93*	*0.06*	*0.04*	*0.00*	*0.00*	*0.00*
DS100%	Mean	676	582	52.4	12.44	8.42	4.57	3.25	1.81	2.49	2.61	6.51
	SD	*334*	*309*	*20.1*	*2.52*	*1.67*	*0.61*	*1.51*	*1.62*	*3.14*	*1.98*	*5.28*
						Surface area (cm²)						
CT 0%	Mean	29.6	13.5	6..06	2.64	1.88	1.01	0.13	0.13	0.00	0.05	0.58
	SD	15.47	7.4	2.15	1.40	1.67	1.41	0.16	0.27	*0.00*	0.01	1.16
CT 100%	Mean	72.8	23.9	9.80	5.30	4.87	5.23	4.75	4.14	2.09	1.17	3.32
	SD	10.4	7.6	2.54	1.11	1.00	0.58	2.29	2.74	1.57	1.11	2.74
DS 0%	Mean	40.6	23.0	5.99	3.14	1.68	0.65	0.06	0.02	0.00	0.00	0.00
	SD	18.7	*13.3*	*2.74*	*0.33*	*1.05*	*0.65*	*0.05*	*0.04*	0.00	0.00	0.00
DS100%	Mean	*87.8*	31.2	10.89	4.77	4.55	3.26	2.78	1.85	2.89	3.48	11.49
	SD	37.3	*16.6*	*4.04*	*0.91*	*0.84*	*0.35*	*1.32*	*1.64*	*3.66*	*2.63*	*9.58*
						Projected area (cm²)						
CT 0%	Mean	9.4	4.29	1.93	0.84	0.60	0.32	0.04	0.04	0.00	0.02	0.18
	SD	4.9	2.36	0.68	0.45	0.53	0.45	0.05	0.09	0.00	0.03	0.37
CT 100%	Mean	23.2	7.61	3.12	1.69	1.55	1.67	1.51	1.32	0.66	0.37	1.06
	SD	3.3	2.43	0.81	0.35	0.32	0.18	0.73	0.87	0.50	0.35	0.87
DS 0%	Mean	12.9	7.31	1.91	1.00	0.54	0.21	0.02	0.01	0.00	0.00	0.00
	SD	6.0	4.25	0.87	0.11	0.33	0.21	0.02	0.01	0.00	0.00	0.00
DS100%	Mean	28.0	9.94	3.47	1.52	1.45	1.04	0.89	0.59	0.92	1.11	3.66
	SD	*11.9*	*5.29*	*1.29*	*0.29*	*0.27*	*0.11*	*0.42*	*0.52*	*1.17*	*0.84*	*3.05*
						Volume (cm³)						
CT 0%	Mean	*0.22*	*0.07*	*0.11*	*0.08*	*0.08*	*0.06*	0.01	*0.01*	0	0.01	*0.07*
	SD	*0.12*	*0.04*	*0.03*	*0.05*	*0.07*	*0.08*	*0.01*	*0.02*	0	*0.01*	*0.14*
CT 100%	Mean	*0.77*	*0.14*	*0.17*	*0.16*	*0.21*	*0.30*	*0.32*	*0.34*	*0.19*	*0.12*	*0.42*
	SD	*0.14*	*0.05*	*0.04*	*0.03*	*0.04*	*0.03*	*0.16*	*0.22*	*0.15*	*0.11*	*0.36*
S 0%	Mean	*0.24*	*0.11*	*0.11*	*0.11*	*0.07*	*0.04*	0.01	0.01	0	0	0
	SD	*0.09*	*0.06*	*0.04*	*0.01*	*0.05*	*0.04*	0.01	0.01	*0*	*0*	*0*
DS100%	Mean	*0.93*	0.18	0.19	0.15	*0.20*	0.19	0.19	0.15	*0.27*	0.04	1.65
	SD	*0.40*	*0.09*	*0.07*	*0.03*	*0.03*	*0.02*	*0.09*	*0.13*	*0.03*	*0.28*	*1.42*
						Tips (number)						
CT 0%	Mean	*1019*	*1011*	*3.00*	*3.00*	*1.50*	*0.50*	*0.25*	*0*	*0*	*0*	*0*
	SD	*422*	*423*	*1.15*	*1.83*	*1.00*	*1.00*	*0.50*	*0*	*0*	*0*	*0*
CT 100%	Mean	*2352*	*2337*	*8.50*	*1.00*	*1.75*	*0*	*1.50*	*0.50*	*0*	*0.25*	*1.25*
	SD	*319*	*315*	*3.42*	*0*	*1.50*	*0*	*0.58*	*0.58*	*0*	*0.50*	*0.96*
DS 0%	Mean	*1885*	*1786*	*5.00*	*2.25*	*1.00*	*0.75*	*0*	*0*	*0*	*0*	*0*
	SD	*913*	*913*	*2.94*	*4.71*	*1.41*	*0.50*	*0*	*0*	*0*	*0*	*0*
DS100%	Mean	*2528*	*2515*	*7.00*	*1.75*	*1.00*	*1.25*	*0.50*	*0.75*	0	*0.25*	*0.75*
	SD	*1255*	*1252*	*4.08*	*1.50*	*1.15*	*0.96*	*0.58*	*0.96*	*0*	*0.50*	*0.96*

