Activity 14
Canola Nutrient Management
Annual Report – March 31, 2016

Overall Objective

The three main objectives of this activity are:

1. Identifying nutrient deficiency 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. Determining a threshold level of micronutrient B deficiency and nutrient balance for canola production; and
3. Developing improved guidelines for canola site-specific nutrient management.

It is anticipated that through the achievement of these objectives, crop need-based N indicators for canola will be developed. Crops grown in an on-farm scale field often encounter multiple abiotic and biotic stresses. Mapping field crop with advanced remote sensing instruments will be able to identify different stresses in action and weighted plant spectral indices may be developed to quantify the dominant stress factors. A new algorithm could then be developed to prescribe the right amount of nutrients required by the crop so that site-specific best nutrient management practices will be developed.

Audience

The audience is crop producers, specifically those who grow or who have an interest in growing canola.

Performance Measures

Peer Reviewed Publications

During this period, seven peer-reviewed publications were developed:

1. Vaillancourt, M., A. Vanasse, M. Chantigny, D. Pageau et D. Angers. 2015. Impact of cover crops and organic and mineral fertilization on canola yields and nitrogen uptake. Soils interfaces for sustainable development. Joint meeting of CSSS, AQSSS and ISMOM. Montréal, Qc. 5-10 juillet 2015.
2. Shang, J., J. Liu, B.L. Ma, T. Zhao, X. Jiao, X. Geng, T. Huffman J. Kovacs, D. Walters. 2015. Mapping spatial variability of crop growth using RapidEye data in northern Ontario, Canada. Remote Sensing of Environment 168:113-125.
3. Wu, W., and B.L. Ma. 2015. Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. Science of the Total Environment 512:415-427.
4. Ma, B.L., and A.W. Herath. 2016. Nitrogen fertilizer application timing and rates on canola seed quality and nitrogen use efficiency. Crop Pasture Sci. 67:167-180.
5. Ma, B.L., D.K. Biswas, A.W. Herath, J.K. Whalen, S.Q. Ruan, C. Caldwell, H. Earl, A. Vanasse, P. Scott, and D.L. Smith. 2015. Growth, yield and yield components of canola as affected by nitrogen, sulphur and boron fertilization. J. Plant Nutr. Soil Sci. 178:658-670.

6. Qi, J., 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.
7. 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. (*in press*).

Information Events

Thirteen events were attended in which presentations were given on the results of this activity:

1. Vaillancourt, M. A. Vanasse, M. Chantigny, D. Pageau et D. Angers. 2015. Effets des engrais verts et de la fertilisation minérale et organique sur le prélèvement de l'azote et le rendement du canola. Colloque de la Faculté d'agriculture et de l'alimentation. Université Laval. Québec, Qc. 20 mai 2015. Gagnant du 2ème prix pour la présentation orale. (150 attendees)
2. Vaillancourt, M. A. Vanasse, M. Chantigny, D. Pageau et D. Angers. 2015. Impact of cover crops and organic and mineral fertilization on canola yields and nitrogen uptake. Soils interfaces for sustainable development. Joint meeting of CSSS, AQSSS and ISMOM. Montréal, Qc. 5-10 juillet 2015. Gagnant de la bourse AQSSS et du 2ème prix pour la présentation orale. (250 attendants)
3. Vaillancourt, M., D. Pageau, M. Chantigny et A. Vanasse. 2016. Engrais verts: impact du trèfle sur les rendements et la fertilisation azotée du canola. Journée grandes cultures. St-Bruno, Qc. 8 mars 2015. (70 attendants)
4. Vaillancourt, M. 2016. Effets d'un engrais vert de trèfle et d'une fertilisation minérale ou organique sur le rendement et la prise d'azote et du canola. Ma thèse en 180 secondes. Concours de la Faculté d'agriculture et de l'alimentation. Université Laval. Québec, Qc, 11 mars 2016. Gagnant du 2ème prix pour la présentation orale. (40 attendants)
5. Vaillancourt, M. 2016. Effets d'un engrais vert de trèfle et d'une fertilisation minérale ou organique sur le rendement et la prise d'azote et du canola. Colloque annuel de l'Institut Hydro-Québec en environnement, développement et société. Université Laval. Québec, Qc. 23-24 mars 2106. Gagnant du prix du grans public au Concours VIE (Vulgariser, Inspirer, Éduquer). (100 attendants)
6. Ma, B.L. 2015. Improving tolerance of crop plants to abiotic stresses for efficient crop production and sustaining the environment. Invited oral presentation at the 1st Qinghai-Tibetan Forum: Grassland Management and Ecological Safety. Institute of Qinghai-Tibetan Plateau, Southwest University for Nationalities. Chengdu, Sichuan, Aug. 21-22. (150 attendants)
7. Ma, B.L. 2015. Sensing root electrical capacitance for delineating canola genotypic differences in response to heat and drought stresses. Oral presentation at the 8th Annual International Symposium on Agriculture, Athens, Greece, 13-16 July. (450 attendants)
8. Makhani, M.M., J. K. Whalen, and B.L. Ma. 2015. In situ quantification of canola root biomass in relation to canola growth and tolerance to climate stress in Québec. Poster presentation at the Soil Interfaces for Sustainable Development - ISMOM 2015 conference Joint meeting: Commission 2.5 of the International Union of Soil Science and Canadian Society of Soil Science. Montréal, Québec, Canada. July 5-10. (150 attendants)
9. Ma, B.L., W. Wu, S. Yao, D. Biswas. 2015. Developing a non-destructive method for assessing canola genotypic differences in tolerance to heat and drought stresses. Oral presentation at the

14th International Rapeseed Congress, Saskatoon, Saskatchewan, Canada, July 5-9. (150 attendants)

10. Herath, A.W., and B.L. Ma. 2015. Impact of rate and timing of nitrogen application on seed yield, quality and nitrogen economy of canola in Eastern Canada. Poster presentation at the Western Society of Crop Science Annual Meeting. Logan, UT, June 16-17. (120 attendants)
11. Ma, B.L. 2015. Developing precision nutrient management strategies for improving crop production efficiency and sustaining the environment. Oral presentation at the ECORC/ACGEO Science Day – Agri-Environmental Science. K.W. Neatby Bldg., Ottawa, ON. February 10-11. (40 attendants).
12. Ma, B.L. 2016. Coping with soil salinity and crop nutrient balance. Invited oral presentation at the Third Science Workshop of the AAFC-Yangzhou University Joint Laboratory in Agricultural Sciences, Lecture Hall, Yangzhou University, Yangzhou, China. March 24 as part of the AAFC Genetics and Genomics Mission to China led by Dr. Denis Petitclerc, Director General, Ontario and Quebec Region. March 21-31, 2016. (110 attendants)
13. Ma, B.L. 2016. Improving Tolerance of crop plants to abiotic stresses for efficient crop production and sustaining the environment. Invited oral presentation at the International Academic Exchange Center, Huazhong Agricultural University, Wuhan, China. March 22 as part of the AAFC Genetics and Genomics Mission to China led by Dr. Denis Petitclerc, Director General, Ontario and Quebec Region. March 21-31, 2016. (70 attendants).

Media Reports

This activity resulted in two media reports:

1. Top Crops Manager "Canola Making Strides in Eastern Canada". Eastern Edition. November 2015.
2. Top Crops Manager "Cashing in on Canola". Eastern Edition. December 2015.

In addition, the researcher was also interviewed by Top Crops Manager East about canola nutrient management and agronomy.

Highlights

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. The following key points can be drawn from preliminary data analysis.

1) In the N fertility study, canola yields increased by both pre-plant and side dressed N application in 12 out of the 15 site-years. Yields at North Bay 2013, McGill 2013, and Canning 2014 showed a similar trend but were not significantly different among the N treatments.
2) In 11 out of the 15 site-years, the plots that received additional side dressed N (50+50, 50+100, 50+150 kg N ha^{-1}) had greater yields than the plots that received the same amounts of total N, but all applied at pre-plant. Canning 2013, McGill 2014 & 2015, and Laval 2015 showed no difference between application methods.

3) At early flowering, plant biomass, height and leaf area all significantly increased with increasing N rates, with the plots that received pre-plant N at 200 kg ha^{-1} having the largest biomass and leaf area and tallest plants of all the treatments. Side dress N did not seem to give the plants an advantage over the plants that only received pre-plant N at this time.
4) In all site-years, the numbers of branches per plant and seeds per pod increased with increasing N levels, sometimes significantly. In most cases the plots that received 200 kg N ha^{-1} either pre-plant or side dressed, had the most branches, pods and seeds. Adding side dressed N did not significantly affect branch, pod or seed numbers, compared to the plots that received the same amount of pre-plant N.
5) In both 2014 and 2015, N treatment did not affect 1000-seed weight (TSW). But at three sites in 2013, the addition of N did significantly increase TSW.
6) For most site-years (except Ottawa 2013 and Elora 2014), neither N rates nor application methods significantly affected harvest index (HI). At the Ottawa and Elora sites, HI values increased with increasing amounts of pre-plant N ($p<0.01$ &.001 respectively).
7) The most economic rate of nitrogen (MERN) for eastern Canada is estimated, on average, at 178 kg N ha^{-1} for pre-plant application and 191 for side dress application. When N fertilizer is applied at the MERN value, the average achievable yield would be 3.39 t ha^{-1} for pre-plant and 3.49 kg ha^{-1} for side dress application. Although the overall MERN values did not differ much between N application methods, side dress application could potentially increase crop yields on a site-specific basis. For example, at the Ottawa site, while the MERN was the same for application methods in 2013, seed yield increased by 17.2 kg ha^{-1} for each kg N ha^{-1} applied as side dress compared to 14.9 kg ha^{-1} for pre-plant application. At McGill 2014, the side dressed MERN value was actually lower than the pre-plant MERN value but produced a higher yield increment (13 kg seed ha^{-1} kg N) than that for pre-plant MERN (10.6 kg ha^{-1} kg N).
8) Only at the GS50 stage, did the Greenseeker and Cropscan instruments detect crop N deficiency between the 0 and the N applied plots. At the 20% flowering (GS 62), NDVI values significantly increased with increasing amounts of pre-plant N. The SPAD chlorophyll metre was able to distinguish the different N treatments as early as the GS15-GS16 stages.
9) Increasing N either as pre-plant or side dress increased seed protein concentration, but decreased oil concentration ($p\leq .001$).
10) The application of sulphur (S) increased seed yields at all site- years. At some sites, it was a significant increase, at others it was the same trend but non-significant. In most cases the highest yields were in plots that received 40 kg S ha^{-1}. The 0 S plots always had the lowest yields. The effects of S application on yield seem to be site-specific. Therefore, examining soil S availability and S mineralization potential are required for site-specific S recommendations.
11) The addition of different S rates did not affect seed oil, protein, or TSW.
12) At all site-years, B application as either pre-plant or foliar spray did not significantly affect yields, HI, branches and pods per plant, seeds per pod or TSW. There was also no effect of B on seed oil or protein. This lack of difference in yields may indicate that the test fields are sufficient in B. More analysis needs to be done on the effect of B on other nutrient uptake and nutrient balance.

Outcomes

Objectives

Three field experiments with two varieties of canola at five 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 nutrient (S, 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 will be determined on the basis of soil fertility status and the number 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 new opportunities to improve farming profitability by including canola in their rotation systems, but lack knowledge and experience growing canola. This study will develop knowledge needed to expand canola production in eastern Canada.

Methods

Experimental Design and Treatments

This is the third year of a four-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 six 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).

Due to planting issues in Elora and poor crop emergence for each experiment, there was no data from this 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 that it was planted. There was no yield data collected at the North Bay site in 2014 due to early frost.

For the first two years of this project, the two canola cultivars used in these experiments were InVigor 5440 (LL) and InVigor L150 (LL). In 2015 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 as the 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 pre-plant, it was in the form of muriate of postash (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 an issue with flea beetles. Metador was used 2-3 times (a week apart) starting at the 2-3 leaf stage.

The three experiments are described below:

1) Canola Nitrogen Fertility Experiment

In Ottawa, Laval, McGill, Canning and Elora, this experiment, testing two canola cultivars under different rates of nitrogen, was arranged in a randomized complete block design with four 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 pre-plant, plus three levels of split applications as 50 kg ha^{-1} pre-plant + 50 kg ha^{-1} at rosette formation (GS 30), 50 kg ha^{-1} pre-plant + 100 kg ha^{-1}, and 50 kg ha^{-1} pre-plant + 150 kg ha^{-1} at GS 30. Any side dressed N fertilizer was done by hand. Ammonium sulphate was applied pre-plant 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, 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 pre-plant to each strip. One of the 0 N strips was divided into nine plots to host the N treatments (0, 17.5, 50, 100, 150, 200, 50+50, 50+100 and 50+150 kg ha^{-1}) and replicated four times. There is only one year of data from the North Bay site.

