# AAFC RESEARCH BRANCH
## Research Project Final Report
Developing Innovative Agri-Products Program (Vote 1 Funding)

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| **RBPI Number:** | 2004 |
| **RBPI Project Title:** | Canola Nutrient Management |
| **Cluster Name (if applicable):** | |
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| **Principal Investigator (PI):** | Bao-Luo Ma |
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**Short Executive Summary of report:**


Field experiments were conducted across Eastern Canada to investigate the growth, yield and quality traits of canola crop to preplant and sidedress application of nitrogen (N) fertilizer as urea at various combinations with soil applied sulphur (S) as ammonium sulphate, and soil and foliar applied boron (B) in the form of Alpine Boron. A greenhouse experiment was also conducted on soils collected from three field sites (Ste- Anne- de- Bellevue, Ottawa, St-Augustin) to determine the impact of application of N, S and B on main soil quality indicators. Overall, the following conclusions can be drawn:

- Canola yields are highly dependent on weather, soil N and S fertility. There is also a definite yield advantage when the application of N was split between planting and the rosette stage. The addition of N fertilizer significantly increased canola yields.
- Sidedressed N fertilizer appeared to be better utilized by the crop and therefore producing greater yields than the crop that received equivalent amounts of N all at preplant. For every kg $ha^{-1}$ N fertilizer, yields increased on average by 9.7 kg $ha^{-1}$ for preplant application, but increased by 13.7 kg $ha^{-1}$ when sidedress N was applied later at the rosette stage.
- The severe drought that occurred in Eastern Ontario and Southern Quebec in 2012, increased variability and lower yield potential that inhibited detection of any yield response to N fertilizer rates, either preplant or sidedress application, indicating devastating drought effect on canola production.
- Preplant S at 20 kg $ha^{-1}$ in the form of ammonium sulphate significantly increased yields over plots that received no sulphur.

- The lack of difference in yields between plots with boron and plots that received no boron may indicate that the tested fields were sufficient in boron or soil boron was unavailable to the crop when it was needed. However there appeared to be a yield advantage when boron is applied foliarly at the 20% flowering stage, suggesting that the plants are very efficient at boron uptake through their leaves.
- Canopy reflectance measured by commercial instruments, CropScan, Greenseeker, or the UniSpec—DC, appeared to be a good indicator of the crop health. Canopy reflectance, expressed as normalized difference vegetation index (NDVI) values from these instruments were strongly correlated with the amounts of N added to the soil before seeding. NDVI readings at the rosette and 20% flowering stage are also strongly correlated to final yields. These data indicate that measurements of canopy reflectance have the potential to be used as a crop need-based indicator for guiding sidedress N application rates.
- Aboveground biomass at the 20% flowering stage and leaf area index (LAI) significantly increased with increasing amounts of preplant N, with the lowest LAI values in the 0 N treatment and the highest LAI readings in the 150 (2011) or 200 kg N $ha^{-1}$ (2012) plots. At the early flowering stage, the plots that received additional N at sidedressing (50+50, 50+100, 50+150 kg N $ha^{-1}$) had similar LAI and biomass values to the plots that received 50 kg $ha^{-1}$ preplant N, indicating that it took some time for the N to be hydrolyzed from the applied urea, taken up by the crop, and exhibited a positive effect on the plant growth.
- Plant heights, number of branches per plant, number of pods per plant, number of seeds/pod and number of seeds per plant all significantly increased with increasing the amounts of preplant N application.
- The seed from all sites was categorised as grade No. 1 canola seed as there was less than 2% distinctly green seed and less than 5% damaged seed (which includes the green seed) at the Ottawa site in both years, indicating high seed quality canola can be produced in Eastern Ontario.
- Nitrogen fertilizer significantly affects the protein and oil content of the seed. Increasing amounts of N generally increased seed protein concentration (meal quality), but actually suppressed seed oil concentration (oil yield) at all sites. This suggests that high level of N application could increase canola meal quality for animal feed, but may reduce the oil extraction rates.
- Soil amendment with sulphur had no effect on either oil or protein levels. However oil levels appeared to be lower in plots that received foliar boron compared to plots that receive no B or soil-applied B (2 kg $ha^{-1}$) at preplant.

- The drought conditions in Ottawa and Montreal in 2012 also affected the seed protein and oil concentrations, with higher protein and lower oil content in 2012 than those in 2011.
- Seed oil concentrations estimated by the Unity Scientific SpectraStar 2500x NIR spectrometer were generally lower than those measured by the Foss Infratec™ 1241 Grain Analyzer. Seed oil concentrations of the same samples estimated in 2011 and 2012 using the same instrument (Unity Scientific SpectraStar 2500x NIR spectrometer) differed by up to 4%, indicating that caution must be taken when interpreting the NIR spectroscopy results and timely and frequent calibration with chemistry procedures are necessary.
- Nitrogen concentrations in plant and seed components increased significantly with increasing amounts of N application ($P < 0.01$) with the highest N concentrations found in plants from plots that received sidedressed N. At early flowering stage, N concentrations of the whole plant were higher for fertilized plots than those receiving no or low N fertilizer, reflecting soil N supply power. At harvest canola seed contained much higher N concentrations than the straw, indicating that N has been translocated from the vegetative components to the grain during the grain filling period.
- Under drought conditions, plant straw at harvest contained much higher N concentrations (10-15 g $kg^{-1}$) than plants that were grown under more or less normal conditions (3-5 g $kg^{-1}$), indicating N remobilization under drought conditions was restricted. This will affect soil N transformation and soil N supplying power to the succeeding crop.
- Biofertilizers identified and screened at the controlled greenhouse conditions showed negligible effect on canola growth and final yield under field conditions. This is likely due to the fact that extreme drought that occurred in 2012 canola growing season had substantially suppressed canola yield potential and that there was a likely confounding effect between biofertilizer and drought stress.

**A. Research Progress and Accomplishments** (to date in relation to expected milestones and deliverables / outputs)

- Include brief summary of:
  - Introduction, literature review, objectives, milestones and deliverables / outputs.
  - Approach / methodology (summary by objectives).
- Include results and discussion (overview by objectives and milestones), next steps and references.

**INTRODUCTION**

The Eastern Canadian Canola Consortium (E3C) brings new economic well-being to the rural communities of Eastern Canada. The E3C is composed of the best Canadian plant science researchers, with a strong focus on dramatically expanding canola production in Eastern Canada. Industry partner TRT-ETGO provides the next link in the value chain, purchasing the harvested crop and processing it into oil for human consumption and biodiesel manufacture, and will interact with other commercial entities to see the oil to the market place. Canola provides two high value products: oil and protein. Because canola yields are as high as small grain cereal yields in Eastern Canada yet are worth more than twice as much per tonne the profit margins, often very thin with small grain cereals, are much greater with canola, providing a significant rejuvenation to the rural communities of Eastern Canada. Our research efforts are focused in three areas that establish the crop as a viable high value alternative to small grain cereals and provide a very beneficial rotation option for potato. The three general areas of research activity (E3C) are Oil Improvement (quantity and quality), Pest Management (diseases and insects) and Agronomy (nutrient management and production regime).

This project aims to address the canola nutrient management and production regime. Specific objectives are to determine the optimum rate and timing of N, S, biofertilizers (identified special strains of soil bacteria) and micronutrients including boron (B), on canola growth, yield and oil content; determine the influence of nutrient addition to canola on the health of soil physical, chemical and biological properties; monitor the dynamics of soil N, S and micronutrients as influenced by soil amendments; define the effect of major preceding crops on canola performance in Eastern Canada; and investigate the individual and interactive effects of seeding rate and N fertility on canola performance. Thus, this project will lead to the development of site-specific best management practices for growing canola in Eastern Canada.

**LITERATURE REVIEW**

*Brassica napus* is usually referred to as Argentine canola, rape, or rapeseed. It may be distinguished from other Brassicaceae based on the partial clasping of the stem by the auricles of the lower leaves, and the elevation of the floral buds above the open flowers on the terminal raceme (Bengtsson *et al.* 1972). *B. napus* is an allotetraploid with 19 haploid chromosomes and a 1200 mega base-pair (mbp) genome. Experimentally produced *B. napus* lines are referred to as amphidiploids (Howard 1942). *B. napus*'s set of chromosomes is derived from *Brassica oleracea* (n = 9, approximately 500 mbp) and *Brassica rapa* (n = 10, approximately 600 mbp, formerly known as *B. campestris*) (Barret *et al.* 1998). *B. napus* has the highest seed yield potential of the Brassicaceae crops, under favourable environmental conditions (Kimber & McGregor 1995).

Wild forms of *B. napus* grow in Denmark, on the beaches of Gothland in Sweden, and in The Netherlands, New Zealand, and the UK (Rakow 2004; Dixon 2007). It may have Mediterranean origins or several centres of evolution (Tsunoda 1980 in Rakow 2004). Cultivation of Brassicaceae

as oil crops can be traced back several thousand years in Asia and North Africa (Dixon 2007). The earliest literary references to sarson (*B. rapa*), of which at least three ecotypes grow on the Indian subcontinent, date from approximately 1500 BC (Singh 1958). Colombini *et al.* (2005) found Brassicaceae oil in lamps dated to the 5th to 7th centuries BC, from the Roman age of Egypt. Brassicaceae seed oil is slow-burning and odourless, and it fuelled lamps for the duration of the Middle Ages in Europe (Dixon 2007).
Scientific research on *B. napus* began in the late 1930s (Juska and Busch 1994). At that time, many countries developed national policies to promote self-sufficiency in production of fats and oils. In the early 1970s, responding to health concerns, Canadian breeders produced varieties with less than two percent erucic acid in the oil and less than 30 micromoles of glucosinolates per gram of air-dried oil-free meal. In 1979, these new varieties were given the name “canola”, *i.e.*, Canadian oil low acid.

**STRATEGY FOR CANOLA IN EASTERN CANADA**

Canola is well established as a very important crop in Western Canada. Indeed, in some years the canola crop has the highest cash value of all crops produced in Canada. However, Eastern Canada has lagged behind in adoption of canola. This has been for two reasons. Firstly, the distances to markets were large. The major seed crushing facilities were in the Hamilton area and this was sufficiently far from Eastern Ontario, Quebec and the Maritime Provinces to make the economics of the crop difficult. Secondly, because the economics were not practical there was little research effort focused on adapting the crop to Eastern Canada and improving its ability to grow and yield in this setting. Twin River Technologies – Enterprises de Transformation de Graines Oléagineuses du Quebec Inc. (TRT-ETGO) has finished construction of a large crushing facility at Bécancour that will dramatically alter the economic aspect of canola production in this part of the country. The E3C consortium addresses the crop adaptation and development aspect. This consortium will focus on genetic and management activities to enhance oil quality and management activities to improve canola yield in Eastern Canada.

**FOCUS**

TRT-ETGO is a canola and soybean crushing plant and oil refinery under construction within Parc Industriel de Bécancour in Centre du Québec. Upon completion the plant will focus on the production of vegetable oil for the food industry, oil for biodiesel manufacture and protein meal for the animal feed industries.

The capacity of the new oil seed crushing facility at Becancour in Quebec is one million tonnes per year, or some 3000 tonnes per day. Of this the plan is that about 40% will be soybean and about

60% canola. This will require a substantial increase in canola production in Eastern Canada. TRT-ETGO's current plan is to target an area encompassed by the Atlantic Provinces, Quebec and Eastern Ontario, reaching about as far west as Belleville. This area will have a clear advantage in terms of the increased proximity to crushing facilities provided by the facility at Becancour. However, it could also receive oilseeds from as far west as Saskatchewan and down into the New England area. There is already limited canola production in parts of Ontario, Quebec and New Brunswick, so that some sense of production practices etc. is available, however, until now there has not been the kind of systematic research effort required to substantially increase the potential of the crop in Eastern Canada. Through a combination of improved processing capacity in the region and focused research effort TRT-ETGO is projecting an increase in canola production of two fold in the Atlantic Provinces and four fold in Eastern Ontario and Quebec. This will provide some excellent alternatives to small grain cereals and a very useful rotation crop for potato. The higher prices for canola than for small grains will substantially improve the well-being of rural communities in these areas. The facility will produce edible oil and can also process oil seeds for the production of biodiesel.

## Activity B.5 – Nutrient Management

While canola is not a major field crop in Eastern Ontario, Quebec and the Maritimes, there is a market demand for growing this crop in the region. Canola seeds contain
> 40% oil. It is generally understood, that one unit of glucose, the initial product of photosynthesis, can make up 0.83 unit of carbohydrate or 0.4 unit of protein or 0.33 unit of oil. Clearly, as a non-legume cash crop, growing canola requires sufficient and timely supply of nitrogen (N) fertilizer and other macro- and micronutrients. However, excessive application of N not only causes negative environmental impact, it may cause crop lodging, reduce canola seed oil content and result in green seeds that increase the chlorophyll content of the seeds (Brennan et al., 2000; Karamanos et al., 2005; Rathke et al., 2005).

Currently, N represents roughly two thirds of farm nutrient use. In a typical grain-oilseed production system, on-farm fertilizer use represents > 60% of total energy input and is by far the single most cost of on-farm expenses. In general, N use efficiency (NUE) by crops ranges from 30 to 50% under various forms of crop and soil management (Raun and Johnson 1999). The rest of the N is lost to volatilization, denitrification, leaching, surface runoff and stabilization into soil organic matter and clay colloids (Malhi et al., 1996; Heaney et al., 1992; Nyborg et al., 1997). The estimated annual economic loss to Canadian farmers due to low NUE is, therefore, at a minimum \$680 M (assuming soil-crop systems are at steady-state and an average price of \$436 $ton^{-1}$ fertilizer-N).

Sulphur is an essential macronutrient and the fourth most important fertilizer input in agricultural systems (after N, P and K). It is well known to be an important and often limiting nutrient for canola production (e.g. Malhi & Gill, 2007) and S can improve NUE and canola seed yield (Karamanos et al., 2007). Sulphur is required for many physiological processes in plants including chlorophyll and protein synthesis. Sulphur also has an important ecological role in the defence of plants against pathogens and pests in many plants, especially in the order *Brassica* species. Canola has a relatively high requirement for S. Its deficiency can affect many growth processes leading to reduced yields. Even mild S deficiency may be symptomless, yet have negative effects on yield (Canola Growers Manual, 2003, Canola Council of Canada). Ironically, excess S availability has negative consequences on canola quality by resulting in higher levels of glucosinolates, an antinutritive factor in canola meal (Falk et al., 2007). In S deficient soils, it appears that balancing N and S nutrition of canola is important to achieving maximum seed yield (Mahli et al., 2005), and adequate supply of S to meet the crop requirement is essential for optimum seed yield and quality of canola at high N rates (Mahli and Gill, 2007). However, balancing N and S to a fixed ratio is unnecessary and wasteful for canola grown on soils with sufficient S (Karamanos et al., 2007). Boron (B) is a micronutrient which can limit canola yields (Malhi et al., 2003; Yang et al., 2009). The physiological role of B in the plant is not well understood. However, boron deficiency can result in decreases in root elongation, restriction in pollen tube growth and decreases in pollen production. These latter two symptoms are particularly important as they can result in very negative effects on fertilization and seed set and consequently in dramatically decreased yields (Shorrocks, 1997). Current soil test methods do not consistently predict responses to B fertilization in canola (Canola Growers Manual, 2003, Canola Council of Canada). This may be related to the fact that B availability in soil is significantly affected by numerous factors (e.g. pH, soil moisture, soil texture [particularly the levels of clay and organic matter], the availability of other nutrient [i.e. sulphur and potassium]).

Special strains of soil bacteria have been identified and tested for their potential to be used as plant growth promoting factor or biofertilizers. In a preliminary study, we have isolated several strains of biofertilizer bacteria that we have shown to improve uptake of key nutrients (most notably, phosphorus) and a set of rhizobacterial signals that improve plant growth by direct stimulation. However, the effect of these new biofertilizer bacteria on the growth of canola crop has not been tested.

Almost all of the fertility studies on canola in Canada have been done on prairie soils (i.e. black, brown, and grey cherozemic soils). While general fertility recommendations exist for canola production in Ontario (OMAFRA, 2002), Quebec (Simard et al., 2009), and the Maritimes (Davison et al., 2005), data on NUE by canola crop and responses of canola to boron and sulphur in soils native to Eastern Canada is lacking. Best management practices developed in the Canadian Western Prairie or elsewhere in the world for growing canola may not be applicable to Eastern Canadian situations, and a site-specific test for fertilization technologies is a prerequisite for adapting and growing canola as a viable crop in this region. The objectives of this proposed study are to

i) determine the optimum rate and timing of N and S fertilizer and micronutrients including boron (B) on canola growth, yield and oil content;
ii) determine the influence of nutrient addition to canola on the health of soil physical, chemical and biological properties;
iii) monitor the dynamics of soil N and the availability of S and micronutrients as influenced by soil amendments; and
iv) develop best management practices for growing canola in Eastern Canada.

# Materials and Methods

## Experimental Design and Treatments

A field experiment was conducted to determine the responses of canola (*Brassica napus*) crop to nitrogen, sulphur and boron fertilizers at six locations in Eastern Canada: 1) the Central Experimental Farm, Ottawa, ON, 2) MacDonald Campus of McGill University, in Sainte-Anne-de-Bellevue, Quebec, 3) the Potato Research Centre, Fredericton, New Brunswick, 4) Lyndhurst Farms Ltd, in Canning, Nova Scotia, 5) Laval University Research Farm, Laval, Quebec and 6) Elora Research Station, Elora, Ontario. 2012 is the third year of the canola fertility experiment for the Ottawa, Nova Scotia (Canning and Truro), and Ste. Anne-de-Bellevue sites, and the second year for the Fredericton (2011, 2012), Elora (2010, 2012) and Laval (2010, 2012) sites. A preliminary canola fertility trial was conducted at Ottawa, Sainte -de-Bellevue, Guelph, Laval and Nova Scotia Agricultural College in 2010. Detailed reports are attached as appendix I. In addition to the field trials, two controlled greenhouse experiments are ongoing in Saint Anne-de-Bellevue, started at the fall of 2011, to illustrate the role of micronutrients B and Zn and to determine the interaction of micronutrients and macronutrients on plant growth, yield and oil concentration of canola seeds. The protocols for the greenhouse experiments are attached as appendix II. Once the biofertilizers screened in the controlled greenhouse conditions became available, field trials were conducted at Ottawa, ON and Sainte-Anne-de-Bellevue, Quebec sites. Results are presented as appendix III.

At all sites, an unbalanced factorial experiment, testing combinations of different rates of nitrogen, sulphur and boron, was arranged in a randomized complete block design with four replications. Nitrogen in the form of urea (46-0-0) was applied at 0, 50, 100, 150 kg ha$^{-1}$, 50 kg ha$^{-1}$ preplant + 50 kg ha$^{-1}$ at rosette formation (growth stage (GS) 30; Weber and Bleiholder, 1990), and 50 kg ha$^{-1}$ preplant + 100 kg ha$^{-1}$. In 2012 two more N treatments were added: 200 kg ha$^{-1}$ and 50 kg ha$^{-1}$ preplant + 150 kg ha$^{-1}$ at rosette formation (GS 30). Any sidedressed N fertilizer was done by hand. Sulphur in the form of ammonium sulphate (21-0-0 with 24% S) was applied preplant at two rates: 0 and 20 kg $ha^{-1}$. To balance the nitrogen contained in the ammonium sulphate, 17.5 kg $ha^{-1}$ of urea was applied by hand to all the 0 N plots prior to planting. Boron in the form of Alpine Boron (10%), derived from boric acid, was made into a solution with water and applied preplant at two rates: 0 and 2 kg B $ha^{-1}$. A third level of foliar application at 500 g B $ha^{-1}$ in 200 L $ha^{-1}$ solution was made 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 boron through the foliage. In 2010 at the Ottawa and Ste-Anne-de-Bellevue site, there were only 16 treatments of preplant N, B and S arranged in a randomized complete block design with four replications. The treatments were N (0, 50, 100, 150 kg $ha^{-1}$), S (0, 20 kg $ha^{-1}$) and B (0, 2 kg $ha^{-1}$). No sidedressing was applied that year.

