AgriInnovation Program Stream B

2016-17 Annual Performance Report

For projects or activities that started late, it is expected that answers may be brief for some questions and not applicable or premature for other questions. Indicate "Not applicable" if the question is not relevant at this time.

Name of Recipient: Eastern Canada Oilseeds Development Alliance Inc. (ECODA)	
Project Title: Market-Driven Research for Soybean and Canola Supply Chain Profitability	
Project Number: AIP-P025	Period Covered by Report: 2016-04-01 to 2017-03-31
Activity #: 14 Name of Activity: Canola Nutrient Management	Principal Investigator: Bao-Luo Ma

1. Performance Measures. See Annex A for an explanation of each measure.

Innovation Items	Results Achieved	Provide a description (2-3 paragraphs) for each item produced and describe its importance to the target group or sector. Explain any variance between results achieved and targets. Use plain language.
# of Intellectual property items flowing from the project		
# of new/improved products		
# of new/improved processes or systems		
# of new/improved practices		
# of new varieties		
# of new/improved genetic materials		
# of new/ improved gene sequences		
# of improved knowledge	2	1. Developed a new microplate assay method for boron analysis in soil and plant tissue. 2. Developed an improved guide/factsheet for best nutrient management practices for canola production in eastern Canada

Information Items	Results Achieved	Provide the complete citation for each item. Please see Annex A for examples.
# of peer reviewed publications	5	1. Saballya, K., J. K. Whalen, and B.L. Ma. 2017. Microplate assay for boron analysis in soil and plant tissue. Can. J. Soil Sci. (accepted).

		2. Wu, W., and B.L. Ma*. 2016. A new method for assessing plant lodging and the impact of management options on lodging in canola crop production. Scientific Reports 6: 31890. 3. Jing, Q., J. Shang, B. Qian, G. Hoogenboom, T. Huffman, J. Liu, B.L. Ma, X. Geng, X. Jiao, J. Kovacs, and D. Walters. 2016. Evaluation of the DSSAT-CROPGRO model for simulating canola growth and yield at West Nipissing in eastern Canada. Agron. J. 108:1-10. 4. Ma, B.L., and Z.M. Zheng. 2016. Relationship between plant nitrogen and phosphorus accumulations in a canola crop as affected by nitrogen management under ample phosphorus supply conditions. Can. J. Plant Sci. 96: 853-866. 5. Ma, B.L., and A.W. Herath. 2016. Timing and rates of nitrogen fertilizer application on seed yield, quality and nitrogen-use efficiency of canola. Crop Pasture Sci. 67:167-180.
# of information items		
# of media reports	1	1. Top Crops Manager “Measurement made easier”. Eastern Edition. February 2017.
# of information events	5	1. Ma, B.L. 2017. Developing a non-destructive method for assessing root lodging in canola. Oral presentation at the Ontario Soybean and Canola Committee Research Activity Workshop. Four Point Sheraton Hotel, London, ON. Jan. 19. (about 60 attendants) 2. Wu, W., and B.L. Ma. 2016. Management options for minimizing lodging of canola and its non–invasive assessment. Oral presentation at the 2nd International Conference on Agronomy and Horticulture (ICAH 2016). Xi’An, China, Aug. 24-26. (> 200 attendants) 3. Herath, A., B.L. Ma, J. Shang, X. Jiao, J. Kovacs, and D. Walters. 2016. Spatial characterization of soil mineral nitrogen, crop growth, and yield of canola as affected by nitrogen application. Poster presentation at joint annual conference for the Canadian Society of Agronomy and the Canadian Society for Horticultural Science. Montreal, QC, Canada. July 24-26. (about 100 attendants) 4. Herath, A., B.L. Ma, J. Shang, X. Jiao, J. Kovacs, and D. Walters. 2016. Soil mineral nitrogen supply and grain yield estimation of canola in relation to growing-season canopy reflectance measurements. Poster presentation at joint annual conference for the Canadian Society of Agronomy and the Canadian Society for Horticultural Science. Montreal, QC, Canada. Jul. 24-26. (about 100 attendants) 5. Ma, B.L., A. Herath, W. Wu, and P. Mason. 2016. Canola: A made-in-Canada crop – research strategies towards sustainable canola production. Poster presentation at the Ottawa Doors Open event. Central Experimental Farm, Ottawa, ON, Canada. Jun 5. (over 1000 attendants)

		Provide the # of attendees
# of individuals attending information events	1,460	A total of approximately 1,460 attendees at events.
		Provide the # of attendees who intended to adopt new information or technology
# of individuals attending information event who intend to adopt new innovation		Not surveyed.
		Provide the name, degree completed and date of completion
# of persons who completed a M.Sc. or Ph.D. during project		

2. Executive Summary

The Executive summary contains two parts: Key highlights of activities and scientific results and Success story. Information may be used for internal and external communication purposes. Write for a general audience using plain language. Do not include sensitive or confidential information.

Key Highlights - This section describes the key activities and final scientific results of an activity/ project in such a way that readers can rapidly become acquainted with a large body of material without having to read it all. Include a brief statement of the problem(s), background information, concise analysis and main conclusions. Suggested length – maximum 1 page.

Canola is a new crop in eastern Canada, although both its production acreage and farm gate profits have increased by 3-7 folds during the past five years. To expand canola production in eastern Canada, adequate plant nutrients applied at the right stage of crop development in the right amount and right type of fertilizers, are the key factors for sustainable and profitable canola production while minimizing the environment footprints. This project aims to develop site-specific nutrient best management technologies and guidelines for successful canola production in eastern Canada. Accordingly, field experiments with different combinations of hybrids, nitrogen (N) application amounts and timing, sulphur (S) rates and boron (B) nutrients have been conducted for 4 years (2013 to 2016). The following key points can be drawn:

1) In the N study, there was a strong correlation between yields and N rates applied both at preplant and sidedress.
2) Split N application (50+50, 50+100, 50+150 kg N ha^{-1}) often produced higher yields (> 5%) than the same amount of N applied at preplant (more analysis needs to be done). Canning 2013, and McGill 2014 & 2015 and Laval 2015 did not show a positive response to sidedressed N and actually had lower yields in the sidedressed plots.
3) At early flowering, plant biomass, height and leaf area all significantly increased with increasing N rates, with the plots that received preplant N at 200 kg ha^{-1} having the largest biomass and leaf area and tallest plants of all the treatments.
4) At all site-years, number of branches and pods per plant and seeds per pod increased with increasing N levels, sometimes significantly.
5) In most site-years, the application of different rates of N did not have any effect on 1000-seed weight as they did not increase linearly with increasing N rates. Other than at Canning 2016, adding sidedressed N did not significantly affect 1000-seed weight, compared to the plots that received the same amount of preplant N.

6) For some sites and years, N did not display any effect on harvest index (HI). In most cases, sidedressing N did not significantly increase HI, compared to the plots that received the same amount of preplant N.
7) The average of the most economic rate of nitrogen (MERN) for Eastern Canada was estimated at 179 kg N ha^{-1} for preplant application and 198 kg N ha^{-1} for sidedress application, both with large ranges among sites-years. When N fertilizer is applied at the MERN value, the average achievable yield would be 3.27 t ha^{-1} for preplant, and 3.40 t ha^{-1} for sidedress application.
8) The Greenseeker and Cropscan instruments were not sensitive at differentiating N treatments before the GS16, but at the GS50 stage, they detected 0N plots from plants in the N treated plots. At 20% flowering, NDVI values significantly increased with increasing amounts of preplant N application.
9) The SPAD chlorophyll reading was able to distinguish N treatments as early as the GS15-GS16 stages.
10) Greenseeker and CropScan measurements at the 7 leaf stage (GS17) and at 20% flowering were strongly correlated to final seed yields. There was also a very strong correlation between SPAD readings at the GS16 stage and final yields.
11) Monitoring the leaf N content at an early growth stage could be helpful in determining the amount of N applied at a later stage.
12) Increasing N application significantly increased seed protein concentration, but decreased oil concentration ($p \leq .001$). Both seed oil and protein yields increased with increasing N application.
13) Preplant S treatment increased seed yields at all sites and years. Plant S uptake for canola appears to be optimized when there is a N:S ratio of 10 at early flowering stage and of 2.1 (straw) or 11.4 (seed) at harvest.
14) At harvest, the seed accumulated about 60 g ha^{-1} of boron (B). The lack of difference in yields between B treatments may indicate that the test fields could provide sufficient B to meet plant growth and yield potential of the current hybrid varieties in eastern Canada.
15) A cover crop (CC) study conducted at St-Augustin-de-Desmaures (SA) and Normandin (NO) between 2013 and 2015 indicated that the clover CC was more valued in the light soil of SA where additional N input was more beneficial compared to the fine textured soil of NO with high mineralization which already provides substantial N supply.

Success Story - A success story presents a significant result or an important milestone achieved. It is intended to showcases achievements in applied research. Focus on research results, successful technology transfer, potential for pre-commercialization, and/or potential impact. A Success Story is not a progress report for each activity (suggested length 2 – 3 paragraphs).

Canola is a minor crop, but has great potential to become a valuable cash crop in eastern Canada. There is, however, a lack of site-specific knowledge for canola production in eastern Canada, particularly with respect to nutrient-use efficiency. To address that need, AAFC scientists at the Ottawa Research and Development Centre (ORDC) are leading a canola nutrient management project in collaboration with four major ag universities and with the Eastern Canada Oilseeds Development Alliance (ECODA). Their up-to-date results have demonstrated that under adequate phosphorus (P) supply conditions, plant P uptake in canola was largely enhanced by nitrogen (N) application, and plant N uptake during crop development was diluted by plant P uptake, a clear indication of the importance of nutrient balance in canola production. During drought, plant straw at maturity contained much higher N concentrations than plants grown under average seasonal rainfall, indicating restricted N translocation to filling the seed.

Under the field conditions, the plots that received additional sidedressed N often produced greater seed yields than the plots that received the same amounts of total N, but all applied before planting, indicating more efficient use of N fertilizer with sidedress application. It is important to realize that sidedress application usually occurs at over a month after seeding. This provides producers with the opportunity to decide if and how much additional N fertilizer should be applied as sidedress, if drought or other unusual weather events occur or are expected. This will make farming more profitable as well as sustaining the environment. Preplant sulfur nutrient application is effective at promoting canola seed yields on a site-specific basis. In general, our data clearly indicates that crop requirements for nutrients are dependent upon environments, cultivars and growth stages. Basic and applied research on site-specific nutrient mineralization and cycling, and timely testing for cultivar-specific nutrient requirements and crop nutrient balance are of critical importance in sustainable crop (including canola) production. This would help meet the profitability required by the producers, and create for the general public safe, nutritious food, clean air and water, and an environment with minimum nitrogen and carbon footprints.

During the study period, a microplate assay for quantification of B concentrations in soil and plant tissue samples has been developed. This method improved the quantification of B in soil and plant tissue samples. As the B microplate assay uses a smaller (40 times less) volume of chemical reagents per sample than conventional spectrometry and microplates permit the simultaneous analysis of samples, quality controls and standards, it is cost-effective and suitable for high throughput analysis in research and commercial laboratories that have not yet acquired an ICP system for multi-elemental analysis.

3. Objectives/Outcomes (technical language is acceptable for this section)

Provide a brief summary that includes introduction, objectives, approach/methodology, deliverables/outputs, results and discussion, and any Ph.D or Master students recruited to work on the project.

Objectives:

Three field experiments with two varieties of canola at 6 locations were conducted to develop nutrient cycling knowledge and best management practices for canola crop production in eastern Canada. The specific objectives are:

1) identify nutrient deficiencies through plant and soil determinations with consideration of genotype by environment by management interactions for improved nutrient use efficiency (NUE) and canola crop productivity.
2) determine a threshold level of micronutrient B deficiency and nutrient balance (N:S) of canola production.
3) develop improved guidelines for canola site-specific nutrient management.

Description:

The overall goal of this project is to determine the economic optimum rate of N, the right balance of N, S, and B nutrients, and to develop site-specific best nutrient management practices for sustainable canola production in eastern Canada. Site-specific nutrient requirement of canola was determined on the basis of soil fertility status and the amount of different nutrients removed from the soil on a per-tonne of canola yield basis at the test site. This will lead to the determination of an efficient nutrient management for canola emphasizing optimum timing and mode of nutrient application with the consideration of interactive effect of macro and micro nutrients. The combined data and information will be used to derive the quantitative relationships between canopy optical signals, level of fertilization, and crop response so that a crop need-based optical sensing guided fertilization technology can be developed.

Outcome:

Canola production in eastern Canada is relatively new. Farmers have the desire to diversify their cropping system and seek for new opportunities to improve farming profitability by including canola in their rotation systems, but lack knowledge and experience with growing canola. This study has developed new knowledge needed to expand canola production in eastern Canada.

Materials and Methods:

Experimental Design and Treatments

This is the final year of a 4-year project. Three field experiments were conducted to determine the response of canola (*Brassica napus*) crop to nitrogen (N), sulphur (S) and boron (B) fertilizers at 6 locations in Eastern Canada: 1) the Central Experimental Farm, **Ottawa**, ON (45°23'N, 75°43'W), 2) Lods Agronomy Research Centre, MacDonald Campus of **McGill** University, Sainte-Anne-de-Bellevue, QC (45°25'N, 73°56'W), 3) Lyndhurst Farms Ltd, **Canning**, NS (45°01'N, 64°26'W), 4) **Laval** University Research Farm, St-Augustin-de-Desmaures, QC (46°44'N, 71°31'W), 5) Elora Research Station, University of **Guelph**, Elora, ON (43°41'N, 80°32'W), and 6) Verner (**North Bay**), ON (46°23'N, 80°06'W) (N study on one hybrid for two years). Due to planting issues in Elora and poor crop emergence for each experiment, there was no data from Guelph (Elora) site in 2013. Due to fertilizer issues at Canning site, the boron experiment was not carried out in the second year at that site. The North Bay site only has data for the first year of the two years. While plant and soil sampling data were collected during the growing season, there was no yield data collected at the North Bay site due to early frost in 2014. In addition, field experiments were conducted at two sites in Quebec (St-Augustin-de-Desmaures (SA) and Normandin (NO)) between 2013 and 2015 to measure the impact of a cover crop (CC) (mix of red (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.)), as well as two fertilizer types (mineral (27-0-0) or organic (pig slurry)) and rates (0, 50, 100, 150 kg N ha-1) on canola (*Brassica napus* L.) yield and N uptake and the soil structural stability.

For the first 2 years of this project, the two canola cultivars used in these experiments were InVigor 5440 (LL) and InVigor L150 (LL). In 2015 and 2016, InVigor L150 was replaced with InVigor L140P, due to its better resistance to lodging.

Urea (46-0-0) was the N source for most sites. Calcium ammonium nitrate (CAN; 27-0-0) was used in Canning and McGill in 2015 and 2016 for an N source. Ammonium sulphate (21-0-0 with 24% S) was the S source. At the Ottawa and Laval sites, Alpine MicroBolt (liquid; 10% B), derived from Boric acid, was the B source. Solubor (liquid; 20.9% B) was used by Laval, Granubor (10% B) was used at McGill and Bortrac (liquid B) was used at Canning. If potassium or phosphorus were added preplant, it was in the form of muriate of potash (0-0-60) and triple superphosphate (0-46-0).

The planting dates, planting rates, size of plots and herbicide treatment varied for each site-year. Planting occurred very late in the first year of the McGill site. Planting and management practices are shown in Table 1. The only sites that used an insecticide were McGill and Elora, as they had significant issues with flea beetles most years. Metador was used starting at the 2-3 leaf stage. In 2016 Elora also used the insecticide Decis.

Table 1. Planting date, seeding rate, herbicide treatment, and plot dimensions for the 3 experiments at each site in (A) 2013, (B) 2014, (C) 2015 and (D) 2016.

A. 2013

	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	North Bay, ON
Planting Date	May 5	May 1	June 20	May 8	May 15
Seeding Rate	5 kg ha^{-1}	5 kg ha^{-1}	5 kg ha^{-1}	130 seeds m^{-2}	5 lb ac^{-1}
No. of rows	16	9	14	16	
Row Length (m)	10	6	4	6	
Row Width (m)	.18	.18	.18	.15	.19
Herbicide	Liberty 200SN	Liberty 200SN	Liberty 200SN	Liberty 200SN	-
Herbicide Rate	2 L ha^{-1}	2 L ha^{-1}	2.5 L ha^{-1}	2 L ha^{-1}	
Insecticide	-	-	Matador	-	-
Insecticide Rate	-	-	83 mL ha^{-1}	-	-

B. 2014

	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Planting Date	May 12 (N&B) May 13 (S)	May 8(B&S), May 16(N)	May 13 (N), May 20 (S), May 21 (B)	May 28	May 27
Seeding Rate	5 kg ha^{-1}	5 kg ha^{-1}	5 kg ha^{-1}	130 seeds m^{-2}	
No. of rows	16	9	14	16	7
Row Length (m)	10	5	5	6	5
Row Width (m)	.18	.18	.19	.15	.18
Herbicide	Liberty 200SN	Liberty 200SN	Liberty 200SN	Liberty 200SN	Rival
Herbicide Rate	2 L ha^{-1}	2 L ha^{-1}	2.5 L ha^{-1}	2 L ha^{-1}	2 L ha^{-1}
Insecticide	-	-	Matador	-	Matador
Insecticide Rate	-	-	83 mL ha^{-1}	-	83 mL ha^{-1}

C. 2015

	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Planting Date	May 2 (N&B) May 5 (S)	May 6 (N) May 7 (S) May 8 (B)	May 20 (N) May 21 (S&B)	May 16	May 15
Seeding Rate	5 kg ha^{-1}	-	5 kg ha^{-1}	130 seeds m^{-2}	120 seeds m^{-2}
No. of rows	16	9	14	12	7
Row Length (m)	6	5	5	6	5
Row Width (m)	.18	.18	.18	.15	.18
Herbicide	Liberty 200SN	Liberty 200SN	Liberty 200SN +Ammonium sulphate	Bonanza (PPI) (2.3 l ha^{-1}) Liberty 200SN + AMS	Rival (PPI)

Herbicide Rate	2.5 L ha^{-1}	2.5 L ha^{-1}	2.5 L ha^{-1} + 3 L ha^{-1}	2.5 L ha^{-1} & 6 L ha^{-1}	2 L ha^{-1}
Insecticide	-		Matador	-	Matador
Insecticide Rate	-		83 mL ha^{-1}	-	83 mL ha^{-1}

D. 2016

	Ottawa, ON	**Laval, QC**	**McGill, QC**	**Canning, NS**	**Elora, ON**
Planting Date	May 6	May 21(N), May 12 (S&B)	May 6	May 12	May 12
Seeding Rate	5 kg ha^{-1}	-	5 kg ha^{-1}	130 seeds m^{-2}	120 seeds m
No. of rows	18	9	14	12	7
Row Length (m)	6	6	5	6	5
Row Width (m)	.19	.18	.18	.15	.18
Herbicide	Liberty 200SN	Liberty 200SN	Liberty 200SN	Liberty 200SN	Rival (PPI); Liberty 200SI
Herbicide Rate	2.0 L ha^{-1}	2.5 L ha^{-1}	2.5 L ha^{-1}	2.0 L ha^{-1}	2 L ha^{-1}; 2 L ha^{-1}
Insecticide	-	-	-	-	Matador; Decis
Insecticide Rate	-	-	-	-	83 mL ha^{-1}; 150 mL ha^{-1}

The three experiments are described below.

1) Canola Nitrogen Fertility Experiment

At each site in each year, this experiment, testing two canola cultivars under different rates and timing of nitrogen application, was arranged in a randomized complete block design with 4 replications. Eight N fertilizer levels (as urea at most sites, or calcium ammonium nitrate at the McGill and Canning sites) were tested, including 0, 50, 100, 150 and 200 kg ha^{-1} applied as preplant, plus 3 levels of split applications as 50 kg ha^{-1} preplant + 50 kg ha^{-1} at rosette formation (GS 30), 50 kg ha^{-1} preplant + 100 kg ha^{-1} and 50 kg ha^{-1} preplant + 150 kg ha^{-1} at GS 30. Any sidedressed N fertilizer was done by hand. Ammonium sulphate was applied preplant at 20 kg S ha^{-1}. To balance the N contained in the ammonium sulphate, 17.5 kg N ha^{-1} as urea was applied by hand to all the 0 N plots prior to planting. Boron was applied foliarly at the 20% flowering stage (GS 62) at 500 g ha^{-1} in 200 L ha^{-1} solution. For the foliar application, the adjunct Agral 90 at 0.125% v/v was used to enhance the absorption of boron by the foliage. The two canola cultivars were InVigor 5440 (LL) and InVigor L150 (LL). In 2015 and 2016, InVigor L150 was replaced with InVigor L140P.

In North Bay only one hybrid, InVigor 5440 was used. It was a small plot experiment imposed on a 50-acre field study. The field was divided into 48 m wide strips where four N levels (0, 50, 100 and 150 kg ha^{-1}) were applied preplant to each strip. One of the 0 N strips was divided into 9 plots (8 rows of canola crop with 20 row spacing and 10 m in length) to host the N treatments (0, 17.5, 50, 100, 150, 200, 50+50, 50+100 and 50+150 kg ha^{-1}) and replicated 4 times.