2) Canola Sulphur Fertility Experiment

This is a 2 x 3 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), is fertilized with combinations of different rates of nitrogen and sulphur. Three rates of urea were applied pre-plant at 0, 75, and 150 kg N ha^{-1}. Ammonium sulphate (21-0-0-24) was applied pre-plant 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 four replications. Boron was applied at three rates: 0 and 2 kg B ha^{-1} applied at pre-plant 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). Pre-plant 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.

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).

Later in the growing season many plots showed signs of lodging. A lodging score of one to five 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 of one represents the plants totally upright and a score of five 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, pre-plant soil samples to 30 cm depth were sent to an accredited laboratory for analysis of pH, K, P, B, 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 (TSW). Grain yield and moisture were determined by combining an area of canola in each plot. The grain yields were adjusted and reported on a 100 g kg^{-1} water basis.

d) Plant/Seed Nitrogen, Phosporus, Boron, Sulphur Concentrations

At each site, analysis of grain and plant samples for total N and P concentrations is taken 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. Plant samples at early flowering will be ground and analyzed for S and B concentrations in a commercial lab.

e) Seed Oil and Protein Measurements

For all years except 2015, seed oil and protein content were determined at the Nova Scotia Truro Agricultural Campus of Dalhousie University, using the Unity Scientific SpectraStar 2500x NIR spectrometer. In 2015, for the Ottawa and Laval sites, oil and protein levels were measured with the FOSS NIRS DS2500 Feed Analyzer at the Ottawa Research Development Centre Chemistry Lab of AAFC, Ottawa, ON.

f) Seed Quality Measurements

At Ottawa, 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:

a) 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.

b) Soil Sampling

Only at the Ottawa site, soil mineral N (NO_3- and NH_4+) and available S and B were measured from soil samples collected twice during the growing season: 1) at the rosette stage (before side dressing 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 Ottawa Research Development Centre Chemistry Lab of AAFC, Ottawa, ON. The sample was extracted with a 2 M KCl solution and then determined for ammonia and nitrate with the Lachat QuikChem ® Flow Injection Analysis system (8000 series). The soil samples have not yet been analyzed for B and S.

c) Canopy Reflectance Measurements/ Leaf Greenness

At Ottawa and Elora sites, canopy reflectance measurements (NDVI) were collected with the Greenseeker Hand Held Optical Sensor Unit (Model 505) and the *CROPSCAN Inc* in Ottawa, and the Unispec DC instrument in Elora. The readings were taken several times at the rosette stage before side dressing N 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.

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

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 at the GS30 and GS62 growth stages.

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.

d) 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) In Ottawa and Canning nondestructively using the LI-COR LAI-2000 Plant Canopy Analyzer at the time of N side dressing (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 five 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 in Ottawa only, AccuPAR instrument was used to measure leaf area index instead of the Plant Canopy Analyzer.

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

Assuming the average canola grain (seed) 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

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

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

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

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. As expected, planting densities were not affected by N rates. 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 and (C) 2015.

A. 2013

	Ottawa, ON	**Laval, QC**	**McGill, QC**	**Canning, NS**
Planting	May 5	May 1	Jun 20	May 8
Emergence	May 13	May 13	Jul 2	May 15
Side dressing N	Jun 10	Jun 12	Jul 18	Jun 17
20% Flowering	Jun 24	Jun 24	Jul 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)	Jun 3	Jun 2
Side dressing N	Jun 17	Jun 17	Jun 18	Jun 29	Jun 20
20% Flowering	Jun 24	Jun 28 (B&S) Jul 1 (N)	Jun 28 (N) Jul 4 (S&B)	Jul 9	Jul 5
Maturity	Aug 25	Aug 19 (B&S) Aug 28 (N)	Aug 20 (N) Aug 26 (S&B)	Sep 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
Side dressing N	Jun 17	Jun 15	Jun 30	Jun 20	Jun 17
20% Flowering	Jun 25	Jun 30 (N) Jul 3 (S&B)	Jul 6	Jul 5	Jul 2
Maturity	Aug 10	Aug 28 (N&B) Aug 19 (S)	Aug 24	Aug 26	Aug 6

Soil Nutrient Status

Pre-plant soil samples were taken at all sites and results are shown in Table 3.

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

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 (ug g^{-1})	25	-	-	<0.50 ppm
S (%)	0.02	-	-	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 soil P (ppm)	82.5	220 kg/ha (N) 90 kg/ha (B&S)	67.5 kg/ha (N&S) 251 kg/ha	570 kg/ha	11.5
Soil test K (ppm)	97	322 kg/ha (N) 496 (B&S)	243 kg/ha (N&S) 206 kg/ha (B)	108 kg/ha	46/5
B (ug g^{-1})	<0.5	0.3 (N)	-	<0.5	0.6
S (%)	<0.01	12.2 ppm (N)	-	26 kg/ha	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 (ug g^{-1})	<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

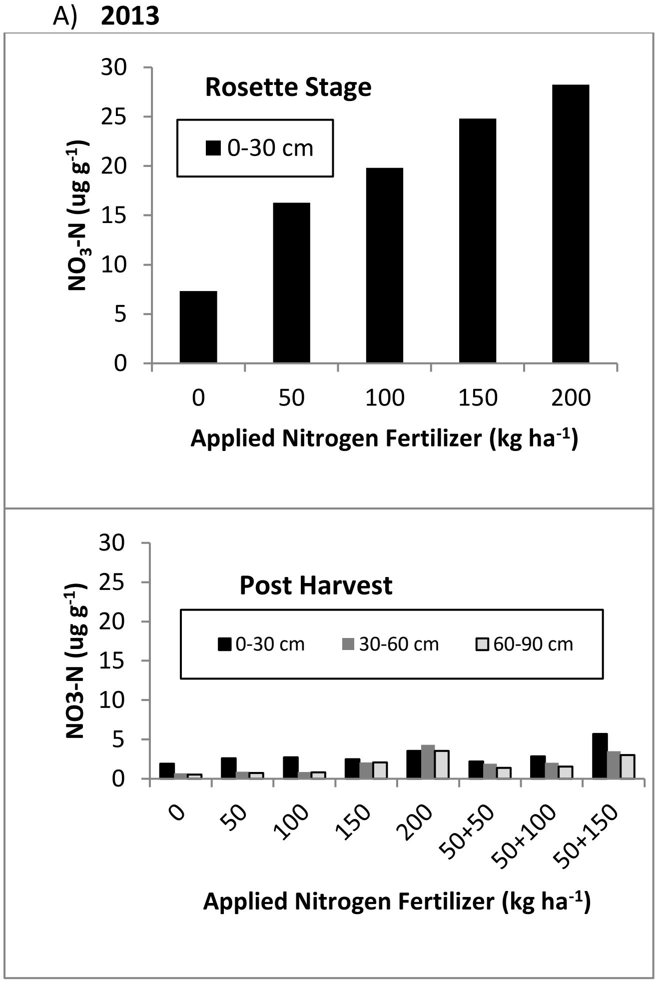
At the Ottawa site, soil samples at pre-side dress were taken from individual plots for the development of PSNT soil indicator for canola. For all years, soil nitrate levels at pre-side dress stage increased with increasing amounts of nitrogen applied to the soil. Without N application, soil NO3-N was on average 7.5

µg/g at the rosette stage in 2013, 3.4 µg/g at early flowering in 2014, and 3.8 ug/g pre-flowering in 2015. This indicates that with the initial low levels of N that 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.

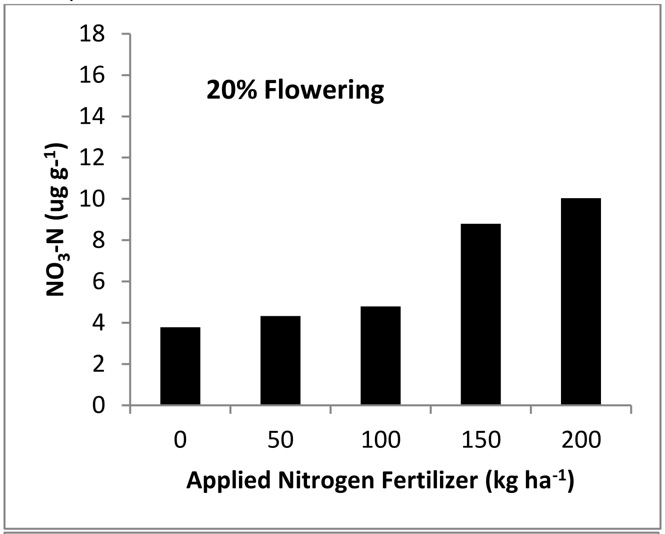
Post-harvest soil samples were taken and used as an indicator if the field was overfertilized and if there is a leaching potential. In most plots, soil NO3-N concentrations after harvest were low, especially in 2013. At high N rates where side dressing occurred, there was high residual soil NO3-N after harvest in 2014 and 2015 (Figure 1 B & C), a potential risk of nitrate leaching.

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

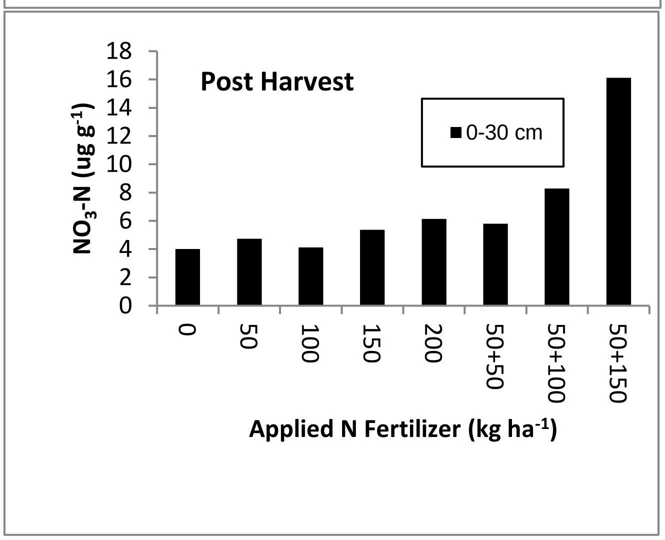
A) **2013**



B) **2014**

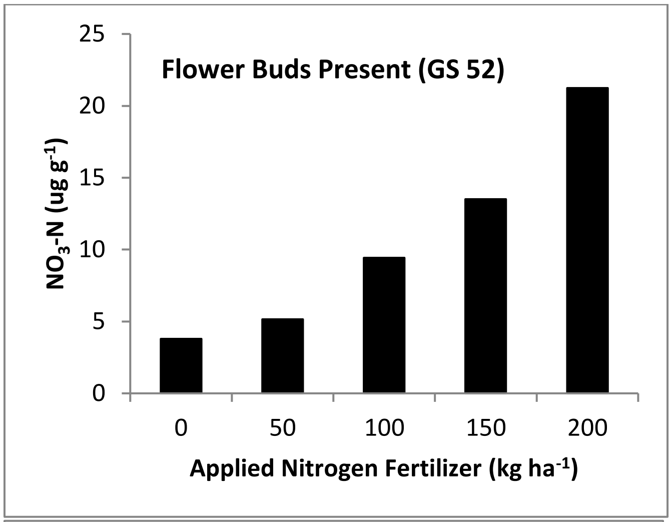


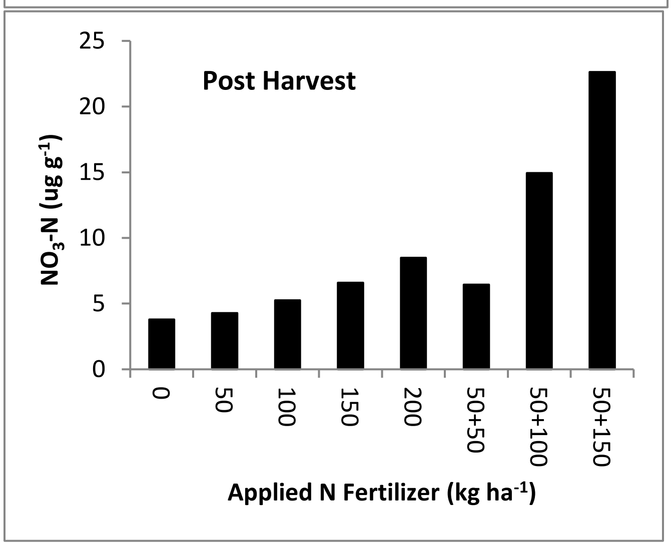
20% Flowering
NO3-N (ug g-1)
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
Applied Nitrogen Fertilizer (kg ha-1)



Post Harvest
0-30 cm
NO3-N (ug g-1)
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
50+50
50+100
50+150
Applied N Fertilizer (kg ha-1)

C) **2015**





Canola N Fertility Study

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. In most cases there were no significant height difference between the two hybrids (Table 4A, B&C). This was also the case for plant biomass (Table 4D&E). LAI was measured only at Ottawa, Canning and North Bay sites (Table 4F). at early flowering stage, L150 had significantly higher LAI than 5440. Plant biomass, height and LAI did significantly increase with increasing rates of N fertilizer (Table 4A, B, C, D&E), with the plots that received pre-plant at 200 kg N ha^{-1} having the largest biomass and leaf area, and the tallest plants of all the treatments. The 0 N plots always had the shortest and smallest plants. At flowering, side dressing nitrogen did not seem to give the plants an advantage over the plants that only received pre-plant N. McGill in 2013 and 2014 was the only site that did not show any significant differences in plant heights or biomass among treatments.