Table 22. Barley (for 5 plants) roots length, surface area, projected area, volume, and number of tips for various diameter (mm) values in different treatments on June 15, 2015.

Treat		Total (cm)	0< 0.5	0.5< 1.0	1.0< 1.5	1.5< 2.0	2.0< 2.5	2.5< 3.0	3.0< 3.5	3.5< 4.0	4.0< 4.50	> 4.5
						Length (cm)						
CT 0%	Mean	781	573	149	24.4	8.6	4.00	4.84	1.84	3.60	2.25	9.21
	SD	46	16	17	4.2	4.5	0.2	4.31	1.22	0.22	1.20	0.31
CT 100%	Mean	900	645	185	30.1	10.5	4.42	3.79	2.55	3.26	2.27	11.91
	SD	119	57	56	6.4	1.6	1.22	0.19	0.87	1.42	0.44	2.52
DS 0%	Mean	739	502	176	25.5	10.1	4.78	3.36	2.33	1.32	1.04	11.58
	SD	169	140	30	6.0	2.1	1.16	0.90	0.63	0.79	0.69	2.05
DS100%	Mean	1269	945	245	37.3	12.9	5.81	4.04	3.10	1.99	1.49	12.27
	SD	334	251	65	9.7	3.8	2.26	1.74	0.91	0.50	0.59	3.32
						Surface area (cm^2)						
CT 0%	Mean	139	44.5	30.5	9.16	4.63	2.79	4.17	1.89	4.25	3.05	18.3
	SD	22.2	3.9	3.8	1.77	2.49	0.17	3.73	1.20	0.28	1.67	3.2
CT 100%	Mean	166	50.0	38.8	11.32	5.68	3.13	3.25	2.58	3.86	3.00	25.5
	SD	26.7	7.3	11.4	2.39	0.80	0.88	0.13	0.85	1.65	0.61	5.9
DS 0%	Mean	144	38.9	36.9	9.53	5.47	3.38	2.86	2.38	1.54	1.39	25.1
	SD	19.7	*11.7*	*7.3*	*2.10*	*1.21*	*0.83*	*0.77*	*0.69*	0.92	0.91	3.6
DS100%	Mean	*211*	69.4	51.2	13.9	6.97	4.07	3.51	3.15	2.32	2.00	28.2
	SD	55.0	*16.6*	*14.1*	*3.68*	*2.05*	*1.58*	*1.55*	*0.87*	*0.60*	*0.79*	*9.6*
						Projected area (cm^2)						
CT 0%	Mean	44.2	14.1	9.7	2.82	1.47	0.89	1.33	0.60	1.35	0.97	5.83
	SD	7.1	1.2	1.2	0.56	0.79	0.06	1.19	0.38	0.09	0.53	1.02
CT 100%	Mean	52.7	15.9	12.4	3.60	1.81	1.00	1.03	0.82	1.23	0.96	8.12
	SD	8.2	2.3	3.6	0.76	0.26	0.28	0.04	0.27	0.53	0.20	1.87
DS 0%	Mean	45.9	12.4	11.7	3.03	1.74	1.07	0.91	0.76	0.49	0.44	7.99
	SD	6.3	3.7	2.3	0.67	0.38	0.26	0.24	0.22	0.29	0.29	1.15
DS100%	Mean	67.3	22.1	16.3	4.44	2.22	1.29	1.12	1.00	0.74	0.64	8.98
	SD	17.5	5.3	4.5	1.17	0.65	0.50	0.49	0.28	0.19	0.25	3.05
						Volume (cm^3)						
CT 0%	Mean	1.98	0.33	0.52	0.28	0.20	0.16	0.29	0.15	0.40	0.33	3.05
	SD	0.51	0.03	0.07	0.06	0.11	0.01	0.26	0.09	0.03	0.18	0.96
CT 100%	Mean	2.43	0.37	0.67	0.34	0.25	0.18	0.22	0.21	0.36	0.32	4.59
	SD	0.45	0.07	0.19	0.07	0.04	0.05	0.01	0.07	0.15	0.07	1.28
DS 0%	Mean	2.26	0.29	0.64	0.29	0.24	0.19	0.19	0.20	0.14	0.15	4.63
	SD	0.16	0.09	0.15	0.06	0.05	0.05	0.05	0.06	0.09	0.10	0.75
DS100%	Mean	2.81	0.49	0.89	0.42	0.30	0.23	0.24	0.25	0.22	0.22	5.58
	SD	0.75	0.11	0.25	0.11	0.09	0.09	0.11	0.07	0.06	0.08	2.53
						Tips (number)						
CT 0%	Mean	1411	1364	36.50	5.00	1.00	0.50	0.50	0.00	1.00	1.00	2.00
	SD	167	187	21.92	0.00	1.41	0.71	0.71	0.00	0.00	1.41	1.41
CT 100%	Mean	1655	1598	48.0	2.00	1.50	1.00	0.25	0.25	0.25	0.25	3.75
	SD	243	235	13.1	1.83	1.00	1.41	0.50	0.50	0.50	0.50	2.06
DS 0%	Mean	1242	1185	47.0	5.00	1.00	1.25	0.25	0.50	0.00	0.00	1.75
	SD	394	385	11.0	2.16	0.82	0.96	0.50	0.58	0.00	0.00	0.50
DS100%	Mean	2548	2473	62.0	5.75	1.75	0.75	1.00	0.25	0.00	0.75	2.50
	SD	708	696	12.5	1.50	1.26	0.96	1.41	0.50	0.00	0.96	1.73