2) Canola Sulphur Fertility Experiment

This is a 2 x 4 factorial experiment, arranged in a randomized complete block design with four replications where canola cultivar InVigor L150 (switched to InVigor L140P in 2015 and 2016), was fertilized with combinations of different rates of nitrogen and sulphur. Three rates of urea were applied preplant at 0, 75, and 150 kg N ha^{-1}. Ammonium sulphate (21-0-0-24) was applied preplant at four S rates: 0, 10, 20 and 40 kg S ha^{-1}. Boron was applied in all plots, foliarly at the 20% flowering stage (GS 62) at 500 g ha^{-1} in 200 L ha^{-1}

solution. For the foliar application, the adjunct Agral 90 at 0.125% v/v was used to enhance the absorption of boron by the foliage.

3) Canola Boron Fertility Experiment

This experiment, testing two canola cultivars under different rates of B was arranged in a randomized complete block design with 4 replications. Boron was applied at 3 rates: 0 and 2 kg B ha^{-1} applied at preplant and at 500 g B ha^{-1} in 200 L ha^{-1} solution foliarly applied at the 20% flowering stage (GS 62). For the foliar application, the adjunct Agral 90 at 0.125% v/v was used to enhance the absorption of B through the foliage. The two canola cultivars were InVigor 5440 (LL) and InVigor L150 (LL). Preplant N at 100 kg N ha^{-1} as urea (46-0-0) or calcium ammonium sulfate (27-0-0) and S at 20 kg S ha^{-1} as ammonium sulphate (21-0-0-24) were applied to all plots.

This experiment was not carried out at the Laval site.

In all experiments, sufficient P and K were applied during the field preparation, according to the soil test recommendations. For example, at Elora site, 400 kg ha^{-1} of 0-20-20 was applied in 2015 and 2016.

4) Cover crop Study in Quebec

The experiment was conducted from 2013 to 2015 at two sites in the province of Quebec, Canada. The first was located at Normandin (NO), on the Agriculture and Agri-Food Canada research farm (48°49'57"N, 72°33'36"W), on a silty clay (Labarre series; fine, mixed, frigid Humic Cryaquept), and the other was located at Saint-Augustin-de-Desmaures (SA), on the Laval University experimental farm (46°43'28"N, 71°30'15"W), on a sandy clay loam (Saint-Laurent series; loamy, mixed, frigid, aeric Umbric Endoaqualf). Selected soil characteristics are presented in Table 1. The monthly temperature and precipitation values during investigation at each experimental site are presented in Fig. 1.

A 2-year cropping system was repeated twice (2013–2014 and 2014–2015) at each site, for a total of four 2-year trials; new plots were established at the beginning of each trial. The factorial experiment was arranged in a split-plot design. The factors were (i) preceding CC (barley alone or barley intercropped with clover CC) in main plots, which were established during the first year, (ii) N fertilizer type (mineral or organic fertilizer) and (iii) N rate (0, 50, 100 and 150 kg N ha^{-1}) in sub-plots, established during the second year. Since the “0N” plot did not receive any fertilizer, only one plot was needed for both mineral and organic fertilizer types, making for a total of seven sub-plots. Treatments were replicated four times in randomized blocks for a total of 56 plots.
All trials were established after a cereal crop that was tilled (moldboard plowing) in the fall. Main plots were established in May after a secondary tillage with field cultivator at a 5 cm depth. Barley (*Hordeum vulgare* L.) was sown 2.5 cm deep at 350 seeds m^{-2} in barley-only plots, and 245 seeds/m^2 in plots with the CC, using a Fiona seeder (Fiona Maskinfabrik A/S, Bogense, Denmark) with 12 cm row spacing at SA, and with a John Deere 452 seeder (John Deere, Moline, IL, USA) with 15 cm row spacing at NO. Red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L. var. Huia) were seeded the same day as barley, each at a rate of 4 kg seed ha^{-1}, in half of the plots with a Brillion seeder (Landoll corporation, Marysville, KS, USA). All plots were fertilized with mineral N, P and K, based on pre-plant soil analyses and recommended rates (CRAAQ 2010). Tropotox Plus® (4.25 L ha^{-1}) was used to control weeds in all plots, as well as Refine® SG (30 g ha^{-1}) in barley-only plots at SA, while Clovitox Plus® (3 L ha^{-1}) was used at NO in all plots. Barley was harvested in August. Clover was chemically terminated with Touchdown Total® (5.5 L ha^{-1}) prior to fall tillage at NO, while no herbicide was used at SA. Plots were moldboard plowed (20 cm) in October at both sites.

For the second year of each trial, soil was prepared with a field cultivator at a 5 cm depth around mid-May at SA and around mid-June at NO. Subplots were established by applying the different fertilization treatments. Sub-plots were 1.44 m wide x 5.5 m long (7.92 m^2) at NO and 1.62 m wide x 6 m long (9.72 m^2) at SA. Rates of 50, 100 and 150 kg N ha^{-1} (Ca-NH_4NO_3, 27-0-0) were applied in mineral fertilized plots ascribed to the mineral N treatments, whereas pig slurry was applied to provide the same rates of "available" N, which was assumed to represent 80% of slurry total N content (CRAAQ 2003). Selected manure characteristics are presented in Table 2.

Plots fertilized with pig slurry were assumed to receive sufficient amounts of P, K and S with the slurry. The other plots including the control (0, 50, 100 and 150N) received 50 kg P ha^{-1} (triple super phosphate, 0-46-0), 51 kg K ha^{-1} (KCl 0-0-60), and 18 kg S ha^{-1} (K_2SO_4 0-0-51-18) at NO, and 20 kg P ha^{-1}, 20 kg K ha^{-1} and 20 kg S ha^{-1} ($MnSO_4$ 0-0-0-32) at SA, according to soil tests and local recommendations (CRAAQ 2010). Mineral fertilizers and pig slurry were surface applied and incorporated within 1-3 h with a chain harrow at NO and a tine harrow at SA.

Canola (*Brassica napus* L. var. 45H29 at NO and var. L150 (2014) and L140 (2015) at SA) was sown at a rate of 6 kg ha^{-1}, at a 1-1.5 cm depth and with 18 cm between rows, using a Wintersteiger plot seeder (Wintersteiger, Salt Lake City, UT). The plots were fertilized with boron at 1 kg ha^{-1} by foliar application at the rosette stage. At the NO site, control of striped flea beetles was done using carbaryl (Sevin® XLR at 750mL ha^{-1}) at 350 g ha^{-1}, and control of weeds was done with glyphosate (650 g ha^{-1} (Touchdown Total® at 1.3 L ha^{-1}) in 2014 and 448 g ha^{-1} (Roundup R/T 540 at 830 ml ha^{-1}) in 2015). No insecticides were used at the SA site, while glufosinate 500 g ha^{-1} (Liberty 200SN at 2.5 L ha^{-1}) was used for weed control in both years. At NO, diquat 480 g ha^{-1} (Reglone ® desiccant at 2 L ha^{-1}) at 480 g ha^{-1} was applied to canola before harvest to accelerate dry down. Harvest was done with a Wintersteiger plot harvester at the end of August or in early September at SA, and at the end of September or early October at NO.

Slurry, Plant and Soil Sampling and Analyses

Pig slurry was obtained from a commercial hog operation, and analyzed prior to application to determine total N by Kjeldahl acid digestion and colorimetry as detailed in Chantigny et al. (2007). Available N content was calculated and application rates determined as indicated above. Composite slurry samples were also taken during application, and analyzed for total N and total P (acid hydrolysis), pH (direct reading with a glass electrode, and NO_3-N and NH_4-N (1 M KCl) as detailed in Chantigny et al. (2007). Slurry total C was determined by wet combustion with an automated analyzer (model TOC-5050, Shimadzu Corp., Kyoto, Japan).

Clover above-ground biomass was measured prior to incorporation. In each plot, plants were sampled in two 50 × 50 cm (SA) or 30 × 30 cm (NO) quadrats, weighed and dried at 55°C for 72 hours for DM yield determination. Samples were then ground with a Wiley mill (model 4, Thomas Scientific, Philadelphia, PA, USA) to pass a 1-mm screen for C and N analyses by dry combustion with a CNS analyser (model Trumac, LECO Corporation, St. Joseph, MI, USA). The N accumulation in clover biomass was determined by multiplying DM yield by the corresponding N concentration.

Canola total above-ground biomass was measured at the 20% bloom stage. In each plot, plants on 50 cm of a row were sampled and then dried and ground as described above for clover. The ground material was analysed for N content by acid digestion with a mixture of sulfuric and selenious acids (Isaac and Johnson 1976) and colorimetry using a continuous flow injection analyzer (QuikChem 8500, Lachat Instruments, Loveland, CO). The N uptake in canola biomass was determined by multiplying DM yield by the corresponding N concentration.

Canola grain yields were determined at harvest, after drying at 35°C for 24h and being manually cleaned with a canola sieve set at SA or with a seed cleaner (Model Eclipse 324, A.T. Ferrel Company Inc., Bluffton, IN, USA) at NO. Grain protein and moisture content were measured with a near-infra-red spectrometer (model DS2500, Foss Company, Hillerød, Denmark), and yield was corrected at 90% DM content.

Soil samples were collected in each plot at seeding, at the 2-4 leaf stage, at the rosette stage, at the 20% bloom stage, at the end of flowering – beginning of green silique stage, and after harvest. Composite soil samples were taken (0-20 cm) using a 2-cm stainless steel corer. Bulk soil density (0-20 cm) was taken at the 2-4 leaf stage and after harvest in 2014, and at the rosette stage in 2015, using the cylinder method as described by Hao et al. (2008). Soil mineral N concentration was determined within 48 h of sampling by shaking 25 g of field-moist soil for 60 min with 125 mL of 1M KCl, as described in Chantigny et al. (2007). The extracts were analyzed for NH_4-N and NO_3-N by continuous flow colorimetry (QuikChem 8500, Lachat Instruments, Loveland, CO). The soil mineral N content (kg ha^{-1}) was calculated as the sum of NH_4-N and NO_3-N concentrations, corrected for moisture content, sampling depth, and bulk density.

Sampling and Data Collection

Measurements that were taken for all three experiments were:

a) Phenology

The phenology was recorded weekly and was based on the Phenological Growth Stage and BBCH-identification Keys of Oilseed Rape (Weber and Bleiholder, 1990; Lancashire et al., 1991).

At certain sites in 2013 and 2014, late in the growing season plant lodging occurred in some plots. A lodging score of 1 to 5 was used to measure the degree of lean to the lower stem of the plants. Lodging was recorded at the time of harvest. A score 1 represents the plants totally upright and score 5 refers flat and completely lodged. This score is used in the canola performance trials (www.canolaperformancetrials.ca) in Western Canada.

b) Soil Sampling

For all sites, composite (2-4 cores per sample) soil samples at 0- to 30 cm depth taken at preplant were sent to an accredited laboratory for analysis of soil pH, available forms of K, P, B and S, and % organic matter.

c) Harvest Index, Yield and Moisture Measurements

At physiological maturity, plants were collected from a 1 m x 2 row area of each plot. These plants were put in the oven at 50°C and later weighed and threshed in order to determine harvest index. Five additional plants per plot were also collected to determine number of pods/ plant, seeds/pod and 1000-seed weight. Grain yield and moisture were determined by direct combining of an area in each plot. The grain yields were adjusted and reported on a 100 g kg^{-1} water basis.

d) Plant/Grain Nitrogen, Boron, Sulphur Concentrations

At the Ottawa site, analysis of grain and plant samples for total N and P concentrations occurred by digesting samples using the Kjeldahl method, and determining % N and P with the Lachat QuikChem ® Flow Injection Analysis system (8000 series), or other analytical methods. At the McGill and Laval sites, total N concentrations of plants samples were determined using the dry combustion method with an CNS analyzer. Plant samples at early flowering still need to be ground and analyzed for S and B concentrations.

e) Grain Oil and Protein Measurements

Grain oil and protein concentrations were determined at 2 places: the Dalhousie Agricultural Campus of Dalhousie University, Truro, Nova Scotia, using the Unity Scientific SpectraStar 2500x NIR spectrometer, and at Ottawa using the FOSS NIRS DS2500 Feed Analyzer.

f) Seed Quality Measurements

At Ottawa and Elora, the percentage of distinctly green (DGR), brown, tan and empty seed (total poor-quality seed) were determined from a 100 seed sample using a colour guide produced by the Ontario Canola Growers Association. According to the Canadian Grain Commission Guidelines, a canola counting paddle which holds 100 seeds, a roller, and double sided masking tape are used to crush the seed to better determine the colour differences. Two 100 seed samples per plot were used.

Other measurements that occurred only in the nitrogen fertility study are listed below.

g) Plant Height

Plant heights were measured at the rosette stage and then at full flowering when plants had reached their maximum height. Readings were taken at both ends of the plot and then averaged.

h) Soil Sampling

Only at the Ottawa site, soil mineral N (NO_3- and NH_4+) were measured from soil samples collected twice during the growing season: 1) at the rosette stage (before sidedressing of N) to a depth of 30 cm using the JMC Backsaver soil sampler in the 0, 50, 100, 150 and 200 kg N ha^{-1} plots of both hybrids and 2) after harvest in all plots using the Giddings coring equipment with a 45 mm core that was used to a depth of 90 cm with the sample cut into 30 cm increments. The soil samples were analyzed at the Centralized Chemistry Lab of the Ottawa Research and Development Centre by extracting them in a 2 M KCl solution and then determining ammonia and nitrate with the Lachat QuikChem ® Flow Injection Analysis system (8000 series).

i) Canopy Reflectance Measurements/ Leaf Greenness

Canopy reflectance measurements (NDVI) were collected with the Greenseeker Hand Held Optical Sensor Unit (Model 505) and the *CROPSCAN Inc.* at the Ottawa site, and with the Unispec DC instrument at the Elora site. The readings were taken several times at the rosette stage before nitrogen sidedressing and at the 20% flowering stage. The Greenseeker sensor head generates red (656 nm) and near infrared (774 nm) radiation. The light generated is reflected off of the crop and measured by a photodiode located at the front of the sensor head. While GreenSeeker reads the reflectance continuous in a row and returns an average of NDVI, the multispectral radiometer CropScan records percent light reflectance in 11 wavelength bands from 460 to 950 nm in two locations within a plot. For CropScan the NDVI was calculated as:

$$NDVI = (R760 – R660) / (R760 + R660)$$

At the Guelph site, canopy reflectance was determined with a hyperspectral meter. In addition to the calculation of NDVI, they found red edge reflectance, another spectral index NDRE to be a good indicator of N-status (data from CropScan can also be used to calculate this index).

$$NDRE = (R850-R720)/(R850+R720)$$

These NDVI or NDRE values were used to simulate the health status of each plot for the further development of crop-based N indicators.

At some of the sites, leaf greenness was measured using the Minolta SPAD-502 chlorophyll metre. Measurements were taken from the six leaf stage (GS 16) to 20% flowering (GS 62). The early readings were done only in the preplant N plots, and then every plot after the sidedressing of nitrogen.

Saturation index (SI) will be determined at each measurement date of each site as follows:

SI = target NDVI (or SPAD) / Reference NDVI (or Reference SPAD)

Reference (NDVI or SPAD) refers to those values from the plots receiving the maximum N rates or maximum value of the field measured at the same date.

j) Plant Biomass and Leaf Area Measurements

Plant biomass was determined by collecting plants at the 20% flowering stage from a 1 m x 1 row area of each plot.

The leaf area index (ratio of foliage area to ground area) of the canopy was determined by two different ways: a) at Ottawa and Canning sites, nondestructively using the LI-COR LAI-2000 Plant Canopy Analyzer at the time of N sidedressing (GS 17), rosette stage (GS30) and at 20% flowering (GS62), and b) At McGill and Ottawa, destructively by measuring total leaf area using the LI-3100 leaf area metre on 5 plants collected at 20% flowering. The LI-COR LAI-2000 Plant Canopy Analyzer determines the overall canopy LAI by measuring the above and below-canopy sky brightness. For the LAI readings, measurements were taken between two rows of canola. Two sets of readings of ABBBBA were taken where "A" is the reading above the canopy, and "B" is at ground level right beside the canola row, ¼ away from the row, ½ way from the row, and then ¾ away from the row. The measurements were done across the rows on a diagonal. Measurements should be taken when there is cloud cover, but in the case of a sunny day, bodies are used to create shade. In 2014, 2015 and 2016 in Ottawa only, the AccuPAR instrument was used to measure leaf area index instead of the Plant Canopy Analyzer.

k) Calculation of Maximum Economic Rate of Nitrogen (MERN)

Assuming the average grain price is \$0.55 kg^{-1} (from the Canola Council of Canada) and fertilizer N costs \$1.00 kg^{-1}, the maximum economic rate of nitrogen (MERN) was calculated at sites that showed a yield response to nitrogen, taking into account the current price of nitrogen and the price of canola. It is a single target nitrogen rate based on the formula of grain yield (Y) response to fertilizer N rate (X):

$$Y = aX^2 + bX + c \qquad (1)$$

Solving this equation to get maximum yield (Y_{max}) when $X = -b/2a$. Therefore

$$Y_{max} = -b^2 / 4a+c \qquad (2)$$

$$MERN = (X_{max}\,(2Y_{max}-X_{max}*B))/\ 2Y_{max} \qquad (3)$$

Where B = the price ratio of the price of N per kg divided by the price of canola seed per kg

$$B = N\ cost/Grain\ value = 1/0.55 = 1.8 \qquad (4)$$

Results and Discussion:

Due to planting issues and poor germination, there was no data from the Elora Research station in the first year of this study. In the second year, due to fertilizer issues the B experiment at Canning did not continue.

Phenological Progression

Emergence and phenology data are all shown in Table 2. Planting at McGill site occurred very late the first year. As expected, planting densities were not affected by N rates (data not shown). Flea beetles were a problem at the McGill and Elora sites for all years. There were enough flea beetles each year that it was sprayed 2-3 times starting at the 2-3 leaf stage. At the Ottawa site, some flea beetles were only observed in the first year, but they did not reach the threshold to warrant spraying.

Table 2. Dates of the phenological stages for canola for all three experiments (Nitrogen Experiment abbreviated as N, sulphur experiment as S and boron experiment as B, grown at the 5 sites for (A) 2013, (B) 2014, (C) 2015 and (D) 2016.

A. 2013

	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS
Planting	May 5	May 1	Jun 20	May 8
Emergence	May 13	May 13	July 2	May 15
Sidedressing N	June 10		July 18	
20% Flowering	Jun 24	Jun 24	July 30	Jun 22
Maturity	Aug 19	Aug 6	Oct 2	Aug 27

B. 2014

	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Planting	May 12 (N&B) May 13 (S)	May 8 (B&S) May 16 (N)	May 13 (N) May 20 (S) May 21 (B)	May 28	May 27
Emergence	May 18	May 18 (B&S) May 26 (N)	May 19 (N) May 26 (S&B)	June 3	June 2
Sidedressing N	June 17	June 17	June 18		June 20
20% Flowering	June 24	June 28 (B&S) July 1 (N)	Jun 28 (N) July 4 (S&B)	June 29	July 5
Maturity	Aug 25	Aug 19 (B&S) Aug 28 (N)	Aug 20 (N) Aug 26 (S&B)	Sept 1	-

C. 2015

	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Planting	May 2 (N&B) May 5 (S)	May 6 (N) May 7(S) May 8(B)	May 20 (N) May 21 (S&B)	May 16	May 15
Emergence	May 11	May 17 (N&S) May 18 (B)	May 27	May 24	May 22
Sidedressing N	June 17	June 15	June 30	June 20	June 17
20% Flowering	June 25	June 30 (N) July 3(S&B)	July 6	July 5	July 2
Maturity	Aug 10	Aug 28 (N&B) Aug 19 (S)	Aug 24	Aug 26	Aug 6

D. 2016

	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Planting	May 6	May 21 (N); May 12 (S&B)	May 6	May 12	May 12
Emergence	May 16	May 28	May 17	June 9	May 26
Sidedressing N	June 16	June 20	June 14	June 17	June 8
20% Flowering	June 25	July 4	Jun 24	June 30	May 27
Maturity	Aug 22	Sept 1	Aug 10	Aug 15	Aug 8

Soil Nutrient Status

Preplant soil samples were taken at all sites and results are shown in Table 3.

Table 3. Results of preplant soil samples (0-30 cm) taken at each of the 5 sites in the spring of (A) 2013, (B) 2014, (C) 2015 and (D) 2016.