The canola hybrid Bayer InVigor 5440 (LL) was planted at a rate of 5 kg $ha^{-1}$ at a seeding depth of 1-2 cm. In 2010 Pioneer 45H26 (RR) was planted at the Ottawa site. The size of the plots varied amongst the sites depending on the number of rows of canola, row widths and lengths. Row widths ranged from 12.5 cm to 17.8 cm. Weeds were controlled with herbicide “Liberty” (post emergence) at various rates at all sites. In Ottawa, just before harvest in 2012, Gramoxone at 2 l/ha was used to remove any green growth. Planting and management practices at each site are shown in table 1.

Table 1. Planting dates, plot dimensions and herbicide treatments for the experiment in Ottawa, Saint Anne-de-Bellevue, Frederiction, Canning, Elora and Laval for all three years.

| Location | Ottawa 2010 | 2011 | 2012 | Ste- Anne-de- Bellevue 2010 | 2011 | 2012 | Fredericton 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|
| Planting Date | May 12 | May 11 | May 14 | May 28 | May 12 | May 7 | June 3 | May 28 |
| No. of rows seeded | 12 | 16 | 16 | - | 14 | 14 | 10 | 10 |
| Row Length (m) | 8 | 8 | 10 | 5 | 4 | 4 | 10 | 10 |
| Herbicide | Round-Up Ultra | Liberty 200 SN | Liberty 200 SN | Liberty 150 SN | Liberty 150 SN | Liberty 150 SN | Liberty 200 SN | Liberty |
| Herbicide Rate | 1.25 l $ha^{-1}$ | 2.5 l $ha^{-1}$ | 2.5 l $ha^{-1}$ | 2.5 l $ha^{-1}$ | 2.5 l $ha^{-1}$ | 2.5 l $ha^{-1}$ | 2 l $ha^{-1}$ | 2.5 l $ha^{-1}$ |

| Location | Canning 2011 | 2012 | Elora 2012 | Laval 2012 |
|---|---|---|---|---|
| Planting Date | May 4 | May 17 | May 8 | May 5 |
| No. of rows seeded | 16 | 16 | 7 | 9 |
| Row Length (m) | 5 | 6 | 5 | 5 |
| Herbicide | Liberty 200 SN | Liberty 200 SN | Rival (preplant) | Liberty 200 SN |
| Herbicide Rate | 2 l $ha^{-1}$ | 2 l $ha^{-1}$ | 2 l $ha^{-1}$ | 2 l $ha^{-1}$ |

Preplant soil samples (0-30 cm) were analyzed for all sites and results are shown in table 2. Amounts of P and K were applied to each site according to their preplant soil test results. For example, in 2011 at the Ottawa site, both P and K at 50 kg $ha^{-1}$ each as 0-20-20 were broadcast and incorporated into the soil on all plots before seeding. In 2012 no P or K was needed.

### Sampling and Data Collection

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).

**a) Soil Sampling**

Soil mineral N ($NO_3$- and $NH_4$+) and available S and B were measured from soil samples collected at all sites to a depth of 30 cm using the JMC Backsaver soil sampler just before N sidedressing, at 20% flowering (GS 62), and after harvest. These soil samples were taken from eight treatments (0N, 0N +S, 0N + soil B, 0N + foliar B, 150 N, 150N + S, 150N + soil B, and 150N + foliar B) in two replications. The soil samples have been analyzed after extracting them in a 2 *M* KCl solution and then by determining ammonium and nitrate with the Lachat QuikChem Flow Injection Analysis system (8000 series) at the Central Experimental Farm Lab in Ottawa. The soil samples have been analyzed for B and S at McGill University. The soil B is extracted using hot water. Organic carbon interferences are removed using charcoal. The extracts are analyzed for B on a microplate using the Azomethine-H method. Buffers containing EDTA and ascorbic acid are added during the process to remove any possible interference. A method to quantify $SO_4^{2-}$ in soil extracts has been under development at McGill University.

Table 2. Results of preplant soil samples (0-30 cm) taken at all 6 sites in the springs of 2010, 2011 and 2012.

| **Location** | **Ottawa** 2010 | **Ottawa** 2011 | **Ottawa** 2012 | **Ste.- Anne-de-Bellevue** 2011 | **Ste.- Anne-de-Bellevue** 2012 | **Fredericton** 2011 | **Fredericton** 2012 | **Canning** 2011 | **Canning** 2012 |
|---|---|---|---|---|---|---|---|---|---|
| Soil Type | Sandy Loam | Sandy Loam | Sandy Loam | Sandy Loam | Sand | Loam | Sandy Loam | Sandy Loam | Sandy Loam |
| Preceding crop | | Barley | Soybean | Wheat | Fallow | Forage | Hay | Spring Wheat | Winter Wheat |
| Soil pH | 6.3 | 7.1 | 6.5 | - | 6.1 | 5.8 | - | 6.5 | -- |
| Organic Matter (%) | 3.7 | 2.6 | 4.03 | - | 2.2 | 1.8 | - | 3.5 | -- |
| Sodium bicarbonate soil test P (ppm) | 86 | 34 | 114 | - | 42.7 | 318 | - | 412 | -- |
| Ammonium acetate soil test K (ppm) | 133 | 60 | 127.7 | - | 86.6 | 205 | - | 120 | -- |

| **Location** | **Elora** 2012 | **Laval** 2012 |
|---|---|---|

| Soil Type | Guelph Loam | Sandy Loam | |
|---|---|---|---|
| Preceding crop | Soybean | Wheat | |
| Soil pH | 7.8 | 6.1 | |
| Organic Matter (%) | 4.2% | 3.7 | |
| Sodium bicarbonate soil test P (ppm) | 24 | 197 | |
| Ammonium acetate soil test K (ppm) | 57 | 345 | |

- Not available

**b) Canopy Reflectance Measurements**

Canopy reflectance measurements (NDVI) were collected with the Greenseeker Hand Held Optical Sensor Unit (Model 505) and the *CROPSCAN Inc (2011 only)* at the Ottawa site and with the UniSpec-DC Spectral Analysis System (PP Systems) at the Elora site. Multispectral radiometer readings were taken just before N sidedressing and at the 20% flowering stage in Ottawa and just before sidedressing in Elora. 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 = near infrared (760) – red (660)/ near infrared (760) + red (660).

These NDVI values were used to indicate the health status of each plot.

**c) Plant Biomass and Leaf Area Measurements**

Plant biomass was determined by collecting five plants at the 20% flowering stage.
The leaf area index (ratio of foliage area to ground area) of the canopy was determined with two different methods in Ottawa:
a) nondestructive measurements using the LI-COR LAI-2000 Plant Canopy Analyzer at the time of N sidedressing in June, and at 20% flowering; and
b) destructively by measuring total leaf area using the LI-3100 leaf area metre on the five plants collected for biomass measurements 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 corn 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. According to the instrument manual, measurements of LAI were taken when there was cloud cover, but in the case of a sunny day, bodies were used to create shade.

**d) Harvest Index, Yield and Moisture Measurements**

At physiological maturity, plants were collected from a 1 m x 2 rows 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 plants per plot were also collected to determine number of pods/per plant, seeds/pod and 1000-seed weight. 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.

**e) Plant/Grain Nitrogen, Boron, Sulphur Concentrations**

Analysis of grain and plant samples for total N and P concentrations took place at the Central Chemistry Lab of the Eastern Cereal and Oilseed Research Centre, AAFC in Ottawa, by digesting samples using the Kjeldahl method and determining %N and %P with the Lachat QuikChem ® Flow Injection Analysis system (8000 series). Plant tissue B and S concentrations were determined at McGill University. Plant tissues are ashed and resolubilized using an acid mixture. The extract is then analyzed for boron on a microplate using the Azomethine-H method. Buffers containing EDTA and ascorbic acid are added during the process to remove any possible interference.

**f) Grain Oil and Protein Measurements**

In 2011, grain percent oil and moisture were determined in Ottawa by taking a small seed sample from each plot and analyzing it with the Foss Infratec™ 1241 Grain Analyzer with a Sample Transport Module. A top load cuvette with a path length of 6 mm was used to hold the seeds. The cuvette was inserted into the machine, and which gave an average of percent oil and percent moisture from 10 subsamples. In 2012, the samples were analyzed for oil in Truro, Nova Scotia, using a Unity Scientific SpectraStar 2500x NIR spectrometer. Protein was also determined using the same spectrometer in both years.

**g) Seed Quality Measurements**

In 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 (2012), a canola counting paddle, which holds 100 seeds, a roller, and double sided masking tape were used to crush the seed to better determine the colour differences. Two 100-seed samples per plot were used. Following are the procedures:

1) from a bulk sample of combine harvested canola a 100 cell canola sample paddle was inserted and a random sample was extracted.
2) The sample was removed from the paddle with a strip of masking tape with all the seeds being held to the tape strip.
3) A glycine bag was placed over the sample and the sample was then slightly crushed using a Canola rolling pin (Seedburo Equipment)
4) The sample was then compared to the Canola damage Guide published by the Canola Council of canada and the results recorded.
5) Procedure was repeated for another replication.

**Data Analysis**

Because the experiment was an unbalanced factorial design, the data was analyzed in three different ways: 1) general linear model (GLM) procedure of statistical analysis system (SAS), which includes the statistical methods of analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA) to estimate partial correlation coefficients, 2) MIXED procedure of SAS to analyze the split verses preplant N application rates using the LSMEANS statement with the print difference (PDIFF) option, and 3) genotype plus genotype-by-environment (GGE) Biplot software to look at the relationship of yield and agronomic traits among year-sites to identify yield limiting factors.

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

Assuming average grain price to be \$0.50 $kg^{-1}$ and fertilizer N cost at \$1.00 $kg^{-1}$ N, the maximum economic rate of N (MERN) was calculated for the sites that had a yield response to N, taking into account the current cost of nitrogen and 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 (Ymax) 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

$$B = N\ Cost/Grain\ value = 1/0.5 = 2 \qquad (4)$$

# Results

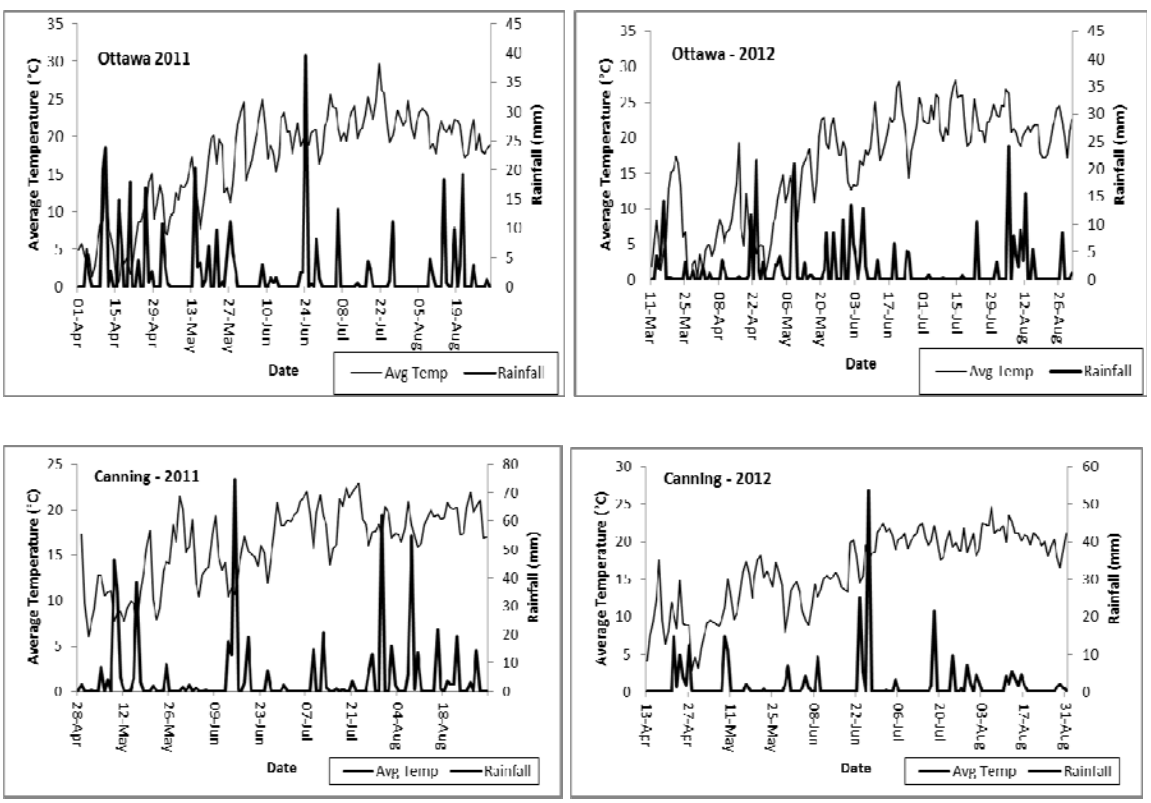
## Phenological Progression

In 2011, even with the extremely wet weather in May, seeding of the canola occurred more or less during the normal time at the Ottawa, Saint-Anne-de-Bellevue and Canning sites. However, seeding did not occur until June in Fredericton. In Ottawa, it was a very cold, wet spring with a total rainfall of 135 mm and average temperature of 7°C from April 4 to May 4 (Fig. 1). June had a lot of rainfall with a record rainfall of 39.5 mm on June 24. None of the sites had any significant problems with insect damage due to flea beetles. In Ottawa, by the middle of July, Japanese beetles were found eating some of the flowers and small pods. In Canning, there was some minor *Sclerotinia*. There was no lodging at any of the sites.

In 2012, Ottawa had a very early spring. March was very warm with maximum temperatures reaching the high 20s by the middle of the month, causing the snow to disappear quickly (Fig. 1). June and July were extremely dry with only 25.4 mm of rain from June 20 to Aug 4. By July 16, the Ottawa area was having a stage 2 drought. Soil moisture also decreased through the summer reaching extremely low water content levels in June and July (Fig. 1). In 2012 there were no signs of flea beetles or Japanese beetles at any of the sites.

In 2012, Canning did not experience the drought conditions of Ottawa or Montreal and received rain at the appropriate times during the grain filling period.

The Laval site also received appropriate rainfall throughout the growing season of 2012.



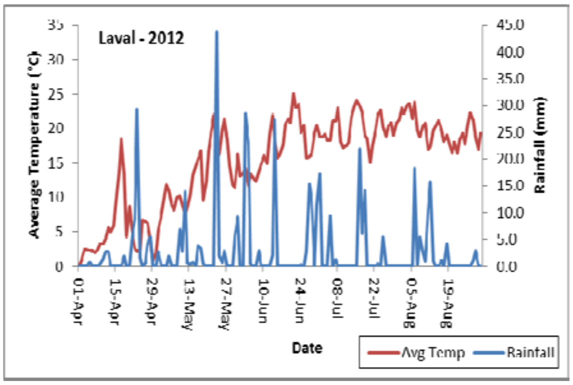



Fig. 1. Average spring and summer temperature and rainfall for 2011 and 2012 at the Central Experimental Farm in Ottawa, ON, Laval, QC, and Canning, NS.

Emergence and phenology data are shown in table 3.

Table 3. Dates of the phenological stages of the canola at the six sites in 2010, 2011 and 2012.

| **Location** | **Ottawa** | | | **Saint-Anne-de-Bellevue** | | **Laval** |
|---|---|---|---|---|---|---|
| | **2010** | **2011** | **2012** | **2011** | **2012** | **2012** |
| **Emergence** | May 19 | May 20 | May 14 | May 19 | May 24 | May 18 |
| **GS 51 (sidedress N)** | Not Done | June 14 | June 7 | - | June 13 | June 11 |
| **20% Flowers (GS 62)** | June 21 | June 20 | June 22 | June 27 | June 26 | June 21 |
| **Maturity** | Aug 3 | Aug 2 | Aug 8 | Aug 17 | Aug 6 | - |

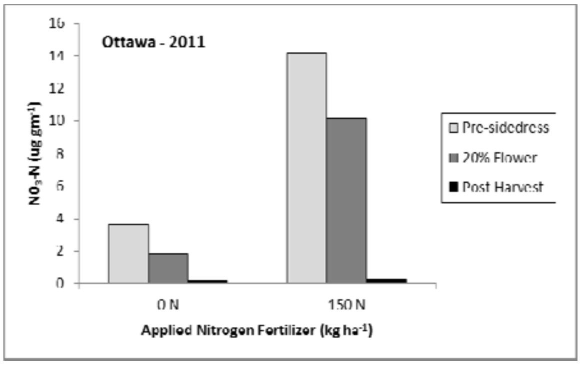
| **Location** | **Guelph** | **Fredericton** | | **Canning** | |
|---|---|---|---|---|---|
| | **2012** | **2011** | **2012** | **2011** | **2012** |
| **Emergence** | May14 | June 7 | June 9 | May 9 | May 24 |
| **GS 51 (sidedress N)** | June 21 | | July 3 | - | June 26 |
| **20% Flowers (GS 62)** | June 28 | June 11 | July 2 | June 20 | July 6 |
| **Maturity** | Aug 1 | Sept 12 | | Aug 18 | Aug 18 |

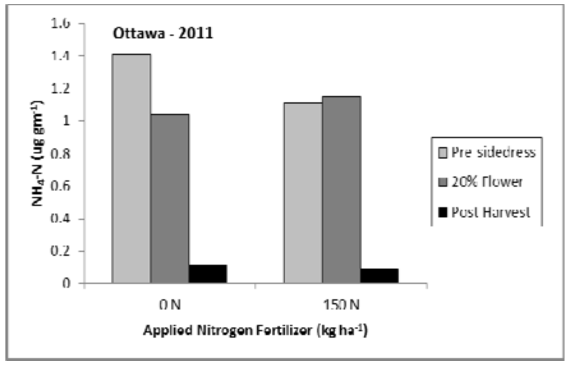
## Soil Nutrient Status

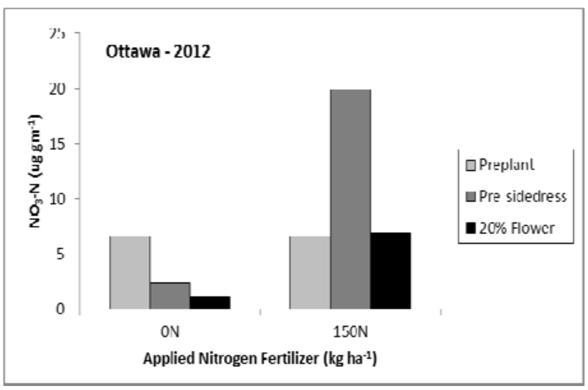
Results for soil samples were received from Ottawa, Laval, Ste-Anne-de-Bellevue and Elora. Soils from Canning and Fredericton still need to be analyzed for nitrate and ammonium. In 2011, in Ottawa, preplant soil samples taken in May indicated that the soil contained low mineral N with 3.5 µg $g^{-1}$ of nitrate-N and 1.3 µg $g^{-1}$ of ammonium -N (data not shown). In 2012, the average preplant values for nitrate-N and ammonium N were 6.5 and 2.5 ug $g^{-1}$ respectively (soybean was the previous crop). At early flowering, soil nitrate and ammonium concentrations were generally higher in the plots that received 150 kg N $ha^{-1}$ (Fig. 2). The levels of soil nitrate and ammonia decreased throughout the growing season.