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

A) Plant Heights (cm) - 2013

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	North Bay, ON
<u>Hybrid</u>					
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	
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 b[Ŧ]	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 Biomass (kg ha^{-1}) – 2013 & 2014

Source	Ottawa, ON 2013	Laval, QC 2014	McGill, QC 2014	Canning, NS 2013	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

E) 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
Application rate (kg N 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

F) **Leaf area index, 2013, 2014 & 2015**

	Ottawa, ON			Canning, NS		North Bay, ON
Source	**2013**	**2014**	**2015**	**2013**	**2015**	**2013**
<u>Hybrid</u>						
5440	2.8 a	5.3 b[∞]	3.62 a	3.6 b [Ŧ]	4.52 a	
L150/140P	2.9 a	5.9 a	3.94 a	4.2 a	4.54 a	
<u>Application rate (kg N ha^{-1})</u>						
0	-	-		-		1.06 e
17.5	1.9 e [x]	4.3 d[Ŧ]	3.93 a	2.42 e [Ŧ]	2.73 d [Ŧ]	1.18 de [x]
50	2.6 cde	5.0 bcd	4.16 a	3.04 d	3.32 d	2.0 bcde
100	3.1 abcd	5.8 abc	3.57 a	4.21 b	4.69 bc	1.78 cde
150	2.6 de	6.4 a	3.33 a	5.50 a	5.5 ab	2.12 abcd
200	3.4 ab	6.5 a	3.44 a	5.27 a	5.54 a	2.38 abc
50+50	2.7 bcd	4.7 cd	3.66 a	3.50 cd	4.37 c	2.01 abcde
50+100	3.4 abc	5.9 ab	3.98 a	3.67 c	4.89 abc	3.0 a
50+150	3.5 a	6.5 a	4.14 a	3.39 cd	5.21 ab	2.90 ab

b) Harvest Index, Branches, Pods, No of Seeds per pod and 1000-seed Weight

In the Nitrogen Fertility study, harvest index (HI) was not significantly different between cultivars in 2013 or 2015. In 2014 at three sites (Elora, McGill and Ottawa) InVigor 5440 had significantly higher HI values than InVigor L150 ($p \leq .001$). For most sites and years, nitrogen did not have any effect on HI. Only in Ottawa 2013 and Elora 2014 did HI increase with increasing amounts of N (Table 5). Side dressing N did not significantly affected HI (data not shown).

Table 5. Effect of N fertilizer application on harvest Index at Ottawa 2013 and Elora 2014 for the nitrogen fertility study. Means with different letters in the same column are significantly different at the .001 and .01 [x] levels.

Nitrogen (kg ha^{-1})	**Ottawa, ON 2013**	**Elora, ON 2014**
17.5	.35 2 c [x]	.31 c [Ŧ]
50	.363 bc	.33 bc
100	.372 ab	.34 ab
150	.378 ab	.35 ab
200	.363 bc	.36 a
50+50	.375 ab	.35 ab
50+100	.380 a	.37 a
50+150	.379 a	.35 ab

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

Table 6. Canola hybrid and nitrogen effect on the number of branches per plant at all 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] level. Means with different letters in the same column are significantly different at the .001[Ŧ], .01[x] and .05[∞] levels.

A) Branches 2013

Source	**Ottawa, ON**	**Laval, QC**	**McGill, QC**	**Canning, NS**	**North Bay, ON**
<u>Hybrid</u>					
InVigor 5440	5.7 a	3.8 a	4.7	3 a	-
InVigor L150	5.6 a	4.0 a	5.1	3 a	-
<u>Nitrogen (kg ha^{-1})</u>					
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**
<u>Hybrid</u>					
InVigor 5440	5.1 a	3.7 a	3.5 a	3.3 a	6.7 b [₸]
InVigor L150	5.1 a	3.9 a	3.3 a	3.8 a	8.4 a
<u>Nitrogen (kg ha^{-1})</u>					
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**
<u>Hybrid</u>					
InVigor 5440	6 a	9	4	3 a	5
InVigor L140P	6 a	8	4	3 a	6
<u>Nitrogen (kg ha^{-1})</u>			3		
17.5	4.5 c	6	4	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

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 and (C) 2015. Means with different letters in the same column are significantly different at the .001 [Ŧ], .01 [x] and .05 [∞] levels.

A) Pods 2013

Source	**Ottawa, ON**	**Laval, QC**	**McGill, QC**	**Canning, NS**	**North Bay, ON**
<u>Hybrid</u>					
InVigor 5440	127 a [x]	63 a [x]	70 a	47 a	-
InVigor L150	102 b	53 b	74 a	45 a	-
<u>Nitrogen (kg ha^{-1})</u>					
0	-	-	-		80 a
17.5	80 c	39 e [Ŧ]	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**
<u>Hybrid</u>					
InVigor 5440	93 a	48 a	57 a	68 a	121 a
InVigor L150	75 a	47 a	55 a	74 a	120 a
<u>Nitrogen (kg ha^{-1})</u>					
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

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

Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	North Bay, ON
Hybrid					
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
<u>Hybrid</u>				
InVigor 5440	23 a	20 b ^{x}	21 b ^{Ŧ}	21 b ^{x}
InVigor L150	23 a	23 a	23 a	23 a
<u>Nitrogen (kg ha^{-1})</u>				
17.5	20 b	20 b	21 b $^{\infty}$	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
<u>Hybrid</u>					
InVigor 5440	22 a	25	24	23 a	
InVigor L140P	23 a	25	25	23 a	
<u>Nitrogen (kg ha^{-1})</u>					
17.5	22 ab	23 ^{x}	23	22.0 d $^{\infty}$	
50	24 a	24	26	22.0 d	
100	24 a	25	25	23.3 abc	
150	23 ab	26	25	23.0 abcd	
200	22 b	26	25	23.6 ab	
50+50	23 ab	25	23	23.1 abcd	
50+100	22 ab	26	25	22.9 bcd	
50+150	21 b	25	23	24.5 a	

Except for Laval, InVigor 5440 had higher 1000-seed weight (TSW) than InVigor L150 or L140P, sometimes significantly (Table 9 A, B, C). Application of N fertilizer had a significantly positive effect on TSW in 2013 and Canning in 2014 with the highest TSW found in the plots that received 150 and 200 kg ha^{-1} side dressed nitrogen. This was not the case for all the other sites in 2014 and 2015, where there were no differences between nitrogen treatments. Side dressing N had no effect on TSW compared to those from plots that received pre-plant N.

Table 9. Canola hybrid and nitrogen effect on 1000-seed weight 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) 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
<u>Nitrogen (kg ha^{-1})</u>			
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**
<u>Hybrid</u>				
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
<u>Nitrogen (kg ha^{-1})</u>				
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
<u>Hybrid</u>					
InVigor 5440	2.25 a	2.92 a Ŧ	3.2 a	3.07 a Ŧ	3.08
InVigor L140P	2.32 a	2.59 b	2.8 b	2.79 b	2.63
<u>Nitrogen (kg ha^{-1})</u>					
17.5	2.31 ab	3.00 Ŧ	2.8	3.05 a Ŧ	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

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, InVigor L140P, used in 2015, did not differ from InVigor 5440 in these traits. Increasing pre-plant N 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 N plots had seed with the lowest protein concentration but highest oil concentration of all the treatments. This was also the case with the side dressed plots, having the same trend with protein and oil concentrations.

In 2013, Pearson's correlation analysis shows that yield was negatively correlated with seed oil concentration (-.661; $p \leq .001$) and positively correlated with seed protein concentration (0.724; $p \leq .001$).

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 Ŧ and .05 ∞ levels.

A) Seed protein concentration (%)

Source	Canning, NS			Ottawa, ON		
	2013	2014	2015	2013	2014	2015
Hybrid						
5440	21.0 a Ŧ	21.0 a∞	22.1 a Ŧ	22.8 a Ŧ	23.6 a Ŧ	19.7 a x
L150/140P	20.0 b	20.2 b	21.3 b	22.3 b	22.4 b	19.4 b
Nitrogen (kg ha^{-1})						
17.5	18.1 e Ŧ	18.6 d Ŧ	20.2 e Ŧ	20.0 g Ŧ	20.9 c Ŧ	16.5 f Ŧ
50	18.2 e	19.2 cd	20.6 e	21.3 f	22.2 b	17.3 e
100	19.5 d	19.8 cd	21.5 d	22.4 e	22.9 ab	19.2 d
150	21.3 c	22.4 a	22.2 bc	23.4 bc	23.3 a	20.5 b
200	22.4 b	23.1 a	22.7 ab	23.8 a	23.8 a	21.1 a
50+50	19.8 d	19.6 cd	21.4 d	22.7 de	23.1 ab	19.7 c
50+100	22.2 b	20.6 bc	22.1 c	23.1 cd	23.8 a	20.8 ab
50+150	23.1 a	21.9 ab	23.1 a	23.6 ab	23.8 a	21.2 a

Source	Laval, QC	McGill, QC	Elora, ON
	2015	2015	2015
Hybrid			
InVigor 5440	18.3	22.8	
InVigor L140P	18.0	22.9	
Nitrogen (kg ha^{-1})			
17.5	17.8 Ŧ	21.6 dŦ	
50	17.3	21.8 cd	
100	17.9	22.4 bcd	
150	18.6	23.4 abc	
200	18.8	24.1 ab	
50+50	17.9	22.5 bcd	
50+100	18.4	23.3 abc	
50+150	18.7	24.3 a	

B) Seed oil concentration (%)

Source	Canning, NS			Ottawa, ON		
	2013	2014	2015	2013	2014	2015
<u>Hybrid</u>						
5440	44.7 b [Ŧ]	42.7 b [Ŧ]	40.6 a	44.8 b [Ŧ]	40.3 b [Ŧ]	45.4 a
L150/140P	46.5 a	44.5 a	40.7 a	46.6 a	44.9 a	45.5 a
<u>Nitrogen (kg ha^{-1})</u>						
17.5	47.8 a [Ŧ]	44.9 a [Ŧ]	41.9 a [Ŧ]	47.6 a [Ŧ]	45.1 a [Ŧ]	48.0 a [Ŧ]
50	47.6 a	44.0 ab	41.8 ab	46.9 a	43.2 b	47.3 b
100	46.0 b	44.7 a	40.9 bcd	45.4 bc	42.9 bc	45.6 c
150	44.8 c	42.1 c	39.9 de	44.9 bc	42.6 bcd	44.5 d
200	44.7 c	41.5 c	40.1 cde	45.2 bc	41.9 cde	44.2 d
50+50	46.0 b	44.5 ab	41.0 abc	45.8 b	42.3 bcd	45.3 d
50+100	44.4 c	44.1 ab	40.4 cd	45.3 bc	41.6 de	44.5 d
50+150	43.3 d	42.9 bc	39.3 e	44.6 c	41.1 e	44.2 d

Source	Laval, QC 2015	McGill, QC 2015	Elora, ON 2015
<u>Hybrid</u>			
InVigor 5440	47.8	40.4 a [Ŧ]	
InVigor L140P	47.4	39.7 b	
<u>Nitrogen (kg ha^{-1})</u>			
17.5	48.1 [x]	41.2 a [Ŧ]	
50	48.4	40.6 ab	
100	47.9	40.5 ab	
150	47.3	39.5 ab	
200	46.9	39.2 ab	
50+50	47.7	40.9 a	
50+100	47.5	40.0 ab	
50+150	47.2	38.8 b	

d) Lodging

Lodging occurred in Ottawa in 2013 and 2014 and 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 were more severe lodging for InVigor L150 than for 5440 (Table 11). Except for the