A. 2013

	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS
Soil Type	Sandy Loam	Sandy Loam	Clay Loam	Loam
Preceding crop	Barley	Wheat	Sweet corn	Soybeans
Soil pH	6.5	6.0	6.0	5.6
Organic matter (%)	3.7	3.3	-	2.9
Available soil P (ppm)	16.2	228	-	1864 kg ha^{-1}
Soil test K (ppm)	207.5	254	-	299 kg ha^{-1}
B (ppm)	<0.50	-	-	<0.50
S (%)	0.03	-	-	30 kg ha^{-1}

B. 2014

	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Soil Type	Sandy Loam	Sandy Loam	Clay Loam(N&S) Sandy Loam (B)	Sandy Loam	London Loam
Preceding crop	Soybean	Spelt	Beans (N&S) Soybeans (B)	Winter Wheat	Soybean
Soil pH	7.1	6.3 (N), 6.8 (B&S)	6.3 (N&S) 5.8 (B)	6.2	7.7
Organic matter (%)	3.5	6.3(N), 6.8 (B&S)	3.9 (N&S) 2.9 (B)	2.8	3.8
Available	82.5	220 kg ha^{-1} (N)	67.5 kg ha^{-1}	570 kg ha^{-1}	11.5

soil P (ppm)		90 kg ha^{-1} (B&S)	(N&S) 251 kg ha^{-1} (B)		
Soil test K (ppm)	97	322 kg ha^{-1} (N) 496 ha^{-1} (B&S)	243 kg ha^{-1} (N&S) 206 kg ha^{-1} (B)	108 kg ha^{-1}	46.5
B (ppm)	<0.5	0.3 (N)	-	<0.5	0.6
S (%)	<0.01	12.2 ppm (N)	-	26 kg ha^{-1}	6 ppm

C. 2015

	Ottawa, ON	**Laval, QC**	**McGill, QC**	**Canning, NS**	**Elora, ON**
Soil Type	Sandy Clay Loam	Sandy Loam	Clay Loam (S&B) Clay Loam/Sandy Loam (N)	Sandy Loam	London Loam
Preceding crop	Oats	Soybeans	Soybean	Grass Forage	Corn, Soybean
Soil pH	6.8	6.9	5.9(N), 5.3(S), 6.0 (B)	5.7	7.4
Organic matter (%)	4.1	2.8 (N) 3.8 (S&B)	3.1	3.1	2.5
Available soil P (ppm)	36	350 kg ha^{-1} (N) 98 kg ha^{-1} (S&B)	61 (N), 77 (S), 56 (B)	812.5	14
Soil test K (ppm)	197	329 kg ha^{-1} (N) 410 kg ha^{-1} (S&B)	86(N), 81 (S), 83 (B)	158.5	47
B (ppm)	<0.5	0.2 (N) 0.23 (S&B)	-	<0.5	0.1
S	473 ug g^{-1}	17.2 ug g^{-1} (S)	-	24 kg ha^{-1}	7

D. 2016

	Ottawa, ON	**Laval, QC**	**McGill, QC**	**Canning, NS**	**Elora, ON**
Soil Type	Sandy Clay Loam	Loam	Chateauguay Clay Loam (N); St-Bernard Clay Loam (S&B)	Sandy Loam	-
Preceding	Spring	Winter	Soybean, alfalfa,	Winter	-

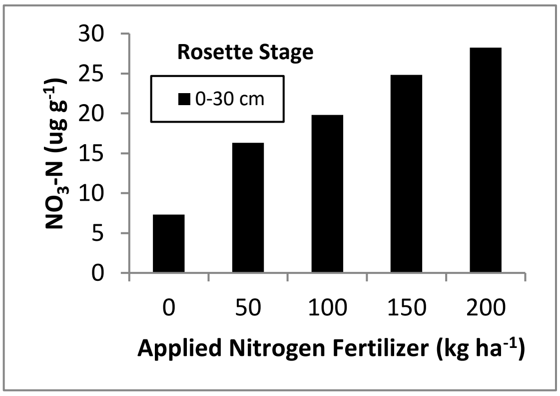
crop	Wheat	Cereals	cereals (N); corn (S&B)	Wheat	
Soil pH	6.7	6.8	5.9 (N); 5.8 (S&B)	6.8	7.7
Organic matter (%)	2.7	4.6	3.7 (N); 3.3 (S&B)	2.7	-
Available soil P (ppm)	29	103 kg ha^{-1}	63.1 (N); 65.3 (S&B)	960	7
Soil test K (ppm)	170	316 kg ha^{-1}	119.7 (N); 74.9 (S&B)	98	40
B (ppm)	-	0.54	-	< 0.5	0.5
S	228 ug g^{-1}	13.5 ppm	-	19	5 ppm

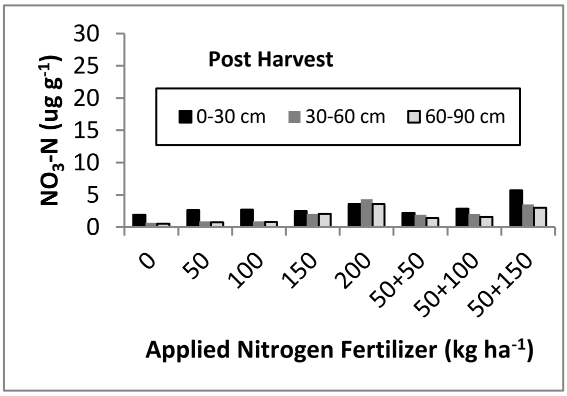
Each year (except for 2014) at the Ottawa site, soil samples at presidedress were taken from individual plots for the development of PSNT soil indicator for canola. In 2014, the soil samples were actually taken a few days after sidedressing. For all years, soil nitrate levels at presidedress stage increased with increasing amounts of nitrogen applied to the soil (Figure 1A, B, C, D). Without N application, soil NO_3-N was 7.5 µg g^{-1} at the rosette stage in 2013, 3.4 µg g^{-1} at early flowering in 2014, 3.8 ug g^{-1} pre-flowering in 2015, and 4.1 ug g^{-1} at the rosette stage in 2016. This indicates that with the initial low levels of soil residual N, there would be positive responses of canola yields to N application at these locations. The low N in the 50 and 100 kg N ha^{-1} application plots in 2014 was likely due to large amounts of canola N uptake by the flowering stage in 2014.

Post-harvest soil samples were taken and used as an indicator to see if the field was over fertilized and if there is a leaching potential. Post-harvest NO_3-N levels were very low in 2013 and 2016 across all treatments (Figure 1A & D). At high N rates where sidedressing occurred, there was a high residual soil NO_3-N concentration after harvest in 2014 and 2015 (Figure 1 B & C), a potential risk of nitrate leaching.

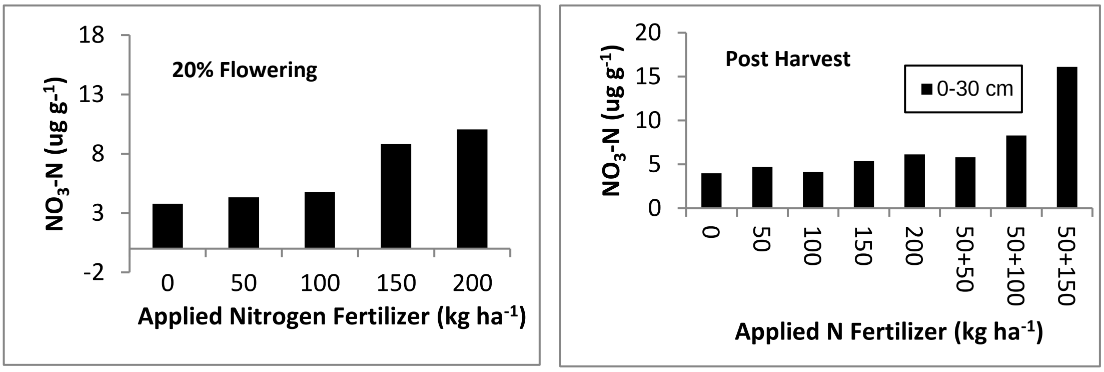
Figure 1 A, B, C & D. Means of nitrate concentrations in (A) 2013, (B) 2014, (C) 2015 and (D) 2016 of soil samples taken just before sidedressing and after harvest in the nitrogen fertility study at the Central Experimental Farm in Ottawa.

A. 2013

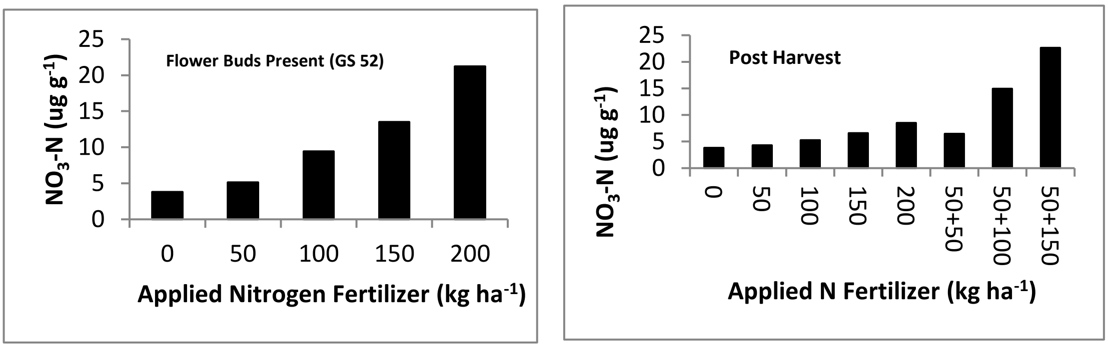




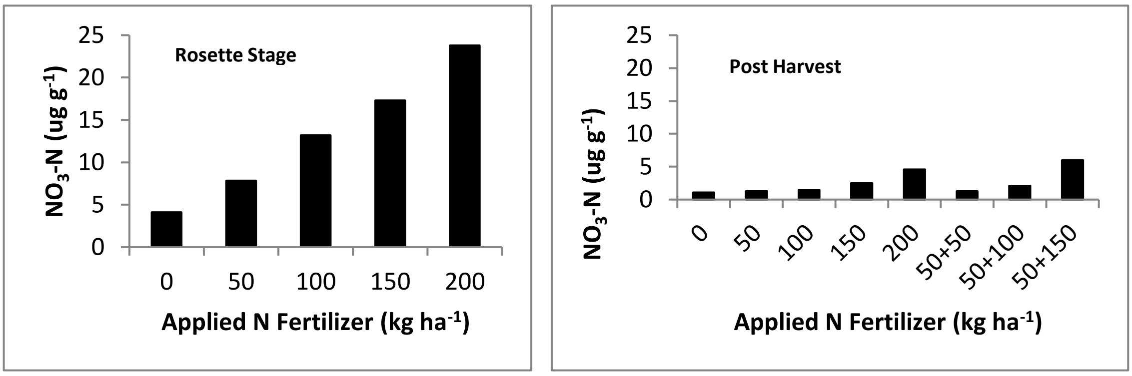
B. 2014



C. 2015



D. 2016



<u>Canola N Fertility Study</u>

a) **Plant Biomass, Plant Height and LAI**

Plant biomass and LAI were measured at the 20% flowering stage (GS62), and plant height at full flowering (GS 65-69). Due to low populations in the plots, Laval did not collect any plant biomass at the GS62 stage in 2015. It was a very dry summer in 2016 in the Ottawa and Montreal areas so plant heights and biomass were much lower than other years. In most cases there was no significant height difference between the two hybrids (Table 4 A, B, C, D). This was also the case for plant biomass (Table 4 E, F, G). LAI was measured at Ottawa, Canning and North Bay sites (Table 4H). In most cases, plant biomass, height and LAI did significantly increase with increasing rates of nitrogen fertilizer (Table 4A, B, C, D, E, F, G, H), with the plots that received preplant N at 200 kg ha^{-1} having the largest biomass and leaf area and tallest plants of all the treatments. The 0 N plots always had the shortest and smallest plants. At flowering, sidedressing N did not seem to give the plants an advantage over the plants that only received preplant N.

Table 4. Canola hybrid and nitrogen effect on: plant height at flowering (GS62) (A, B, C, D), plant biomass (E, F, G) and leaf area index (H) for all years at the specific sites. Means with different letters in the same column are significantly different at the .001Ŧ, .01x and .05∞ levels.

A. Plant Heights (cm) - 2013

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	North Bay, ON
Hybrid					
5440	140.4 a	97.8 b x	71.0	121.5 a	
L150	141.6 a	100.4 a	74.4	120.9 a	
Nitrogen (kg ha^{-1})					
0	-	-	-	-	118.2 d x
17.5	130.9 c Ŧ	91.6 f Ŧ	72.1	99.6 d Ŧ	121.8 cd
50	136.3 bc	95.6 de	72.5	117.5 c	130.0 abc
100	143.1 a	102.1 bc	71.8	127.6 b	134.8 ab
150	144.8 a	104.9 ab	75.2	134.7 a	136.6 a
200	146.1 a	107.7 a	74.2	137.7 a	130.2 abc
50+50	140.9 ab	97.4 de	72.5	119.2 c	131.3 ab
50+100	143.3 a	94.4 ef	73.9	117.2 c	129.5 abc
50+150	142.8 a	98.8 cd	69.2	116.0 c	127.5 bc

B. Plant Heights (cm) - 2014

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
5440	153.7 a x	136.7 a	85.9 a	138.7 a	158.0 a
L150	151.1 b	136.9 a	84.3 a	136.0 a	159.2 a
Nitrogen (kg ha^{-1})					
17.5	143.1 d Ŧ	128.0 d Ŧ	81.0 ab	128.3 e Ŧ	155.2 a
50	151.8 bc	134.9 c	79.9 ab	133.7 de	155.4 a
100	154.4 b	137.9 b	85.0 ab	140.8 abc	161.5 a
150	158.3 a	144.4 a	91.5 ab	143.6 ab	156.9 a
200	159.0 a	142.9 ab	93.0 a	145.3 a	162.6 a
50+50	151.9 bc	135.1 c	90.4 ab	134.6 cde	157.5 a
50+100	150.1 c	137.4 bc	78.4 b	137.9 bcd	157.1 a
50+150	150.1 c	133.7 cd	83.7 ab	134.8 cde	162.7 a

C. Plant Heights (cm) - 2015

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
5440	117.1 bŦ	103.1	131	143.6 a	148.1
L140P	122.5 a	106.9	125	145.2 a	137.7

Nitrogen (kg ha^{-1})					
17.5	106.8 d[Ŧ]	101.4	118	136.5 c	136
50	120.8 bc	106	131	141.1 bc	139
100	125.1 a	108.4	132	147.0 ab	145
150	123.3 ab	106.3	128	149.8 a	145.3
200	125.3 a	107.7	132	147.3 ab	150.8
50+50	119.4 c	102.6	129	145.5 ab	147.1
50+100	118.6 c	105.4	130	144.0 abc	143.4
50+150	119.2 c	102.3	129	143.9 abc	136.9

D. Plant Heights (cm) – 2016

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
5440	84.4 a	119 a [Ŧ]	73.5 a	85.7 a	86.1 a [x]
L140P	87.3 a	111 b	74.5 a	95.5 a	83.9 b
Nitrogen (kg ha^{-1})					
17.5	84.3 a	106 [Ŧ]	71.2 bc[∞]	78.4 b	84.4 bc
50	87.6 a	113	75.7 ab	83.2 ab	87.9 a
100	83.9 a	120	74.7 ab	82.3 ab	85.4 abc
150	83.9 a	118	75.3 ab	83.0 ab	85.3 abc
200	87.9 a	121	75.9 ab	84.6 ab	83.2 c
50+50	84.6 a	115	69.6 c	85.2 a	85.8 abc
50+100	87.0 a	112	76.4 a	87.0 a	83.6 bc
50+150	87.1 a	116	76.8 a	86.3 a	87.0 ab

E. Plant Biomass (kg ha^{-1}) – 2013 & 2014

Source	Ottawa, ON 2013	Laval, QC 2014	McGill, QC 2014	Canning, NS 2013	Canning, NS 2014
Hybrid					
5440	2255.6 a	4533.1 a	4675.0 a	3239.9 a	2550.6 a
L150	2297.5 a	4589.2 a	5039.2 a	3403.2 a	2531.7 a
Nitrogen (kg ha^{-1})					
17.5	1724.5 c [∞]	3583.5 c[∞]	4626.5 b	1710.3 c [Ŧ]	1782.2 c[∞]
50	2141.3 abc	3820.5 c	4792.6 b	2616.9 bc	2448.9 ab
100	2409.5 ab	5634.6 a	4576.6 b	3197.2 b	2821.1 ab
150	1966.3 bc	5253.3 ab	5300.5 ab	5471.2 a	3056.7 a
200	2581.5 a	5267.0 ab	6904.1 a	4951.8 a	2714.4 ab
50+50	2164.5 abc	4091.0 c	4178.1 b	2939.4 b	2210.0 bc
50+100	2554.6 a	4530.6 abc	3537.0 b	3032.2 b	2676.7 ab
50+150	2670.5 a	4308.5 bc	4861.1 b	2599.0 bc	2618.9 ab

F. Plant Biomass (kg ha^{-1}) – 2015

Source	Ottawa, ON 2015	McGill, QC 2015	Canning, NS 2015
Hybrid			
5440	6611.0 a	5661	5591.6 a
L140P	6033.9 a	6071	5915.3 a
Nitrogen (kg ha^{-1})			
17.5	3361.4 c[∞]	5187	4535.6 c
50	5402.1 bc	5283	6039.9 abc

100	6651.3 ab	5497	5014.4 bc
150	8013.7 a	6096	6910.0 a
200	7179.4 ab	7720	6246.7 ab
50+50	6076.5 b	5262	5365.6 abc
50+100	5185.6 b	5182	6042.2 abc
50+150	5975.4 ab	4925	5882.2 Abc

G. Plant Biomass (kg ha^{-1}) – 2016

Source	Ottawa, ON 2016	Laval, QC 2016	McGill, QC 2016	Canning, NS 2016
Hybrid				
5440	2727.9 a	3939 a	2020.3 a	2528.9 a
L140P	2830.3 a	4045 a	2099.2 a	2440.6 a
Nitrogen (kg ha^{-1})				
17.5	2301.8 b	2671 [Ŧ]	1726.3 a	2166.7 c
50	2423.5 b	3671	1907.6 a	2143.3 c
100	2813.7 ab	4023	1790.3 a	2260.0 bc
150	3141.7 a	4609	2132.4 a	2902.2 ab
200	3259.0 a	4925	2500.9 a	3070.0 a
50+50	2894.4 ab	3701	2072.6 a	2320.2 bc
50+100	2646.5 ab	4081	2046.4 a	2594.5 abc
50+150	2754.2 ab	4255	2305.8 a	2439.0 abc

H. Leaf area index - 2013, 2014, 2015 & 2016

Source	Ottawa, ON 2013	2014	2015	2016	Canning, NS 2013	2015	2016	North Bay, ON 2013
Hybrid **5440**	2.8 a	5.3 b[∞]	3.6 a	2.6 a	3.6 b [Ŧ]	4.5 a	1.6 a	
L150/140P	2.9 a	5.9 a	3.9 a	2.4 a	4.2 a	4.5 a	1.8 a	
Nitrogen (kg ha^{-1})								
0	-	-	-	-	-	-	-	1.1 e [x]
17.5	1.9 e [x]	4.3 d[Ŧ]	3.9 a	1.5 d	2.4 e [Ŧ]	2.7 d [Ŧ]	1.3 d	1.2 de
50	2.6 cde	5.0 bcd	4.2 a	2.1 cd	3.0 d	3.3 d	1.4 d	2.0 bcde
100	3.1 abcd	5.8 abc	3.6 a	2.8 ab	4.2 b	4.7 bc	1.7 bcd	1.8 cde
150	2.6 de	6.4 a	3.3 a	2.8 ab	5.5 a	5.5 ab	2.0 ab	2.1 abcd
200	3.4 ab	6.5 a	3.4 a	3.2 a	5.3 a	5.5 a	2.1 a	2.4 abc
50+50	2.7 bcd	4.7 cd	3.7 a	2.3 bc	3.5 cd	4.4 c	1.7 bcd	2.0 abcde
50+100	3.4 abc	5.9 ab	4.0 a	2.7 abc	3.7 c	4.9 abc	1.5 cd	3.0 a
50+150	3.5 a	6.5 a	4. a	2.4 bc	3.4 cd	5.2 ab	1.9 abc	2.9 ab

b) Harvest Index, Branches, Pods, Number of Seeds per pod and 1000-Seed Weight

For some sites and years, nitrogen did not have any effect on harvest index. In Ottawa 2013 and 2015, Elora 2014 and 2016, Laval 2016, and Canning 2016, harvest index increased with increasing amounts of nitrogen (Table 5). In most cases, sidedressing nitrogen did not significantly increase harvest index over harvest index taken from the preplant N plots (data not shown).

Table 5. Nitrogen effect on harvest Index at Ottawa, Elora, Laval and Canning for the nitrogen fertility study. Means with different letters in the same column are significantly different at the .001[Ŧ], .01 [x] and .05 [∞] levels.

Nitrogen (kg ha^{-1})	Ottawa, ON 2013	Ottawa, ON 2016	Elora, ON 2014	Elora, ON 2016	Laval, QC 2016	Canning, NS 2016
17.5	.352 c [x]	.37 c [Ŧ]	.31 c [Ŧ]	.36 d [Ŧ]	.28 [x]	.14 c [∞]
50	.363 bc	.41 b	.33 bc	.39 c	.30	.15 bc
100	.372 ab	.43 ab	.34 ab	.41 ab	.29	.147 c
150	.378 ab	.44 a	.35 ab	.40 bc	.30	.14 c
200	.363 bc	.44 a	.36 a	.41 ab	.30	.18 ab
50+50	.375 ab	.45 a	.35 ab	.41 ab	.29	.16 abc
50+100	.380 a	.44 a	.37 a	.41 ab	.32	.16 abc
50+150	.379 a	.44 a	.35 ab	.42 a	.33	.20 a

In most cases, number of branches and pods per plant were not significantly different between cultivars (Tables 6 A, B, C, D & 7 A,B,C, D). In 2013 and 2014, InVigor L150 had more seeds/pod than InVigor 5440 (Table 8A & B), most significantly. However in 2015 and 2016, there was usually no significant difference in number of seeds/pod between the new variety InVigor L140P and InVigor 5440 (Table 8C&D). At all sites and years, pods, branches, and seeds per pod increased in numbers with increasing nitrogen levels, sometimes significantly (Tables 6, 7 & 8). In all cases the plots that received the least amount of nitrogen had the least number of branches, pods and seeds. In most cases the plots that received either 200 kg ha^{-1} preplant or sidedressed, had the most branches, pods and seeds. However adding sidedressed nitrogen did not always significantly increase number of branches, pods or seed numbers compared to the plots that received the same amount of preplant nitrogen.