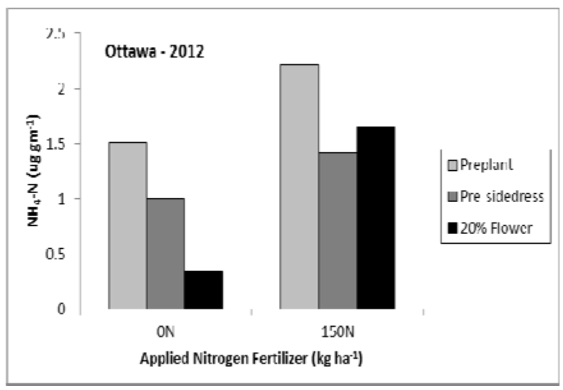
## Nitrate

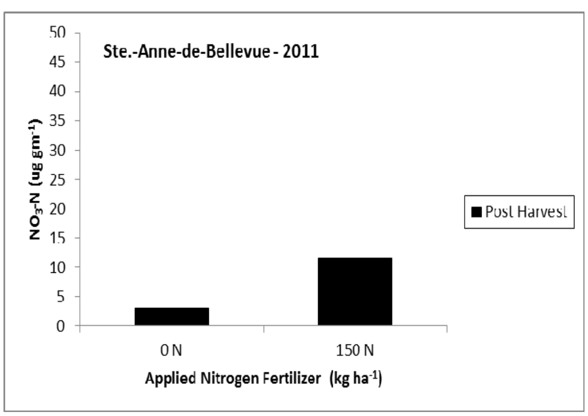
## Ammonium

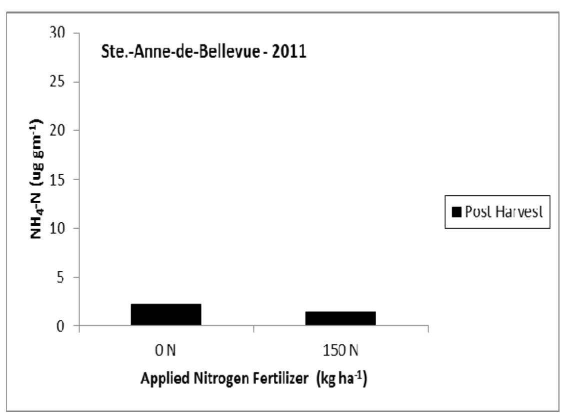


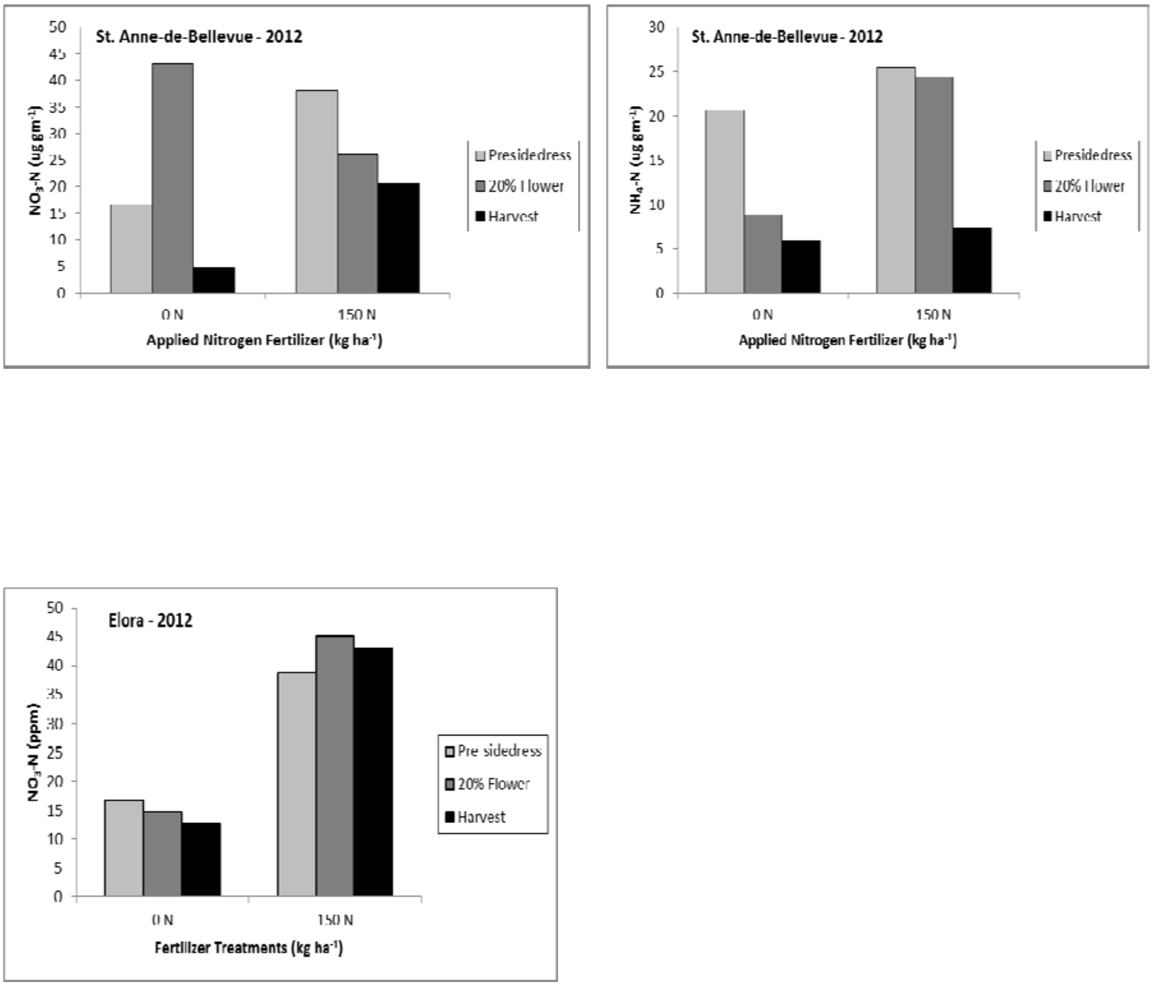



Fig. 2. Means of nitrate ($NO_3$-N) and ammonium ($NH_4$-N) concentrations of soil samples (0-30 cm depth) taken in the 0 and 150 kg N $ha^{-1}$ plots before sidedressing, at the 20% flowering stage, and after harvest in Ottawa in 2011, Ste.- Anne-de-Bellevue in 2011 and 2012 and Elora in 2012. In 2012 of Ottawa site, sampling occurred preplant, before sidedressing and at 20% flowering.
(note: the Elora data is reported in units of ppm)

The only results for soil boron are from Canning (Fig. 3). All other samples for boron and sulphur still need to be analyzed. In Canning, the plots that received 2 kg $ha^{-1}$ boron had the highest values for soil B both at sidedressing and at harvest. The plots that received foliar B also had higher soil B levels than the plots that received no boron.

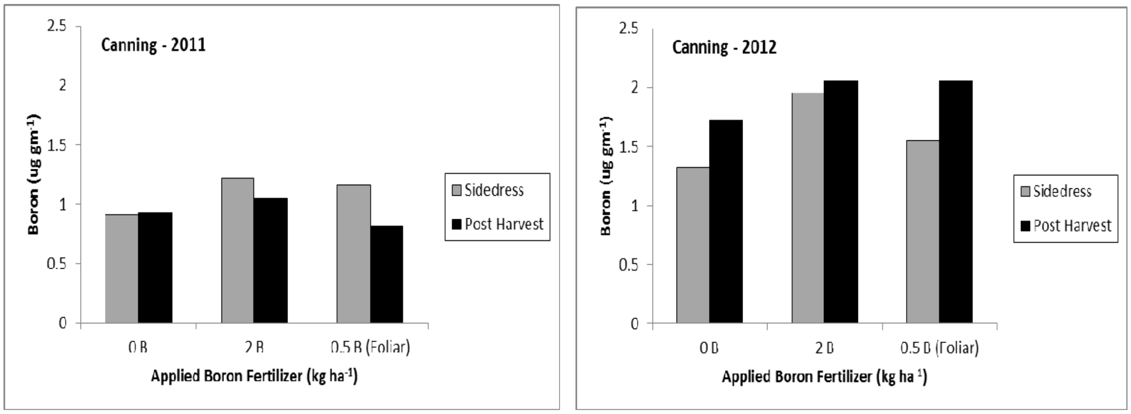



Fig. 3. Soil boron (ug $gm^{-1}$) results of samples taken at sidedress and after harvest for 2011 and 2012 in Canning, Nova Scotia.

## Plant Biomass and Leaf Area Index

In Ottawa and Laval, aboveground plant biomass at 20% flowering significantly increased with increasing amount of preplant N at rates of 0, 50, 100, 150 and 200 kg $ha^{-1}$ ($p\leq.001$) (Fig. 4). The plots that received additional N at sidedressing (50+50, 50+100, 50+150), had similar biomass results as the plots that received 50 kg $ha^{-1}$ preplant N, indicating that the N may not have been utilized to its full potential by 20% flowering. Because of the warm weather in 2012, plant biomass was 60-80% greater in 2012 than in 2011 at the Ottawa site.

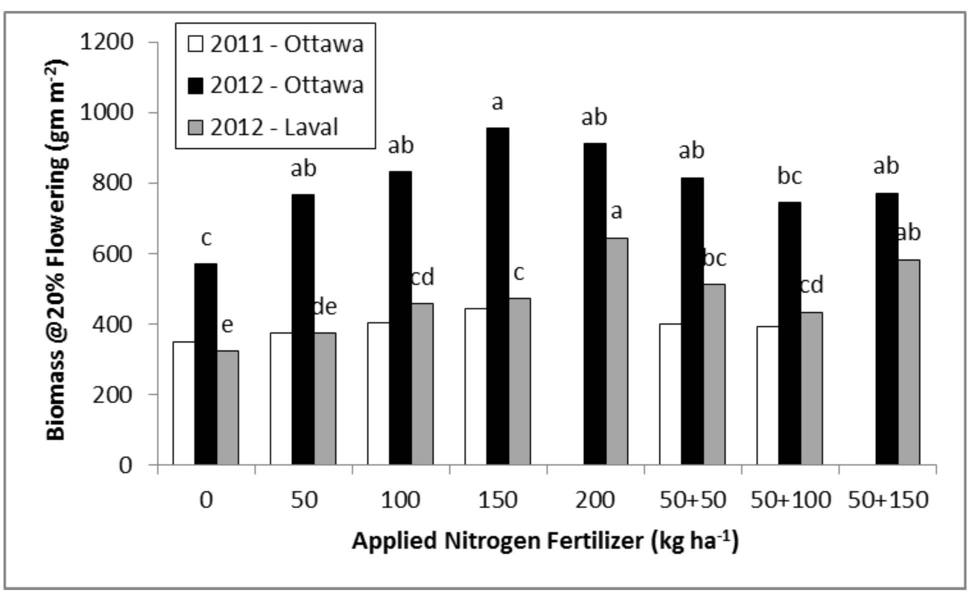



Fig. 4. Aboveground plant biomass at 20% flowering for both 2011 and 2012 in Ottawa and for 2012 in

Laval. Means with different letters in the same site-year are significantly different at the 0.001 level.

For both years, LAI significantly increased with increasing amounts of preplant N applied to the soil, with the 0 N plots having the lowest LAI readings and the plots that received 150 (2011) and 200 kg N $ha^{-1}$ (2012) having the highest LAI readings (Fig. 5). The plots that received additional N at sidedressing (50+50, 50+100, 50+150), had similar LAI readings to the plots that received 50 kg $ha^{-1}$ preplant N. LAI values in Ottawa in 2012 were nearly twice as much as those in 2011, again due to the warm weather.

There were no significant LAI differences between plots that received different amounts of sulphur or boron (data not shown).

## Plant Height, Yield Components, Seed Yield and Quality Traits

For most of the sites and years, the addition of N significantly increased plant heights (table 4a). The plots that received no N had the shortest plants, and those plots that received 150 or 200 kg $ha^{-1}$ had the tallest plants. Plant heights also increased with increasing amounts of sidedressed N, but were not significantly bigger than the plants that received equivalent amounts of preplant N, indicating that sidedressed N may have been more available for reproductive growth than preplant nitrogen.

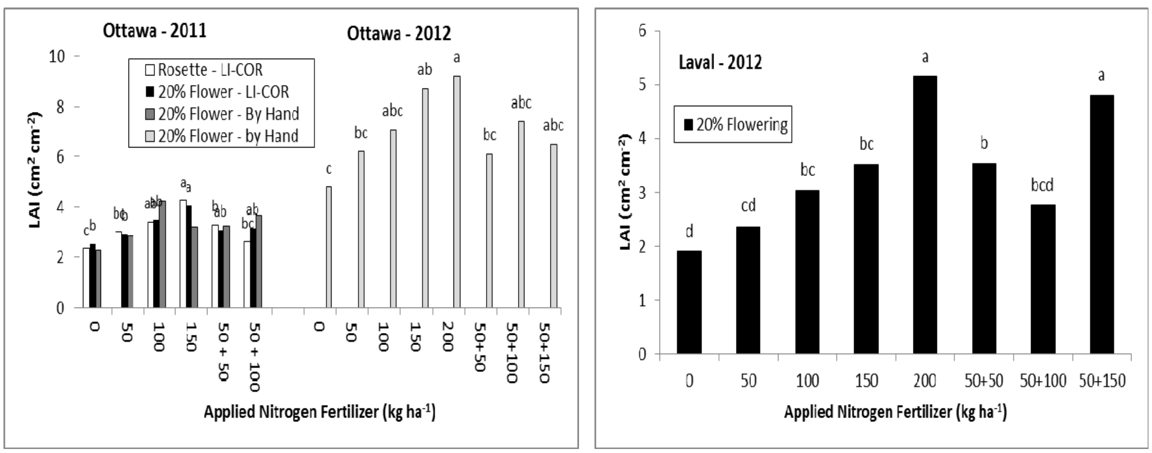



Fig. 5. Effects of different N fertilizer levels on the leaf area index (LAI) measured two ways in Ottawa (2011 & 2012) and Laval (2012): a) with the LI-COR LAI-2000 Plant Canopy Analyzer just before sidedressing of N and at the 20% flowering stage, and
b) destructively by hand both years using the LI-COR 3100 Leaf Area Metre. Means with different letters within a site-year are significantly different at the 0.001 level.

The number of branches tended to increase with increasing preplant N application, with the 0 N plots having the least number of branches (table 4b). For some sites (Ottawa, Fredericton, Canning, and Elora 2012) this increase in number of branches was significant. Adding sidedressed N did not show a significant increase in branches.

There was no significant correlation between N treatments and 1000-seed weight (table 4c). Only the site at Canning, NS, in 2012 showed an increase in seed weight with increasing amounts of preplant N ($p \leq 0.001$).

For most sites and years, increasing amounts of preplant N significantly increased the number of pods per plant, number of seeds per pod and number of seeds/plant, in that the 0 N plots had the lowest values and the 150-200 kg ha$^{-1}$ plots had the highest values (table 4d, e, f). An equal, positive correlation between the addition of sidedressed N and these same traits wasn't observed. The seed yield to total plant biomass ratio (harvest index) tended to increase with increasing amounts of preplant and sidedressed N applied to the soil (table 4g), on some sites more significantly than on others (i.e. Ottawa, St Anne-de-Bellevue, $p \leq 0.001$). At several sites, sidedressing at 100 and 150 kg N ha$^{-1}$ significantly increased harvest index values compared to the plots that received only preplant N.

The application of ammonium sulphate and boron had no significant effects on plant heights, harvest index, 1000-seed weight, number of seeds/plant, number of pods per plant or number of seeds per pod for both 2011 and 2012 (data not shown).

Table 4. Nitrogen effect on a) plant height, b) number of branches, c) 1000 seed weight, d) pods per plant, e) seeds per pod, f) seeds per plant, and g) harvest index of canola grown in Ottawa, Saint - Anne-de-Bellevue, Fredericton, Canning, Elora, and Laval for both years.

**a) Plant Heights (cm)**

| Nitrogen (kg ha$^{-1}$) | Ottawa | | Saint - Anne-de-Bellevue | | Fredericton | | Canning |
|---|---|---|---|---|---|---|---|
| | 2011 | 2012 | 2011 | 2012 | 2011 | 2012 | 2011 |
| **0** | 163.4 c [ŧ] | 123.7ab [∞] | 107.5 d [ŧ] | 116.1 ab | 124.8 b [ŧ] | 115.7 d [ŧ] | 83.8 c [ŧ] |
| **50** | 173.9 bc | 124.4 ab | 108.9 cd | 118.5 ab | 130.9 b | 120.7 cd | 96.8 b |
| **100** | 186.8 a | 127.7 ab | 112.9 cb | 116.7 ab | 138.9 a | 125.5 bc | 103.8 a |
| **150** | 190.9 a | 131.2 a | | 117.7 ab | 140.1 a | 129.0 ab | 109.5 a |
| **200** | | 129.3 ab | | 121.4 a | 143.3 a | 133.8 a | |
| **50 + 50** | 175.4 b | 122.3 b | 108.8 d | 113.1 b | 142.3 a | 125 bc | 96.3 b |
| **50 + 100** | 188.2 a | 122.3 b | 114.4 ab | 112.5 b | | 123 bc | 95.3 b |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **50 + 150** | | 131.0 a | | 116.9 ab | | 125 bc | |

| Nitrogen (kg ha$^{-1}$) | Elora 2012 | Laval 2012 |
|---|---|---|
| **0** | 98.5 a | 101.7 f [Ŧ] |
| **50** | 104.3 a | 107.0 def |
| **100** | 106.4 a | 110.7 bcd |
| **150** | 105.8 a | 114.6 abc |
| **200** | 105.8 a | 118.0 a |
| **50 + 50** | 103.0 a | 109.5 cde |
| **50 + 100** | 102.0 a | 103.5 ef |
| **50 + 150** | 105.7 a | 116.5 ab |

## b) Number of Branches/plant

| Nitrogen (kg ha$^{-1}$) | Ottawa 2011 | Ottawa 2012 | Saint - Anne-de-Bellevue 2012 | Fredericton 2011 | Fredericton 2012 | Canning 2011 | Canning 2012 |
|---|---|---|---|---|---|---|---|
| **0** | 3 | 2.4 b [x] | 6 a | 6 a | 5 c [x] | 1.8 a | 1.8 bc [∞] |
| **50** | 3.0 | 3.3 ab | 6 a | 6 a | 5.5 c | 2.4 a | 2.2 bc |
| **100** | 4 | 4 a | 6 a | 8 a | 5.8 bc | 2.4 a | 2.7 ab |
| **150** | 4 | 3.6 ab | 6 a | 7 a | 6.3 abc | 2.4 a | 2.2 bc |
| **200** | | 4 a | 6 a | | 7.5 ab | | 2.0 bc |
| **50 + 50** | 3 | 4 a | 5 a | 6 a | 5.8 c | 2.5 a | 1.3 c |
| **50 + 100** | 3 | 3 ab | 5 a | 7 a | 6.3 abc | 2.7 a | 3.3 a |
| **50 + 150** | | 3 ab | 4 a | | 7.8 a | | 2.3 abc |

| Nitrogen (kg ha$^{-1}$) | Elora 2012 | Laval 2012 |
|---|---|---|
| **0** | 2.6 b [∞] | 4.7 b |
| **50** | 3.0 ab | 5.5 b |
| **100** | 3.1 ab | 5.0 b |
| **150** | 3.4 a | 5.7 b |
| **200** | 3.6 a | 6.5 b |
| **50 + 50** | 3.05 ab | 9.2 a |
| **50 + 100** | 3.25 ab | 7.2 ab |
| **50 + 150** | 3.15 ab | 5.5 b |