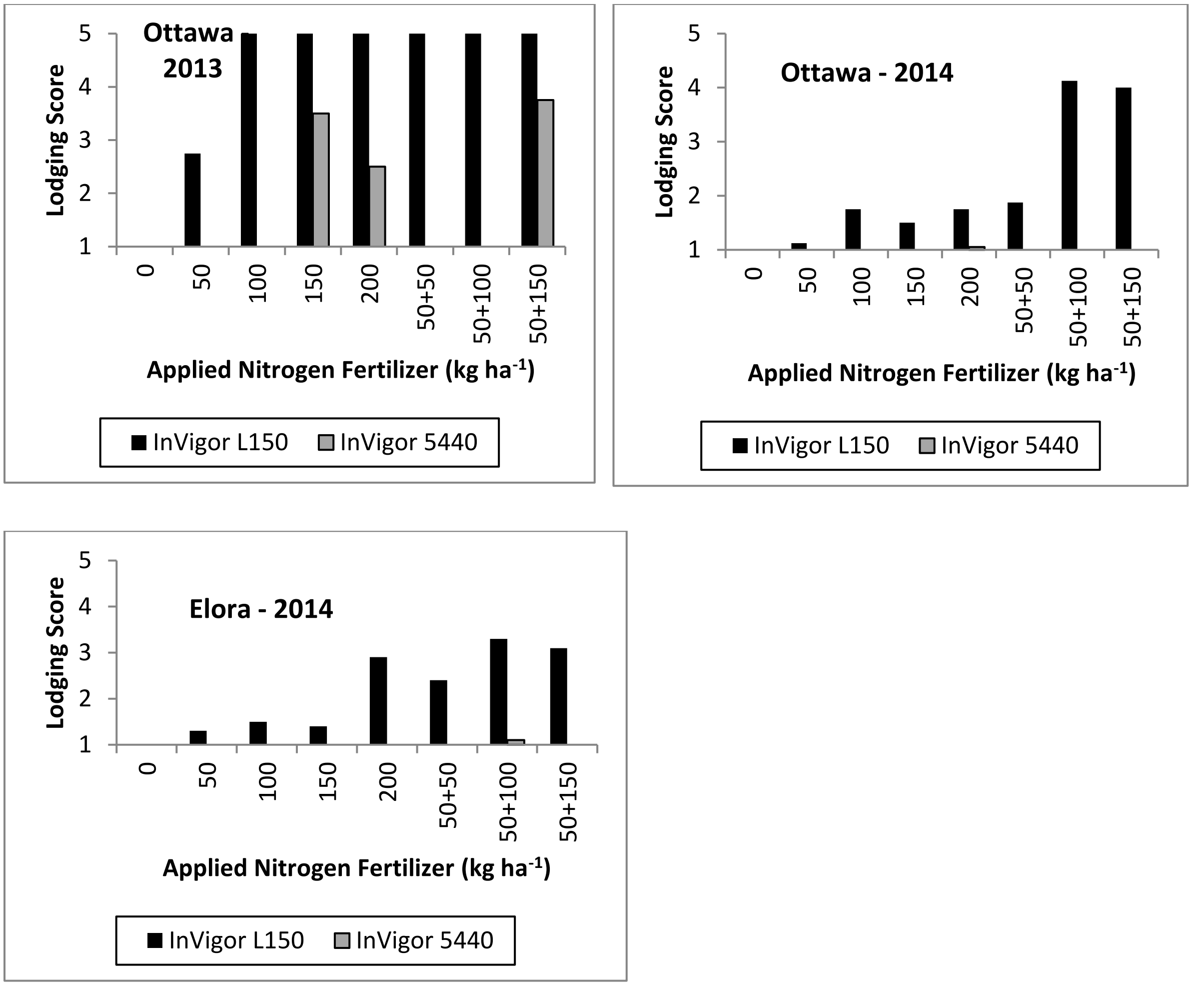
Ottawa site in 2013, hybrid InVigor 5440 did not lodge at any other site-years. The most severe lodging occurred in InVigor L150 at Ottawa and Elora (Figure 2). Nitrogen rates did have a significant effect on the intensity of lodging for L150 ($p \leq .001$) with higher lodging scores in plots that received more than 50 kg ha^{-1} nitrogen (Figure 2). At the Ottawa and Elora sites, lodging was significantly higher in the pre-side dressed plots (PS) compared to the pre-plant 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. In 2015 neither Invigor 5440 or 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 one (upright; no lodging) to five (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**				
	2013	**2014**	**Elora, ON**	**Laval, ON**	**Canning, NS**
<u>Hybrid</u>					
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
<u>Nitrogen Application Method</u>					
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 one (upright; no lodging) to five (flat crop; total plot lodged).



e) Final Yields

In the Nitrogen Fertility study, Ottawa (all three years), Elora (2014 & 2015) and Canning 2015 sites had a significant yield difference between the two hybrids ($p \leq .001$) with InVigor 5440 having higher yields (Table 12 A, B & C). For the first two years at Ottawa, there was such a significant yield difference between the two varieties due to the heavy lodging that occurred in the high nitrogen plots of InVigor L150, which made combining very difficult.

In twelve of the fifteen site-years, there was a strong correlation between yields and amount of nitrogen applied both pre-plant and side dressed (Figure 3). Pre-plant nitrogen application significantly increased yields ($p \leq .001$) (Table 12 A, B & C). Seed yields at the North Bay 2013, McGill 2013 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 nitrogen but InVigor L150 did not. In fact, because of the lodging in the high N plots, in particular the side dressed plots, the side dressed plots had low yields, and in 2014 were even lower than the 0 N plots (Table 12).

At eleven of the fifteen site-years, the plots that received additional side dressed nitrogen as urea (50+50, 50+100, 50+150 kg N ha^{-1}) had higher yields than the plots that received only pre-plant nitrogen. But the differences between the pre-plant and side dressed methods were not significant (Table 12). Ottawa (InVigor L150 only), Canning 2013, and McGill 2014 & 2015 and Laval 2015 did not show a positive response to side dressed nitrogen and had lower yields in the side dressed plots (Table 12; Figure 3).

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

A) Yields - 2013

Source	**Ottawa, ON**		**Laval, QC**	**McGill, QC**	**Canning, NS**	**North Bay**
Hybrid	InVigor 5440	InVigor L150				
InVigor 5440	3204.5 a Ŧ		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 Ŧ	2552.8 d Ŧ	2490 d Ŧ	3852 a	2379.6 e Ŧ	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

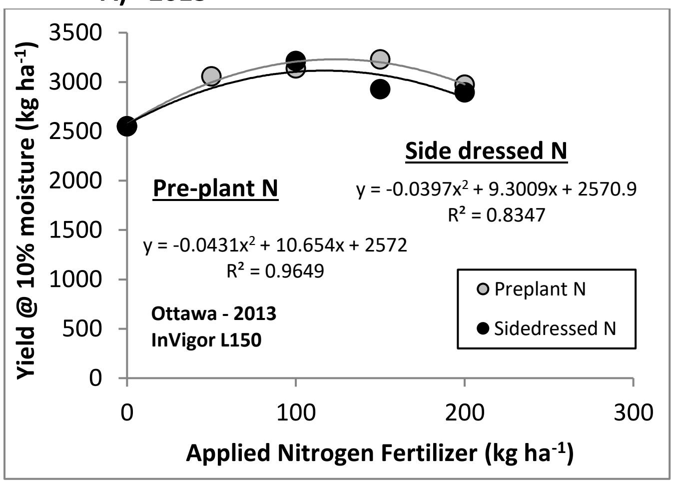
Source	Ottawa, ON		Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid	InVigor 5440	InVigor L150				
InVigor 5440	3485.4 a [Ŧ]		3456.5 b [x]	1538.3 a	2241.3 a	3299.2 a [x]
InVigor L150		2874.4 b	3700.5 a	1388.6 a	2051.6 a	3085.2 b
Nitrogen (kg ha^{-1})						
17.5	2855.5 c [Ŧ]	2902.6 c [Ŧ]	2730.1 d [Ŧ]	751.7 d [Ŧ]	1824.6 b	2669.9 d [Ŧ]
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

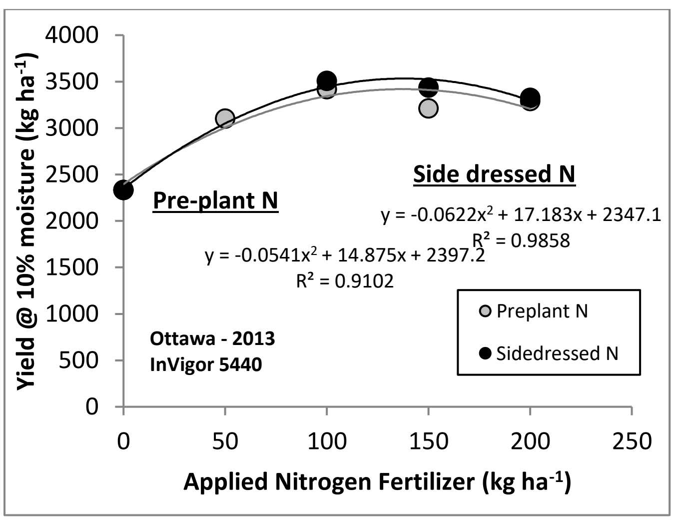
C) Yields 2015

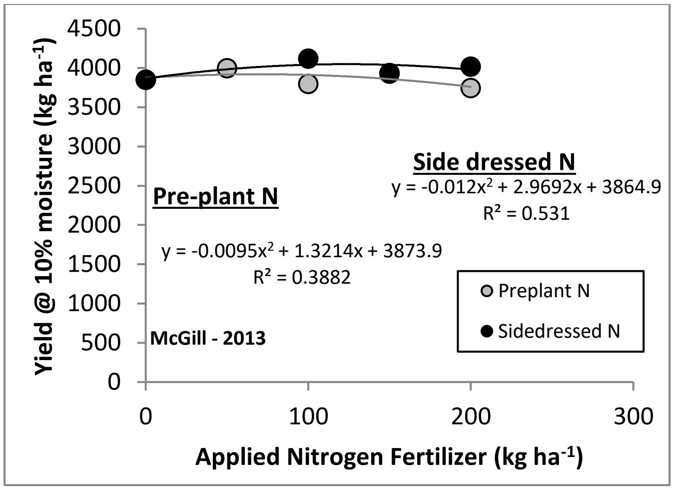
Source	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
Hybrid					
InVigor 5440	3324.1 b [x]	3984	4151.0	3071.7 a [∞]	3203.2
InVigor L140	3495.3 a	4003	4119.1	2878.0 b	3554.2
17.5	2254.5 e[Ŧ]	3263 [Ŧ]	3278.0 [x]	2163.8 d [Ŧ]	2505.1
50	2973.0 d	3645	3734.2	2748.6 c	3086.2
100	3535.4 bc	4066	4172.2	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

Figure 3 A, B & C. Regression analysis of grain yield as a function of the amount of N fertilizer added at pre-plant compared to the plots that received the same amount of N split between pre-plant and side dressing at each site and year.

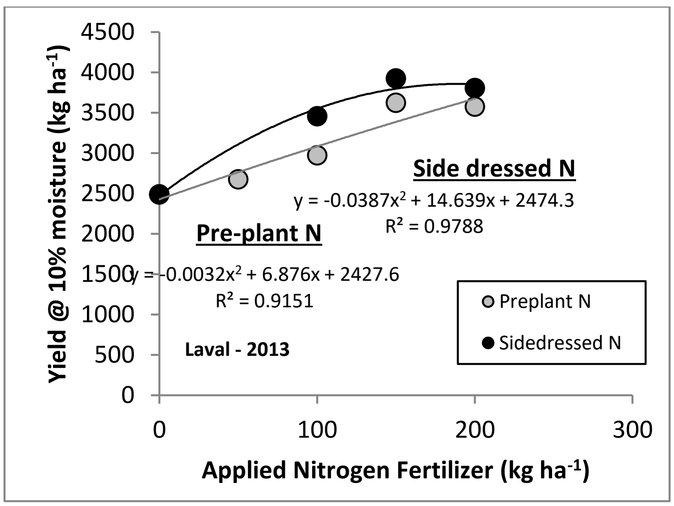
A) 2013



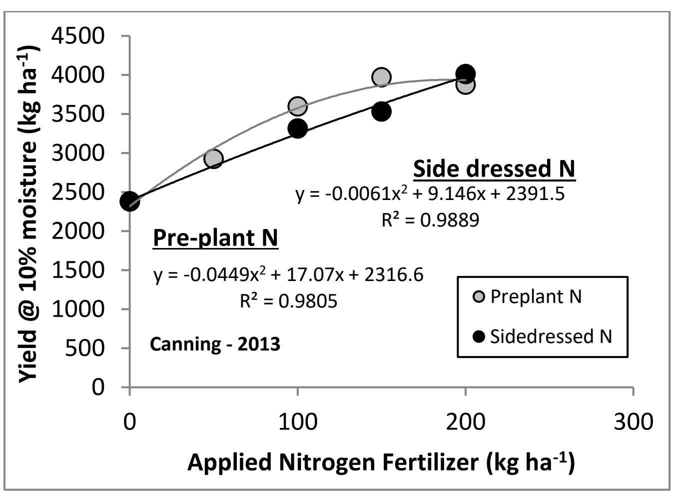




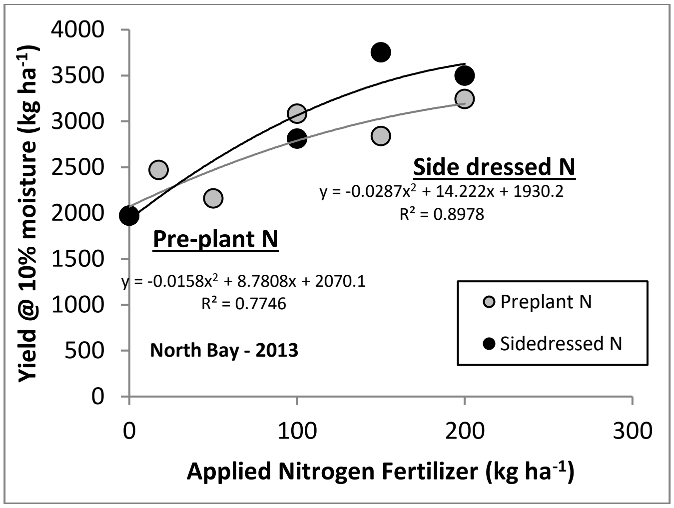
Yield @ 10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)
Side dressed N
y = -0.012x2 + 2.9692x + 3864.9
R² = 0.531
Pre-plant N
y = -0.0095x2 + 1.3214x + 3873.9
R² = 0.3882
Preplant N
Sidedressed N
McGill - 2013