Table 6. Canola hybrid and nitrogen effect on number of branches per plant at all sites in the nitrogen fertility study in (A) 2013, (B) 2014, (C) 2015 and (D) 2016. Means with different letters in the same column are significantly different at the .001 Ŧ level. Means with different letters in the same column are significantly different at the .001Ŧ, .01x and .05∞ levels.

A. Branches 2013

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	North Bay, ON
Hybrid					
InVigor 5440	5.7 a	3.8 a	4.7	3 a	-
InVigor L150	5.6 a	4.0 a	5.1	3 a	-
Nitrogen (kg ha^{-1})					
0	-	-	-	-	2.3 bc
17.5	4.8 b	3.0 c [Ŧ]	4.6 b [Ŧ]	2.0 b	2.1 c
50	6.3 b	3.4 c	4.5 b	2.6 ab	2.7 bc
100	5.0 b	3.5 bc	4.0 b	3.0 ab	3.0 bc
150	7.2 a	3.6 bc	4.7 b	3.2 ab	3.0 bc
200	5.8 ab	4.1 ab	5.5 ab	3.8 a	4.6 a
50+50	5.5 b	4.2 a	4.7 b	3.2 ab	2.7 bc

50+100	5.3 b	4.6 a	5.4 ab	3.6 a	3.1 abc
50+150	5.2 b	4.7 a	6.1 a	3.6 a	3.7 ab

B. Branches 2014

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	5.1 a	3.7 a	3.5 a	3.3 a	6.7 b [Ŧ]
InVigor L150	5.1 a	3.9 a	3.3 a	3.8 a	8.4 a
Nitrogen (kg ha^{-1})					
17.5	4.1 b	2.8 d [x]	2.5 d	2.4 b[∞]	6.0 b
50	5.3 ab	3.3 cd	3.2 bcd	2.7 b	7.6 ab
100	5.7 ab	3.4 cd	3.4 abcd	3.5 ab	6.8 ab
150	5.3 ab	4.6 ab	3.7 abc	3.6 ab	8.0 a
200	5.0 ab	4.0 abc	4.5 a	4.1 a	8.3 a
50+50	6.2 a	3.7 bcd	2.8 dc	3.5 ab	7.1 ab
50+100	5.0 ab	3.9 abcd	3.4 bcd	4.2 a	8.0 a
50+150	4.5 ab	4.9 a	4.1 ab	4.5 a	8.3 a

C. Branches 2015

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	6 a	9	4	3 a	5
InVigor L140P	6 a	8	4	3 a	6
Nitrogen (kg ha^{-1})					
17.5	4.5 c	6	3	2.4 c [x]	4
50	5.0 bc	7	4	3 bc	5
100	6.0 abc	8	4	3 bc	5
150	6.2 abc	9	4	3 bc	5
200	7.0 ab	10	4	3.6 ab	7
50+50	5.5 bc	9	4	3.0 bc	5
50+100	7.0 ab	10	4	3.0 bc	6
50+150	7.8 a	9	4	4.1 a	6

D. Branches 2016

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	5.0 a	5.6 [∞]	2.9 a	2 a	5 a
InVigor L140P	5.4 a	6.4	2.6 a	2 a	5 a
Nitrogen (kg ha^{-1})					
17.5	3.5 d [x]	5.3 [∞]	2.4 b	1.1 c [∞]	3.4 e [Ŧ]
50	4.2 cd	5.5	2.8 ab	1.6 bc	3.9 de
100	6.2 ab	6.4	2.6 b	2.1 ab	6.4 a
150	5.2 bc	5.6	2.8 ab	1.8 abc	6.3 ab

200	6.8 a	6.0	2.6 b	2.5 a	6.1 ab
50+50	4.2 cd	5.7	2.5 b	1.8 abc	5.6 abc
50+100	6.0 ab	6.2	2.9 ab	1.8 abc	5.0 cd
50+150	5.8 bc	7.2	3.4 a	2.1 ab	5.3 bc

Table 7. Canola hybrid and nitrogen effect on number of pods per plant at all five sites in the nitrogen fertility study in (A) 2013, (B) 2014, (C) 2015 and (D) 2016. Means with different letters in the same column are significantly different at the .001 ᵀ, .01 ˣ and .05 ∞ levels.

A. Pods 2013

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	North Bay, ON
Hybrid					
InVigor 5440	127 a ˣ	63 a ˣ	70 a	47 a	-
InVigor L150	102 b	53 b	74 a	45 a	-
Nitrogen (kg ha^{-1})					
0	-	-	-		80 a
17.5	80 c	39 e ᵀ	66 b ˣ	25 b	43 a
50	127 ab	48 de	66 b	27 b	55 a
100	102 bc	51 cde	57 b	44 ab	42 a
150	141 a	57 bcd	75 ab	48 ab	60 a
200	125 ab	63 abc	80 ab	70 a	70 a
50+50	122 ab	64 abc	71 ab	46 ab	61 a
50+100	107 abc	69 abc	79 ab	48 ab	59 a
50+150	110 abc	72 a	87 a	51 ab	48 a

B. Pods 2014

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	93 a	48 a	57 a	68 a	121 a
InVigor L150	75 a	47 a	55 a	74 a	120 a
Nitrogen (kg ha^{-1})					
17.5	63 a	26 c ˣ	39 c	50 b ∞	93 b
50	87 a	39 bc	54 abc	51 b	112 ab
100	77 a	46 ab	51 abc	64 ab	118 ab
150	101 a	60 a	66 ab	79 ab	125 a
200	90 a	55 ab	68 a	94 a	138 a
50+50	91 a	47 ab	44 bc	54 b	113 ab
50+100	102 a	49 ab	67 a	74 ab	132 a
50+150	60 a	63 a	63 ab	101 a	135 a

C. Pods 2015

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	102 a	164	76	76 a ˣ	69
InVigor L140P	100 a	139	71	60 b	78
Nitrogen (kg ha^{-1})					

17.5	71 d ∞	107 x	54	54 c x	48
50	88 bcd	103	59	58 bc	67
100	109 abc	152	68	78 ab	70
150	105 abcd	164	89	69 bc	87
200	124 a	174	96	66 bc	100
50+50	83 cd	169	72	63 bc	69
50+100	105 abcd	180	65	67 bc	69
50+150	121 ab	163	74	91 a	80

D. Pods 2016

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	108 a x	96 a Ŧ	60 a	34 a ∞	108 a
InVigor L140P	82 b	73 b	59 a	28 b	108 a
Nitrogen (kg ha^{-1})					
17.5	53 d x	57 Ŧ	50 b	22 c	54 e Ŧ
50	85 bcd	71	60 ab	28 bc	79 de
100	109 ab	88	50 b	33 ab	138 ab
150	99 abc	94	60 ab	30 abc	131 ab
200	135 a	94	66 ab	38 a	148 a
50+50	65 cd	81	54 b	30 abc	111 bc
50+100	113 ab	95	64 ab	33 ab	91 cd
50+150	102 ab	96	72 a	33 abc	110 bc

Table 8. Canola hybrid and nitrogen effect on number of seeds per pod at all five sites in the nitrogen fertility study in (A) 2013, (B) 2014 and (C) 2015. Means with different letters in the same column are significantly different at the .001 Ŧ, .01 x and .05 ∞ levels.

A. Seeds/Pod 2013

Nitrogen (kg ha^{-1})	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	North Bay, ON
InVigor 5440	24.0 a	21.4 b Ŧ	27.0 a	19.5 b Ŧ	-
InVigor L150	24.4 a	23.1 a	27.2 a	20.7 a	-
Nitrogen (kg ha^{-1})					
0	-	-	-	-	21 ab
17.5	22.6 c x	21.5 bc	26.7 a	18.9 c	21 ab
50	23.7 bc	20.7 c	26.8 a	21.0 ab	21.6 ab
100	24.2 ab	22 abc	26.6 a	21.2 a	21.5 ab
150	25.1 a	23.1 ab	27.2 a	20.5 abc	20.7 ab
200	23.6 bc	22.1 abc	27.2 a	21.0 ab	22.3 a
50+50	24.2 ab	22.0 abc	26.5 a	19.4 bc	21.5 ab
50+100	25.2 a	23.7 a	28.1 a	19.5 abc	21.6 ab
50+150	24.6 ab	23.1 ab	28.0 a	19.5 abc	20.3 b

B. Seeds/Pod 2014

Source	Ottawa, ON	Laval, QC	McGill, QC	Elora, ON
Hybrid				
InVigor 5440	23 a	20 b x	21 b Ŧ	21 b x

InVigor L150	23 a	23 a	23 a	23 a
Nitrogen (kg ha^{-1})				
17.5	20 b	20 b	21 b ∞	21 b
50	23 ab	21 ab	21 b	22 ab
100	24 a	21 ab	22 ab	22 ab
150	24 a	22 a	23 a	22 ab
200	24 a	22 a	24 a	24 a
50+50	24 a	22 a	22 ab	22 ab
50+100	24 a	22 a	22 ab	23 a
50+150	24 a	21 ab	21 b	22 ab

C. Seeds/Pod 2015

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	22 a	25	24	23 a	22 a
InVigor L140P	23 a	25	25	23 a	22 a
Nitrogen (kg ha^{-1})					
17.5	22 ab	23 x	23	22.0 d ∞	22
50	24 a	24	26	22.0 d	21
100	24 a	25	25	23.3 abc	21
150	23 ab	26	25	23.0 abcd	23
200	22 b	26	25	23.6 ab	22
50+50	23 ab	25	23	23.1 abcd	22
50+100	22 ab	26	25	22.9 bcd	23
50+150	21 b	25	23	24.5 a	22

D. Seeds/Pod 2016

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	22 a Ŧ	24 a	24 a x	20 a	23 a
InVigor L140P	21 b	24 a	22 b	20 a	22 a
Nitrogen (kg ha^{-1})					
17.5	20.6 b	22 x	23 a	19 a	23 a
50	20.7 ab	23	24 a	19 a	24 a
100	21.5 ab	24	24 a	19 a	23 a
150	21.4 ab	23	22 a	20 a	23 a
200	21.8 a	24	24 a	21 a	18 b
50+50	21.2 ab	25	22 a	20 a	22 ab
50+100	21.1 ab	24	23 a	20 a	24 a
50+150	21.3 ab	24	23 a	20 a	21 ab

In most cases, InVigor 5440 had higher 1000-seed weight than InVigor L150 or L140P, sometimes significantly (Table 9 A, B, C, D). In most cases, nitrogen did not affect 1000-seed weight as they did not increase linearly with increasing nitrogen levels. Other than in Canning 2016, sidedressing nitrogen had no significant effect on 1000-seed weights compared to those from plots that received preplant nitrogen.

Table 9. Canola hybrid and nitrogen effect on 1000-seed weight in (A) 2013 (B) 2014, (C) 2015 and (D) 2016. Means with different letters in the same column are significantly different at the .001 [Ŧ], .01 [x] and .05 [∞] levels.

A. 1000-Seed Weight 2013

Nitrogen (kg ha^{-1})	**Ottawa, ON**	**Laval, QC**	**Canning, NS**
InVigor 5440	3.21 a	3.39 a	3.3 a [Ŧ]
InVigor L150	3.14 a	3.41 a	3.2 b
Nitrogen (kg ha^{-1})			
17.5	2.90 c [x]	3.23 c [∞]	3.29 b [Ŧ]
50	2.97 bc	3.32 bc	3.12 d
100	3.20 ab	3.48 ab	3.12 d
150	3.27 a	3.41 abc	3.20 bcd
200	3.23 a	3.37 abc	3.15 cd
50+50	3.26 a	3.32 bc	3.24 bc
50+100	3.33 a	3.54 a	3.42 a
50+150	3.24 a	3.55 a	3.45 a

B. 1000- Seed Weight 2014

Source	**Ottawa, ON**	**Laval, QC**	**Canning, NS**	**Elora, ON**
Hybrid				
InVigor 5440	3.4 a	3.4 a	3.2 a [Ŧ]	3.1 a [Ŧ]
InVigor L150	3.3 a	3.4 a	3.1 b	2.9 b
Nitrogen (kg ha^{-1})				
17.5	3.30 ab	3.4 abc	3.02 cd [Ŧ]	3.0 ab
50	3.22 b	3.3 c	2.98 d	3.0 ab
100	3.34 ab	3.4 abc	3.21 ab	3.04 a
150	3.41 ab	3.3 bc	3.19 b	3.0 ab
200	3.28 ab	3.4 abc	3.17 b	2.9 b
50+50	3.40 ab	3.4 abc	3.11 bc	3.0 ab
50+100	3.42 ab	3.4 ab	3.15 b	3.0 ab
50+150	3.46 a	3.5 a	3.32 a	3.0 ab

C. 1000-Seed Weight 2015

Source	**Ottawa, ON**	**Laval, QC**	**McGill, QC**	**Canning, NS**	**Elora, ON**
Hybrid					
InVigor 5440	2.25 a	2.92 [Ŧ]	3.2 a	3.07 a [Ŧ]	3.08
InVigor L140P	2.32 a	2.59	2.8 b	2.79 b	2.63
Nitrogen (kg ha^{-1})					

17.5	2.31 ab	3.00 ͳ	2.8	3.05 a ͳ	2.86
50	2.35 ab	2.84	2.9	2.96 abc	2.76
100	2.37 a	2.68	3.0	2.88 cd	2.89
150	2.39 a	2.75	3.0	2.93 bc	2.84
200	2.16 b	2.71	3.1	3.02 ab	2.89
50+50	2.33 ab	2.71	2.9	2.90 cd	2.85
50+100	2.16 b	2.71	2.9	2.80 d	2.89
50+150	2.22 ab	2.64	3.1	2.91 c	2.86

D. 1000-Seed Weight 2016

Source	**Ottawa, ON**	**Laval, QC**	**McGill, QC**	**Canning, NS**	**Elora, ON**
Hybrid					
InVigor 5440	3.4 a	3.02 a ͳ	2.7 a ͳ	3.7 a	3.1 a ͳ
InVigor L140P	3.5 a	2.75 b	2.6 b	3.6 a	3.0 b
Nitrogen (kg ha^{-1})					
17.5	3.1 d ͳ	3.11 ͳ	2.6 bc	3.56 cd	3.0 ab ͳ
50	3.3 c	3.06	2.7 ab	3.58 cd	2.98 b
100	3.3 c	2.89	2.64 abc	3.65 bcd	3.0 ab
150	3.5 ab	2.75	2.63 abc	3.61 cd	2.96 b
200	3.5 ab	2.75	2.56 c	3.46 d	2.98 b
50+50	3.4 bc	2.84	2.65 abc	3.71 bc	3.06 ab
50+100	3.55 ab	2.84	2.7 a	3.98 a	3.1 a
50+150	3.6 a	2.83	2.69 abc	3.88 ab	3.06 ab

c) Protein and Oil Concentrations

InVigor 5440 and InVigor L150 differed significantly in seed protein and oil concentrations (Table 10 A & B), with 5440 having the highest protein concentration but lowest oil concentration ($p \leq 0.001$). However in most cases, InVigor L140P (tested in 2015 and 2016), did not differ from InVigor 5440 in these traits. Increasing preplant nitrogen significantly increased seed protein concentration, but significantly decreased oil concentration ($p \leq .001$). In all cases, the plots that received 200 kg N ha^{-1} had the highest seed protein concentration but the lowest seed oil concentration. Plants from the lowest nitrogen plots had seed with the lowest protein concentration but highest oil concentration of all the treatments. The same trend occurred in the plots that received increasing amounts of sidedressed nitrogen. When comparing the preplant versus sidedressed methods, for some sites and years, sidedressing nitrogen significantly increased seed protein and significantly decreased seed oil over those in the corresponding preplant nitrogen plots. However, both seed protein and oil yields (kg ha^{-1}) increased with increasing the amount of N application either as preplant or sidedress (data not shown).

Table 10 A & B. Canola hybrid and nitrogen effect on (A) seed protein (B) oil concentrations in the Canola Fertility study. Means with different letters in the same column are significantly different at the .001 ͳ and .05 ∞ levels.

A. Seed Protein Concentration (%)

Source	**Canning, NS** 2013	2014	2015	2016	**Ottawa, ON** 2013	2014	2015	2016
Hybrid								
5440	21.0 aͳ	21.0 a∞	22.1 aͳ	24.7 a	22.8 aͳ	23.6 a ͳ	19.7 a ˣ	21.1 b ͳ
L150/140P	20.0 b	20.2 b	21.3 b	25.0 a	22.3 b	22.4 b	19.4 b	22.3 a
Nitrogen (kg ha^{-1})								

17.5	18.1 e[T]	18.6 d [T]	20.2 e[T]	21.7 f[T]	20.0 g[T]	20.9 c [T]	16.5 f [T]	16.5 g [T]
50	18.2 e	19.2 cd	20.6 e	22.9 e	21.3 f	22.2 b	17.3 e	19.0 f
100	19.5 d	19.8 cd	21.5 d	24.3 d	22.4 e	22.9 ab	19.2 d	20.6 e
150	21.3 c	22.4 a	22.2 bc	25.1 c	23.4 bc	23.3 a	20.5 b	22.8 c
200	22.4 b	23.1 a	22.7 ab	25.5 c	23.8 a	23.8 a	21.1 a	23.4 bc
50+50	19.8 d	19.6 cd	21.4 d	25.4 c	22.7 de	23.1 ab	19.7 c	21.9 d
50+100	22.2 b	20.6 bc	22.1 c	26.5 b	23.1 cd	23.8 a	20.8 ab	24.2 b
50+150	23.1 a	21.9 ab	23.1 a	27.5 a	23.6 ab	23.8 a	21.2 a	25.3 a

Source	**Laval, QC 2015**	**McGill, QC 2015**	**Elora, ON 2015**
Hybrid			
InVigor 5440	18.3 a	22.8 a	23.2
InVigor L140P	18.0 a	22.9 a	22.7
Nitrogen (kg ha^{-1})			
17.5	17.8 [T]	21.6 d[T]	22.0
50	17.3	21.8 cd	22.1
100	17.9	22.4 bcd	22.5
150	18.6	23.4 abc	23.5
200	18.8	24.1 ab	23.9
50+50	17.9	22.5 bcd	22.5
50+100	18.4	23.3 abc	23.4
50+150	18.7	24.3 a	23.8

B. Seed Oil Concentration (%)

Source	**Canning, NS 2013**	**2014**	**2015**	**2016**	**Ottawa, ON 2013**	**2014**	**2015**	**2016**
Hybrid								
5440	44.7 b[T]	42.7 b [T]	40.6 a	37.9 a	44.8 b[T]	40.3 b [T]	45.4 a	45.7 a [x]
L150/140P	46.5 a	44.5 a	40.7 a	37.9 a	46.6 a	44.9 a	45.5 a	44.9 b
Nitrogen (kg ha^{-1})								
17.5	47.8 a[T]	44.9 a [T]	41.9 a[T]	40.6 a[T]	47.6 a[T]	45.1 a [T]	48.0 a [T]	50.1 a [T]
50	47.6 a	44.0 ab	41.8 ab	39.8 a	46.9 a	43.2 b	47.3 b	47.7 b
100	46.0 b	44.7 a	40.9 bcd	38.5 b	45.4 bc	42.9 bc	45.6 c	46.3 c
150	44.8 c	42.1 c	39.9 de	37.5 c	44.9 bc	42.6 bcd	44.5 d	44.3 de
200	44.7 c	41.5 c	40.1 cde	37.2 c	45.2 bc	41.9 cde	44.2 d	43.7 e
50+50	46.0 b	44.5 ab	41.0 abc	37.5 c	45.8 b	42.3 bcd	45.3 d	45.0 d
50+100	44.4 c	44.1 ab	40.4 cd	36.0 d	45.3 bc	41.6 de	44.5 d	43.3 e
50+150	43.3 d	42.9 bc	39.3 e	35.9 d	44.6 c	41.1 e	44.2 d	42.3 f

Source	**Laval, QC 2015**	**McGill, QC 2015**	**Elora, ON 2015**
Hybrid			
InVigor 5440	47.8 a	40.4 a[T]	40.0 a
InVigor L140P	47.4 a	39.7 b	40.0 a

Nitrogen (kg ha^{-1})			
17.5	48.1 [x]	41.2 a [Ŧ]	40.9
50	48.4	40.6 ab	40.6
100	47.9	40.5 ab	40.8
150	47.3	39.5 ab	39.6
200	46.9	39.2 ab	39.4
50+50	47.7	40.9 a	40.1
50+100	47.5	40.0 ab	39.9
50+150	47.2	38.8 b	39.3

d) Lodging

Lodging occurred at Ottawa in 2013 and 2014, and at Elora, Canning and Laval in 2014. There was no lodging at the McGill site. The other sites followed similar lodging trends, but did not affect the yields as it did at the Ottawa and Elora sites.