## c) 1000 seed weight (g)

| Nitrogen (kg ha$^{-1}$) | Ottawa 2011 | Ottawa 2012 | Saint - Anne-de-Bellevue 2011 | Saint - Anne-de-Bellevue 2012 | Fredericton 2011 | Fredericton 2012 | Canning 2011 | Canning 2012 | Laval 2012 |
|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **0** | 3.06 a [x] | 3.2 a | 2.8 ab | 2.93 c [ǂ] | 3.49 a | 3.24 a [∞] | 3.5 a | 3.0 e [ǂ] | 3.5 a |
| **50** | 2.94 ab | 3.3 a | 2.8 ab | 2.96 c | 3.42 a | 3.15 ab | 3.29 ab | 3.11 de | 3.5 a |
| **100** | 2.90 b | 3.2 a | 2.8 ab | 3.1 abc | 3.37 a | 3.14 ab | 3.29 ab | 3.14 cd | 3.5 a |
| **150** | 2.95 ab | 3.3 a | 2.75 b | 3.04 bc | 3.36 a | 3.2 ab | 3.28 b | 3.14 cd | 3.4 a |
| **200** | | 3.3 a | | 2.98 c | | 3.1 b | | 3.3 a | 3.5 a |
| **50 + 50** | 2.98 ab | 3.4 a | 2.9 a | 3.0 c | 3.4 a | 3.2 ab | 3.45 a | 3.13 de | 3.5 a |
| **50 + 100** | 3.04 a | 3.3 a | 2.75 b | 3.15 ab | 3.4 a | 3.25 a | 3.48 a | 3.2 bc | 3.5 a |
| **50 + 150** | | 3.1 a | | 3.2 a | | 3.08 b | | 3.27 ab | 3.4 a |

## d) Pods per plant

| Nitrogen (kg ha$^{-1}$) | Ottawa 2011 | Ottawa 2012 | Saint - Anne-de-Bellevue 2011 | Saint - Anne-de-Bellevue 2012 | Fredericton 2011 | Fredericton 2012 | Canning 2011 | Canning 2012 |
|---|---|---|---|---|---|---|---|---|
| **0** | 43 b [ǂ] | 48 b [∞] | 60 a | 96 ab [ǂ] | 121 b | 84 c [ǂ] | 21 b [x] | 25 b [∞] |
| **50** | 54 ab | 59 ab | 74 a | 88 b | 122 b | 94 bc | 26 ab | 28 b |
| **100** | 71 a | 68 ab | 75 a | 133 a | 149 ab | 99 bc | 33 ab | 30 b |
| **150** | 71 a | 72 ab | 79 a | 126 ab | 140 ab | 116 b | 35 a | 27 b |
| **200** | | 84 a | | 108 ab | | 146 a | | 32 b |
| **50 + 50** | 68 a | 59 ab | 69 a | 118 ab | 123 b | 95 bc | 21 b | 23 b |
| **50 + 100** | 68 a | 60 ab | 80 a | 102 ab | 173 a | 103 bc | 32 ab | 58 a |
| **50 + 150** | | 57 b | | 113 a | | 96 bc | | 31 b |

| Nitrogen (kg ha$^{-1}$) | Elora 2012 | Laval 2012 |
|---|---|---|
| **0** | 37 b [ǂ] | 71 c [∞] |
| **50** | 45 ab | 87 bc |
| **100** | 50 ab | 86 bc |
| **150** | 57 a | 102 abc |
| **200** | 58 a | 124 a |
| **50 + 50** | 45 ab | 68 c |
| **50 + 100** | 47 ab | 110 ab |
| **50 + 150** | 45 ab | 101 abc |

## e) Seeds per pod

| Nitrogen (kg ha$^{-1}$) | Ottawa 2012 | Saint - Anne-de-Bellevue 2012 | Fredericton 2012 |
|---|---|---|---|

| | | | |
|---|---|---|---|
| **0** | 19 c [ŧ] | 20 a | 20 c [∞] |
| **50** | 21 bc | 23 a | 20 c |
| **100** | 23 b | 19 a | 20 c |
| **150** | 23 b | 21 a | 21 bc |
| **200** | 23 b | 18 a | 24 a |
| **50 + 50** | 23 b | 20 a | 21 bc |
| **50 + 100** | 26 a | 20 a | 21 bc |
| **50 + 150** | 22 b | 20 a | 23 ab |

## f) Seeds/Plant

| Nitrogen (kg ha$^{-1}$) | Ottawa 2011 | Ottawa 2012 | Fredericton 2012 |
|---|---|---|---|
| **0** | 477 c [ŧ] | 923 c [ŧ] | 1714 c [ŧ] |
| **50** | 622 c | 1267 bc | 1870 bc |
| **100** | 930 b | 1535 ab | 1944 bc |
| **150** | 1109 ab | 1662 ab | 2411 b |
| **200** | | 1913 a | 3482 a |
| **50 + 50** | 950 .b | 1360 abc | 2008 bc |
| **50 + 100** | 1210 a | 1554 ab | 2134 bc |
| **50 + 150** | | 1237 bc | 2186 bc |

## g) Harvest Index

| Nitrogen (kg ha$^{-1}$) | Ottawa 2011 | Ottawa 2012 | Saint - Anne-de-Bellevue 2011 | Saint - Anne-de-Bellevue 2012 | Fredericton 2011 | Fredericton 2012 | Canning 2011 | Canning 2012 |
|---|---|---|---|---|---|---|---|---|
| **0** | .25 c [ŧ] | .23 a | .38 c [ŧ] | .38 b | .34 a | .37 a | .30 b | .25 d [x] |
| **50** | .25 c. | .22 a | .38 bc | .39 ab | .36 a | .39 a | .31 b | .28 bcd |
| **100** | .28 b | .24 a | .39 b | .40 ab | .35 a | .37 a | .32 ab | .29 abc |
| **150** | .30 ab | .24 a | .39 bc | .40 ab | .36 a | .37 a | .32 ab | .249 cd |
| **200** | | .23 a | | .38 b | | .38 a | | .317 ab |
| **50 + 50** | .31 a | .22 a | .38 bc | .39 ab | .34 a | .36 a | .34 ab | .30 ab |
| **50 + 100** | .31 a | .21 a | .42 a | .41 a | .31 a | .37 a | .36 a | .32 a |
| **50 + 150** | | .23 a | | .41 a | | .39 a | | .32 a |

| Nitrogen (kg ha$^{-1}$) | Elora 2012 | Laval 2012 |
|---|---|---|
| **0** | .32 a | .38 b |
| **50** | .32 a | .37 b |

| | | |
|---|---|---|
| **100** | .32 a | .385 ab |
| **150** | .32 a | .38 b |
| **200** | .33 a | .40 ab |
| **50 + 50** | .32 a | .40 ab |
| **50 + 100** | .32 a | .42 a |
| **50 + 150** | .32 a | .41 ab |

Means with different letters in the same column within a site are significantly different at the 0.001[Ŧ], 0.01[x] and 0.05[∞] levels.

In Ottawa in 2011, there was no difference in amount of distinctly green seed between N treatments (table 5). However, the percentage of brown, tanned and empty seed were highest in the higher N treatments. The plots that received no N application had the lowest number of green, brown and tanned seed. In 2011, the percentage of damaged seed (a total of the green, brown, tanned and empty seed) increased significantly with increasing amounts of applied N. The same trend was seen in 2012, although it was not significant. The plots that received sidedressed N had significantly higher percent damaged seed. In 2012 there was no green seed for any of the treatments. The seed for both years and from each treatment is considered grade No. 1 Canola seed as there was less than 2% distinctly green seed and less than 5% damaged seed.

Table 5. Percentage of distinctly green seed, brown, tanned, empty and damaged seed (including green, tanned, brown and empty seed) for the different nitrogen treatments in Ottawa in 2011 and 2012.

| Nitrogen (kg ha$^{-1}$) | % Green | % Brown | % Tan | % Empty | 2011 % Damaged | 2012 % Damaged |
|---|---|---|---|---|---|---|
| **0** | .04 a | .35 c | .35 c | .23 b | .69 d[Ŧ] | 1.5 a |
| **50** | .06 a | .71 bc | 0.7 bc | .13 b | 1.1 cd | 1.2 a |
| **100** | .08 a | 1.6 ab | 1.6 ab | .29 b | 2.1 bc | 2.1 a |
| **150** | .15 a | 1.6 b | 1.6 b | .25 b | 2.0 bc | 1.4 a |
| **200** | | | | | | 2.0 a |
| **50 + 50** | .13 a | 2.5 a | 2.5 a | .88 a | 3.5 a | 1.1 a |
| **50 + 100** | | | | | | 2.4 a |
| **50 + 150** | .12 a | 1.6 ab | 1.6 ab | 0.5 ab | 2.3 b | 2.2 a |

[Ŧ] Means with different letters in a column are significantly different at the 0.001 level.

## Seed Protein and Oil Content

Oil was measured in 2011 with the Foss Infratec[TM] 1241 Grain Analyzer and in 2012 using the Unity Scientific SpectraStar 2500x NIR spectrometer. Protein was also determined both years using the same spectrometer. The NIR spectrometer was calibrated in 2012.

### a) Seed Protein Content

At most sites and years, the protein content of the canola seed significantly increased with increasing amounts of nitrogen applied to the soil (table 6). The plots that received additional sidedressed N (50+50, 50+100, 50+150) had higher protein content than the plots that received the same amount of N before planting (100, 150, 200 kg N $ha^{-1}$) (table 6). The plots that received 150 kg $ha^{-1}$ sidedressed N generally had the highest protein levels of all the N treatments. The samples from Canning 2011 were measured for protein in 2011 and then again in 2012 using the same NIR spectrometer (table 6). The values measured in 2012 were lower than those measured in 2011, indicating that either the protein levels had decreased over the year or there was likely a calibration problem.

Most sites, except for Canning and Elora in 2012, did not show that sulphur had any effect on seed protein levels (table 7). The addition of 20 kg $ha^{-1}$ of sulphur at Canning and Elora significantly increased the levels of protein. Boron did not have any effect of protein levels.

Table 6. Nitrogen effect on percent protein of canola seed from the six sites and two years. In Canning in 2011 the same samples were measured in 2011 (**) and then later again at the end of 2012 (***) using the Unity Scientific SpectraStar 2500x NIR spectrometer.

| Nitrogen (kg $ha^{-1}$) | Ottawa 2011 | Ottawa 2012 | Saint - Anne-de-Bellevue 2011 | Saint - Anne-de-Bellevue 2012 | Canning 2011** | Canning 2011*** | Canning 2012 |
|---|---|---|---|---|---|---|---|
| **0** | 17.7 d ŧ | 27.8 b | 21.7 c ŧ | 21.9 d | 22.13 ed ŧ | 19.9 cd ŧ | 21.1 f ŧ |
| **50** | 17.9 d | 27.8 b | 22.3 c | 23.0 cd | 21.98 e | 19.4 d | 22.9 e |
| **100** | 20 c | 28.4 ab | 24.3 ab | 24.2 b | 23.0 cd | 20.6 c | 24.6 d |
| **150** | 22 b | 28.7 ab | 24.4 ab | 24.4 b | 23.92 cb | 21.9 b | 25.4 c |
| **200** | | 29.2 a | | 24.2 b | | | 27.6 a |
| **50 + 50** | 22.8 b | 28.8 ab | 24.1 b | 24.0 bc | 24.17 b | 21.7 b | 25.6 c |
| **50 + 100** | 25.7 a | 28.9 ab | 25.0 a | 25.1 ab | 26.14 a | 22.9 a | 26.1 bc |
| **50 + 150** | | 29.2 a | | 25.6 a | | | 26.7 b |

| Nitrogen (kg ha$^{-1}$) | Fredericton 2012 | Elora 2012 | Laval 2012 |
|---|---|---|---|
| 0 | 21 d ǂ | 23.5 c ǂ | 22.5 c ˣ |
| 50 | 21.1 d | 23.8 c | 22.5 c |
| 100 | 27.7 cd | 24.6 b | 22.67 c |
| 150 | 22 c | 25.0 ab | 22.7 c |
| 200 | 23.3 ab | 25.6 a | 23.5 ab |
| 50 + 50 | 22.5 bc | 24.6 b | 22.74 bc |
| 50 + 100 | 23.9 a | 24.4 b | 23.3 bc |
| 50 + 150 | 23.8 a | 24.8 b | 24.1 a |

Means with different letters in the same column within a site are significantly different at the 0.001 ǂ and 0.01 ˣ levels.

Table 7. Effect of sulphur on the protein content of seed at the Canning and Elora sites in 2012. These two sites showed significant differences between the two treatments.

| Sulphur (kg ha$^{-1}$) | Canning 2012 | Elora 2012 |
|---|---|---|
| 0 | 23.1 b ∞ | 23.9 b ǂ |
| 20 | 24.5 a | 24.6a |

Means with different letters in the same column are significantly different at the 0.001 ǂ and 0.01 ∞ levels.

### b) Seed Oil Content

At all sites, the canola seed oil content significantly decreased with increasing amounts of preplant N application (table 8). When comparing the percent oil content of canola seed from plots that received preplant N (100, 150, 200 kg ha$^{-1}$) to those plots that received equivalent amounts of N with sidedressed application (50+50, 50+100, 50+150 kg ha$^{-1}$), the oil results were very similar for all sites and years. In general, seed oil content was lower in 2012 than in 2011, especially at the Ottawa and Montreal sites, indicating that drought had a negative effect on seed oil accumulation. It should be noted that seed oil concentrations may differ significantly, if different machines are used. For Ottawa (2012), the samples were measured using the FOSS Infratec Grain Analyzer which showed a significant difference between treatments ($p \leq 0.01$) (table 8). The same samples were also measured using the NIR spectrometer, but the oil values were lower and showed no significant differences between treatments. The Canning and Ste.- Anne-de-Bellevue 2011 samples were also analyzed by both machines and showed similar results.

Table 8. Nitrogen effect on percent oil of canola seed from the six sites and two years. All samples that were analyzed using the Infratec™ 1241 Grain Analyzer are indicated with (*). In 2012 the samples were

analyzed using the Unity Scientific SpectraStar 2500x NIR spectrometer(**). Bracketed values are the same samples measured using the NIR.

| Nitrogen (kg ha$^{-1}$) | Ottawa 2011* | Ottawa 2012* | Canning 2011* | Canning 2012** |
|---|---|---|---|---|
| **0** | 50.6 a[Ŧ] | 43.3 a[x] (29.4 a) | 49.4 a[x] (45.9 a[Ŧ]) | 41.5 a[Ŧ] |
| **50** | 50.5 a | 43.2 a (39.3 a) | 49.5 a (45.6 a) | 39.8 b |
| **100** | 49.3 b | 42.7 ab (38.9 a) | 48.3 c (44.8 ab) | 37.6 cd |
| **150** | 47.7 c | 42.7 ab (38.7 a) | 47.1 c (43.6 bc) | 36 d |
| **200** | | 42.3 b (38.7 a) | | 37.5 cd |
| **50 + 50** | 47.0 d | 42.7 ab (38.9 a) | 48.0 b (43.8 bc) | 37.9 c |
| **50 + 100** | 44.8 e | 42.9 ab (39.3 a) | 46.7 c (43.5 c) | 37.6 cd |
| **50 + 150** | | 42.2 b (38.7 a) | | 38.6 bc |

| Nitrogen (kg ha$^{-1}$) | Saint - Anne-de-Bellevue 2011* | Saint - Anne-de-Bellevue 2012** | Fredericton 2011* | Fredericton 2012** | Elora 2012** | Laval 2012** |
|---|---|---|---|---|---|---|
| **0** | 48.2 a[Ŧ] (44.3a[Ŧ]) | 44.3 ab | 46.9 a[Ŧ] | 44.3 a | 43.7 a[Ŧ] | 42.9 ab |
| **50** | 47.9 a (43.5 b) | 44.6 a | 46.2 b | 44.6 a | 43.8 ab | 43.1 a |
| **100** | 46.6 b (42.2 b) | 43.9 abc | 45.5 c | 43.9 abc | 43.0 abc | 42.8 ab |
| **150** | 46.2 b (42.1 b) | 43.7 abc | 45.5 c | 43.7 abc | 42.1 cd | 42.9 ab |
| **200** | | 43.8 abc | | 43.8 abc | 41.4 d | 42.3 ab |
| **50 + 50** | 46.1 bc (42.1 b ) | 44 abc | 44.9 cd | 44.1 abc | 42.9 abc | 43.4 a |
| **50 + 100** | 45.6 c (41.3 b) | 42.9 c | 44.7 d | 42.9 a | 42.5 bc | 41.9 b |
| **50 + 150** | | 43.1 bc | | 43.1 bc | 42.7 abc | 43.3 ab |

Means with different letters in the same column within a site are significantly different at the 0.001[Ŧ] and 0.01[x] levels.

When comparing the two sulphur treatments, S did not have a significant effect on oil content. Soil applied boron (0 & 2 kg ha$^{-1}$) had no significant effect on the oil content. However, the addition of foliar spray at 0.5 kg ha$^{-1}$ seemed to decrease oil content compared to the other two boron treatments at several of the sites (table 9).

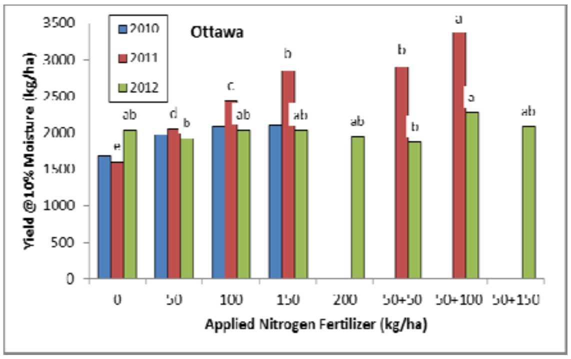
Table 9. Effect of soil and foliar application of boron on percent oil in the canola seed for all four sites.

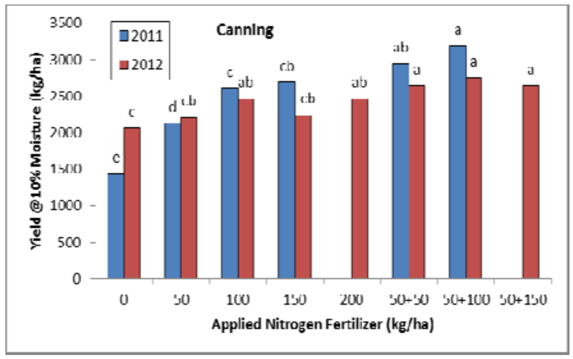
| Boron (kg ha$^{-1}$) | Ottawa 2011 | Ste.- Anne-de-Bellevue 2011 | Fredericton 2011 | Frederiction 2012 | Laval 2012 |
|---|---|---|---|---|---|
| **0** | 49.7 a | 47.3 a | 45.9 a | 44.5 a | 43.4 a |
| **2** | 49.5 a | 47.2 a | 45.9 ab | 44.0 ab | 42.9 a |

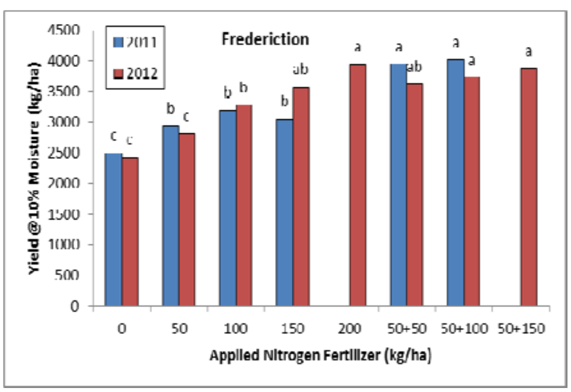
| | | | | | |
|---|---|---|---|---|---|
| **0.5 (foliar)** | 48.6 b | 46.8 b | 45.5 b | 43.8 a | 42.7 a |

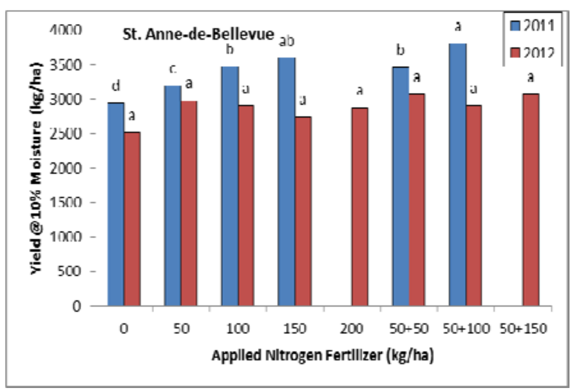
## Final Yields

Yields were collected from six sites over three years. The Ottawa (2012) and St. Anne-de-Bellevue (2012) sites had poor yields and showed no significant differences on yields among different rates of nitrogen (Fig. 6). This is probably a result of the terrible drought in 2012 that occurred in Ottawa and Eastern Quebec during the grain filling period.