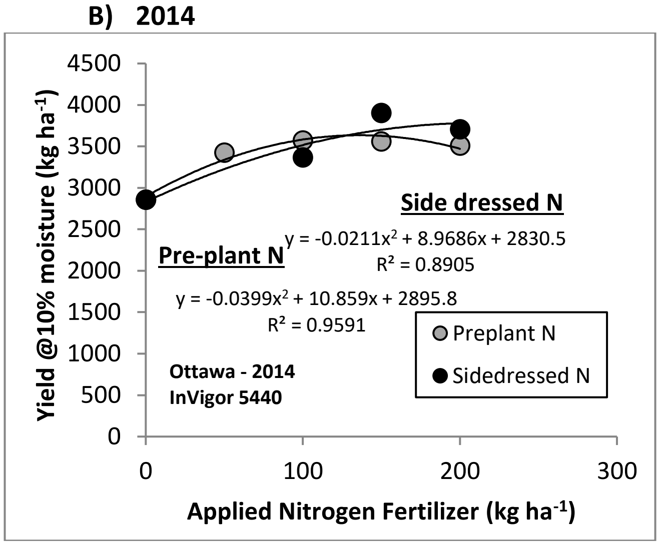
Yield @ 10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)
Side dressed N
y = -0.0387x2 + 14.639x + 2474.3
R² = 0.9788
Pre-plant N
y = -0.0032x2 + 6.876x + 2427.6
R² = 0.9151
Preplant N
Sidedressed N
Laval - 2013

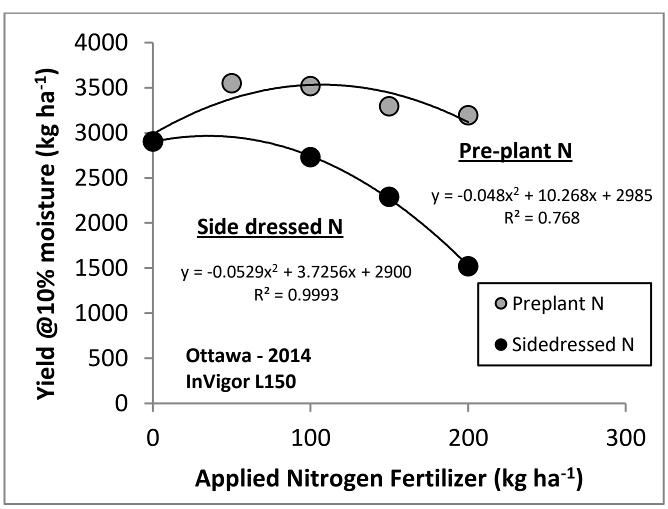


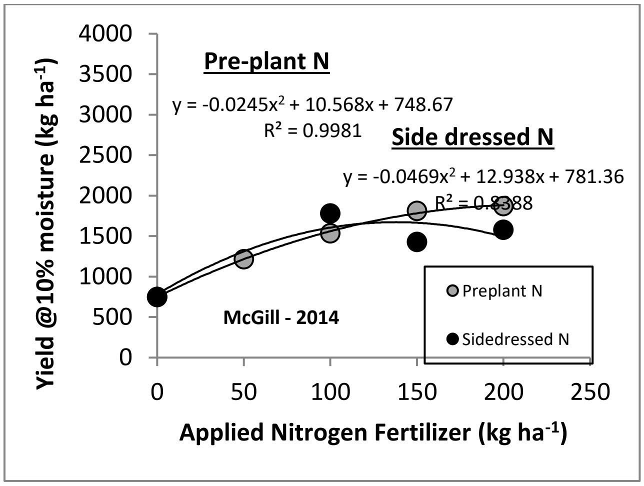
Yield @ 10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)
Side dressed N
y = -0.0061x2 + 9.146x + 2391.5
R² = 0.9889
Pre-plant N
y = -0.0449x2 + 17.07x + 2316.6
R² = 0.9805
Preplant N
Sidedressed N
Canning - 2013


Yield @ 10% moisture (kg ha-1)
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
Applied Nitrogen Fertilizer (kg ha-1)
Side dressed N
y = -0.0287x² + 14.222x + 1930.2
R² = 0.8978
Pre-plant N
y = -0.0158x² + 8.7808x + 2070.1
R² = 0.7746
North Bay - 2013
Preplant N
Sidedressed N

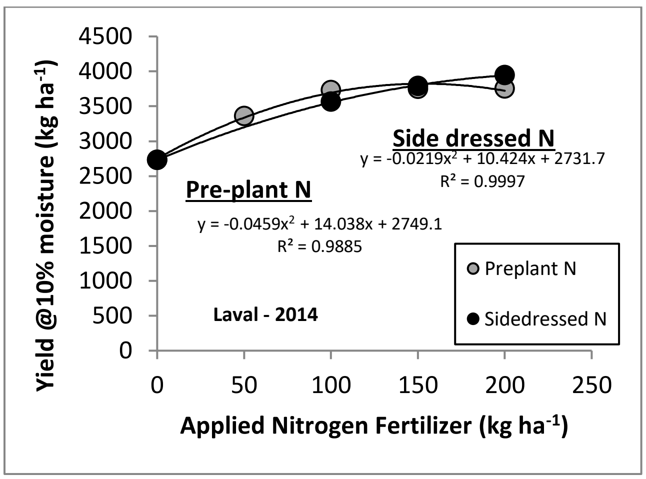
B) 2014


Yield @10% moisture (kg ha-1)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
Applied Nitrogen Fertilizer (kg ha-1)
Side dressed N
y = -0.0211x² + 8.9686x + 2830.5
R² = 0.8905
Pre-plant N
y = -0.0399x² + 10.859x + 2895.8
R² = 0.9591
Ottawa - 2014
InVigor 5440
Preplant N
Sidedressed N

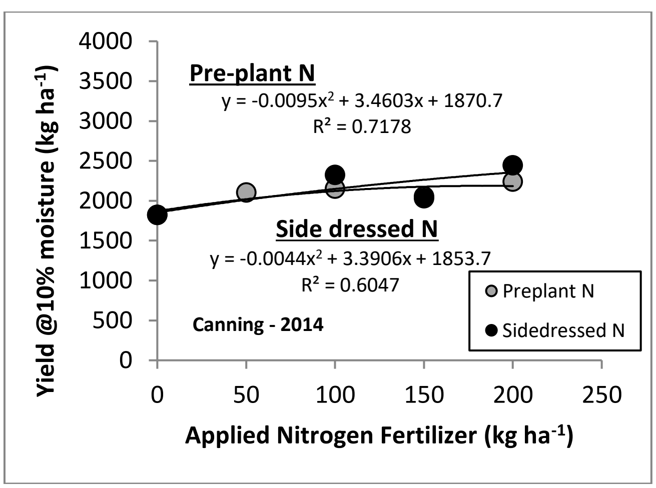

Yield @10% moisture (kg ha-1)
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
Applied Nitrogen Fertilizer (kg ha-1)
Pre-plant N
y = -0.048x² + 10.268x + 2985
R² = 0.768
Side dressed N
y = -0.0529x² + 3.7256x + 2900
R² = 0.9993
Ottawa - 2014
InVigor L150
Preplant N
Sidedressed N



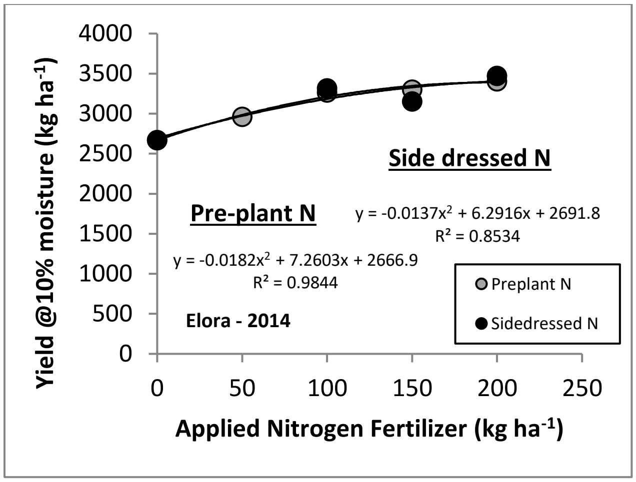
Pre-plant N
y = -0.0245x² + 10.568x + 748.67
R² = 0.9981
Side dressed N
y = -0.0469x² + 12.938x + 781.36
R² = 0.8388
Preplant N
Sidedressed N
McGill - 2014
Yield @10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)



Side dressed N
y = -0.0219x² + 10.424x + 2731.7
R² = 0.9997
Pre-plant N
y = -0.0459x² + 14.038x + 2749.1
R² = 0.9885
Preplant N
Sidedressed N
Laval - 2014
Yield @10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

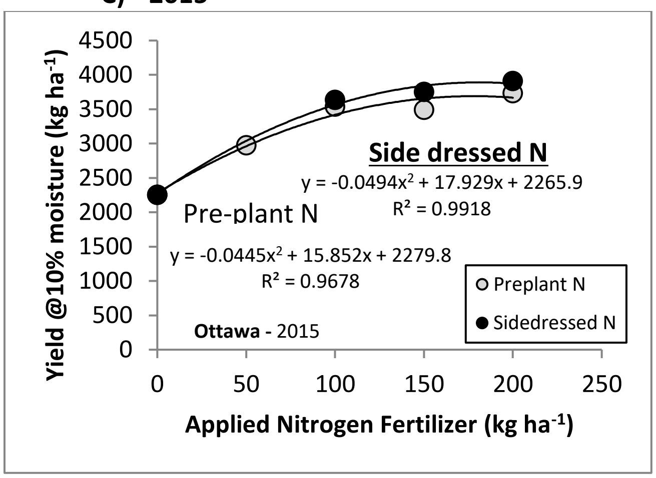


Pre-plant N
y = -0.0095x² + 3.4603x + 1870.7
R² = 0.7178
Side dressed N
y = -0.0044x² + 3.3906x + 1853.7
R² = 0.6047
Preplant N
Sidedressed N
Canning - 2014
Yield @10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)

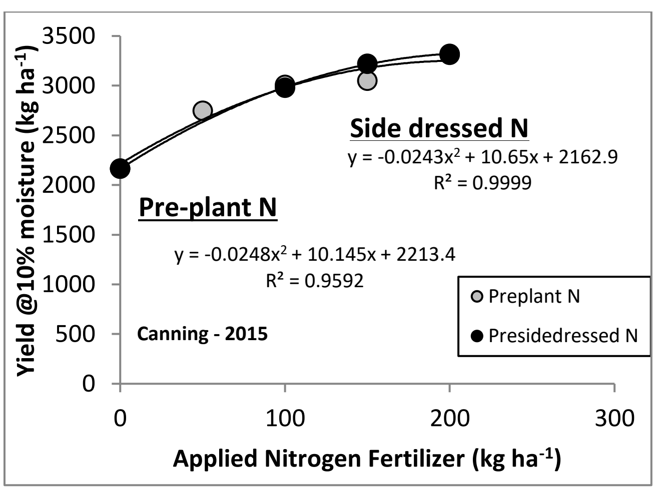


Yield @10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)
Side dressed N
Pre-plant N
y = -0.0137x² + 6.2916x + 2691.8
R² = 0.8534
y = -0.0182x² + 7.2603x + 2666.9
R² = 0.9844
Elora - 2014
Preplant N
Sidedressed N