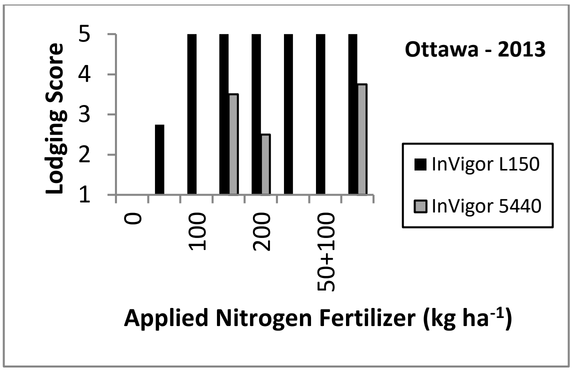
At all sites there was more severe lodging for InVigor L150 than for 5440 (Table 11). Except for the Ottawa site in 2013, hybrid InVigor 5440 did not lodge at any other site-years. The most severe lodging occurred in InVigor L150 at Ottawa and Elora (Figure 2). Nitrogen rates did have a significant effect on the intensity of lodging for L150 ($p \leq .001$) with higher lodging scores in plots that received more than 50 kg ha^{-1} N (Figure 2). At the Ottawa and Elora sites, lodging was significantly higher in the sidedressed plots (PS) compared to the preplant plots (PP) (Table 11; Figure 2).

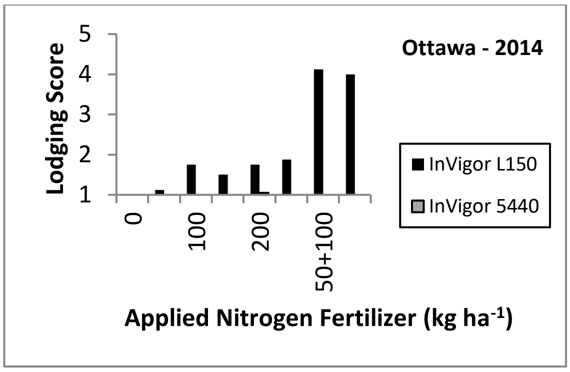
Because InVigor L150 had such a high lodging score most years, it was replaced with InVigor L140P in 2015 and 2016. In 2015 neither Invigor 5440 nor InVigor L140P showed any signs of lodging at any of the sites except for Elora. But the lodging score was low, and it was the same value of 1.5 for both hybrids, and for all nitrogen treatments (also 1.5).

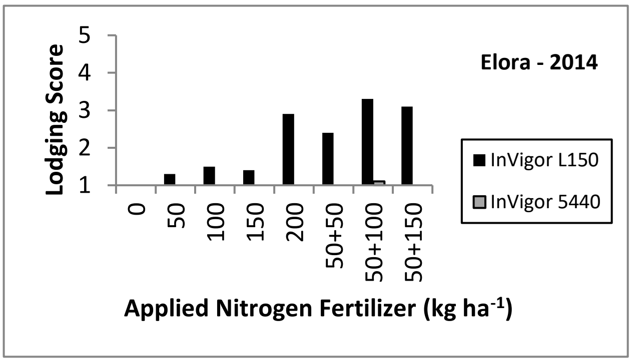
Table 11. Lodging scores as affected by canola hybrids and N application methods at 4 sites where lodging occurred. Scores range from 1 (upright; no lodging) to 5 (flat crop; total plot lodged). Means with different letters in the same column are significantly different at the .001 [Ŧ] and .01 [x] levels.

Source	Ottawa, ON		Elora, ON	Laval, ON	Canning, NS
	2013	2014			
Hybrid					
5440	2.0 b [Ŧ]	1.0 b [Ŧ]	1 b [Ŧ]	1.1 b [x]	1.2 b [x]
L150	4.1 a	2.1 a	2 a	1.2 a	1.9 a
Nitrogen Application Method					
PP	2.8 b	1.2 b [Ŧ]	1.3 b [Ŧ]	1.5 a	1.2 a
PS	3.8 a	2.2 a	2.0 a	1.5 a	1.2 a

Figure 2. Lodging scores of each hybrid treated with different nitrogen rates at the Ottawa and Elora sites. Scores range from 1 (upright; no lodging) to 5 (flat crop; total plot lodged).







e) Final Yields

At Ottawa (2013 & 2014) and Elora (2014) InVigor 5440 had significantly higher yields than InVigor L150 ($p \leq .001$) (Table 12 A & B). This was due to the heavy lodging that occurred in the high N plots of InVigor L150, which made combining very difficult.

Preplant N had a significantly positive effect ($p \leq .001$) on yields with yields increasing with increasing N rates (Table 12 A, B, C & D). Yields at North Bay 2013, McGill 2013 and 2016, and Canning 2014 showed a similar trend but were not significantly different among N treatments. For Ottawa in 2013 and 2014, InVigor 5440 responded positively to N but InVigor L150 did not. In fact because of the lodging in the high N plots, in particular the sidedressed plots, the sidedressed plots had low yields, and in 2014 were even lower than the 0 N plots (Table 12 A &B).

At sixteen of the twenty site-years, the plots that received additional sidedressed N as urea (50+50, 50+100, 50+150 kg N ha^{-1}) had higher yields than the plots that received the same amount of N but only at preplant application. The differences between the preplant and sidedressed methods were often not significant (Table 12; Figure 3). InVigor L150 at Ottawa in 2013 &2014, and Canning 2013, McGill 2014 & 2015, and Laval 2015 did not show a positive response to sidedressed N and actually had lower yields in the sidedressed plots (Table 12; Figure 3).

A regression analysis was done by taking grain yield as a function of the amount of N added at preplant compared to the plots that received the same amount of N split between preplant and sidedressing. There was a very strong correlation between yields and amount of N applied both preplant and sidedressed (Figure 3 A, B C, D), except at McGill in 2013. The values from the quadratic polynomial equations were used to determine MERN (maximum economic rate of nitrogen).

Table 12. Comparing grain yield response (kg ha^{-1}) of both canola hybrids and of the different levels of preplant and sidedressed nitrogen at the 5 sites in (A) 2013 (B) 2014, (C) 2015, and (D) 2016. Means with different letters in the same column are significantly different at the .001 Ͳ and .01 x levels.

A. Yields - 2013

Source	Ottawa, ON		Laval, QC	McGill, QC	Canning, NS	North Bay
Hybrid						
InVigor 5440	3204.5 a Ͳ		3306 a	3881 a	3481.0 a	
InVigor L150		2998.8 b	3325 a	3967 a	3418 5 a	
Nitrogen (kg ha^{-1})						
0			-	-	-	1972.3 c
17.5	2336.3 d Ͳ	2552.8 d Ͳ	2490 d Ͳ	3852 a	2379.6 e Ͳ	2472.3 abc
50	3101.7 c	3058.0 abc	2676 cd	3998 a	2924.3 d	2159.5 bc
100	3420.3 ab	3137.0 ab	2971 c	3798 a	3597.0 b	3083.3 abc
150	3212.2 bc	**3229.75 a**	3624 ab	3929 a	3970.0 a	2841.8 abc
200	3293.9 abc	2974.5 bc	3575 ab	3744 a	3878.5 a	3243.0 abc
50+50	3508.0 a	3212.8 a	3457 b	4119 a	3317.0 c	2812.5 abc
50+100	3437.9 a	**2927.4 bc**	3924 a	3937 a	3531.5 bc	3754.7 a
50+150	3327.0 ab	**2897.1 c**	3806 ab	4017 a	4013.9 a	3500.0 ab

B. Yields - 2014

Source	Ottawa, ON		Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid						
InVigor 5440	3485.4 a Ͳ		3456.5 b x	1538.3 a	2241.3 a	3299.2 a x
InVigor L150		2874.4 b	3700.5 a	1388.6 a	2051.6 a	3085.2 b
Nitrogen (kg ha^{-1})						
17.5	2855.5 c Ͳ	2902.6 c Ͳ	2730.1 d Ͳ	751.7 d Ͳ	1824.6 b	2669.9 d Ͳ
50	3424.0 b	**3548.1 a**	3361.9 c	1217.9 c	2103.0 ab	2961.1 c
100	3569.2 ab	3516.8 ab	3731.6 ab	1536.2 abc	2150.1 ab	3263.1 ab
150	3560.0 ab	3294.7 ab	3747.7 ab	1813.3 a	2056.9 ab	3300.0 ab
200	3507.5 b	3195.1 bc	3753.8 ab	1871.6 a	2240.0 ab	3405.1 ab
50+50	3366.2 b	***2727.7 c***	3564.8 bc	1783.7 ab	2323.6 a	3315.8 ab
50+100	3900.6 a	***2289.3 d***	3790.6 ab	1428.7 bc	2030.2 ab	3153.0 bc
50+150	3704.4 ab	***1520.7 e***	3946.4 a	1580.4 abc	2443.2 a	3469.5 a

C. Yields 2015

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	3324.1 b x	3984	4151.0	3071.7 a ∞	3203.2
InVigor L140	3495.3 a	4003	4119.1	2878.0 b	3554.2
Nitrogen (kg ha^{-1})					

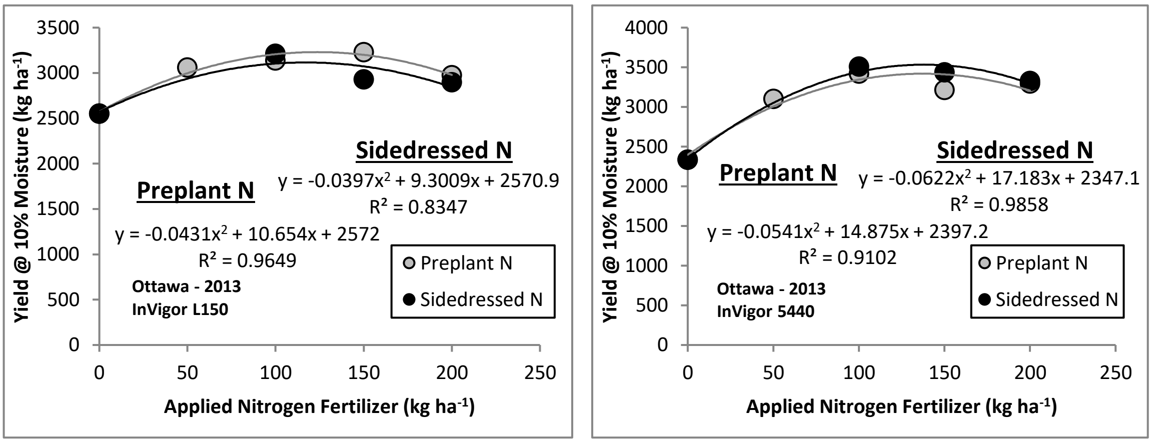
17.5	2254.5 e[T]	3263 [T]	3278.0 [x]	2163.8 d [T]	2505.1
50	2973.0 d	3645	3734.2	2748.6 c	3086.2
100	3535.4 bc	4066	4172.2	3007.5 abc	3338.1
150	3489.6 c	4291	4431.5	3050.4 abc	3592.1
200	3733.0 ab	4327	4751.4	3309.2 ab	3654.3
50+50	3632.8 bc	3994	4203.6	2979.3 bc	3445.0
50+100	3751.4 ab	4190	4173.9	3221.6 ab	3613.4
50+150	3908.0 a	4172	4599.9	3318.6 a	3795.4

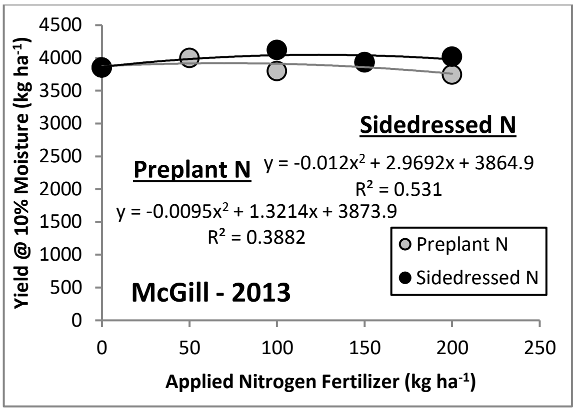
D. Yields 2016

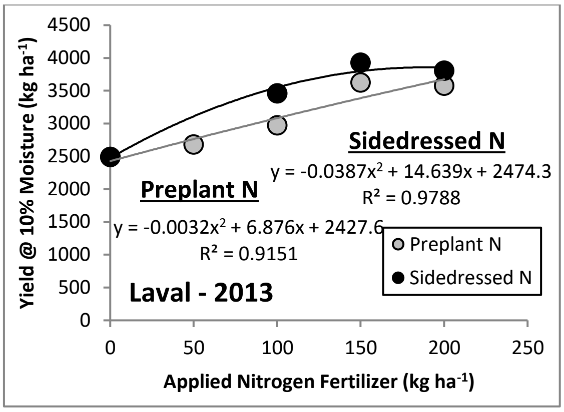
Source	**Ottawa, ON**	**Laval, QC**	**McGill, QC**	**Canning, NS**	**Elora, ON**
Hybrid					
InVigor 5440	2557 a	2666 b [T]	1298 b [x]	1835 a	2916 b [T]
InVigor L140	2523 a	2946 a	1506 a	1870 a	3607 a
Nitrogen (kg ha^{-1})					
17.5	1438 e [T]	1695 [T]	1202 b	886 d [T]	2740 d [T]
50	2271 d	2269	1441 ab	1411 c	3238 c
100	2529 c	2796	1295 ab	1906 b	3362 bc
150	2755 bc	3077	1444 ab	1917 b	3371 bc
200	2990 a	3168	1441 ab	2284 ab	3202 c
50+50	2585 c	2936	1406 ab	1905 b	3465 bc
50+100	2923 ab	3205	1377 ab	2070 ab	3616 ab
50+150	2826 ab	3303	1611 a	2450 a	3789 a

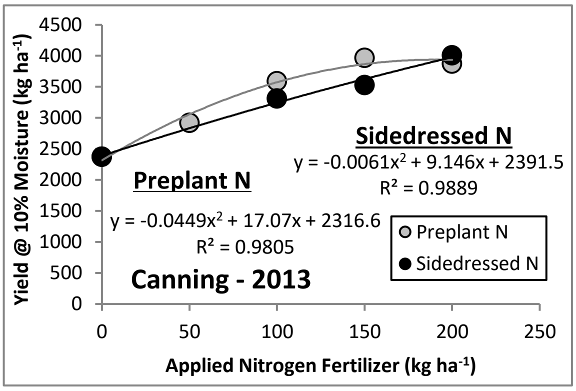
Figure 3 A, B, C & D. Regression analysis of grain yield as a function of the amount of nitrogen fertilizer added at preplant compared to the plots that received the same amount of nitrogen split between preplant and sidedressing at each site and year.

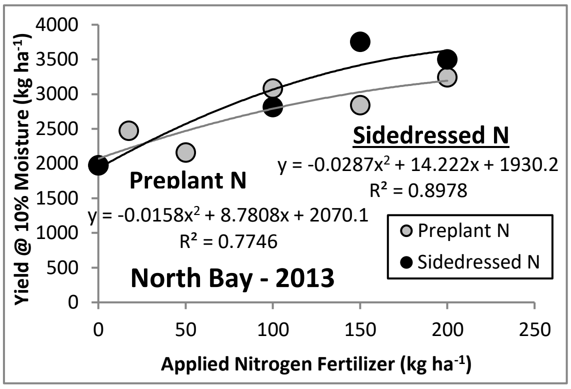
A. 2013



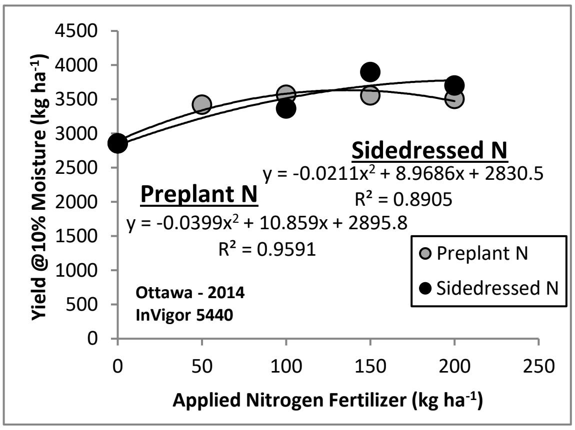

Sidedressed N
$y = -0.012x^2 + 2.9692x + 3864.9$
$R^2 = 0.531$
Preplant N
$y = -0.0095x^2 + 1.3214x + 3873.9$
$R^2 = 0.3882$
McGill - 2013
Preplant N
Sidedressed N
Yield @ 10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

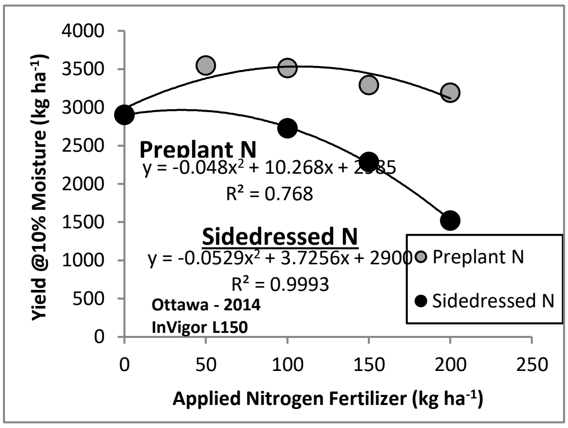

Sidedressed N
$y = -0.0387x^2 + 14.639x + 2474.3$
$R^2 = 0.9788$
Preplant N
$y = -0.0032x^2 + 6.876x + 2427.6$
$R^2 = 0.9151$
Laval - 2013
Preplant N
Sidedressed N
Yield @ 10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

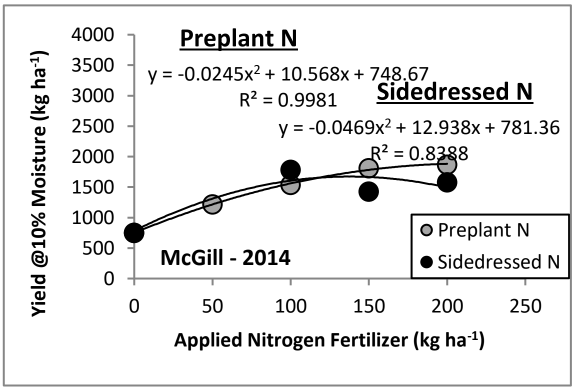

Sidedressed N
$y = -0.0061x^2 + 9.146x + 2391.5$
$R^2 = 0.9889$
Preplant N
$y = -0.0449x^2 + 17.07x + 2316.6$
$R^2 = 0.9805$
Canning - 2013
Preplant N
Sidedressed N
Yield @ 10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

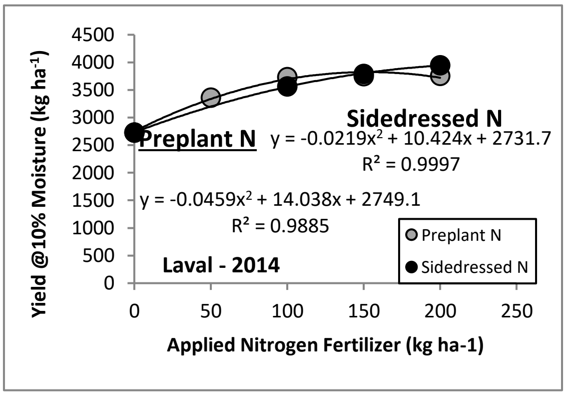

Sidedressed N
$y = -0.0287x^2 + 14.222x + 1930.2$
$R^2 = 0.8978$
Preplant N
$y = -0.0158x^2 + 8.7808x + 2070.1$
$R^2 = 0.7746$
North Bay - 2013
Preplant N
Sidedressed N
Yield @ 10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

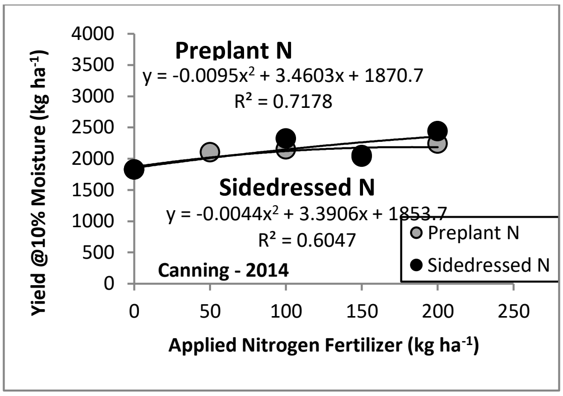
B. 2014

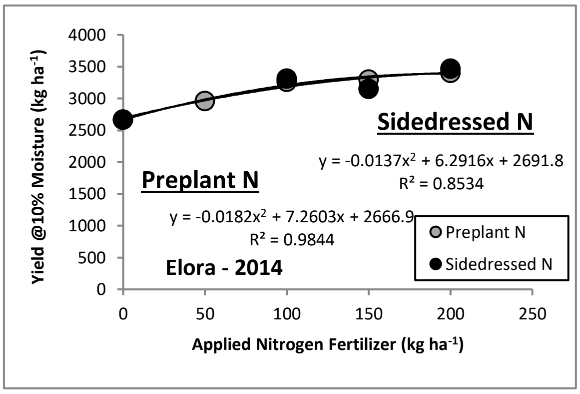

Sidedressed N
$y = -0.0211x^2 + 8.9686x + 2830.5$
$R^2 = 0.8905$
Preplant N
$y = -0.0399x^2 + 10.859x + 2895.8$
$R^2 = 0.9591$
Ottawa - 2014
InVigor 5440
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)