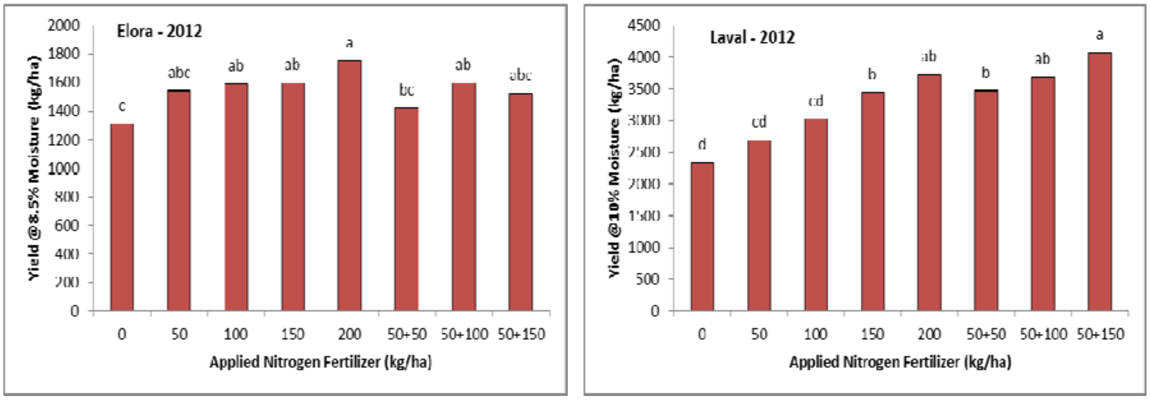
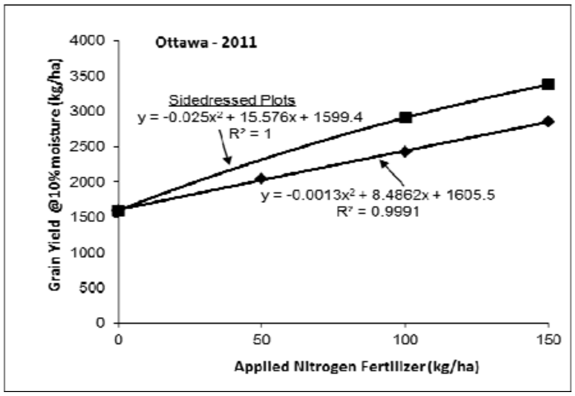
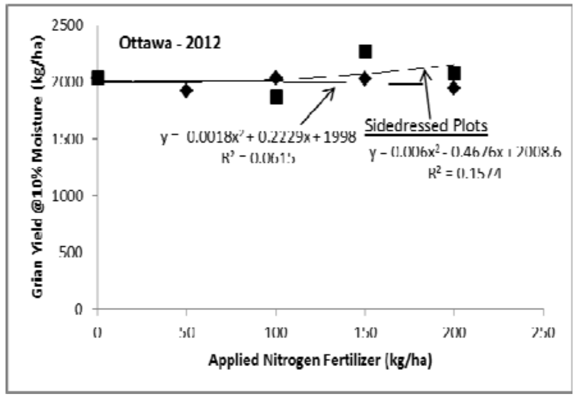


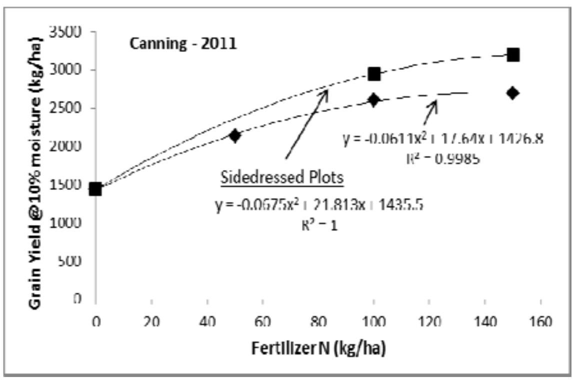

Fig. 6. Grain yield response in Ottawa, Canning, Ste.- Anne-de-Bellevue, Fredericton, Elora and Laval to urea applied both preplant (0, 50, 100 and 150 kg ha-1) and at preplant plus sidedressing (50+50, 50+100). Means with different letters within each year are significantly different at the 0.001 level.

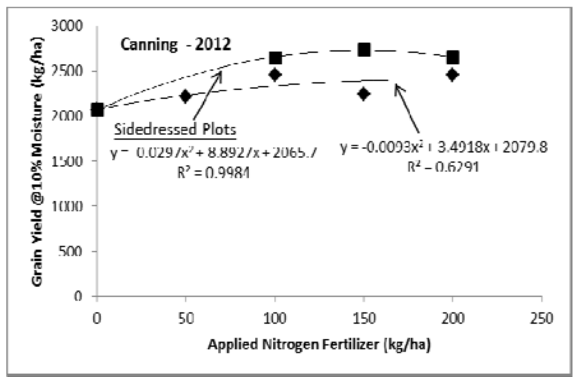
For all the other sites and years, there was a strong correlation between yields and amounts of N added both as preplant and as sidedressed with yields increasing significantly ($p \leq 0.001$) with increasing amounts of N applied (Fig.s 7 & 8).

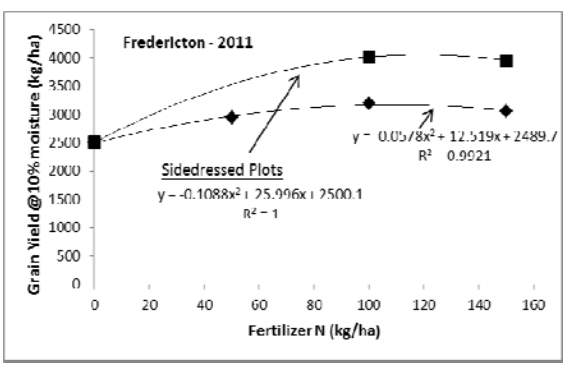
In most cases, except for Elora 2012, the plots that received additional sidedressed N (50+50, 50+100, 50+150) had significantly higher yields than the plots that received the same amount of N before planting (100, 150 and 200 kg $ha^{-1}$) (Fig. 7). On average for every kilogram of N applied, canola yields increased by 9.7 kg $ha^{-1}$ for preplant application. However, when additional N was sidedressed later in June, yield increased by 13.7 kg $ha^{-1}$ for sidedressed application.

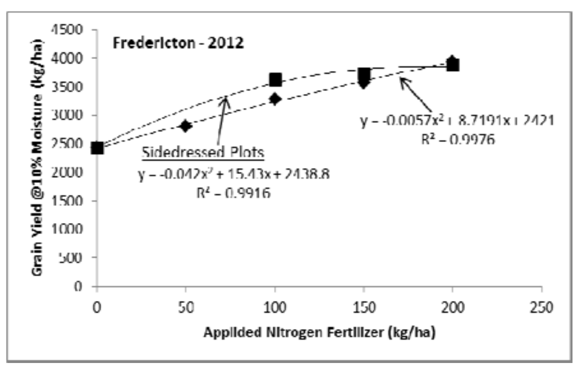

Ottawa - 2011
Grain Yield @10% moisture (kg/ha)
Applied Nitrogen Fertilizer (kg/ha)
Sidedressed Plots
$y = -0.025x^2 + 15.576x + 1599.4$
$R^2 = 1$
$y = -0.0013x^2 + 8.4662x + 1605.5$
$R^2 = 0.9991$


Ottawa - 2012
Grian Yield @10% Moisture (kg/ha)
Applied Nitrogen Fertilizer (kg/ha)
$y = 0.0018x^2 + 0.2229x + 1998$
$R^2 = 0.0615$
Sidedressed Plots
$y = -0.006x^2 - 0.4676x + 2008.6$
$R^2 = 0.1574$


Canning - 2011
Grain Yield @10% moisture (kg/ha)
Fertilizer N (kg/ha)
$y = -0.0611x^2 + 17.64x + 1426.8$
$R^2 = 0.9985$
Sidedressed Plots
$y = -0.0675x^2 + 21.813x + 1435.5$
$R^2 = 1$


Canning - 2012
Grain Yield @10% Moisture (kg/ha)
Applied Nitrogen Fertilizer (kg/ha)
Sidedressed Plots
$y = 0.0297x^2 + 8.8927x + 2065.7$
$R^2 = 0.9984$
$y = -0.0093x^2 + 3.4918x + 2079.8$
$R^2 = 0.6291$


Fredericton - 2011
Grain Yield @10% moisture (kg/ha)
Fertilizer N (kg/ha)
$y = 0.0578x^2 + 12.519x + 2489.7$
$R^2 = 0.9921$
Sidedressed Plots
$y = -0.1088x^2 + 25.996x + 2500.1$
$R^2 = 1$


Fredericton - 2012
Grain Yield @10% Moisture (kg/ha)
Applided Nitrogen Fertilizer (kg/ha)
$y = -0.0057x^2 + 8.7191x + 2421$
$R^2 = 0.9976$
Sidedressed Plots
$y = -0.042x^2 + 15.43x + 2438.8$
$R^2 = 0.9916$

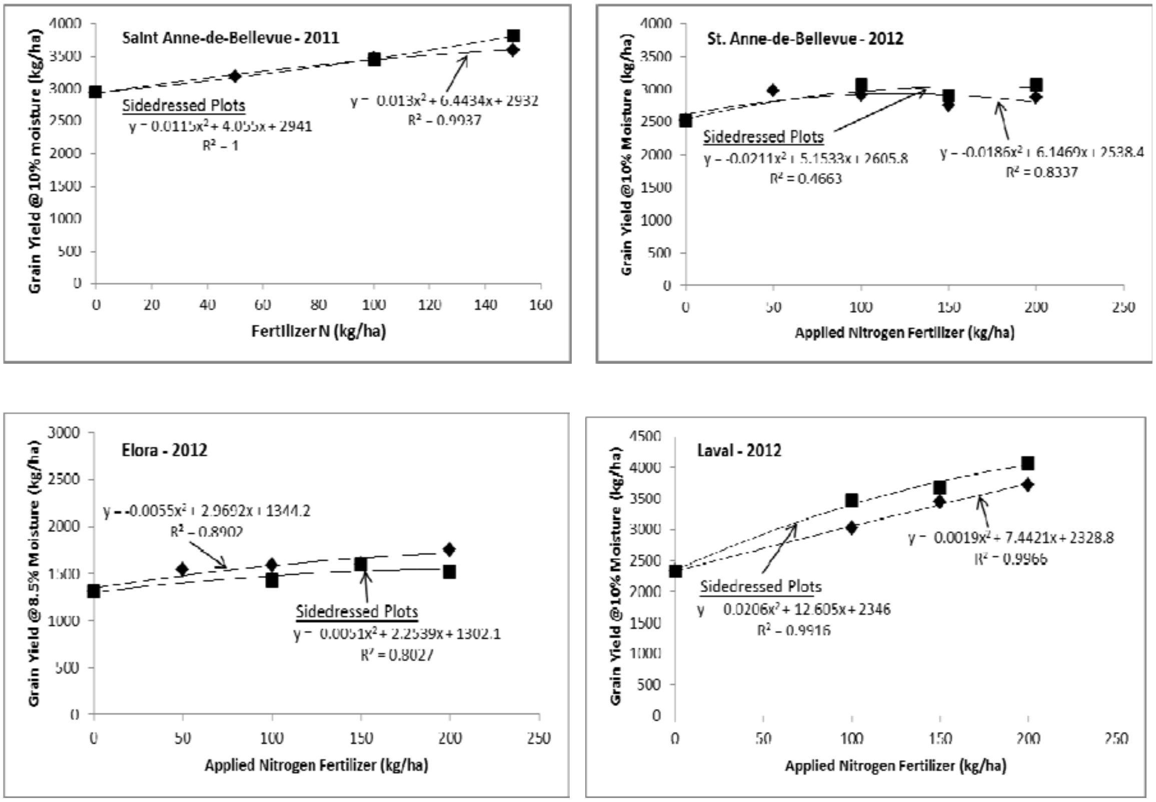



Fig. 7. Regression analysis of grain yield as a function of the amount of N fertilizer added at preplant compared with split N applied as sidedress in June.

In most cases (except Ottawa 2012), the addition of preplant S as ammonium sulphate at 20 kg ha$^{-1}$ had a significantly positive effect on yields compared to the plots that received no sulphur (table 10). There was an average yield increase of 15.5% in 2011 and 11.7% in 2012 with the addition of S at each N level (0, 50, 100, 150 kg ha$^{-1}$) compared to the same plots that received no S (Fig. 8).

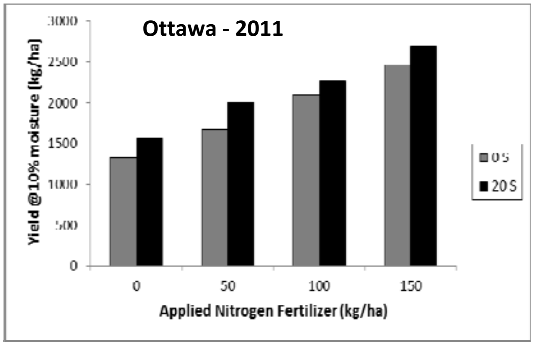
Table 10. Sulphur effect on canola yields from the six sites and two years.

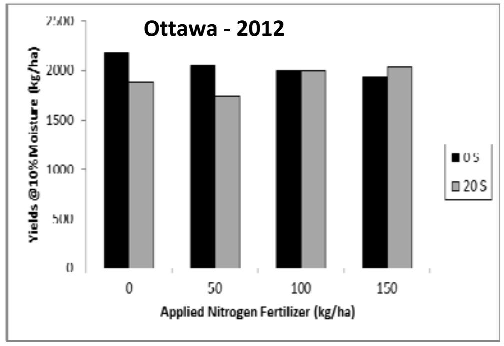
| Sulphur (kg ha$^{-1}$) | Ottawa 2011 | Ottawa 2012 | Saint - Anne-de-Bellevue 2011 | Saint - Anne-de-Bellevue 2012 | Fredericton 2011 | Fredericton 2012 | Canning 2011 | Canning 2012 |
|---|---|---|---|---|---|---|---|---|
| **0** | 1697.7 b [ǂ] | 2052.3 a | 3274 b | 2730.1a | 2575.9 b [ǂ] | 2955.2 b | 2101.3 b [∞] | 2116.3 b [x] |
| **20** | 2007.4 a | 1965.6 a | 3372.4 a | 2881.5 a | 3371.6 a | 3257.1 a | 2433.9 a | 2425.5 a |

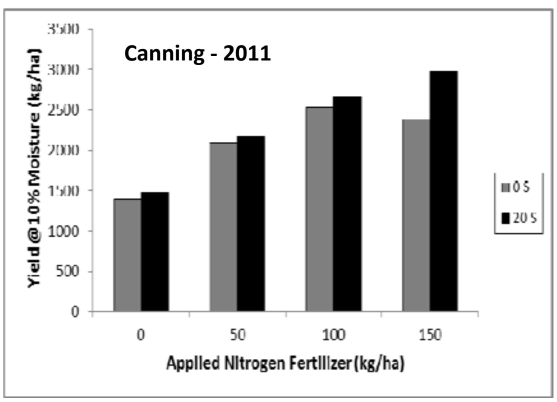
| Sulphur (kg ha$^{-1}$) | Elora 2012 | Laval 2012 |
|---|---|---|
| **0** | 1350 a | 2722 b [ǂ] |

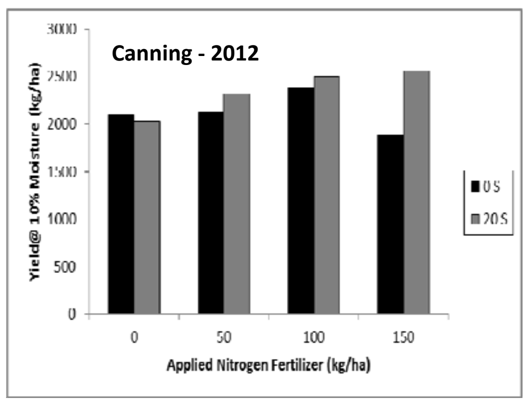
| | | |
|---|---|---|
| **20** | 1511.2 a | 3169.9 a |

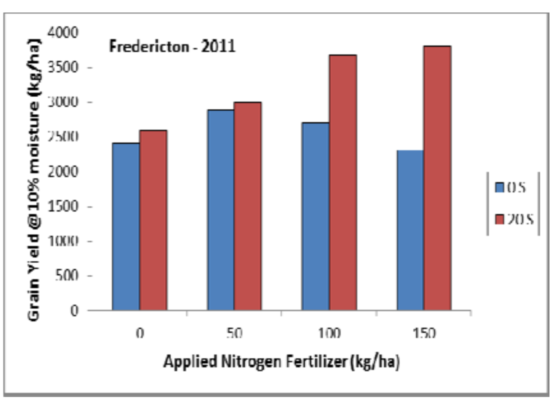
Means with different letters in the same column within a site are significantly different at the 0.001 [Ŧ], 0.01 [x] and 0.5 [∞] levels.