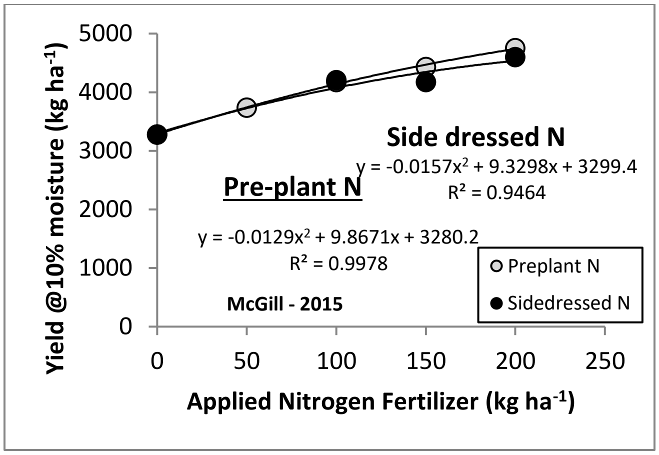
C) 2015

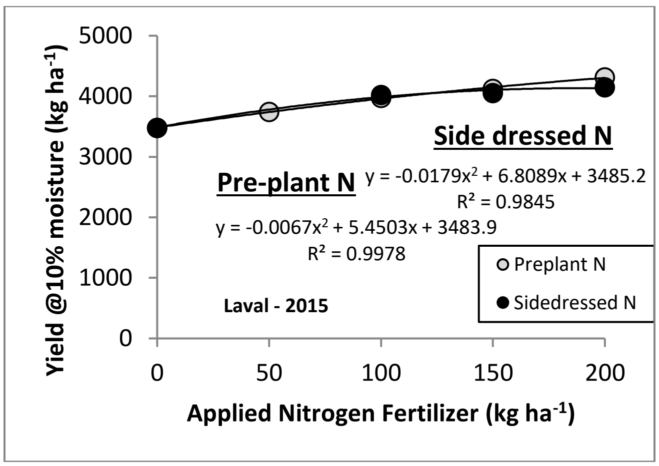


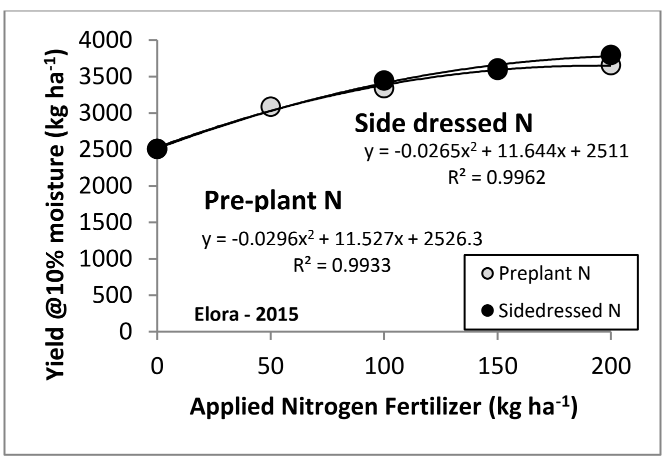
Yield @10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)
Side dressed N
y = -0.0494x² + 17.929x + 2265.9
R² = 0.9918
Pre-plant N
y = -0.0445x² + 15.852x + 2279.8
R² = 0.9678
Ottawa - 2015
Preplant N
Sidedressed N



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







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, Canning 2014, Laval 2015 and McGill 2015 were not included in the MERN calculations because they did not show a significantly positive yield response to the addition of side dressed nitrogen over pre-plant nitrogen.

The estimated MERN values for the Laval 2013 and Canning 2013 sites are not shown 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 for eastern Canada is estimated at 177 kg N ha^{-1} for pre-plant application and 189 kg N ha^{-1} for side dress application. The yield increments at these N levels would be 11.6 kg ha^{-1} for pre-plant application and 12.2 kg ha^{-1} for side dress application. 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 side dressed N application is higher than the estimated yield for pre-plant 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, including Ottawa 2014, potential yields would also be higher for the side dressed N application method, but with a higher MERN value than that of pre-plant 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 pre-plant application (PP) and side dress 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 seed / 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	3418
		PS	.99	133	17.2	3508	50+50	3532
2013	**Laval**	**PP**	.92	- †	6.8	3624	150	-
		PS	.98	184	14.6	3924	50+100	3881
2013	**Canning**	**PP**	.98	182	17.1	3970	150	3933
		PS	.99	- †	9.1	4014	50+150	-
2013	**North Bay**	**PP**	.77	257	8.7	3243	200	3283
		PS	.89	233	14.2	3755	50+100	3686
2014	**Elora**	**PP**	.98	189	7.3	3405	200	3389
		PS	.85	216	6.3	3470	50+150	3411
2014	**Ottawa (InVigor 5440)**	**PP**	.96	131	10.9	3560	150	3634
		PS	.89	202	9.0	3901	50+100	3781
2014	**Laval**	**PP**	.99	147	14.0	3753	200	3821
		PS	.99	225	10.4	3946	50+150	3969
2014	**McGill**	**PP**	.99	194	10.6	1872	200	1876
		PS	.84	128	13.0	1784	50+50	1669
2015	**Ottawa**	**PP**	.97	170	15.85	3733	200	3691
		PS	.99	174	17.93	3908	50+150	3893
2015	**Canning**	**PP**	.96	193	10.14	3309	200	3251
		PS	.999	206	10.65	3318	50+150	3330
	Elora	**PP**	.99	185	11.5	3654	200	3649
		PS	.99	208	11.6	3795	50+150	3790
Overall mean		**PP**		178	11.6	3413		3394
		PS		191	12.1	3575		3494

† 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 and Greenseeker several times during the growing season in the nitrogen fertility study at Ottawa and with a similar spectrometer at Guelph in 2014 and 2015. The data is expressed as the normalized difference vegetation index (NDVI) or other indices for indicating the crop N status. Three sets of measurements are discussed below: at side dressing, one week after side dressing (seven leaf stage) and at 20% flowering.

Well before side dressing (GS14-15) neither CropScan or Greenseeker detected significant differences between plants under different N treatments (Table 14 A & B). Just before side dressing (GS 17) the instruments could detect that the plants in the 0 N plots were significantly less green than all the other plants ($p \leq .001$), but there were no significant differences between plants of the other nitrogen treatments. At 20% flowering (GS62), NDVI readings of both CropScan and Greenseeker significantly increased with increasing amounts of pre-plant urea added to the soil ($p \leq .001$). The plants that received side dressed nitrogen had similar NDVI readings as plants in the corresponding plots that received similar amounts of pre-plant nitrogen.

Table 14 A & B. Canopy reflectance readings (NDVI) for both Greenseeker (A) and CropScan (B) taken before side dressing and post side dressing (20% Flowering GS62) for all years at the Ottawa site.

A. Greenseeker

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

	GreenSeeker 2014				
N (kg/ha)	**GS14**	**GS15**	**GS17**	**GS52**	**GS62**
17.5	.6311 a ns	.6142 a	.7845 c ₸	.7497 e ₸	.7065 c ₸
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

	GreenSeeker 2015			
N (kg/ha)	**GS16**	**GS18**	**GS50**	**GS62**
17.5	.6460 c ₸	.7194 b ₸	.6539 c ₸	.6686 c ₸
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

B. Cropscan

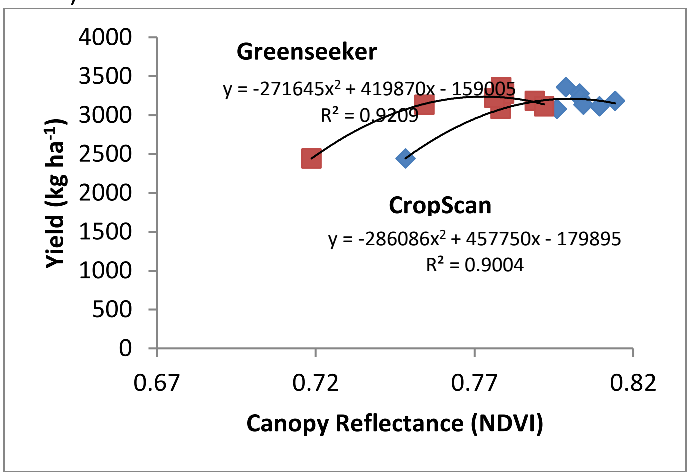
	CropScan 2013			
N (kg/ha)	**GS15**	**GS16**	**GS17**	**GS62**
17.5	.6815 a	.6380 c ∞	.7483 b ₸	.8100 c ₸
50	.7053 a	.7120 ab	.7959 a	.8344 b
100	.7155 a	.7184 ab	.8030 a	.8440 a
150	.7216 a	.7283 a	.8033 a	.8451 a
200	.6759 a	.6725 bc	.8043 a	.8426 a
50+50	-	-	.7989 a	.8425 a
50+100	-	-	.8141 a	.8430 a
50+150	-	-	.8093 a	.8418 a

Greenseeker and CropScan measurements taken one week after side dressing (seven leaf stage) and at 20% flowering were very strongly correlated to final plant yields. (Figure 5 A, B & C).

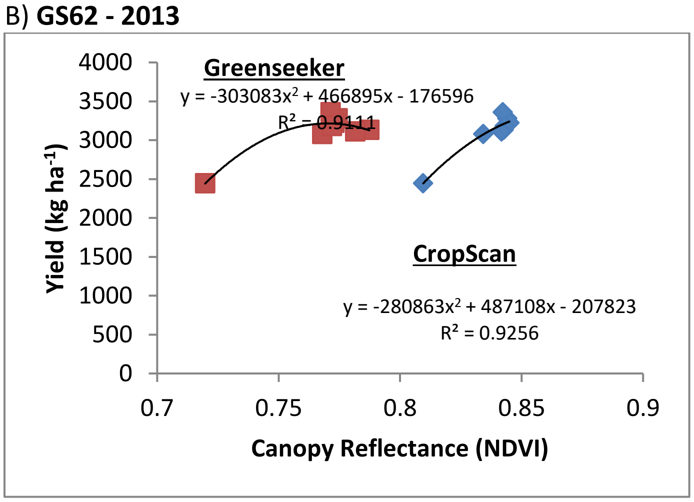
Greenseeker and CropScan NDVI measurements taken at 20% flowering also had a strong correlation ($r^2 > 0.95$) with soil nitrate levels measured after side dressing (Figure 6).

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

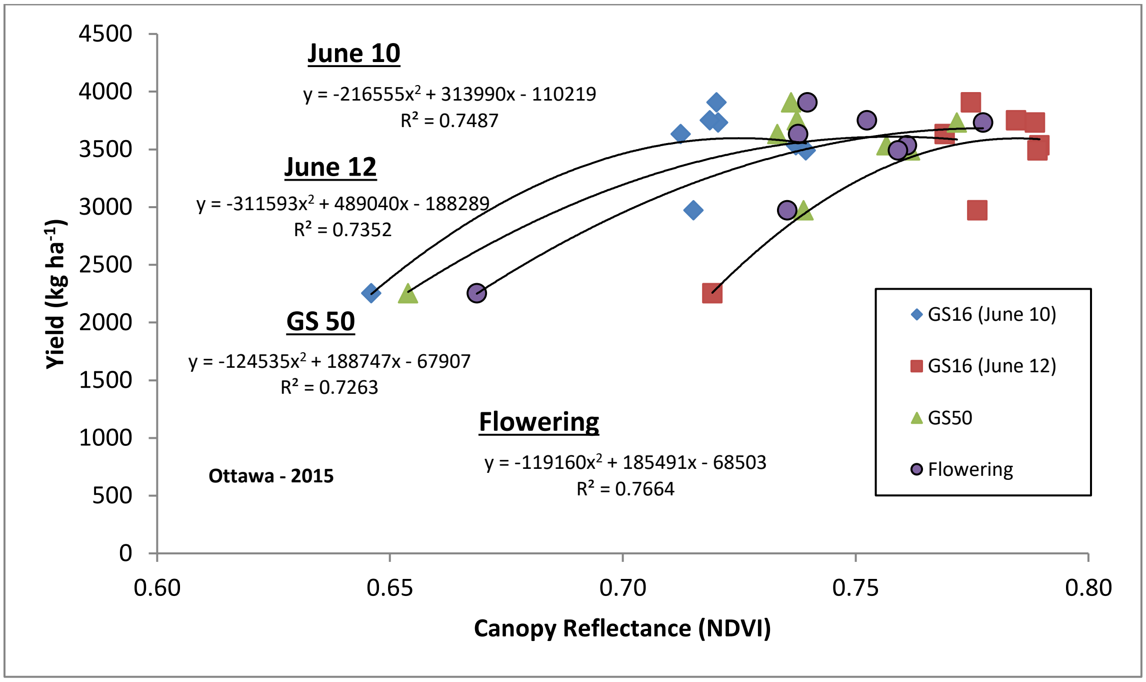


Figure 6. The relationship between canopy reflectance (NDVI) measured at 20% flowering and soil nitrate levels measured from plots that received pre-plant nitrogen rates of 0, 50, 100, 150, 200 kg ha^{-1} at the Ottawa site in 2013.