Preplant N
$R^2 = 0.768$
Sidedressed N
$R^2 = 0.9993$
Ottawa - 2014
InVigor L150
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

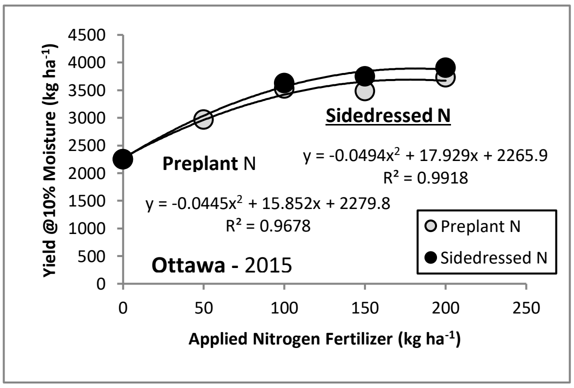

Preplant N
$y = -0.0245x^2 + 10.568x + 748.67$
$R^2 = 0.9981$
Sidedressed N
$y = -0.0469x^2 + 12.938x + 781.36$
McGill - 2014
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

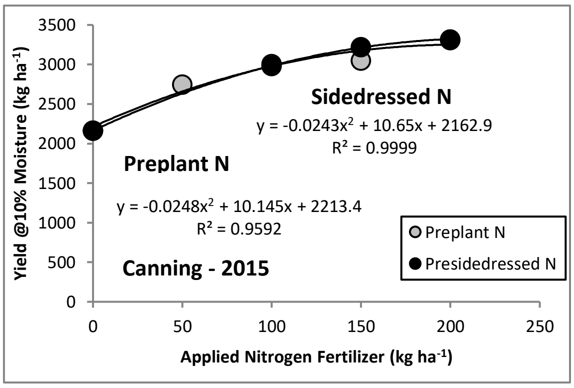

Sidedressed N
Preplant N
$y = -0.0219x^2 + 10.424x + 2731.7$
$R^2 = 0.9997$
$y = -0.0459x^2 + 14.038x + 2749.1$
$R^2 = 0.9885$
Laval - 2014
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

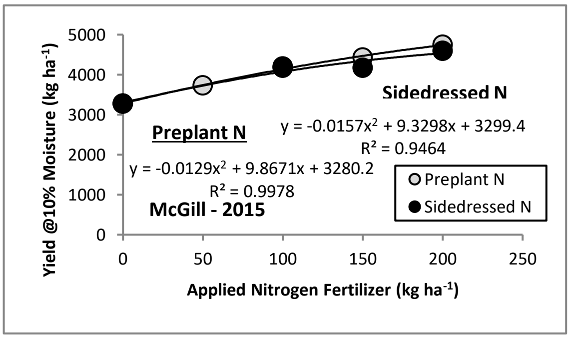

Preplant N
y = -0.0095x² + 3.4603x + 1870.7
R² = 0.7178
Sidedressed N
y = -0.0044x² + 3.3906x + 1853.7
R² = 0.6047
Canning - 2014
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

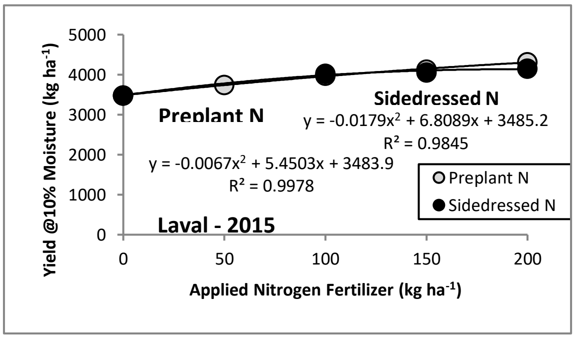

Sidedressed N
y = -0.0137x² + 6.2916x + 2691.8
R² = 0.8534
Preplant N
y = -0.0182x² + 7.2603x + 2666.9
R² = 0.9844
Elora - 2014
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

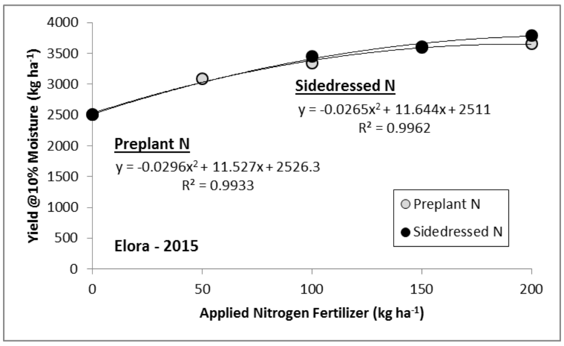
C. 2015


Sidedressed N
y = -0.0494x² + 17.929x + 2265.9
R² = 0.9918
Preplant N
y = -0.0445x² + 15.852x + 2279.8
R² = 0.9678
Ottawa - 2015
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

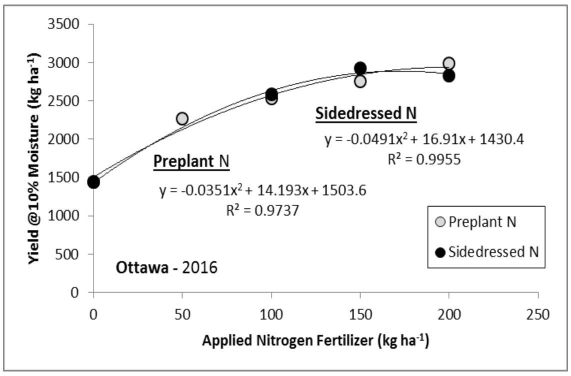

Sidedressed N
y = -0.0243x² + 10.65x + 2162.9
R² = 0.9999
Preplant N
y = -0.0248x² + 10.145x + 2213.4
R² = 0.9592
Canning - 2015
Preplant N
Presidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

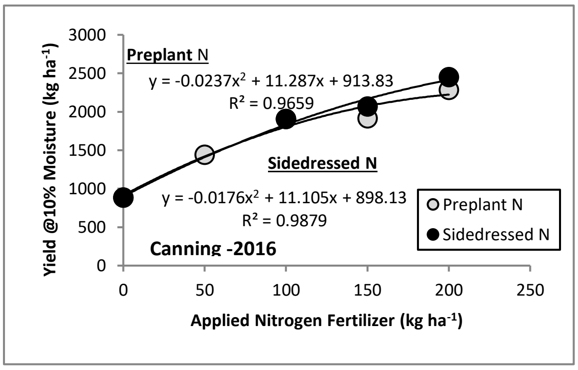

Sidedressed N
y = -0.0157x² + 9.3298x + 3299.4
R² = 0.9464
Preplant N
y = -0.0129x² + 9.8671x + 3280.2
R² = 0.9978
McGill - 2015
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

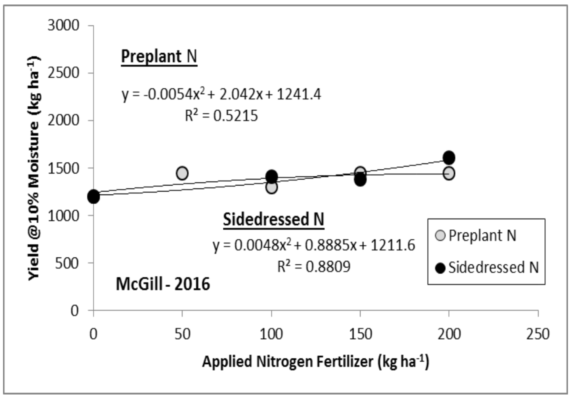

Preplant N
Sidedressed N
y = -0.0179x² + 6.8089x + 3485.2
R² = 0.9845
y = -0.0067x² + 5.4503x + 3483.9
R² = 0.9978
Laval - 2015
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

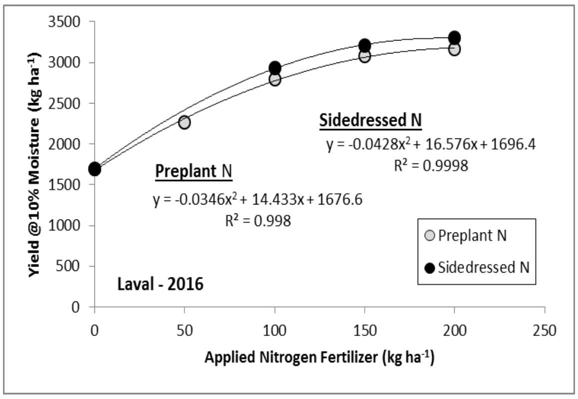

Sidedressed N
y = -0.0265x² + 11.644x + 2511
R² = 0.9962
Preplant N
y = -0.0296x² + 11.527x + 2526.3
R² = 0.9933
Elora - 2015
Preplant N
Sidedressed N
Yield @10% Moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

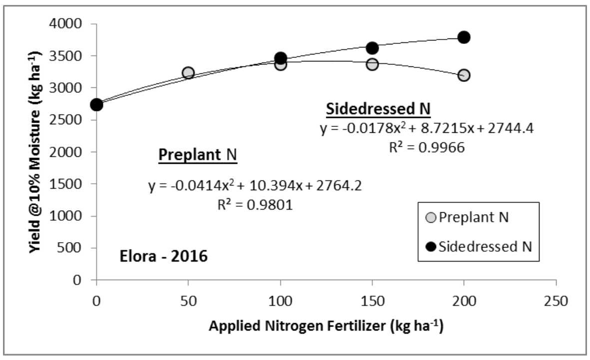
D. 2016


Sidedressed N
y = -0.0491x² + 16.91x + 1430.4
R² = 0.9955
Preplant N
y = -0.0351x² + 14.193x + 1503.6
R² = 0.9737
Preplant N
Sidedressed N
Ottawa - 2016
Yield @10% Moisture (kg ha⁻¹)
Applied Nitrogen Fertilizer (kg ha⁻¹)
0
500
1000
1500
2000
2500
3000
3500
0
50
100
150
200
250


Preplant N
y = -0.0237x² + 11.287x + 913.83
R² = 0.9659
Sidedressed N
y = -0.0176x² + 11.105x + 898.13
R² = 0.9879
Preplant N
Sidedressed N
Canning -2016
Yield @10% Moisture (kg ha⁻¹)
Applied Nitrogen Fertilizer (kg ha⁻¹)
0
500
1000
1500
2000
2500
3000
0
50
100
150
200
250


Preplant N
y = -0.0054x² + 2.042x + 1241.4
R² = 0.5215
Sidedressed N
y = 0.0048x² + 0.8885x + 1211.6
R² = 0.8809
Preplant N
Sidedressed N
McGill - 2016
Yield @10% Moisture (kg ha⁻¹)
Applied Nitrogen Fertilizer (kg ha⁻¹)
0
500
1000
1500
2000
2500
3000
0
50
100
150
200
250


Sidedressed N
y = -0.0428x² + 16.576x + 1696.4
R² = 0.9998
Preplant N
y = -0.0346x² + 14.433x + 1676.6
R² = 0.998
Preplant N
Sidedressed N
Laval - 2016
Yield @10% Moisture (kg ha⁻¹)
Applied Nitrogen Fertilizer (kg ha⁻¹)
0
500
1000
1500
2000
2500
3000
3500
0
50
100
150
200
250


Sidedressed N
y = -0.0178x² + 8.7215x + 2744.4
R² = 0.9966
Preplant N
y = -0.0414x² + 10.394x + 2764.2
R² = 0.9801
Preplant N
Sidedressed N
Elora - 2016
Yield @10% Moisture (kg ha⁻¹)
Applied Nitrogen Fertilizer (kg ha⁻¹)
0
500
1000
1500
2000
2500
3000
3500
4000
0
50
100
150
200
250

f) MERN Calculation

For the sites that showed a positive yield response to nitrogen fertilizer, regression analysis of grain yield as a function of nitrogen fertilizer for each site and nitrogen treatment method was performed to produce quadratic polynomial equations. The coefficients of that equation, along with the canola grain price per kg ($0.55) and fertilizer price per kg ($1) were used to determine the maximum economic rate of nitrogen (MERN) for each site and year (Table 13). McGill 2013, 2105 and 2016, Canning 2014, and Laval 2015 were not included in the MERN calculations because they did not show a significantly positive yield response to the addition of N application.

The estimated MERN values for the Laval 2013 and Canning 2013 sites are not included in the table because their yield responses to N were linear and at the highest tested N treatment yield did not reach a plateau (Table 13; Figure 3). The average MERN of fertilizer for Eastern Canada is estimated at 179 kg N ha^{-1} for preplant application and 198 kg N ha^{-1} for sidedress application. The yield increments at these N levels would be 11.9 kg ha^{-1} for preplant application and 12.5 kg ha^{-1} for sidedress application. It was noted that both MERN values and yield increments by each N application method varied largely among sites within a year and among years within a site. MERN values also varied between canola hybrid varieties. Apparently, environments (site-year) played a critical role in yield formation and the final achievable yield. For example, at Ottawa in 2013 and 2015, the estimated yield for sidedressed N application was higher than the estimated yield for preplant application, even though both applications have similar MERN values (in 2013: 133 (PP) & 133(PS); in 2015: 170 (PP) and 174 (PS)). North Bay in 2013 showed a similar trend. However at all the other sites, except McGill 2014 and Ottawa 2016, potential yields would also be higher for the sidedressed N application method, but with a higher MERN value than that of preplant application.

A location-sensitive N recommendation is therefore, critical to achieve profitable and environmentally sustainable canola production in eastern Canada.

Table 13. The calculated most economical rate of N (MERN) for preplant application (PP) and sidedress application (PS) for the site-years that showed a positive yield response to N.

Year	Site	N Method	r^2	MERN (kg N ha^{-1})	Estimated yield increment (kg / kg N)	Observed the highest yield (kg ha^{-1})	N rate (kg ha^{-1}) at the highest yield	Estimated yield at MERN (kg ha^{-1})
2013	**Ottawa (InVigor 5440)**	**PP**	.91	133	14.9	3420	100	3420
		PS	.99	133	17.2	3508	50+50	3534
2013	**Laval**	**PP**	.92	- †	6.8	3624	150	-
		PS	.98	184	14.6	3924	50+100	3884
2013	**Canning**	**PP**	.98	182	17.1	3970	150	3936
		PS	.99	- †	9.1	4014	50+150	-
2013	**North Bay**	**PP**	.77	257	8.7	3243	200	3290
		PS	.89	233	14.2	3755	50+100	3692
2014	**Elora**	**PP**	.98	189	7.3	3405	200	3391
		PS	.85	216	6.3	3470	50+150	3414

2014	**Ottawa (InVigor 5440)**	**PP**	.96	131	10.9	3569	100	3635
		PS	.89	202	9.0	3901	50+100	3784
2014	**Laval**	**PP**	.99	147	14.0	3753	200	3822
		PS	.99	225	10.4	3946	50+150	3972
2014	**McGill**	**PP**	.99	194	10.6	1872	200	1888
		PS	.84	128	13.0	1784	50+50	1674
2015	**Ottawa**	**PP**	.97	170	15.8	3733	200	3691
		PS	.99	174	17.9	3908	50+150	3893
2015	**Canning**	**PP**	.96	193	10.1	3309	200	3251
		PS	.999	206	10.6	3318	50+150	3330
2015	**Elora**	**PP**	.99	185	11.5	3654	200	3649
		PS	.99	208	11.6	3795	50+150	3790
2016	**Ottawa**	**PP**	.97	190	14.2	2990	200	2941
		PS	.99	163	16.9	2923	50+100	2887
2016	**Canning**	**PP**	.97	216	11.3	2284	200	2258
		PS	.99	282	11.1	2450	50+150	2650
2016	**Laval**	**PP**	.99	196	14.4	3168	200	3182
		PS	.99	183	16.6	3305	50+150	3301
2016	**Elora**	**PP**	.98	121	10.4	3371	150	3417
		PS	.99	231	8.7	3789	50+150	3813
Overall mean		**PP**	.96	179	11.9	3290		3269
		PS	.96	198	12.5	3453		3401

† non-estimable due to un-plateaued yield within the N treatment levels.

g) Plant Health Status

Canopy reflectance measurements determining plant greenness, were taken by both CropScan (in 2013 only) and Greenseeker several times during the growing season in the nitrogen fertility study at Ottawa, and with a similar spectrometer at Guelph. The data is normally expressed as the normalized difference vegetation index (NDVI) for indicating the crop N status.

CropScan and Greenseeker were not good at detecting differences between plant greenness before the GS16 stage, because the plants were too small and their canopies were not big enough to cover the bare ground (Figure 4). By the GS16-17 stage, CropScan and Greenseeker could detect that the plants in the 0 N plots were significantly less green than all the other plants ($p \leq .001$), but often there were no significant differences between plants of the other nitrogen treatments. By the time flower buds were starting to form (GS 50), only the NDVI readings of Greenseeker significantly increased with increasing amounts of preplant N added to the soil ($p \leq .001$). CropScan did not appear to be able to distinguish the plant greenness as well at the different N levels (Figure 4 B). The plants that received sidedressed nitrogen had similar NDVI readings as plants in the corresponding plots that received similar amounts of preplant N.

Figure 4 A, B, C, D & E. Canopy reflectance readings (NDVI) for both CropScan and Greenseeker taken before sidedressing and post sidedressing (GS 50 & 20% Flowering GS62) for all years at the Ottawa site only.

A. Ottawa 2013

	GreenSeeker 2013				
N (kg/ha)	**GS15**	**GS16**	**GS17**	**GS50**	**GS62**
17.5	.4653 a [x]	.6545 d [Ŧ]	.7186 c [Ŧ]	.6597 c [Ŧ]	.7198 d [Ŧ]
50	.4843 a	.7161 ab	.7781 a	.7534 ab	.7679 c
100	.4617 a	.7164 ab	.7794 a	.7639 a	.7743 bc
150	.4818 a	.6914 bc	.7763 a	.7575 ab	.7730 bc
200	.4122 b	.6646 cd	.7541 b	.7384 b	.7874 a
50+50	.4613 a	.7184 a	.7782 a	.7620 a	.7715 bc
50+100	.4937 a	.7216 a	.789 a	.7658 a	.7719 bc
50+150	.4676 a	.7130 ab	.7921 a	.7647 a	.7816 ab

B. Ottawa 2013 (CropScan)

	CropScan 2013			
N (kg/ha)	**GS16**	**GS17**	**GS50**	**GS62**
17.5	.6815 ab	.6380 c [∞]	.7483 b [Ŧ]	.8095 c
50	.7053 ab	.7120 ab	.7959 a	.8344 b
100	.7155 ab	.7184 ab	.8030 a	.8440 a
150	.7216 a	.7283 a	.8033 a	.8450 a
200	.6759 ab	.6725 bc	.8043 a	.8426 a
50+50	.6998 ab	.6912 ab	.7959 a	.8425 a
50+100	.6970 ab	.7212 ab	.8141 a	.8430 a
50+150	.6666 b	.6817 abc	.8093 a	.8418 a

C. Ottawa 2014

	GreenSeeker 2014				
N (kg/ha)	**GS14**	**GS15**	**GS17**	**GS52**	**GS62**
17.5	.6311 a [ns]	.6142 a	.7845 c [Ŧ]	.7497 e [Ŧ]	.7065 c [Ŧ]
50	.6174 ab	.6119 a	.8006 b	.7812 d	.7457 b
100	.6153 ab	.5950 a	.8090 a	.8001 abc	.7675 a
150	.6198 ab	.6030 a	.8092 a	.8045 ab	.7769 a
200	.5917 b	.5776 a	.8138 a	.8087 a	.7761 a
50+50	-	-	-	.7905 cd	.7643 a
50+100	-	-	-	.7912 cd	.7621 ab
50+150	-	-	-	.7940 bc	.7681 a

D. Ottawa 2015

	GreenSeeker 2015			
N (kg/ha)	**GS16**	**GS18**	**GS50**	**GS62**
17.5	.6460 c [Ŧ]	.7194 b [Ŧ]	.6539 c [Ŧ]	.6686 c [Ŧ]
50	.71513 b	.7763 a	.7388 b	.7354 b
100	.7371 ab	.7895 a	.7568 ab	.7610 ab
150	.7395 a	.7890 a	.7618 ab	.7591 ab
200	.7206 ab	.7886 a	.7718 a	.7773 a
50+50	-	-	-	.7396 b

50+100	-	-	-	.7376 b
50+150	-	-	-	.7525 ab

E. Ottawa 2016

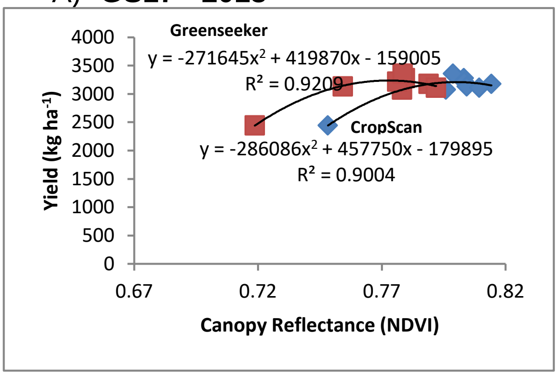
	GreenSeeker 2016						
N (kg/ha)	**June 8 (GS15)**	**June 10 (GS15)**	**June 13 (GS17)**	**June 16 (GS17)**	**June 20 (GS53)**	**June 23 (GS59**	**June 28 (GS62)**
17.5	.40 b ∞	.36 d Ŧ	.48 c Ŧ	.46 b Ŧ	.39 c Ŧ	.39 c Ŧ	.38 e Ŧ
50	.51 a	.47 bc	.60 ab	.63 a	.52 b	.53 b	.49 cd
100	.49 a	.45 c	.60 ab	.66 a	.53 b	.55 b	.51 bc
150	.55 a	.53 a	.65 ab	.69 a	.54 ab	.55 b	.53 b
200	.50 a	.52 ab	.66 a	.69 a	.59 a	.60 a	.56 a
50+50	-	-	-	-	.51 b	.51 b	.479 d
50+100	-	-	-	-	.52 b	.53 b	.49 cd
50+150	-	-	-	-	.52 b	.53 b	.48 cd

Greenseeker and CropScan measurements taken 1 week after sidedressing (7 leaf stage) and at 20% flowering (GS 62) were very strongly correlated to final plant yields (Figure 5 A, B & C).