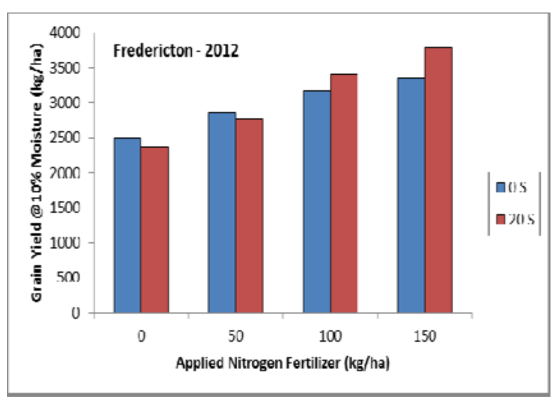


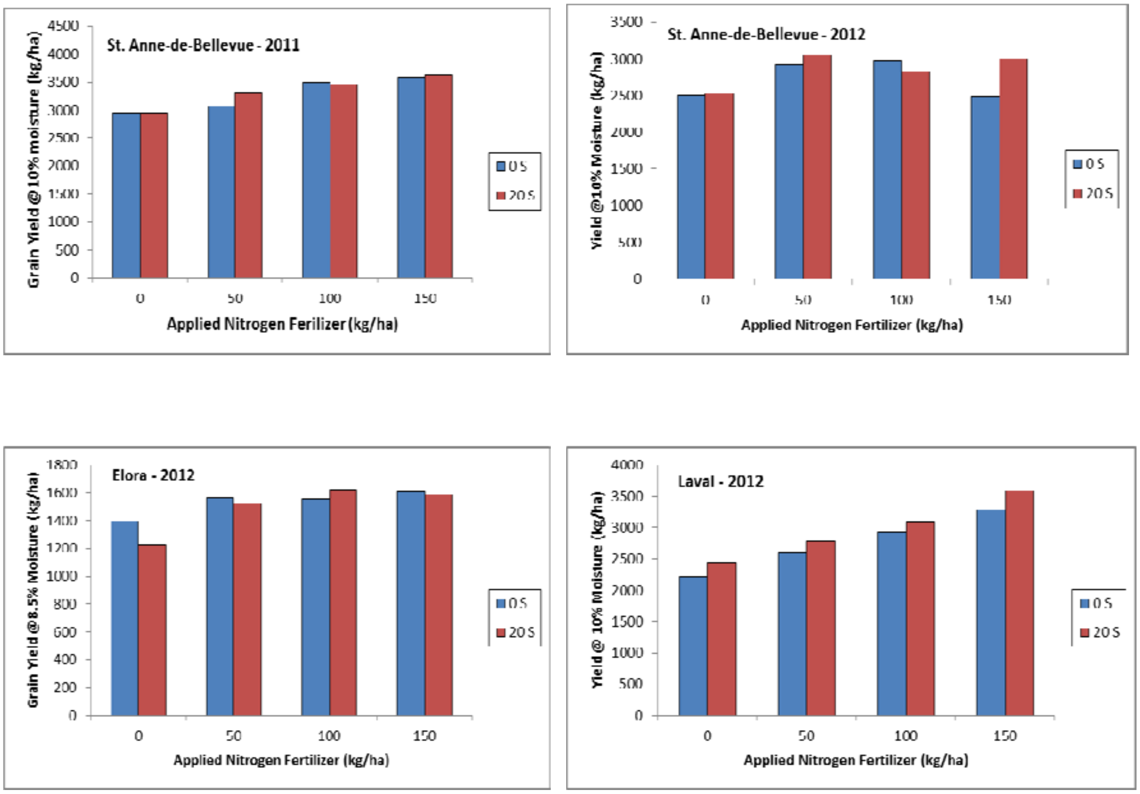



Fig. 8. Comparing grain yield response of canola in 0, 50, 100 and 150 kg ha$^{-1}$ N plots that have received no sulphur and sulphur at 20 kg ha$^{-1}$ S.

There appears to be no yield advantage adding 2 kg ha$^{-1}$ boron to the soil before planting when comparing it to plots with no boron added (table 11). However, the foliar application of boron at the 20% flowering stage produced higher yields than those plots that received boron at preplant. This was, however, only significantly higher in Ottawa 2011, Fredericton 2012 and Canning 2012.

Table 11. Grain yield response (kg ha$^{-1}$) to boron applied preplant at 0, 20 kg ha$^{-1}$ and foliarly (0.5 kg ha$^{-1}$) at the 20% flowering stage.

| Boron (kg ha$^{-1}$) | Ottawa 2011 | Ottawa 2012 | Saint Anne-de-Bellevue 2011 | Saint Anne-de-Bellevue 2012 | Fredericton 2011 | Fredericton 2012 | Canning 2011 | Canning 2012 |
|---|---|---|---|---|---|---|---|---|
| **0** | 1975.5 b | 1963.3 a | 3299.2 a | 2739.0 a | 2994.7 a | 3060.1 b | 2205.0 a | 2166.2 b |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **2** | 2011.9 b | 2052.1 a | 3333.7 a | 2937.9 a | 2970.4 a | 3004.2 b | 2256.4 a | 2310.8 a |
| **0.5** | 2198.7 a | 1996.0 a | 3343.8 a | 2715.3 a | 3039.3 a | 3257.3 a | 2359.9 a | 2365.6 a |

| Boron (kg ha$^{-1}$) | Elora 2012 | Laval 2012 |
|---|---|---|
| **0** | 1482.1 a | 2827.9 b |
| **2** | 1572.2 a | 2836.5 b |
| **0.5** | 1522.4 a | 3196.7 a |

The maximum economic rate of nitrogen (MERN) was calculated for each site that had a yield response. Using the current cost of nitrogen and price of canola in the calculation, the results ranged from 105 – 175 kg N/ha for preplant application and 118 – 233 kg N/ha for sidedress application. Clearly, MERN values are largely affected by site-specific dominate weather conditions and soil environment. It is difficult to get a general conclusion on the amounts of N should be applied. However, as a rule of thumb, at current yield level and average weather, the optimum rate of N is between 120 and 150 kg N ha$^{-1}$, and sidedress N application could save 10 – 20 kg N ha$^{-1}$ with similar potential yield, or more N is required for sidedress N application when yield potential is high.

## Plant Health Status

At Ottawa and Elora in 2011 and 2012, NDVI measurements, determining plant greenness, taken by CropScan, Greenseeker, and the UniSpec-DC instruments significantly increased ($p \leq 0.001$ for Ottawa; $p \leq 0.05$ for Elora) with increasing amounts of N added to the soil (Fig. 9). For both years, when comparing the two dates of Greenseeker measurements, the NDVI readings suggested that the plants were greener just before sidedressing than those at the 20% flowering stage. The additional sidedressed N did not necessarily improve the greenness of the plots by the 20% flowering stage, compared to the plots that received the same amounts of N applied preplant (Fig. 9a, 9b). Those sidedressed treatments had similar NDVI readings to the plots that received only 50 kg/ha N preplant. At the Elora site, There were minimal differences in NDVI values among the N treatments (Fig. 9c).

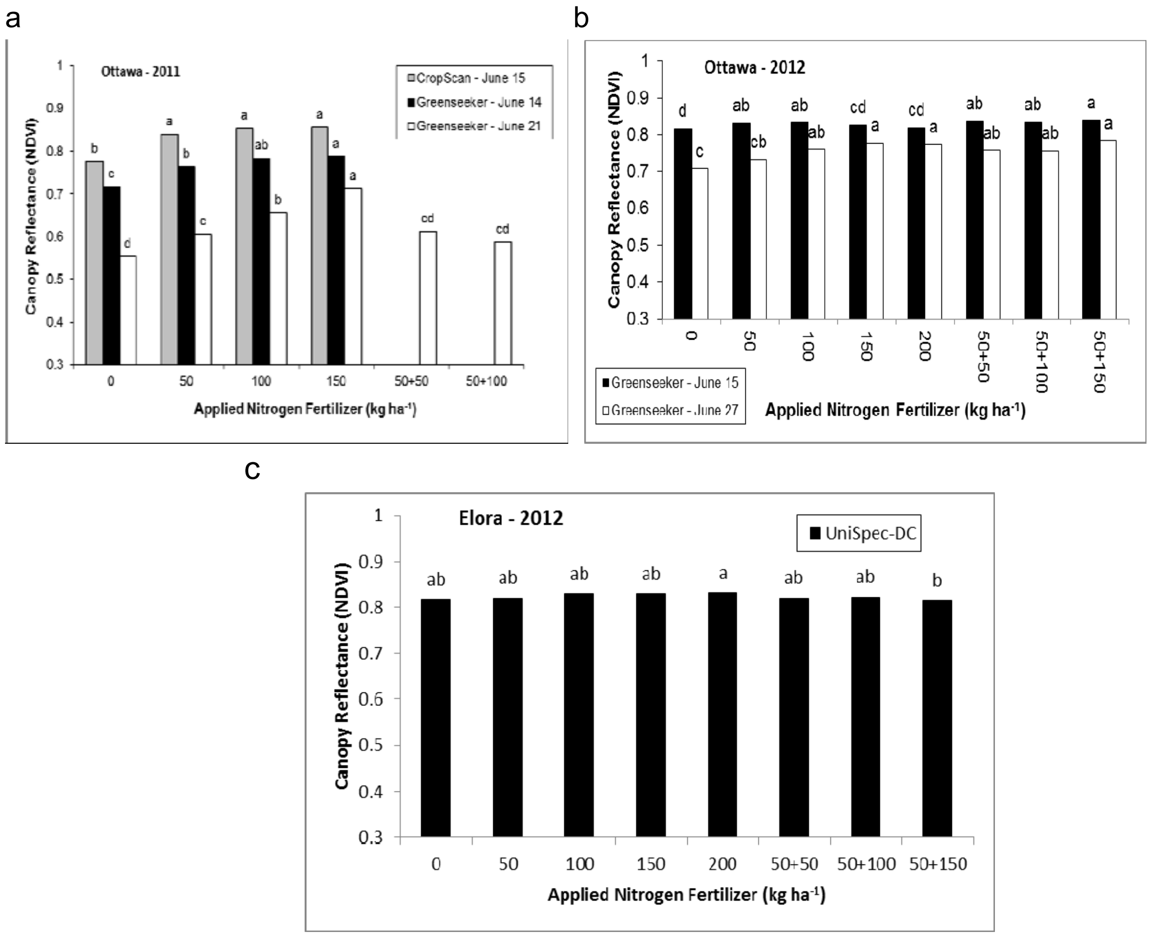



Fig. 9. Effects of the applied nitrogen levels on canopy reflectance readings (NDVI) measured by the Greenseeker (Model 502), CropScan (2011 only) and UniSpec-DC instruments just before sidedressing of N (June 15 in Ottawa; June 20 in Elora) and at the 20% flowering stage (June 21 in 2011; June 27 in 2012) in Ottawa and in Elora.

For both years, at the 20% flowering stage, Greenseeker NDVI readings in Ottawa had a strong correlation with soil nitrate levels also measured at this stage (Fig. 10).

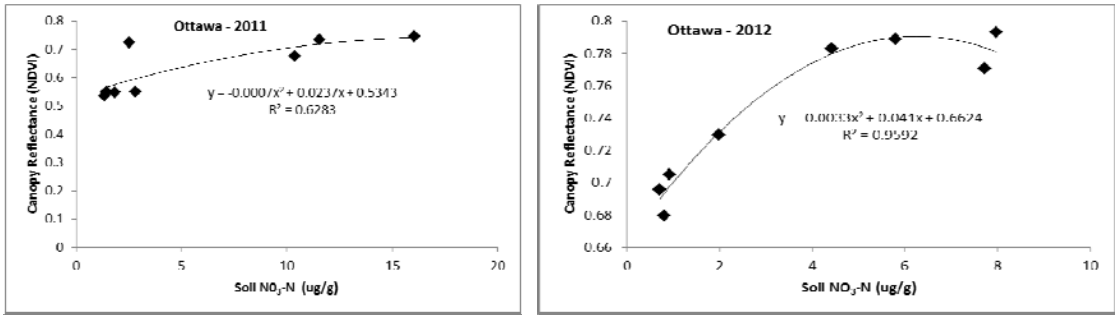



Fig. 10. The relationship between canopy reflectance measured by Greenseeker and soil test results of nitrate both taken at the 20% flowering stage in Ottawa in 2011 and 2012.

Both CropScan and Greenseeker did not detect any significant differences between plots that received different amounts of sulphur or boron for both years (data not shown).
There was a very strong correlation between NDVI values and yields of plots that received preplant N at 50, 100, 150 and 200 kg $ha^{-1}$ in Ottawa and Elora, with yields increasing with increasing NDVI values (Fig. 11).

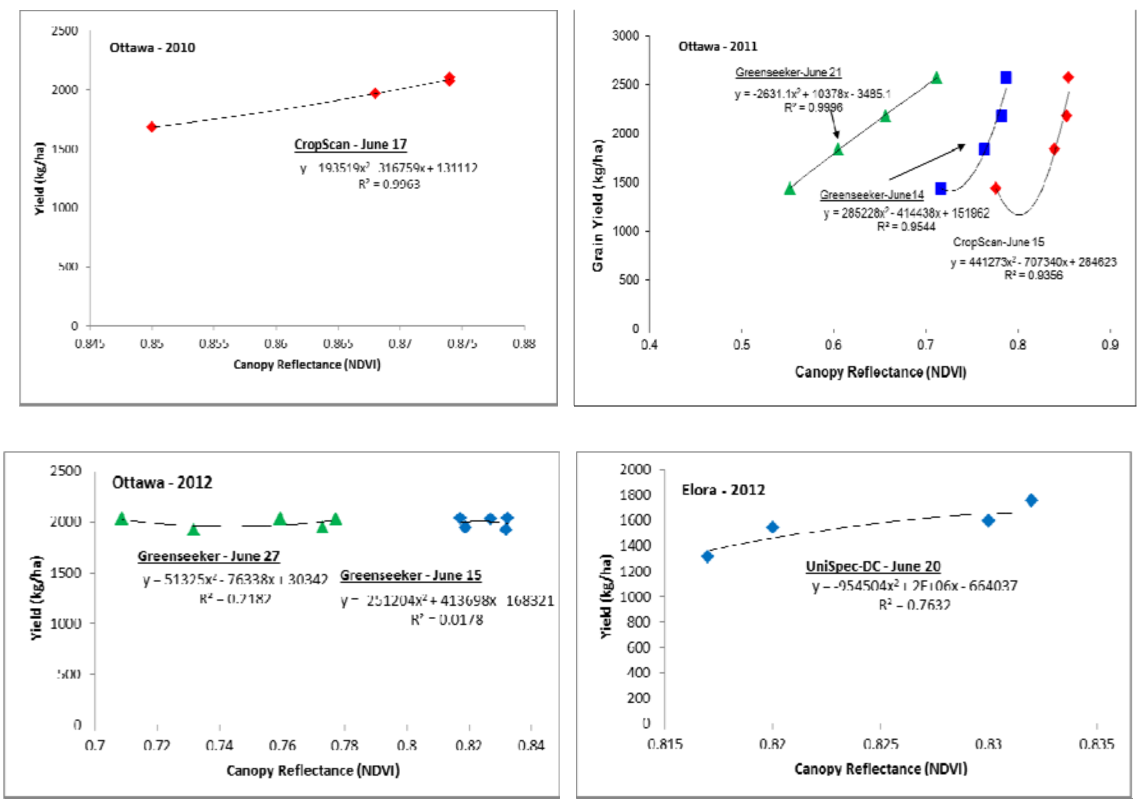



Fig. 11. The relationship between canopy reflectance (NDVI) and canola grain yields in plots that received N before planting at rates of 0, 50, 100, 150 and 200 kg N $ha^{-1}$ in Ottawa and Elora for

three different years.

## Plant Nitrogen Concentration and Accumulation

Plant samples from only two sites have been analyzed for plant N concentration: Ottawa in both 2011 and 2012, and Ste.- Anne-de-Bellevue, 2011.

In general, nitrogen concentrations of plant material in Ottawa were higher in 2012 than in 2011 (Fig. 12). The plants had higher concentration of N at flowering than at harvest. Nitrogen stored in the plants was translocated to the growing seeds during grain filling, therefore, causing grain at harvest to have higher concentrations of N than the straw. Nitrogen concentrations in plant material (both straw and grain) significantly increased ($p \leq 0.001$) with increasing amounts of N application. The highest N concentrations were found in plant material from plots that have received sidedressed N.

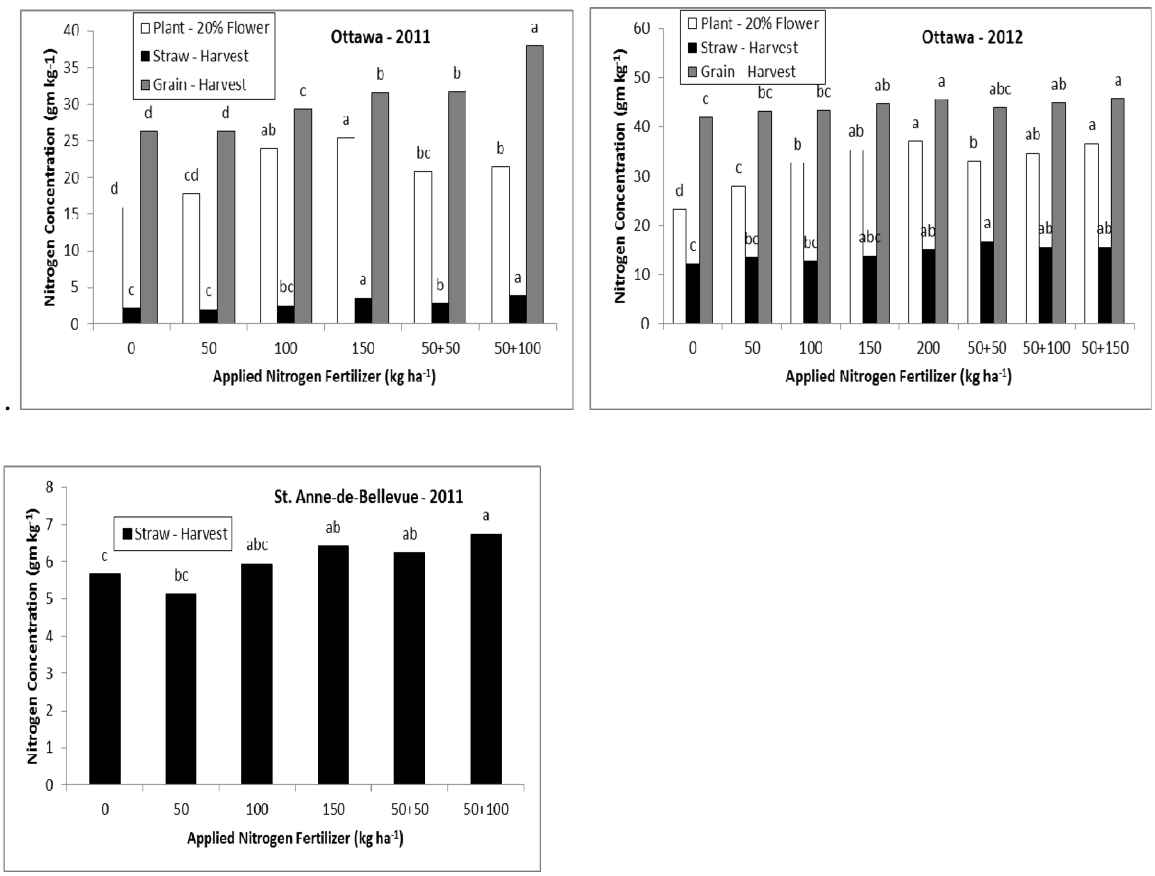



Fig. 12. Effect of N treatment on nitrogen concentration (g $kg^{-1}$) of plants at 20% flowering, and of straw and grain at harvest in Ottawa (2011 & 2012) and Saint- Anne-de-Bellevue (2011). Means with different letters are significantly different at the 0.001 level.

In Ottawa in 2011, the addition of ammonium sulphate at 20 kg ha$^{-1}$ had a positive effect ($p \leq 0.1$) on plant N concentrations at the 20% flowering stage only at the higher N rates. But the addition of S had no effect in 2012 (Fig. 13).

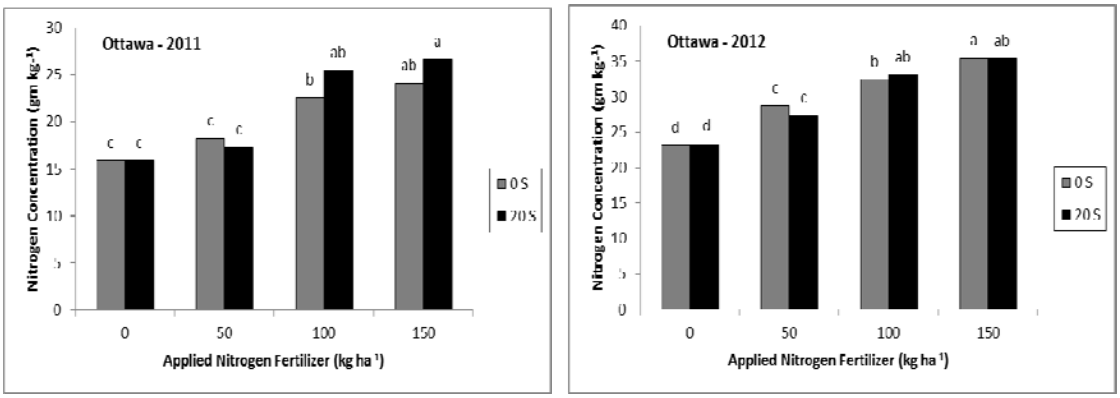



Fig. 13. Interaction of nitrogen and sulphur on plant nitrogen concentration (gm kg$^{-1}$) at the 20% flowering stage in Ottawa, 2011 and 2012. Means with different letters are significantly different at the 0.001 level.