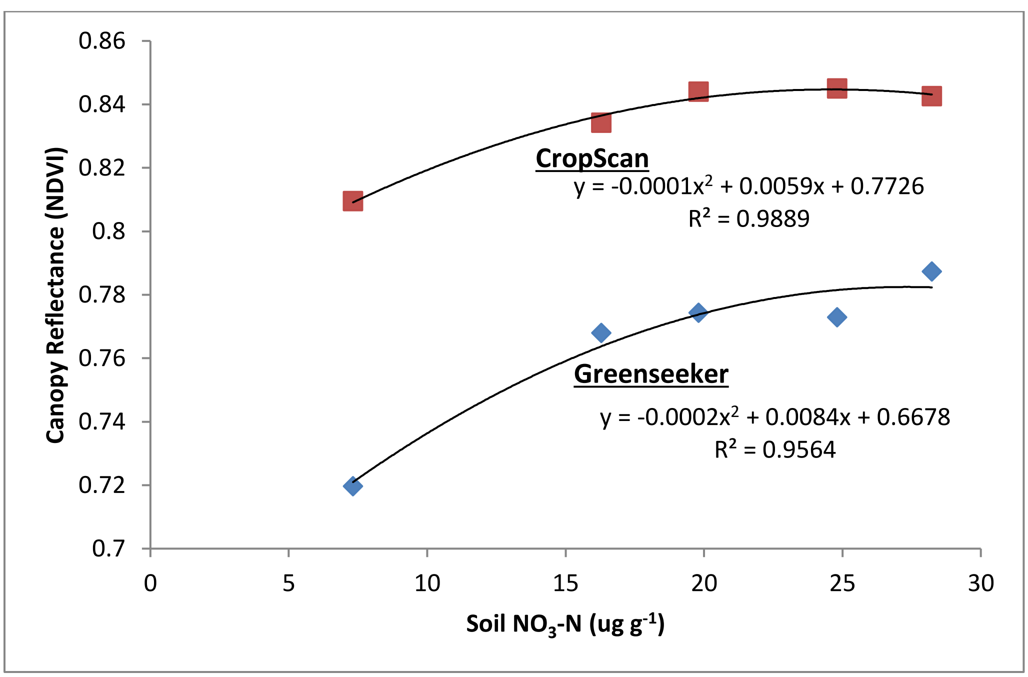


Table 15 shows that there is a very positive Pearson's correlation between yield and NDVI readings by both the Greenseeker and the Cropscan units from the seven leaf stage (June 17) to 20% flowering ($p \leq .001$).

Table 15. Pearson's correlation coefficients comparing CropsCan and Greenseeker NDVI with canola yields in the nitrogen fertility study in Ottawa.

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

Leaf Chlorophyll Readings

Values from the leaf chlorophyl meter (SPAD-502) were significantly affected by nitrogen as early as the four-leaf stage (GS14) in 2014 and 2015 (Table 16). SPAD readings increased significantly with increasing nitrogen rates (in many cases $p \leq .001$). Laval was the only site that did not see any effect of nitrogen on SPAD readings at an early stage in both years. In general, leaf chlorophyll metre readings were sensitive to N nutrition levels of the canola crop before side dress. 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} pre-plant level, when measured at GS-16 stage (Figure 7). This suggests that the chlorophyll metre could be used to monitor leaf N status and guide fertilizer N timing.

Table 16. SPAD readings taken pre-side dress as early as the four-leaf stage, at all locations in 2014 and 2015. Means with different letters in the same column are significantly different at the .001 [Ŧ], .01 [x] and .05 [∞] levels.

A) SPAD 2014

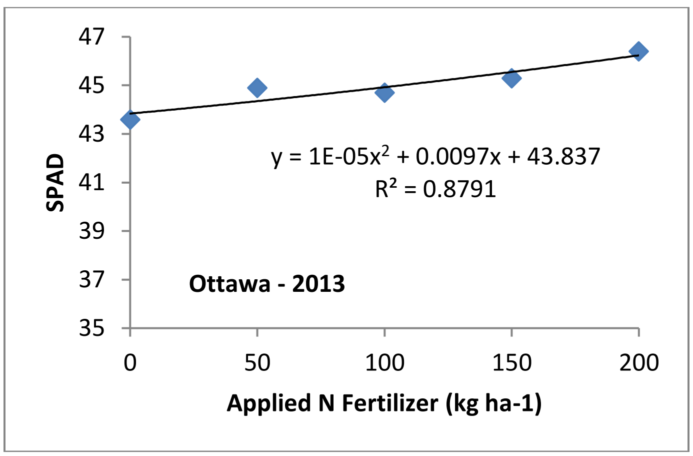
	Ottawa, ON			Elora, ON		Canning, NS	McGill, QC	Laval, QC
N (kg/ha)	**GS14**	**GS15**	**GS16**	**June 23**	**June 27**	**GS30**	**GS16**	**GS16**
17.5	37.3 b [c]	47.6 c [Ŧ]	48.6 c [Ŧ]	44.6 c[Ŧ]	39.7 c [Ŧ]	36.9 c [Ŧ]	45.8 b [∞]	41.3 a
50	35.9 c	50.7 b	49.1 b	46.7 b	42.5 b	40.9 b	46.9 b	41.7 a
100	37.3 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	5.2.9 a	48.7 a	44.3 a	41.2 b	48.0 a	42.2 a

B) SPAD 2015

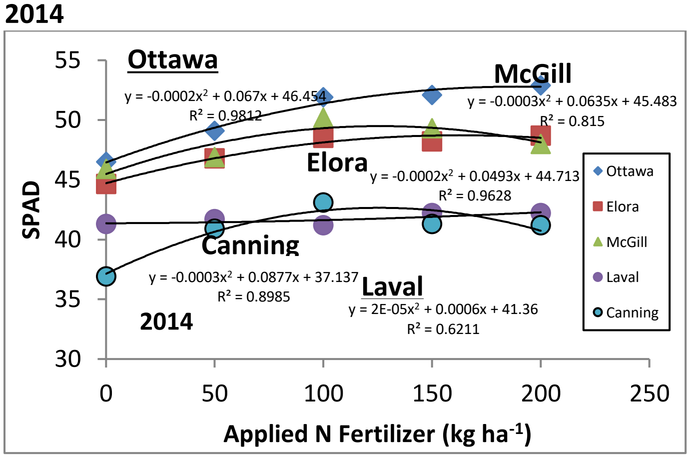
	Ottawa, ON			Elora, ON	Canning, NS	McGill, QC	Laval, QC
N (kg/ha)	**GS14**	**GS16**	**GS50**	**GS16**	**GS16**	**GS16**	**GS16**
17.5	43.7 c ⁊	42.5 c x	44.9 d ⁊	43.3	40.4 b x	47 b x	43.2
50	45.6 b	42.9 bc	46.5 cd	44.4	40.1 b	49 ab	43.6
100	47.4 a	43.7 abc	48.1 bc	45.2	42.3 a	50 ab	42.8
150	48.2 a	45.0 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

Figure 7. The relationship between leaf chlorophyll meter readings (SPAD-502) and pre-plant 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 and 2015.

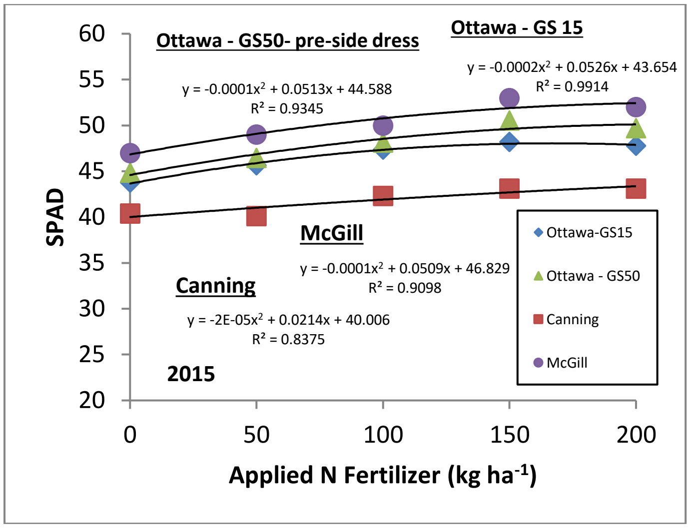
2013

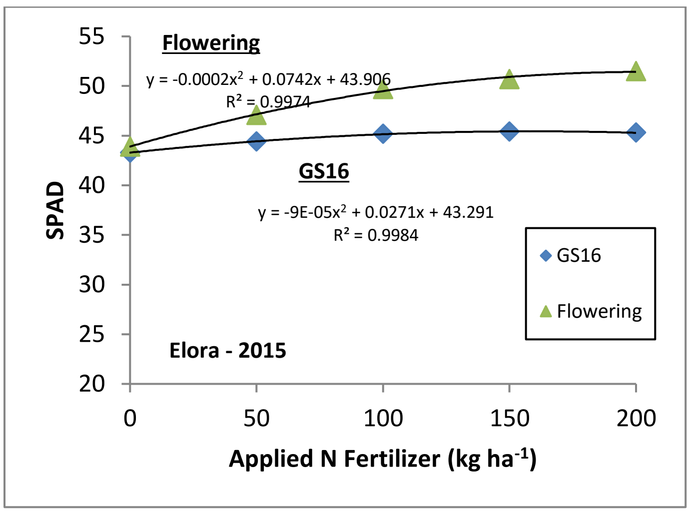


2014



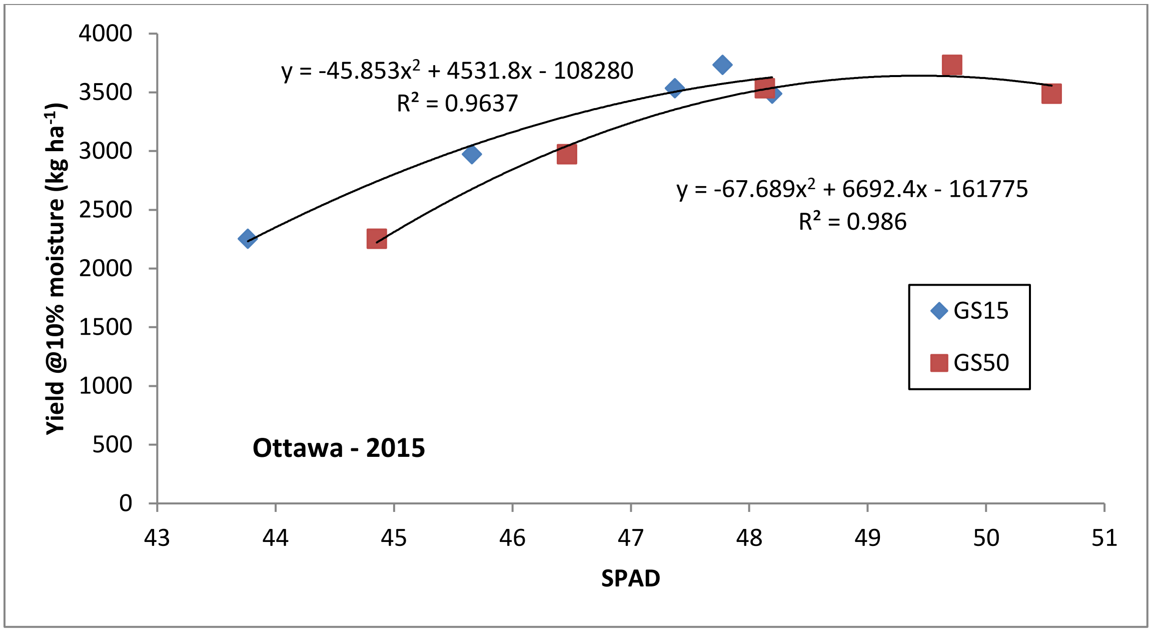
2015





There is a very strong correlation between early SPAD readings at the GS16 stage and the final yields (Figure 8) as seen at the Ottawa site in 2015.

Figure 8. The relationship between leaf chlorophyll readings (SPAD) and final yields at the Ottawa site in 2015.



Sulphur Fertility Study – Results

Ottawa, Laval, McGill, Elora and Canning all ran the sulphur (S) experiment for two or three years, depending on the site.

At all sites and years, the addition of S nutrient had no significant effect on harvest index, 1000-seed weight, number of branches and pods per plant. There was also no N by S interaction on any of these traits.

Only Ottawa 2015 had a significant effect of S on the number of seeds per pod with the increased numbers of seeds with increasing S added ($p \leq 0.001$)

Table 18. Number of seeds per pod for the Ottawa site in 2015. Means with different letters in the same column are significantly different at the .001 ₸.