Table 23. Comparison of canola and barley root measurements.

Measurement	**Canola roots**	**Barley roots**
Length, cm	320 to 676	739 to 1269
Surface area, cm^2	29.6 to 87.8	139 to 211
Projected area, cm^2	9.4 to 28.0	44.2 to 67.3
Volume, cm^3	0.22 to 0.93	1.98 to 2.81
Number of tips, #	1019 to 2828	1411 to 2548

Table 24. Mass (mg per 5 plants) of roots, shoots and root mass/ shoot mass ratio for June 15, 2015 plant samples of canola and barley.

		Canola			Barley		
Treat	Treat	Root	Shoot	Root/Shoot	Root	Shoot	Root/Shoot
CT 0%	**Mean**	**55**	**349**	**190**	**605**	**1.730**	**351**
	SD	*43*	*365*	*44*	*87*	*165*	*54*
CT 100%	**Mean**	**298**	**2,045**	**153**	**619**	**1,597**	**391**
	SD	*98*	*877*	*30*	*64*	*249*	*38*
DS 0%	**Mean**	**49**	**302**	**170**	**640**	**2,006**	**351**
	SD	*13*	*122*	*36*	*61*	*696*	*134*
DS100%	**Mean**	**363**	**2,960**	**128**	**727**	**2,544**	**284**
	SD	*184*	*1,815*	*21*	*236*	*698*	*35*