In 2011, the plant total nitrogen, straw total nitrogen and seeds total nitrogen increased significantly ($p \leq 0.001$) with increasing amount of N fertilizer application (table 12). The uptake of nitrogen by plants from 20% flowering to harvest increased with the 0N plots having the smallest uptake and the 50+150 treatment having the largest N uptake. The average plant uptake of total nitrogen from 20% flowering to harvest was 95.9 kg ha$^{-1}$. On average 12.1 kg ha$^{-1}$ nitrogen was translocated from the plants to the seed.

In 2012, the total nitrogen uptake by the plants was greater than in 2011 with an average N uptake from flowering to harvest of 251.2 kg ha$^{-1}$ (table 12). However less N was translocated to the seed due to severe drought that occurred in 2012. As a result, canola straw contained high N concentrations in 2012.

Table 12. Total nitrogen accumulation (kg ha$^{-1}$) of plants at 20% flowering and of straw, seed and plants at harvest in Ottawa for 2011 and 2012.

**2011**

| N (kg ha$^{-1}$) | 20% Flower Plant TN | Harvest Straw TN | Harvest Seed TN | Harvest Plant TN | Plant N Uptake | Translocated N From Plant to Seed |
|---|---|---|---|---|---|---|
| 0 | 19.89 c ǂ | 7.68 e ǂ | 32.26 d ǂ | 43.17 d ǂ | 63.06 | 12.21 |
| 50 | 22 bc | 9.61 de | 40.37 d | 53.11 cd | 75.11 | 12.39 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 100 | 27.73 ab | 11.41 cd | 50.85 c | 61.13 c | 88.86 | 16.32 |
| 150 | 32.76 a | 17.47 b | 66.46 b | 80.13 b | 112.89 | 15.29 |
| 50+50 | 25.22 bc | 13.47 c | 67.45 b | 76.87 b | 102.09 | 11.75 |
| 50+100 | 26.07 bc | 21.55 a | 93.65 a | 107.25 a | 133.32 | 4.52 |
| | | | | **AVG:** | **95.9** | **12.1** |

**2012**

| N (kg ha$^{-1}$) | 20% Flower Plant TN | Harvest Straw TN | Harvest Seed TN | Harvest Plant TN | Plant N Uptake | Translocated N From Plant to Seed |
|---|---|---|---|---|---|---|
| 0 | 41.95 c ǂ | 72.55 ab x | 83.47 x | 156.01 bc | 197.96 | -30.6 |
| 50 | 67.66 b | 96.36 bc | 72.63 | 169.01 bc | 236.67 | -28.7 |
| 100 | 85.53 ab | 72.66 bc | 73.69 | 146.35 c | 231.88 | 12.87 |
| 150 | 105.81 a | 84.16 ab | 84.58 | 168.75 bc | 274.56 | 21.65 |
| 200 | 106.63 a | 68.48 c | 62.47 | 130.95 c | 237.58 | 38.15 |
| 50+50 | 83.68 b | 104.08 a | 92.1 | 196.18 ab | 279.86 | -20.4 |
| 50+100 | 80.7 b | 126.75 ab | 87.42 | 214.13 a | 294.83 | -46.05 |
| 50+150 | 87.93 ab | 89.2 ab | 79.3 | 168.5 bc | 256.43 | -1.27 |
| | | | | **AVG:** | **251.2** | **-6.79** |

ǂ Means with different letters in the same column are significantly different at the 0.001 level of probability.

x Means with different letters in the same column are significantly different at the 0.01 level of probability.

## Plant Boron Concentrations

Preliminary results at a few of the sites showed that the different boron treatments did not significantly affect boron concentrations in canola seed at harvest (table 13). However there are significant differences in straw boron levels. The plants that received no boron had significantly lower straw boron concentrations than plants that received foliar or soil applied boron. In most cases the highest concentrations of straw B were from plants that received 2 kg ha$^{-1}$ B (except Fredericton 2011). The determination of B of plant material from the other sites is still ongoing. These data will be useful for determining critical B concentration at the early flowering and soil available B at seeding.

Table 13. Boron concentration (ug g$^{-1}$) of straw and seed at harvest for Fredericton, Canning and Montreal (2011 & 2012).

| B (kg ha$^{-1}$) | Fredericton – 2011 Straw | Fredericton – 2011 Seed | Fredericton 2012 Seed | Canning – 2011 Straw | Canning – 2011 Seed | Canning 2012 Straw | Montreal 2011 Seed | Montreal 2012 Straw |
|---|---|---|---|---|---|---|---|---|
| **0** | **21.8 c ǂ** | **12.7 a** | **12.7 a** | **20.0 b** | **12.2 a** | **15.9 b ǂ** | **16.86 a** | **25.89 b ǂ** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2 | 24.9 b | 12.5 a | 12.6 a | 21.6 a | 12.1 a | 22.8 a | 17.58 a | 32.59 a |
| 0.5 (foliar) | 32.3 a | 13.1 a | 12.0 a | 20.7 a | 11.8 a | 20.6 a | 15.48 a | 27.26 b |

ₜ Means with different letters in the same column within a site are significantly different at the 0.001

## Plant Phosphorus Concentrations

Nitrogen treatment did not have any significant effect on phosphorus levels in plant, grain or straw in Ottawa and Ste.- Anne-de-Bellevue in 2011.  The average P concentration in plants at flowering was 4.35 g $kg^{-1}$, and at harvest 0.59 g $kg^{-1}$ (0.38 g $kg^{-1}$ in St. Anne) in straw and 7.7 g $kg^{-1}$ in grain.

## Correlations of canola seed yield and agronomic traits

Grain yield was correlated positively with pods per plant, seeds per plant and seed weight. These yield components affected dominantly by the prevailing environmental conditions, especially rainfall during the specific yield formation stages at each site (table 14). In general, seed yield was positively correlated with seed protein concentration and sometimes with oil concentration. It appeared that shortage of rainfall negatively affected oil concentrations.

Table 14. Partial correlation coefficients of canola seed yields with various agronomic traits at different site-years.

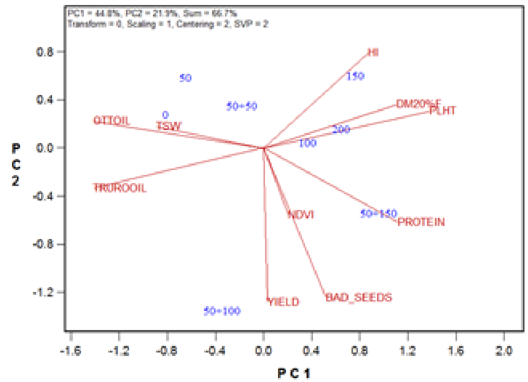
| (Yield) | Plant Heig ht | Oil | Protein | HI | TSW | Branches /Plant | Pods/ Plant | Seeds/ Pod | Seeds/ Plant |
|---|---|---|---|---|---|---|---|---|---|
| Ottawa 2011 | .48xx | | | -0.22 | -0.12 | | .36x | -0.08 | .42xx |
| Ottawa 2012 | .18 | -0.38x | .25 | .60xx | .43x | .08 | .08 | .02 | .05 |
| St. Anne 2011 | | | | | | | | | |
| St. Anne 2012 | .66xx | .32x | -0.12 | 0.05 | -0.21 | -0.02 | .20 | | -.24 |
| Fredericton 2011 | .67xx | | | -0.06 | | .19 | .29 | | |
| Fredericton 2012 | .67xx | -0.21 | .32x | .05 | .20 | -0.12 | -.02 | | .003 |
| Canning 2011 | .68xx | -0.25x | .34xx | .12 | .31x | .18 | .42xx | | |
| Canning 2012 | | .02 | .46xx | .63xx | .44xx | .16 | .28x | | |
| Laval 2012 | .53xx | -0.08 | .46xx | .18 | -0.19 | .15 | .39xx | | |
| Elora 2012 | .67xx | .18 | -0.3x | -0.02 | | .35xx | .49xx | | |

xx Significantly different at the .001 level.
x Significantly different at the .01 level.

## Example of Using GGE Biplot Software to Graphically Analyze the Data

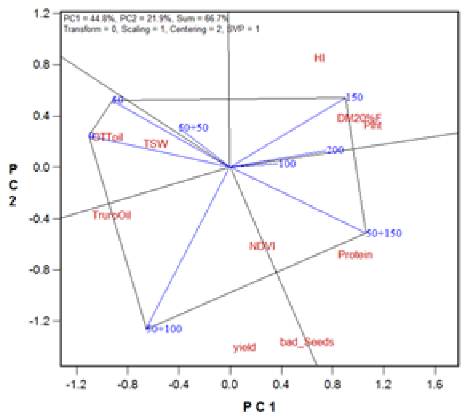
Using the GGE Biplot software, biplot could be used to visualize the nitrogen by environment two-way data and identify major yield limiting factor at each site. The following are some examples to illustrate these (Fig. 14). Detailed analyses of the data are on-going. For example, at the Ottawa site in 2012, high grain yield and grain protein are associated with split application of N both at 50+100 and 50+150 kg N $ha^{-1}$. It appeared that canopy reflectance, expressed as normalized difference vegetation index (NDVI) had a close relationship with the yield parameters. High seed yield at Truro appeared to be closely related to thousand seed weight. At Guelph, there was a closely positive correlation between yield and NDVI. Once all the data are compiled into the appropriate format, interrelationships between the measured parameters will be examined.

Ottawa 2012 - GGE Biplot Analysis




Relationship among testers

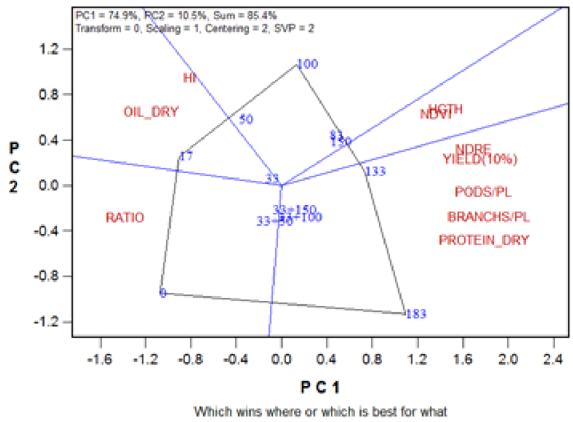
Ottawa 2012




Which wins where or which is best for what

## AAFC RESEARCH BRANCH
## Research Project Final Report

Guelph 2012




Canning 2012

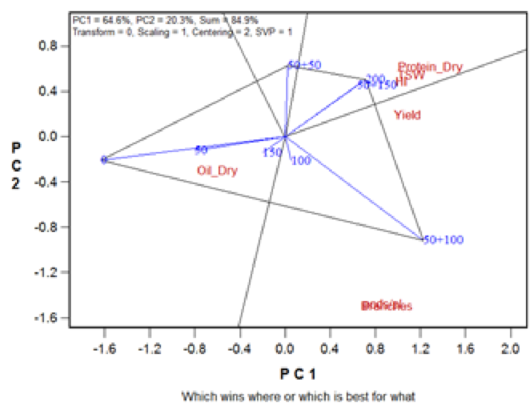



Fig. 14. GGE biplot of nitrogen by environment two-way data, showing which nitrogen level had the highest yields, and an environment by factor biplot summarizing the interrelationship among yield components.

# Appendix I

# Canola fertility study in 2010 (Guelph)

## 1. OBJECTIVES

Two small-plot trials were conducted at the Elora Research Station (University of Guelph) in 2010 to test the effects of various planting and fertility practices on growth, yield and quality of spring canola.

1) The first trial tested the effects of various N fertility rates, in combination with the presence or absence of soil applied S (sulfate) and B fertilizers.

2) The second trial tested the effects of row width (18 or 36 cm) and seeding rate.

## 2. MATERIALS AND METHODS

### 2.1 Trial Location and Agronomy

The trials were conducted at the University of Guelph Elora Research Station in Ponsonby, Ontario (43° 39’ N / 80° 24’ W) on a clay loam soil. Composite soil samples for the field were taken on May 16, from both the 0-15 cm and 15-30 cm depths. Because the original soil test did not include analyses for either S or B, a second composite sample was taken after harvest (December) from the alleyways where no S or B fertilizers were applied, and analyzed for these two elements. Soil test results are shown in Table 1.

Both trials received 50 kg / ha each of P and K (i.e., 50 kg / ha each of $P_2O_5$ and $K_2O$ equivalents), which were incorporated by tillage. In addition, the seeding rate trial received 20 kg / ha S and 17 kg / ha N as ammonium sulfate pre-plant, 60 kg / ha N as ammonium nitrate pre-plant, and then an additional 60 kg / ha N as ammonium nitrate as a topdress application on June 18. See Section 2.2 below for fertilizer rates on the fertility trial.

Conventional tillage was used. For weed control, Bonanza 480 Liquid (trifluralin, UAP Canada) was applied pre-plant at 2.5 L / ha and incorporated by tillage. No post emergence herbicides were required.

Plots were seeded May 18 using a cone seeder. The variety was InVigor 5440 (Bayer Crop Science), a glufosinate-tolerant hybrid variety. For the fertility trial, a row width of 18 cm and seeding rate of 7.5 kg / ha was used. Individual plots were planted 1.5 m wide x 7 m long, and then trimmed to 5 m length after emergence. Each entire 1.5 x 5 m plot was harvested using a plot combine on August 26. Seed was dried in a 35°C forced air drier prior to weighing. Final moisture was determined with a moisture meter. Reported yields are adjusted to 8.5% moisture.

**2.2. Experimental Design and Treatments**

The fertility trial was a complete factorial design with four N rates, two S rates and two B rates, for a total of 16 treatment combinations. There were four replications. The rates of actual N, S and B applied for each treatment are shown in Table 2.

N was applied as ammonium nitrate (34% N), S as ammonium sulfate (21% N, 24% S), and Boron as borax (15% B). Because application of ammonium sulfate supplied 17 kg / ha N in addition to the 20 kg S / ha, plots that did not receive ammonium sulfate were supplied with an additional 17 kg N/ ha as ammonium nitrate. This means that the lowest N fertilizer rate in the trial was 17 kg / ha, not 0 kg / ha. Fertilizers were pre-weighed and applied to individual plots by hand. Because the borax was applied in a very small quantity of a fine granule size, it was mixed with 100 g per plot of an inert carrier (Turface) to facilitate even application across the plot area. The inert carrier alone was applied to plots that did not receive B fertilizer.

The seeding rate trial was a split-plot design, with row width as the main plot factor (18 or 35 cm), and one of four seeding rates (2.5, 5.0, 7.5 or 10.0 kg / ha) as the sub-plot factor. Since the 1000-seed weight was 4.25 g, these seeding rates equate to approximately 60, 120, 180 and 240 seeds / $m^2$.

**2.3 Measurements**

In addition to the yield measurements, the following data were collected:

i) *Canopy spectral reflectance* – On June 25 (bud stage) a dual channel reflectance spectrometer (model Unispec DC, PP Systems) was used to measure spectral reflectance of incoming solar radiation by the crop canopy. Two scans were made per plot. These data were used to calculate the Normalized Difference Vegetation Index (NDVI), a measure of canopy cover strongly related to leaf area index, and also the ratio of the Normalized Difference Red Edge (NDRE) Index to the NDVI; the NDRE:NDVI ratio is primarily an indicator of canopy colour ("greenness").

ii) *Plant height* – measured just prior to harvest

iii) *Final plant stand* – measured just after harvest. Based on stem counts from one complete 5-m row per plot. Completed for the seeding rate trial only.

iv) *Percent establishment* – the final plant stand as a percentage of the seeding rate. Calculated for the seeding rate trial only.

iv) *Green and brown seed percent* – based on crushing 200 seeds per plot

v) *1000-seed weight* – based on weighing 200 seeds per plot

**2.4 Data Analysis**

The fertility trial was analyzed as a randomized complete block factorial design using the GLM procedure in SAS to identify significant main effects of N rate (four levels), S fertilizer and B fertilizer on each response variable, as well as significant 2- and 3-way interactions between the three fertilizers. Where significant effects were found, individual treatment means were compared using protected LSD tests.

The seeding rate trial was analyzed as a replicated split plot design, using the GLM procedure in SAS. The effect of row width (main plot factor) was tested using block x row width as the error term, and the effects of seeding rate and row width x seeding rate were tested using the overall error term. Where significant effects were found, the individual treatment means were compared using protected LSD tests, again using the appropriate error term in each case.

**3. RESULTS**

**3.1 Fertility Trial**

The mean yield across all treatments in the fertility trial was 2379 kg / ha, with a CV of 13.6%. P-values for treatment main effects and interactions for all measured parameters are shown in Table 3. There were strong main effects of N rate for all measured parameters except green seed, brown seed, and 1000-seed weight. The main effect of S application was significant for yield, NDVI, green seed and brown seed. There were no significant treatment effects on seed size (1000-seed weight).

There were no main effects of B application on any measured parameter, and the N x B, S x B and N x S x B interactions were also not significant. Therefore, there is no evidence from this trial that soil B application had any effect, despite the relatively low soil B levels indicated in the soil test (Table 2), and so the B treatments will not be discussed further.

For green seed percent, there was no significant interaction between N and S. Across N rates, sulphur application decreased green seed content from 2.75% to 1.25% ($P < 0.0001$).

Apart from green seed, for all parameters where there was a main effect of N and / or S, there was also a statistically significant N x S interaction. The N x S interaction for yield is shown in Fig. 1. In the absence of S fertilizer, there was no benefit realized from the application of N fertilizer. By contrast, when ammonium sulfate was applied, yield increased 38% from 2175 to 3010 kg / ha from the lowest to the highest N rate.

The N x S interaction for NDVI indicated that canopy cover (essentially, leaf area) was stable across N rates when S was applied, but in the absence of S, NDVI increased with N rate (Fig. 2). In contrast, the NDRE / NDVI ratio (a measure of "greenness") increased with N rate, but this increase was strongest at the high N rates when S fertilizer was applied (Fig. 3). Taken together, the canopy spectral reflectance results indicate that at high N rates the S-deficient crop had greater leaf area but was lighter green in colour.

The N x S interaction for plant height was such that, in the presence of S fertilizer, plant height was significantly reduced at both of the lowest N rates (17 and 67 kg / ha), while in the absence of S fertilizer plant height was significantly reduced only at the lowest N rate (Fig. 4).

At the three lowest N rates, S fertilizer had no effect on the brown seed content. However, at the highest N rate, brown seed content increased significantly (P = 0.01) in the absence of S fertilizer (Fig. 5).

**3.2 Seeding Rate Trial**

The mean yield for the seeding rate trial was 2585 kg / ha, and the CV for yield was essentially identical to that of the fertility trial (13.5%). P-values for the main effects of row width, seeding rate, and their interaction are shown in Table 4 for each response variable.

There were no significant effects of either row width or seeding rate on yield, indicating that the lowest rate used here (2.5 kg / ha, which is about 60 seeds per $m^2$ and about 50% of the typical seeding rate for the region) was not low enough to induce a yield penalty (Fig. 6).

There were also no treatment effects on percent establishment, green seed, brown seed, or seed size (1000-seed weight). The average percent establishment was 65.9; that is, 65.9% of seeds that were sown successfully produced plants that were present at the time of final harvest.