Sulphur (kg ha^{-1})	**Ottawa, ON**
0	21 c ₸
10	22 b
20	22 b
40	23 a

All sites and years showed a positive increase in yields with increasing amounts of S added, most significantly so (Table 19 A, B & C). Elora in 2013 also showed a significant difference ($p \leq 0.05$) between S treatments, but it is not a linear relationship (Figure 8D).

Table 19. The effect of different levels of pre-plant sulphur in the form of ammonium sulphate on InVigor L150 (L140P in 2015) grain yields in 2013 (A), 2014 (B), and 2015 (C). 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 [Ŧ]	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 ab

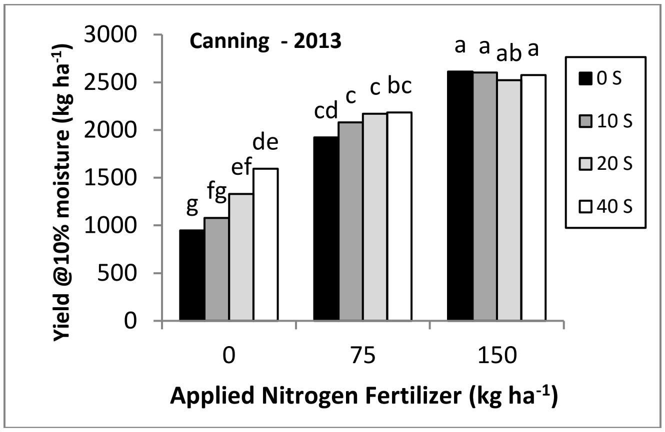
C) 2015

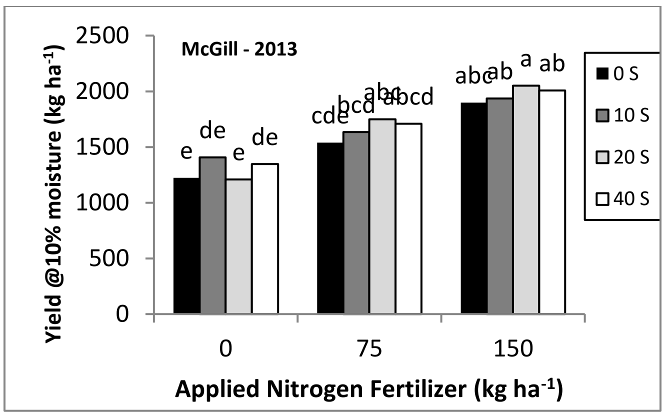
Sulphur (kg ha^{-1})	Ottawa, ON	Laval, QC	McGill, QC	Canning, NS	Elora, ON
0	3145 b [x]	2199 [x]	4210 b [x]	2704	2873.8
10	3056 b	2278	4199 b	2676	3022.2
20	3236 b	2410	4271 ab	2784	3207.9
40	3446 a	2552	4556 a	2991	3230.8

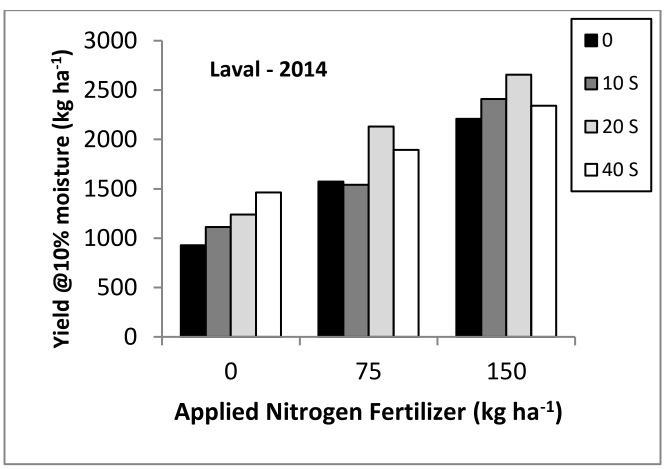
There were no S x N interactions at any site except Elora 2014. At this site canola yields increased ($p < 0.01$) with increasing S rates, but significant effect only seen at the high N rates (Figure 9A). At the Ottawa site in 2013 and 2014, InVigor L150 had a significantly high lodging score in the plots that received 150 kg N ha^{-1} ($p < 0.001$), but no lodging occurred in the 0 N plots. This may explain why there was no significant yield difference between the plots that received both 75 and 150 kg ha^{-1} nitrogen in 2013 (Figure 9D). In 2014, the lodging was so severe in the high N plots that the yields in the 150 kg N plots were the lowest (Figure 9).

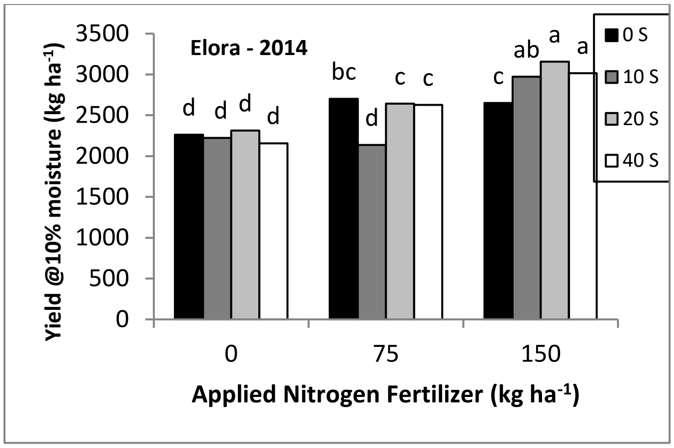
The addition of sulphur had no effect on lodging (data not shown).

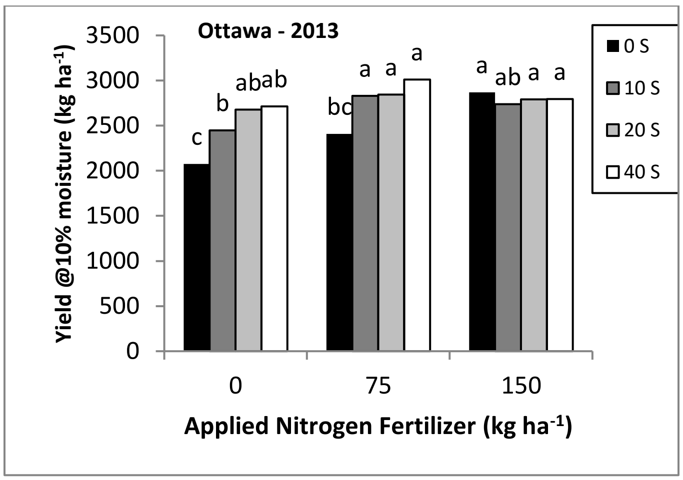
Figure 9. Comparing grain yield responses to the sulphur by nitrogen interaction at all sites.

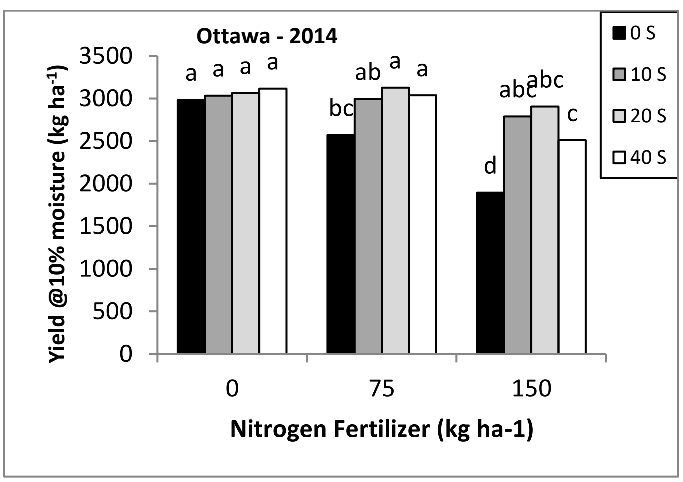


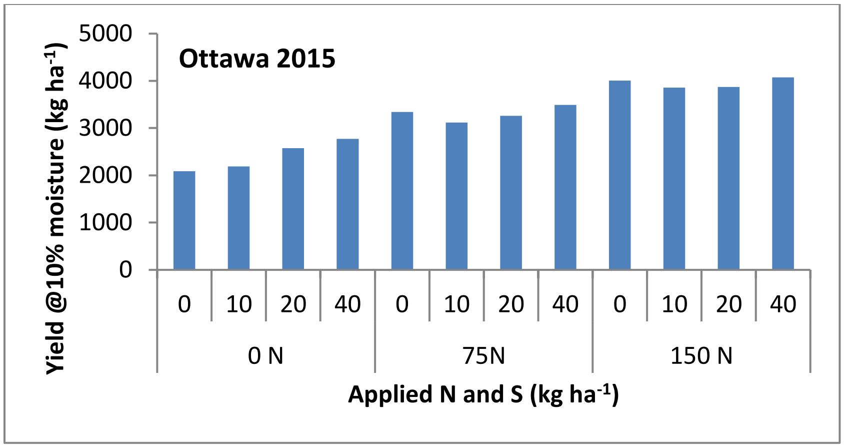





Elora - 2014
Yield @10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)
0 S
10 S
20 S
40 S
3500
3000
2500
2000
1500
1000
500
0
75
150
d d d d
bc d c c
c ab a a

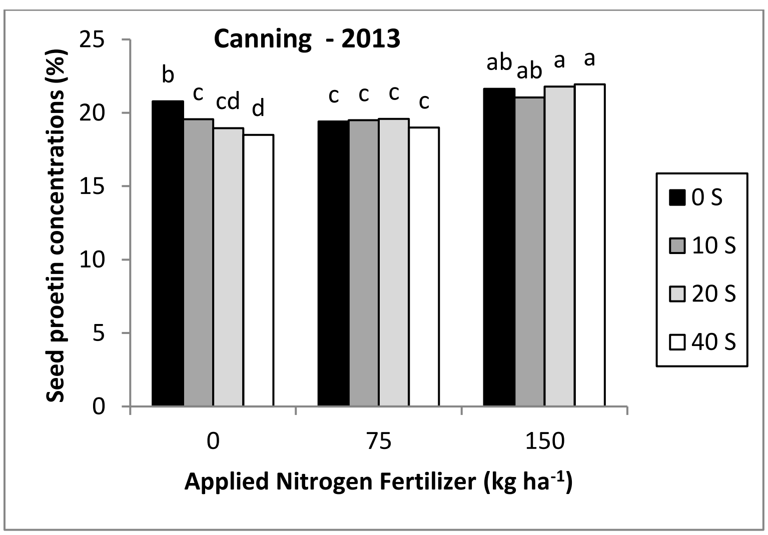

Ottawa - 2013
Yield @10% moisture (kg ha-1)
Applied Nitrogen Fertilizer (kg ha-1)
0 S
10 S
20 S
40 S
3500
3000
2500
2000
1500
1000
500
0
75
150
c b ab ab
bc a a a
a ab a a


Ottawa - 2014
Yield @10% moisture (kg ha-1)
Nitrogen Fertilizer (kg ha-1)
0 S
10 S
20 S
40 S
3500
3000
2500
2000
1500
1000
500
0
75
150
a a a a
bc ab a a
d abc abc c



Sulphur had no effect on oil concentrations for all years. There was also no effect of sulphur on protein concentrations except for Canning in 2013 where sulphur had a significantly negative effect on protein seed concentrations with the plots that received no sulphur having significantly higher protein concentrations than the plots that received sulphur ($p \leq .05$) (data not shown). There was a significant nitrogen x sulphur interaction ($p \leq .01$) on protein concentrations (Figure 10) where the addition of sulphur, especially in the 0 N plots reduced protein levels. This effect was not obvious in the high N plots.

Figure 10. Seed protein concentrations at different levels of nitrogen and sulphur fertilizers in Canning in 2013. The nitrogen x sulphur interaction was significant at the .01 level.



Boron Fertility Study – Results

At the Ottawa and Guelph sites, hybrid InVigor L150 had a significantly higher lodging score than InVigor 5440, causing its yields to be significantly lower ($p<0.001$) at both sites. This was due to the 100 kg N ha^{-1} added to all the plots. Boron did not have any effect on lodging. There was no lodging in 2015, because

InVigor L140P replaced InVigor L150.

For all years and all sites, the addition of pre-plant 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 pre-plant B or foliar B on seed oil and protein content.

Future Work

Additional funds are needed for the physical and chemical determinations of plant and soil samples in a common chemistry lab. This should be considered in future project applications.

Data collected so far and preliminary analysis of the 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 to meet the profitability required by the producers, and the safe and nutritious food and clean air, water and the environment with minimum nitrogen and carbon footprints, by the general public. As such research activities are generally in thepublic good, it would be unwise and non-sustainable to rely totally on industry-sponsors, especially for new crops such as canola in eastern Canada.

The experiment will be implemented again next year.