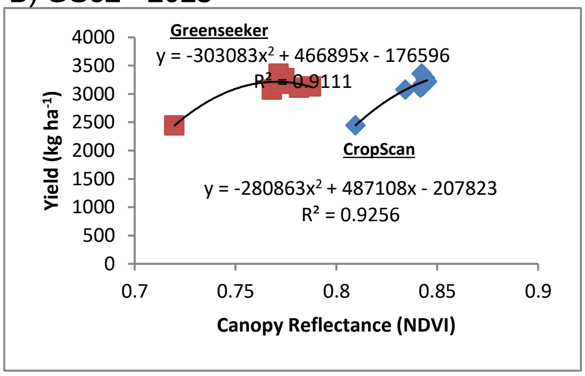
Greenseeker and CropScan NDVI measurements taken at 20% flowering also had a strong correlation (r^2 > 0.95) with soil nitrate levels measured after sidedressing (Figure 6).

Figure 5. The relationship between canopy reflectance (NDVI) and canola grain yield at nitrogen rates of 0, 50, 100, 150, 200, 50+50, 50+100 and 50+150 kg N ha^{-1} at the Ottawa site.

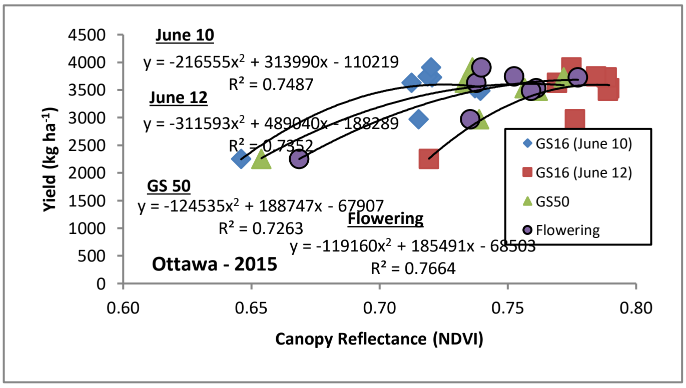
A) **GS17 - 2013**



B) **GS62 - 2013**



2015



2016

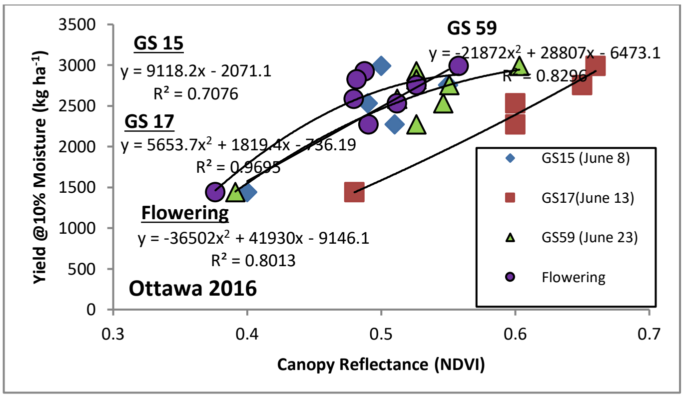


Figure 6. The relationship between canopy reflectance (NDVI) measured at 20% flowering and soil nitrate levels measured from plots that received preplant nitrogen rates of 0, 50, 100, 150, 200 kg ha^{-1} at the Ottawa site in 2013.

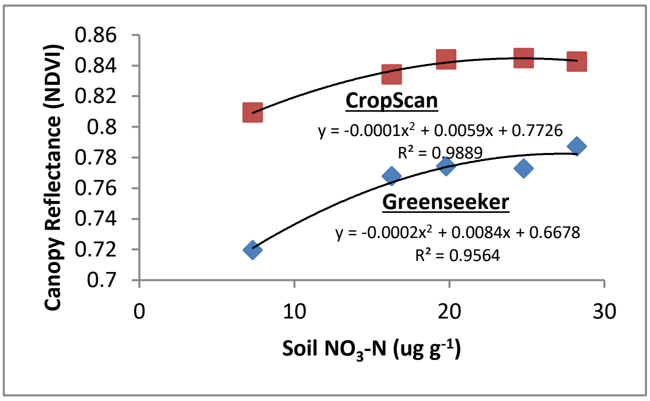


Table 14 shows that there is a very positive correlation between yield and NDVI readings by both the Greenseeker and the Cropscan units from the 7 leaf stage (June 17) to 20% flowering ($p \leq .001$).

Table 14. Pearson's correlation coefficients comparing CropsCan and Greenseeker NDVI with canola yields in the nitrogen fertility study in Ottawa in 2013.

Greenseeker					Crop Scan			
June 10	June 13	June 17 (GS 17)	June 20 (GS 50)	June 25 (GS 62)	June 12	June 14	June 18 (GS 17)	June 25 (GS 62)
-.016 .91	.233 .063	.325 .0086	.603 <.0001	.575 <.0001	.024 .85	.178 .16	.455 .0002	.671 <.0001

Leaf Chlorophyll Readings

Leaf chlorophyll readings from the SPAD-502 leaf chlorophyll metre were done in Ottawa and in Elora. Readings were taken from the rosette stage (GS16) every three days to 20% flowering. Before sidedressing, readings were done in the preplant N plots only, then after sidedressing in every plot. Values from the leaf chlorophyll meter (SPAD-502) were significantly affected by nitrogen as early as the 4 leaf stage (GS14) in 2014 and 2015 (Table 15). SPAD readings increased significantly with increasing nitrogen rates (in many cases $p \leq .001$). Laval (2015 & 2016) and McGill (2016) were the only sites that did not see any effect of nitrogen on SPAD readings at an early stage. In general, leaf chlorophyll metre readings were sensitive to N nutrition levels of the canola crop before sidedress. There is a strong correlation between SPAD readings (r^2 between .81 and .99) and applied N as early as the GS 16 (6 leaf stage) stage. With increasing N application rates, SPAD values increased linearly and often plateaued at the 100 kg N ha^{-1} preplant level, when measured at GS-16 stage (Figure 7A, B & C). This suggests that the chlorophyll metre could be used to monitor leaf N status and guide fertilizer N rates.

Table 15. SPAD readings taken presidedress as early as the 4 leaf stage, at all locations in 2014, 2015 and 2016. Means with different letters in the same column are significantly different at the .001 Ŧ, .01 x and .05 ∞ levels.

A. SPAD 2014

	Ottawa, ON			Elora, ON		Canning, NS	McGill, QC	Laval, QC
N (kg/ha)	GS14	GS15	GS16	June 23	June 27	GS30	GS16	GS16
17.5	37.3 b Ŧ	47.6 c Ŧ	48.6 c Ŧ	44.6 cŦ	39.7 c Ŧ	36.9 c Ŧ	45.8 b ∞	41.3 a
50	35.9 c	50.7 b	49.1 b	46.7 b	42.5 b	40.9 b	46.9 b	41.7 a
100	37.3 b	53.8 a	51.9 a	48.6 a	43.8 ab	43.4 a	50.2 a	41.2 a
150	38.5 a	53.4 a	52.1 a	48.2 a	43.0 b	41.3 ab	49.3 a	42.2 a
200	38.7 a	52.9 a	52.9 a	48.7 a	44.3 a	41.2 b	48.0 a	42.2 a

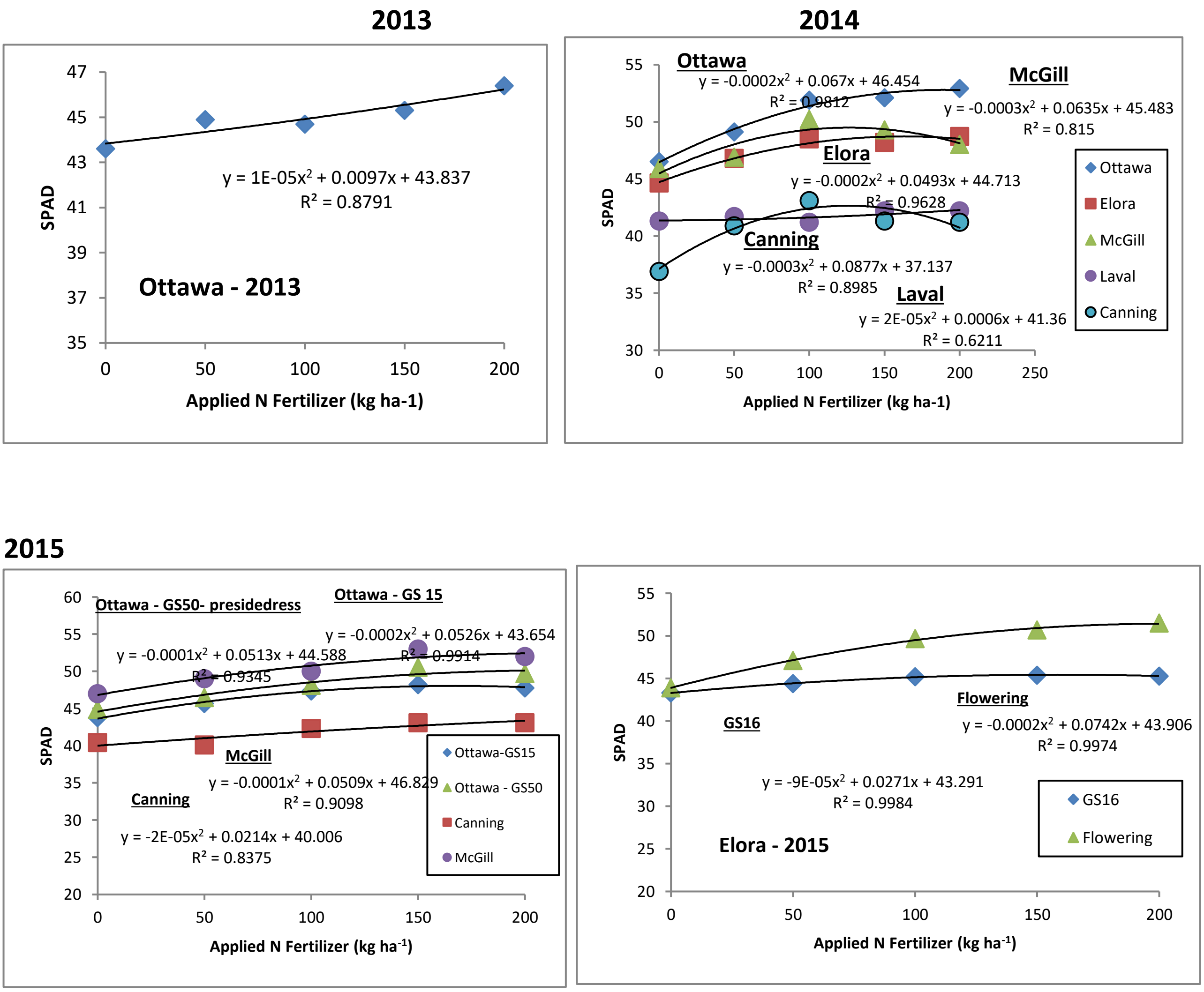
B. SPAD 2015

	Ottawa, ON			Elora, ON	Canning, NS	McGill, QC	Laval, QC
N (kg/ha)	GS14	GS16	GS50	GS16	GS16	GS16	GS16
17.5	43.7 c Ŧ	42.5 c x	44.9 d Ŧ	43.3	40.4 b x	47 b x	43.2
50	45.6 b	42.9 bc	46.5 cd	44.4	40.1 b	49 ab	43.6
100	47.4 a	43.7 abc	48.1 bc	45.2	42.3 a	50 ab	42.8
150	48.2 a	45.0 a	50.5 a	45.4	43.1 a	53 a	42.1
200	47.8 a	44.2 ab	49.7 ab	45.3	43.1 a	52 ab	43.7

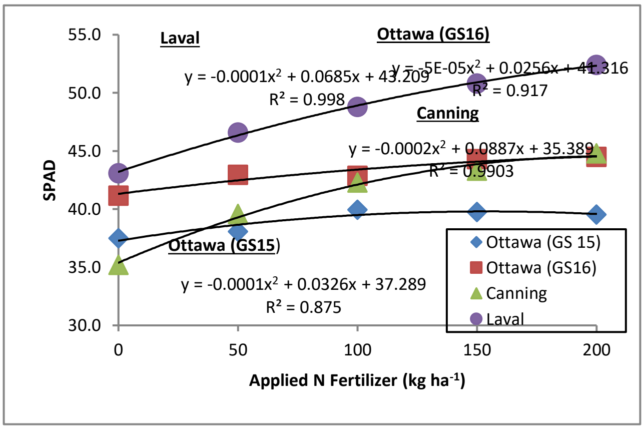
C. SPAD 2016

	Ottawa, ON				Elora, ON	Canning, NS	McGill, QC	Laval, QC
N (kg/ha)	GS15	GS16	GS17	GS18	GS16	GS16	GS16	GS16
17.5	37.5 b Ŧ	41.2 b ∞	45.0 c Ŧ	48.4 d Ŧ	36.4 a	35.2 d Ŧ	37.6 a	43.1 Ŧ
50	38.1 b	43.0 a	48.0 ab	52.2 c	36.1 a	39.6 c	37.9 a	46.6
100	40.1 a	42.9 a	47.6 b	54.7 b	37.4 a	42.3 b	38.0 a	48.8
150	39.8 a	44.3 a	49.0 a	55.4 ab	36.2 a	43.3 ab	38.3 a	50.8
200	39.5 a	44.5 a	48.4 ab	56.3 a	38.0 a	44.8 a	38.5 a	52.4

Figure 7. The relationship between leaf chlorophyll meter readings (SPAD-502) and preplant nitrogen rates of 0, 50, 100, 150, 200 kg N ha^{-1} at the GS15-16 stage (5-6 leaves) across different sites in Eastern Canada in 2013, 2014, 2015 and 2016.



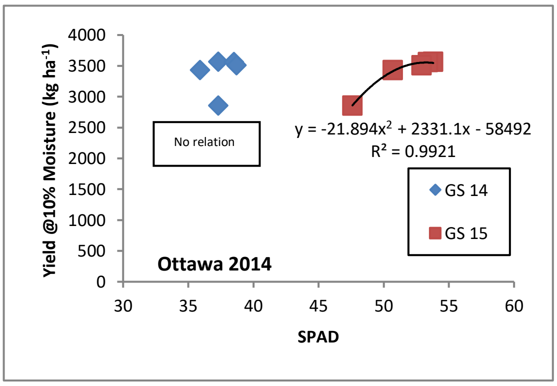
2016

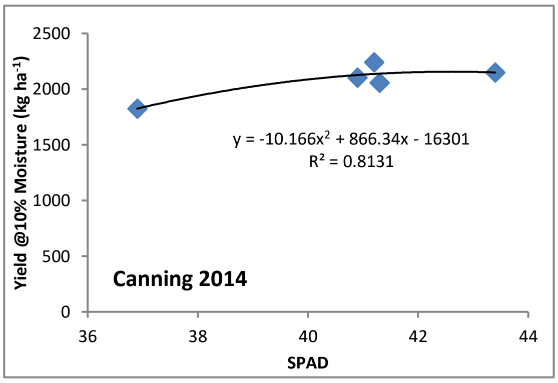


There was a very strong correlation between early SPAD readings at the GS16 stage and the final yields (Figure 8) as seen at Ottawa, Canning and Laval for different years.

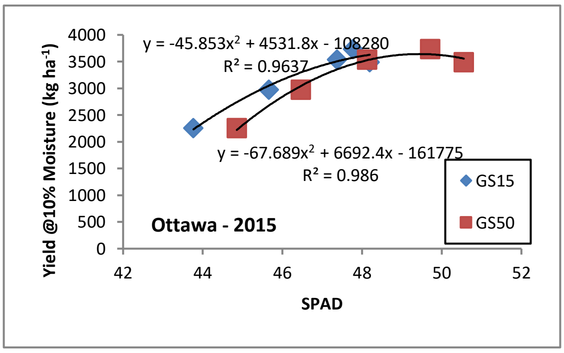
Figure 8. The relationship between leaf chlorophyll readings (SPAD) and final yields at the different sites in 2014, 2015 and 2016.

2014

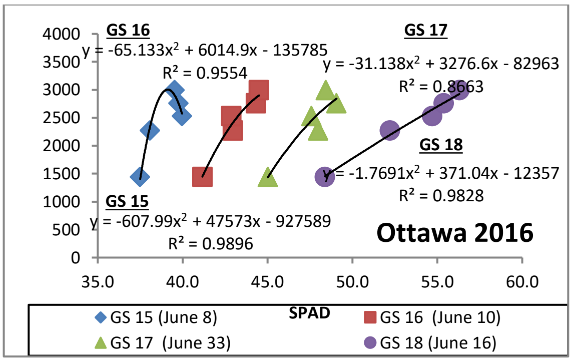


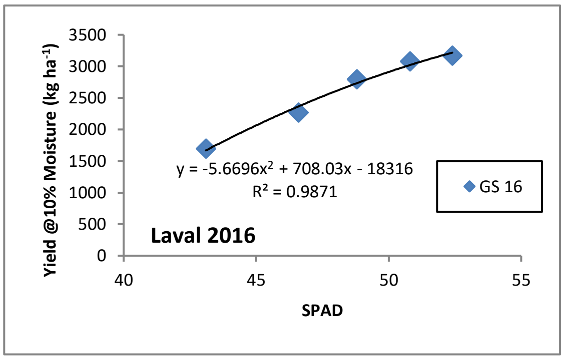


2015



2016





Now that it is known at what growth stage to take NDVI and SPAD measurements to distinguish one treatment from another, further work needs to be done to determine the saturation index (SI) of the NDVI in order to predict optimum grain yields and nitrogen rates. Using these optical sensors is a promising method to improve nitrogen use efficiency and reduce the amount of unused nitrogen polluting the environment.

Sulphur Fertility Study – Results

At all sites and years, the addition of sulphur had no significant effect on plant height, harvest index, number of branches, pods per plant and seeds/pod, except at Ottawa 2015 for which number of seeds per pod was significantly increased with increasing S application ($p \leq 0.001$). There was also no nitrogen by sulphur interaction on any of these traits.

At only three out of the 19 site years (Ottawa, McGill, and Canning in 2016) did sulphur show a positive effect on thousand seed weight (Table 16). The plots with no sulphur had significantly the lowest thousand seed weights of all the sulphur treatments. There was no Sulphur x nitrogen interaction on thousand seed weight.

Table 16. The effect of sulphur on thousand seed weight at three sites in 2016 (Ottawa, McGill and Canning). Means with different letters in the same column are significantly different at the .001 Ŧ, .01 x and .05 ∞ levels.

Sulphur (kg ha^{-1})	**Ottawa, ON**	**McGill, QC**	**Canning, NS**
0	3.1 b Ŧ	2.6 b ∞	3.2 b Ŧ
10	3.3 a	2.7 a	3.6 a
20	3.3 a	2.8 a	3.6 a
40	3.3 a	2.8 a	3.6 a

All sites and years showed a positive increase in yields with increasing amounts of sulphur added, many significantly so (Table 17 A, B, C & D).

Table 17 A, B, C, D. The effect of different levels of preplant sulphur in the form of ammonium sulphate on grain yields of InVigor L150 (L140P in 2015 and 2016) in 2013 (A), 2014 (B), 2015 (C) and

2016 (D). Means with different letters in the same column are significantly different at the .001 [Ŧ], .01 [x] and .05 [∞] levels.

A. 2013

Sulphur (kg ha^{-1})	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS
0	2452 b [x]	2930	1554 a	1827 b [∞]
10	2672 a	2891	1659 a	1921 b
20	2771 a	2755	1663 a	2007 ab
40	2852 a	3014	1719 a	2118 a

B. 2014

Sulphur (kg ha^{-1})	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
0	2483 b [x]	1564 d [x]	1077	2171	2567 ab[∞]
10	2939 a	1688 c	1307	2131	2444 b
20	3021 a	2008 a	1147	2203	2703 a
40	2867 a	1899 b	1174	2250	2601 a

C. 2015

Sulphur (kg ha^{-1})	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
0	3145 b [x]	2199 [x]	4210 b [x]	2704	2873.8
10	3056 b	2278	4199 b	2676	3022.2
20	3236 b	2410	4271 ab	2784	3207.9
40	3446 a	2552	4556 a	2991	3230.8

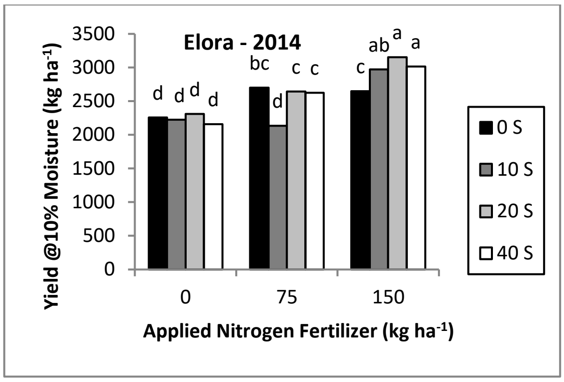
D. 2016

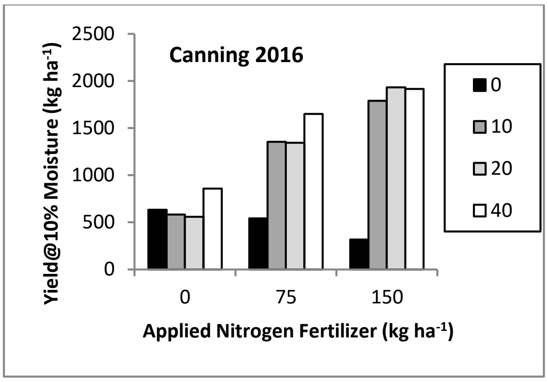
Sulphur (kg ha^{-1})	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
0	1749 b [Ŧ]	2619 a	673 c [Ŧ]	499 c [Ŧ]	3239 a
10	1855 b	2689 a	1195 b	1243 b	3339 a
20	2229 a	2674 a	1448 ab	1280 ab	3385 a
40	2303 a	2696 a	1542 a	1476 a	3276 a

In most cases, the sulphur x nitrogen interaction had no effect on yields except Elora 2014 and Canning 2016. At these sites there was a greater increase in seed yields ($p < 0.01$ & $< .001$ respectively) with increasing sulphur at N applied plots than the 0 N plots (Figure 9).

The addition of sulphur had no effect on lodging (data not shown).

Figure 9. Comparing grain yield responses to sulphur application at different nitrogen levels at the Elora 2014 and Canning 2016.





Sulphur had a significant effect on oil and protein for only two of the eleven site years where they were measured. In 2016 for Ottawa and Canning, increasing sulphur amounts significantly decreased oil concentration in Ottawa, but increased it in Canning and significantly increased protein levels at both sites (Table 18).

There was no effect of sulphur x nitrogen interaction on oil and protein concentrations for all the sites.

Boron Fertility Study – Results

For all years and all sites, the addition of preplant and foliar boron had no significant effect on yields, harvest index, number of branches and pods per plant or 1000-seed weight. There was also no effect of the addition of either preplant B or foliar B on seed oil and protein content.

During the study period, a microplate assay for quantification of B concentrations in soil and plant tissue samples has been developed. This method improved the quantification of B in soil and plant tissue samples. As the B microplate assay uses a smaller (40 times less) volume of chemical reagents per sample than conventional spectrometry and microplates permit the simultaneous analysis of samples, quality controls and standards, it is cost-effective and suitable for high throughput analysis in research and commercial laboratories that have not yet acquired an ICP system for multi-elemental analysis.

Effect of N, S and B on Nitrogen and Phosphorus Concentrations in Plant Material (Ottawa Site only in 2016)

Ground seed and plant tissue were analyzed in the lab for N and P concentrations (as a percentage in the sample). N concentration to P concentration ratio was calculated. Using the final biomass, total nitrogen and phosphorus (kg ha^{-1}) were also determined.

The application of boron both preplant and foliarly had no significant effect on seed or straw nitrogen and phosphorus concentrations (%) and no effect on total nitrogen or phosphorus (kg ha^{-1}) of straw or seed.

Sulphur had a very positive effect on seed N concentration (%) and the seed N:P ratio, but no effect on straw N concentrations (Table 19). Sulphur also had no effect on P concentrations of either seeds or straw (Table 19).

When calculating the total N and P using the dry weight of seed and straw material, the results showed that sulphur had a significantly positive effect ($p \leq 0.001$) on total N and P of the seed material, but no effect on the N and P of the straw material (Table 20).

Table 19. The effect of different levels of sulphur fertilizer on seed and straw nitrogen and phosphorus concentrations (%) and their N:P ratios at the Ottawa site in 2016. Means with different letters in the same column are significantly different at the .001 ₸, .01 ˣ and .05 ∞ levels.

	Seed			Straw		
P (kg ha^{-1})	**N (%)**	**P(%)**	**N:P**	**N (%)**	**P(%)**	**N:P**
0	3.66 b ₸	.86 a	4.27 c ˣ	.47 a	.086 a	5.86 a
10	3.74 b	.84 a	4.67 ab	.45 a	.073 a	6.39 a
20	3.77 b	.86 a	4.37 bc	.47 a	.079 a	6.22 a
40	3.90 a	.86 a	4.58 a	.49 a	.079 a	6.34 a

Table 20. The effect of different levels of sulphur fertilizer on seed, straw and plant total dry matter, nitrogen and phosphorus (kg ha^{-1}) at the Ottawa site in 2016. Means with different letters in the same column are significantly different at the .001 ₸, .01 ˣ and .05 ∞ levels.

	Seed			Straw			Plant	
P (kg ha^{-1})	**Dry Matter (kg ha^{-1})**	**Total N (kg ha^{-1})**	**Total P (kg ha^{-1})**	**Dry Matter (kg ha^{-1})**	**Total N (kg ha^{-1})**	**Total P (kg ha^{-1})**	**Total N (kg ha^{-1})**	**Total P (kg ha^{-1})**
0	1574	58.4 b ₸	13.5 b ₸	2724 a	14.1 a	2.6 a	72.5 b ₸	16.1 b ˣ
10	1669	64.4 b	14.0 b	2760 a	12.42 a	2.0 a	76.8 b	16.0 b
20	2006	76.7 a	17.3 a	2797 a	13.4 a	2.2 a	90.1 a	19.5 a
40	2073	82.6 a	17.8 a	2828 a	14.6 a	2.3 a	97.3 a	20.1 a

Increasing rates of nitrogen significantly increased the N and P concentrations (%), the N:P ratio and the total N and P of the plant biomass ($p \leq 0.001$) both at the GS7 stage and at flowering stage (Table 21A & B). The N and P concentrations decreased from the GS7 stage to flowering, as did the N:P ratio. However total N and P of the plant biomass increased with time.

Table 21 A & B. The effect of different levels of nitrogen fertilizer on plant N and P concentrations, N:P ratio and total N and P (kg ha^{-1}) at the Ottawa site in 2016 on June 15 (A) and at flowering on June 29 (B). Means with different letters in the same column are significantly different at the .001 ₸, .01 ˣ and .05 ∞ levels.

A.

	June 15 (GS7; before sidedressing of N)

N (kg ha^{-1})	N (%)	P(%)	N:P	Total N (kg ha^{-1})	Total P (kg ha^{-1})
17.5	3.0 d ^{T}	0.37 c ^{T}	8.2 e ^{T}	20.6 e ^{T}	2.4 d ^{T}
50	3.8 c	0.38 bc	10.2 cd	39.7 d	3.9 cd
100	4.6 b	0.40 b	11.5 ab	49.4 bcd	4.4 bc
150	4.8 ab	0.42 a	11.3 abc	60.9 ab	5.4 ab
200	5.2 a	0.44 a	11.8 a	73.1 a	6.2 a
50+50	-	-	-	-	-
50+100	-	-	-	-	-
50+150	-	-	-	-	-

B.

	June 29 (Flowering)				
N (kg ha^{-1})	**N (%)**	**P (%)**	**N:P**	**Total N (kg ha^{-1})**	**Total P (kg ha^{-1})**
17.5	1.9 d ^{T}	0.32 b $^{\infty}$	6.0 e ^{T}	44.6 e ^{T}	7.5 c $^{\infty}$
50	2.8 c	0.37 a	7.6 d	68.7 d	9.0 bc
100	2.9 c	0.34 ab	8.4 cd	80.2 cd	9.6 bc
150	3.4 a	0.37 a	9.5 a	104.8 ab	11.2 ab
200	3.4 a	0.37 a	9.3 ab	111.5 a	12.1 a
50+50	2.9 bc	0.36 ab	8.2 cd	83.5 cd	10.2 ab
50+100	3.2 abc	0.37 a	8.6 bc	83.4 cd	9.9 ab
50+150	3.3 ab	0.37 a	8.8 abc	89.2 bc	10.7 ab

At harvest, The seed material had a much higher concentration of N and P than the straw material (Table 22). The increasing rates of N fertilizer still had a significantly positive effect on the N concentration (%) and N:P ratio of both seeds and straw material (Table 22). The 0 N plots had the lowest N concentrations and the sidedressed plots that received a total of 200 kg N ha^{-1} had the highest N concentrations in both the seed and straw. This is the same for the N:P ratio. At this stage, N fertilizer no longer had a positive effect on the P concentration of both the seed and straw (Table 22). However the total N and P of the seed and straw biomass increased significantly with increasing N rates.

Table 22. The effect of nitrogen fertilizer on seed and straw N and P concentrations (%), and total N and P (kg ha^{-1}) of samples taken at harvest in Ottawa in 2016. Means with different letters in the same column are significantly different at the .001 ^{T}, .01 ^{x} and .05 $^{\infty}$ levels.

	Seed					**Straw**				
N (kg ha^{-1})	**N (%)**	**P (%)**	**N:P**	**Total N (kg ha^{-1})**	**Total P (kg ha^{-1})**	**N (%)**	**P(%)**	**N:P**	**Total N (kg ha^{-1})**	**Total P (kg ha^{-1})**

17.5	3.1 f Ŧ	.79 ab ∞	4.0 f Ŧ	40.6 eŦ	10.3 d Ŧ	.39 dŦ	.064 a	6.5 f Ŧ	9.1 c Ŧ	1.5 b ∞
50	3.6 e	.82 a	4.5 e	74.2 d	16.7 c	.45 cd	.071 a	7.1 ef	13.3 bc	2.2 ab
100	3.9 d	.77 bc	5.1 d	88.7 c	17.5 bc	.48 cd	.065 a	8.3 de	14.5 b	2.0 ab
150	4.3 bc	.78 bc	5.6 bc	106.1 b	19.3 ab	.61 b	.067 a	10.1 bc	19.7 a	2.2 ab
200	4.2 bc	.74 c	5.8 ab	113.9 ab	19.9 a	.69 ab	.071 a	10.9 ab	24.2 a	2.6 a
50+50	4.1 cd	.77 bc	5.4 cd	94.9 c	17.8 bc	.51 c	.063 a	8.9 cd	14.5 b	1.8 ab
50+100	4.4 ab	.77 bc	5.7 ab	114.5 a	20.3 a	.65 ab	.075 a	9.2 cd	21.9 a	2.5 a
50+150	4.6 a	.77 bc	6.0 a	116.0 a	19.4 ab	.72 a	.066 a	11.8 a	23.1 a	2.2 a

Post-flowering uptake of both N and P is calculated by subtracting the plant total N or P at flowering from the plant total N or P at harvest. Translocation, on the other hand, is the plant total N at flowering minus the total N of the plant straw material at harvest.

Results showed that plant uptake of both N and P was positively correlated ($p \leq 0.001$) with the increasing amounts of N fertilizer (Table 23). The plants in the sidedressed plots of 50+100 and 50+150 kg N ha^{-1} took up significantly more N and P than those in plots received the same amount of N but only applied at preplant, indicating sidedress N application improved post-flowering N uptake to meet the demand for seed filling; a healthy plants need a balanced uptake of nutrients other than N. therefore post-flowering uptake of P was also enhanced.

The translocation of N and P from the flowering stage to harvest increased significantly with increasing fertilizer N amounts (Table 23). The plants that received 200 kg N ha^{-1} preplant, had the highest translocation of N and P. The significantly higher translocation of plant N and P from vegetative tissues for the preplant N than for sidedress N application suggests that under favourable environment conditions, N required for achieving potential yield may have been restricted with the preplant N treatment, resulting in lower seed yield and lower agronomic nitrogen use efficiency, compared to those of sidedress N application.

Table 23. The effect of nitrogen fertilizer at harvest on post-flowering uptake of N and P, and the translocation of N and P from the vegetative tissue during seed filling period at the Ottawa site in 2016. Means with different letters in the same column are significantly different at the .001 Ŧ, .01 x and .05 ∞ levels.

	Post-Flower Uptake		**Translocation**	
N (kg ha^{-1})	**N (kg ha^{-1})**	**P (kg ha^{-1})**	**N (kg ha^{-1})**	**P (kg ha^{-1})**
17.5	7.1 c Ŧ	4.6 c Ŧ	35.1 d Ŧ	6.1 c ∞
50	22.7 b	10.4 ab	55.1 c	6.8 bc
100	23.7 b	9.9 b	65.5 c	7.7 bc
150	23.7 b	10.9 ab	84.2 ab	8.9 ab
200	25.4 b	9.8 b	89.8 a	10.1 a
50+50	28.6 b	9.6 b	68.8 bc	8.6 ab
50+100	54.9 a	12.9 a	62.2 c	7.6 bc

50+150	54.7 a	11.7 ab	65.9 c	8.0 abc

Results of the Cover Crop Study in Quebec

The objectives of this study were to measure the impact of a clover CC and two different types of fertilizer on the N uptake and yields of a canola crop in the cool and humid climate of the province of Quebec. Clover yield varied from 718 to 5455 kg DM ha^{-1} between sites and years, leading to significant differences in N accumulated in the cover crop biomass which ranged from 28.3 to 150.5 kg N ha^{-1}. Although growing a clover intercrop did not have a significant impact on canola N uptake, it did have an impact on its yield. For each of the four trials of this experiment, the cover crop led to the greatest increase in canola yield when it was not fertilized, with increases of 6 to 42 %, and this positive response to clover decreased with increasing N rates, indicating that the contribution of clover to canola yields was mainly through nitrogen-related effects. Canola response to cover crop appeared to be greater when the contribution of N from the soil was low, as was the case in SA on a sandy loam compared to a silty clay in NO. The clover fertilizer replacement value ranged from 21.8 to 81.8 kg N ha^{-1}. There was no interaction between the CC and the type of supplemental nitrogen used for canola fertilization on canola N uptake or yields. However, N uptakes and yields of canola were lower when fertilized with pig slurry, which was less efficient than expected. In light of these results, it appears that an increase in yield and a reduction in the use of nitrogen fertilizers in canola could be achieved by implanting a clover intercropping in barley as a CC, particularly in lighter soils. The use of an organic fertilizer in canola such as pig manure is an interesting avenue to reduce the costs of mineral fertilizers but requires good management to avoid losses of nitrogen.

4. Issues

- Describe any challenges or concerns faced during the project. How were they overcome or how do you plan to overcome?
- Describe any potential changes to the work plan and the budget. How were or how will they be managed?

During the 2016 growing season, all activities have been undertaken and the project is in progress according to the plan, except at the Guelph site, where there was a mistake made when soil samples taken at pre-sidedress were tested for total N, instead of NO_3-N in the hybrid x N experiment. This was a big error and cost the program thousands of dollars, in addition to the effect of course of not having those important data. There is unfortunately no way to recover from this error because the samples were not retained. Other than that all three experiments went very well in this and other sites.

The canola crop has suffered from an extended period of drought that occurred shortly after the rosette stage to mid grain filling period, especially in eastern Ontario and southern Quebec. As a result, canola crop did not respond to sidedressed N fertilizer in some of the sites.

This change did not affect the overall project objectives and the budget.

5. Lessons Learned:

Describe the key lessons learned gained as a result of executing the project (e.g., a more efficient approach to performing a specific task for activity / project).

Reduction of budget has led no funds for chemical analysis of S and B concentrations of plant samples, which has limited to the comprehensive understanding of plant nutrients cycling in the soil-crop-atmosphere agroecosystem.

6. Future Related Opportunities:

Describe the next steps for the innovation items produced by the activity/project. Is additional research required? Is there potential for commercialization or adoption?

Systems approach should be used to develop best management agronomic practices in the preparation of new projects. We are working with scientists from west Canada to develop a project tentatively titled “Improving nitrogen use efficiency and canola production profitability while sustaining the environment through efficient nitrogen acquisition and robust root architecture system”. In this work, we plan to develop a site-specific N fertilizer application technology, targeting concurrent improvements in nitrogen use efficiency (NUE), yield, profitability and environment sustainability; and identifying traits for improved root system and lodging resistance for future canola variety improvement. If our project is funded through canola cluster led by the Canola Council of Canada with the support from ECODA, we will be able to develop site-specific nutrient best management practices with consideration of agronomic indicator (yield, nitrogen use efficiency), economic indicator (output/input, profitability), and environmental indicator (N balance, greenhouse gas emission and NO_3 leaching). Investigation of newer canola hybrid varieties to the timing and N rates on different soil types and in different preceding crops (e.g. following a cereal vs. following a legume or forage crop) is of critical importance in the development of knowledge and technologies for implementing best nutrient management practices, especially in eastern Canada.

Annex A

Innovation Items	
Performance Measures	**Description**
# of Intellectual property items flowing from the project	These include: declaration of invention, patent application, patents, trademarks, copyrights, trade secrets, signed license agreements, and royalties generated. This does not include IP for plant varieties; those should be reported under "# of new varieties" below.
# of new/improved products	New products could include: a new commercial product, bacterial strain, cartographic product, cell culture, analysis certificate, computer software, database, enzyme, equipment/instrument, fertilizer, hormone, methodology, model, monoclonal antibody, pest control product, polyclonal antibody, standard reference-chemical, standard reference-biological, standard reference-plant, etc.
# of new/improved processes or systems	This is the set of operations performed by equipment in which variables are monitored or controlled to produce an output. A combination of inter-related components or processes is arranged to perform a specific function and generate a given outcome.
# of new/improved practices	This is for a research that generated new knowledge that can be applied directly on the ground by the sector. This is mostly for new agronomic practices but can also cover new practices by processors.
# of new varieties	This includes registered varieties, cultivars, or breeds. This includes invention disclosure, protection and license for new plant varieties. For each new variety, please provide the registration number and the variety name.
# of new/improved genetic materials	This could include genetic map and gene probes. Include new varieties, cultivars or breeds in category "New varieties."
# of new/ improved gene sequences	The discovery of order of bases of a DNA [segment] making up a gene.
# of improved knowledge	This category is for reporting results following completion of the final year of the activity, or results against an activity's improved knowledge target. It is intended for results that do not fit in any of the above categories.
Information Items	
Performance Measures	**Description**
# of peer reviewed publications	These are published items such as: research papers published in scientific journals, books, book chapters, review articles, conference proceedings, research notes, or other that receive peer-review. Items that are not yet published (ex. manuscripts in development or review) should not be reported. For each reported item, please provide the following: author(s), year of publication, article title, title of journal, volume (issue), and page number(s). If the item is a book or a book chapter, add name of publisher. If the item is an article for conference proceedings, add title of published proceedings, location, and year/month/day.
# of information items	Information items include: posters, abstracts, pieces in publications such as trade journals, articles in industry magazines or press, industrial reports (confidential or not), technical bulletins, brochures, guides, flyers, newsletters, other technical transfer publications. If an item is published in a medium whose audience is the general public, it should be reported in the # of media reports category below. For each reported item, please provide the following: author(s), article title, title of magazine/trade publication etc., page number(s), type of information item such as poster or abstract or guide etc., and year/month/day.

# of media reports	Examples include articles or interviews about project results in media such as newspaper, tv, radio, and internet (announcements about project funding are excluded). (These are items prepared by a third party, usually with input by the project). If an item is published in an industry journal, newspaper, or magazine, it should be reported in the # of information items category above. For each reported item, please provide the following: author(s), article title, name of interviewee(s), source of reports (TV or radio interview etc.), and year/month/day.
# of information events	These are events such as a scientific meeting, symposium, conference, industry meeting, or field day where a project participant has been invited to present a talk or presentation directly related to the activity. For each reported item, please provide the following: name of presenter, title of presentation, name of the event, location, and year/month/day.
# of individuals attending information events	Please provide the number of attendees per event.
# of individuals attending information event who intend to adopt new innovation	Please provide the number of attendees intending to adopt the new innovation per event.
# of persons who completed a MSc or PhD during project	Only students who completed their MSc or PhD in the last year should be included in this category. For each reported graduate, please provide the following: the name of the student, degree completed and date of completion.