Of course there was a strong main effect of seeding rate on plant stand (Fig. 7). Higher seeding rates also produced greater canopy cover (NDVI) at the bud stage (Fig. 8). The NDRE / NDVI ratio was also affected by seeding rate (Fig. 9), but it is not clear if this truly indicates more "greenness" at the higher seeding rates, since this parameter also has some sensitivity to canopy cover. As plant populations increased at higher seeding rates, plant height was reduced (Fig. 10).

**4. GENERAL CONCLUSIONS**

Although these trials were planted later than the optimum seeding date for canola in the region, yields were in general quite high, averaging over 2500 kg / ha, with the best treatments yielding over 3000 kg / ha. Yield CVs were higher than normal for this type of trial, but nonetheless it was possible to identify significant treatment effects and draw conclusions.

The fertility trial clearly demonstrated the potential for strong N x S interactions in spring canola. The fact that no yield benefit was realized from even high rates of N in the absence of S fertilizer strongly supports the now-common practice of routine application of ammonium sulfate to this crop. Also potentially important is the finding that S deficiency could increase green seed content across N rates, and also brown seed content at high N rates.

The lack of a significant response to soil-applied B was in agreement with the majority of the literature. There is much better evidence for yield responses to mid-season foliar B applications in spring canola, so in future trials foliar B treatments should also be included.

In the seeding rate trial, the lack of a yield response to row width was as expected, given the results of past studies of this type. What was perhaps more interesting was the stability of yield across seeding rates. If these results are typical, rates could be reduced to 50% of what is currently typical for the region, without incurring a yield penalty. This should be studied further, with the inclusion of even lower rates to permit the true yield response to seeding rate to be defined.

*Table 1.* Soil test results for the field trial location. Samples were taken from two depths: 0 to 15 cm, and 15 to 30 cm.

| **Element** | **Units** | **0-15 cm** | **15-30 cm** |
|---|---|---|---|
| Ammonium N | mg / kg dry | 0.374 | 0.295 |
| Nitrate N | mg / kg dry | 28.7 | 4.4 |
| Phosphorous, extractable | mg / L | 14 | 3 |
| Potassium, extractable | mg / L | 99 | 93 |
| Magnesium, extractable | mg / L | 320 | 290 |
| pH | | 7.5 | 7.8 |
| Sulphur* | % dry | 0.03 | 0.01 |
| Boron* | ppm | 0.53 | 0.20 |

*Soil samples were taken May 16, except for analysis of S and B; the sample for those elements was taken in December following the field season, from the alleyways where no S or B fertilizers had been applied.

*Table 2.* Combinations of N, S and B fertilizer application rates for each treatment in the fertility trial.

| Treatment No. | N kg / ha | S kg / ha | B kg / ha |
|---|---|---|---|
| 1 | 17 | 0 | 0 |
| 2 | 67 | 0 | 0 |
| 3 | 117 | 0 | 0 |
| 4 | 167 | 0 | 0 |
| 5 | 17 | 20 | 0 |
| 6 | 67 | 20 | 0 |
| 7 | 117 | 20 | 0 |
| 8 | 167 | 20 | 0 |
| 9 | 17 | 0 | 2 |
| 10 | 67 | 0 | 2 |
| 11 | 117 | 0 | 2 |
| 12 | 167 | 0 | 2 |
| 13 | 17 | 20 | 2 |
| 14 | 67 | 20 | 2 |
| 15 | 117 | 20 | 2 |
| 16 | 167 | 20 | 2 |

*Table 3.* P-values for the main effects of N rate, S fertilizer application and B fertilizer application, and their interactions, on all response variables. P-values for significant effects ($P < 0.05$) are shown in bold.

| Effect | Yield | NDVI | NDRE / NDVI | Height | Green Seed | Brown Seed | 1000-seed wt |
|---|---|---|---|---|---|---|---|
| **N** | **0.03** | **<0.0001** | **<0.0001** | **0.0002** | 0.06 | 0.13 | 0.41 |
| **S** | **<0.0001** | **<0.0001** | 0.08 | 0.86 | **<0.0001** | **0.0009** | 0.33 |
| **B** | 0.96 | 0.24 | 0.57 | 0.25 | 0.18 | 0.15 | 0.33 |
| **N x S** | **<0.0001** | **<0.0001** | **0.0009** | **0.03** | 0.2 | **0.002** | 0.42 |
| **N x B** | 0.99 | 0.43 | 0.80 | 0.73 | 0.8 | 0.34 | 0.39 |
| **S x B** | 0.24 | 0.33 | 0.36 | 0.38 | 0.57 | 0.60 | 0.31 |
| **N x S x B** | 0.59 | 0.19 | 0.50 | 0.95 | 0.94 | 0.85 | 0.39 |

*Table 4.* P-values for the effects of row width, seeding rate, and their interaction on all response variables. P-values for significant effects (P < 0.05) are shown in bold.

| Effect | Yield | plants $m^{-2}$ | % establishment | NDVI | NDRE / NDVI | Height | Green Seed | Brown Seed | 1000-seed wt |
|---|---|---|---|---|---|---|---|---|---|
| **row width** | 0.68 | 0.45 | 0.79 | **0.02** | **0.05** | 0.58 | 0.78 | 0.30 | 0.46 |
| **seeding rate** | 0.99 | **<0.0001** | 0.15 | **<0.0001** | **<0.0001** | **0.0001** | 0.53 | 0.99 | 0.26 |
| **width x rate** | 0.41 | 0.08 | 0.11 | 0.11 | 0.47 | 0.71 | 0.95 | 0.62 | 0.11 |

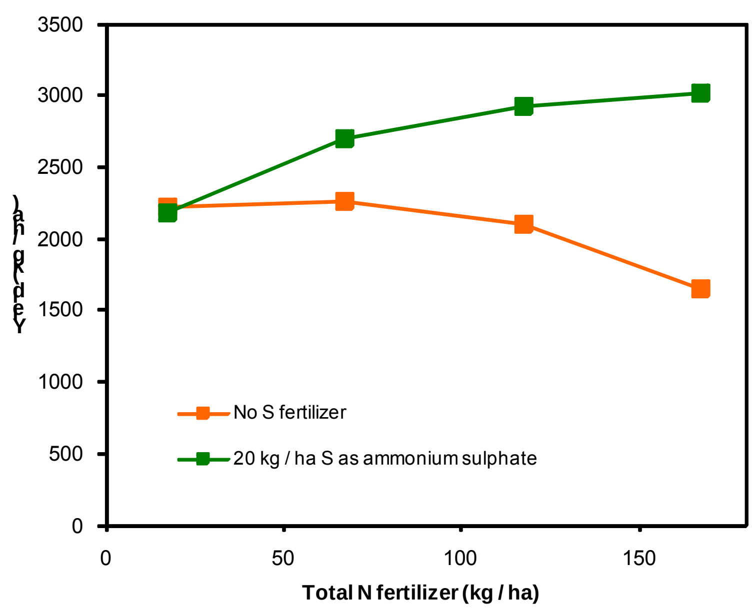



*Fig. 1.* Response of yield to S fertilizer and N rate. The effect of S was significant (P < 0.05) at all N rates except the lowest one.

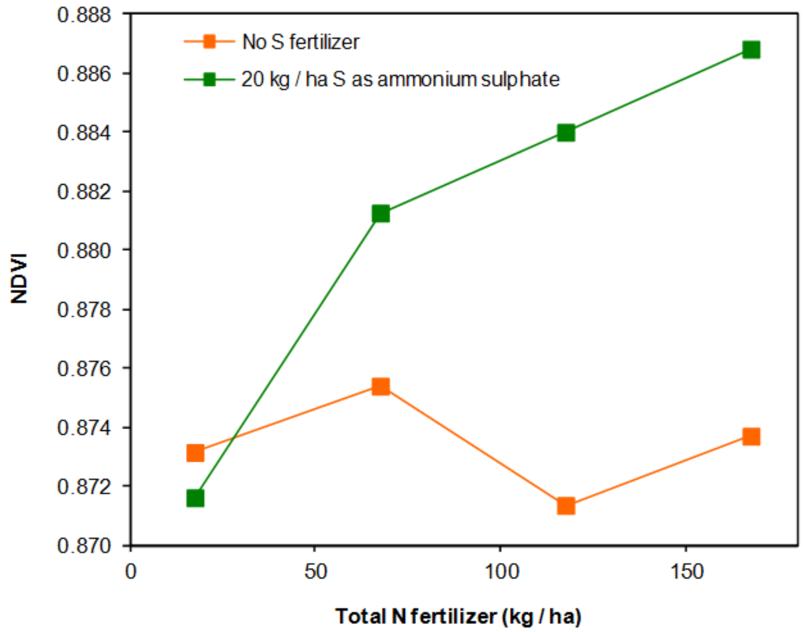



*Fig. 2.* Response of NDVI to S fertilizer and N rate. There was a significant ($P < 0.05$) effect of N rate in the presence of S fertilizer, but not in its absence.

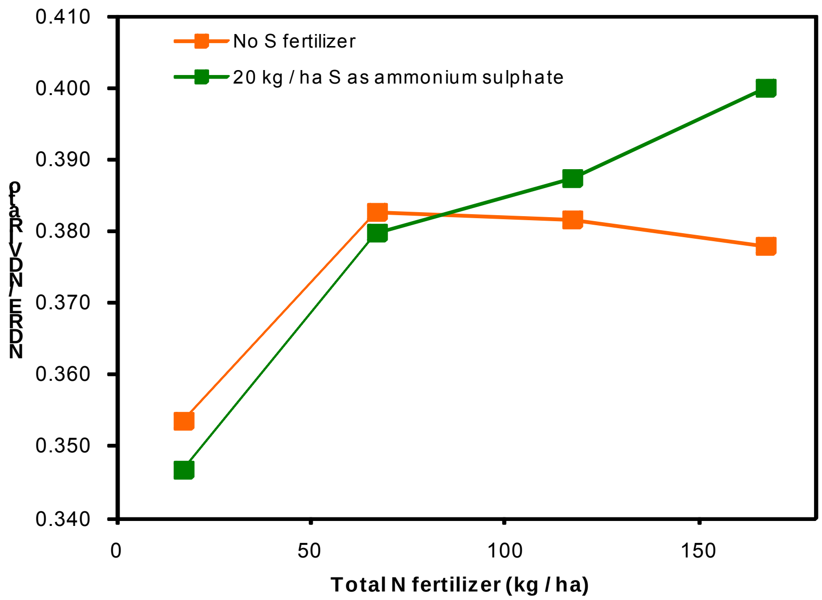



*Fig. 3.* Response of the NDRE to NDVI ratio to S fertilizer and N rate. The two S treatments differed significantly (P < 0.05) only at the highest N rate.

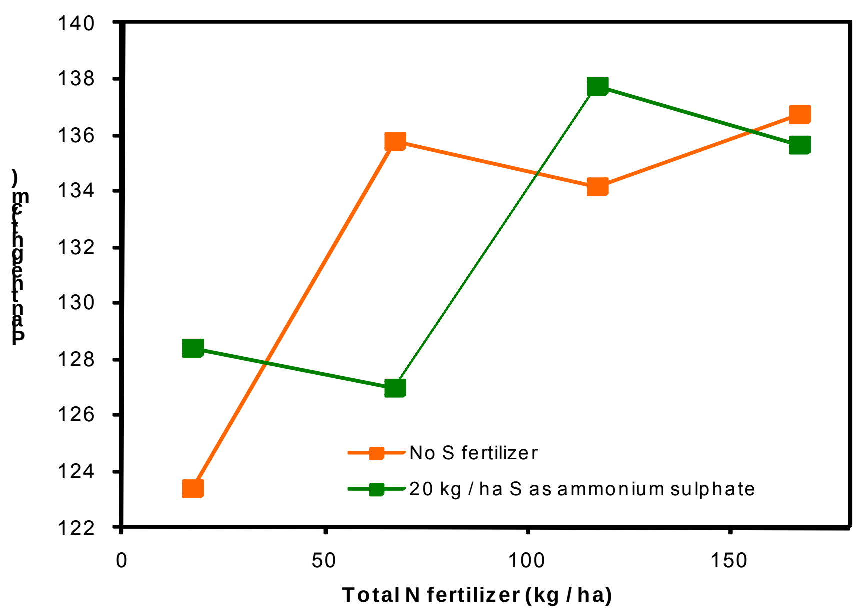



*Fig. 4.* Response of plant height to S fertilizer and N rate. Increasing the N rate increased plant height, but the N rate required to induce a significant increase in height was lower in the absence of S fertilizer.

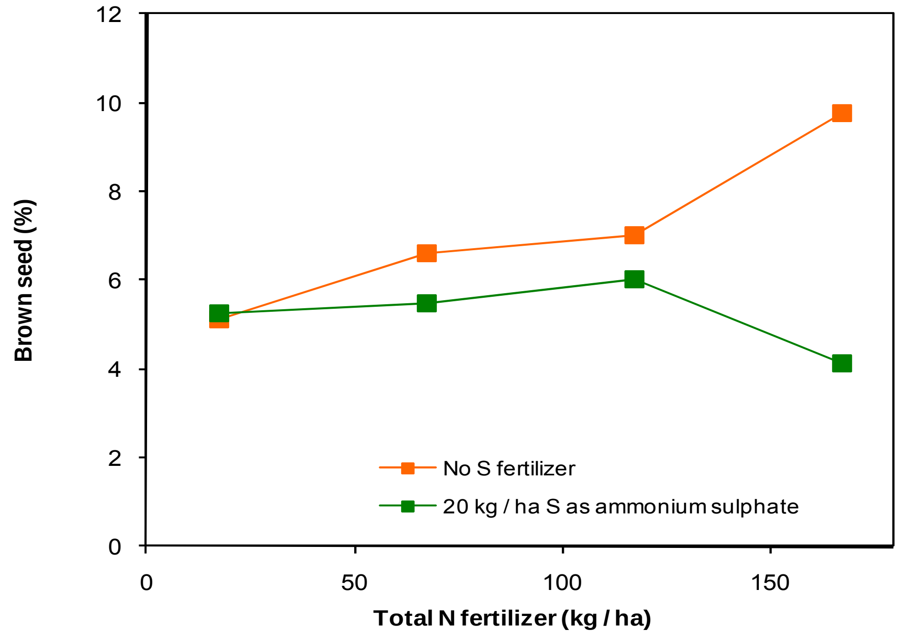



*Fig. 5.* Response of brown seed content to S fertilizer and N rate. There was no significant N effect on brown seed, but there was a significant S effect, and a significant N x S interaction. At the highest N rate, brown seed content was significantly higher in the absence of S fertilizer.

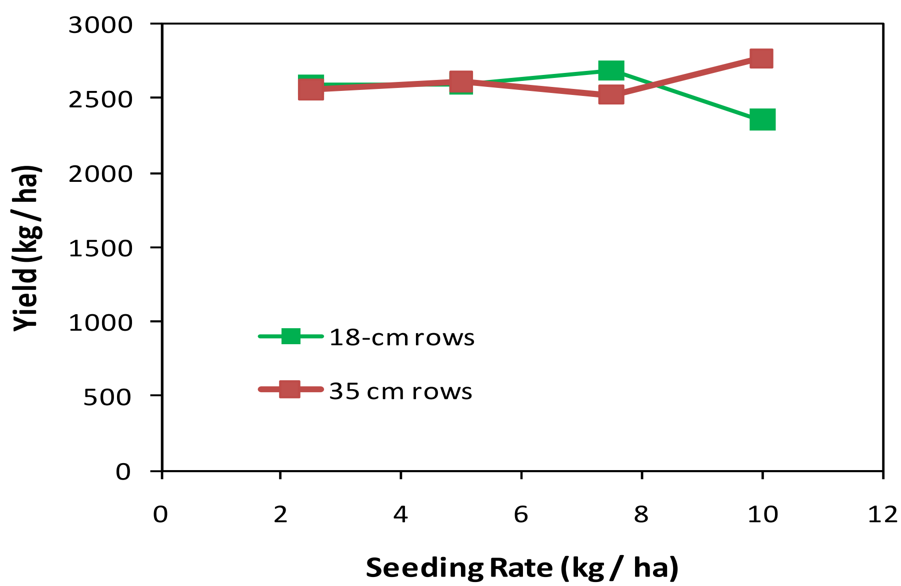


*Fig. 6.* Response of yield to row width and seeding rate. Neither row width nor seeding rate had a significant effect on yield.

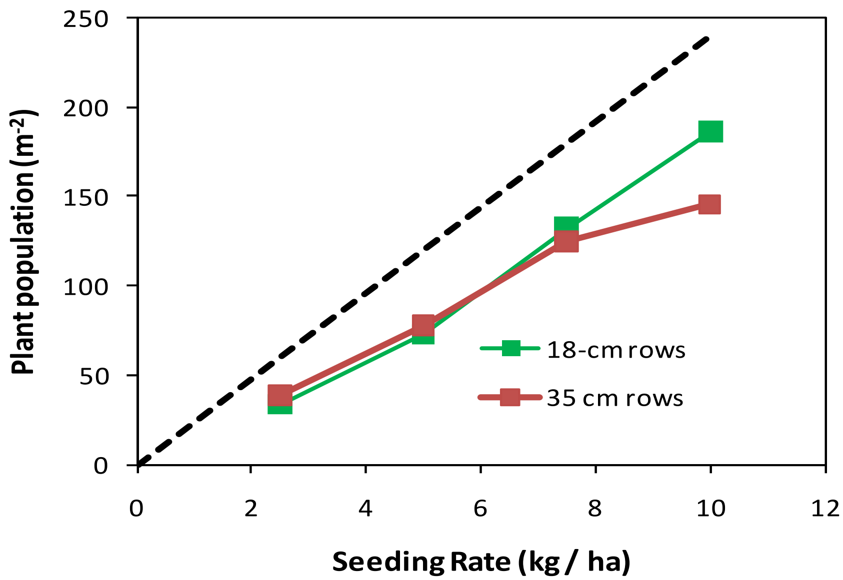



*Fig. 7.* Effect of row width and seeding rate on plant population. The seeding rate effect was highly significant but there was no effect of row width, and no width x rate interaction. The dashed line represents 100% establishment (i.e., plant population = seeding rate).

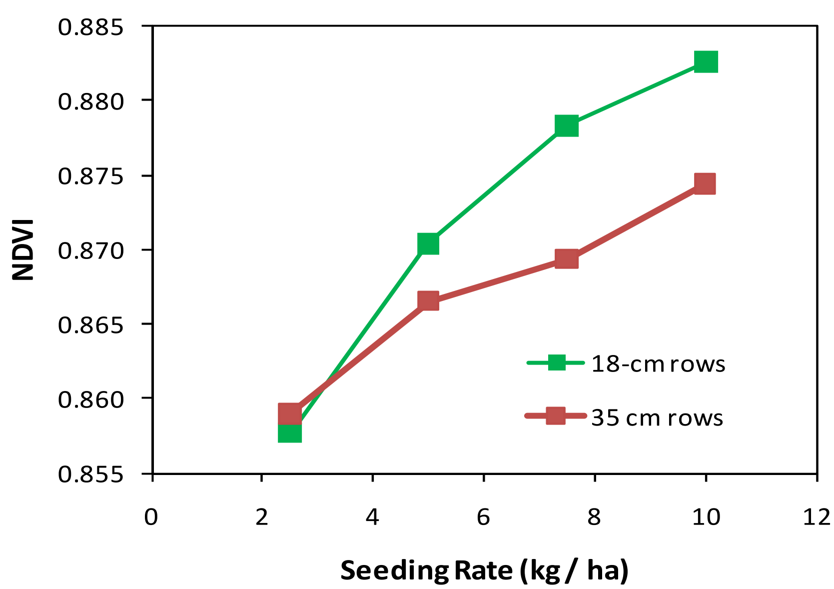


*Fig. 8.* Response of NDVI to row width and seeding rate. The main effects of both row width and seeding rate were significant, but the interaction was not.

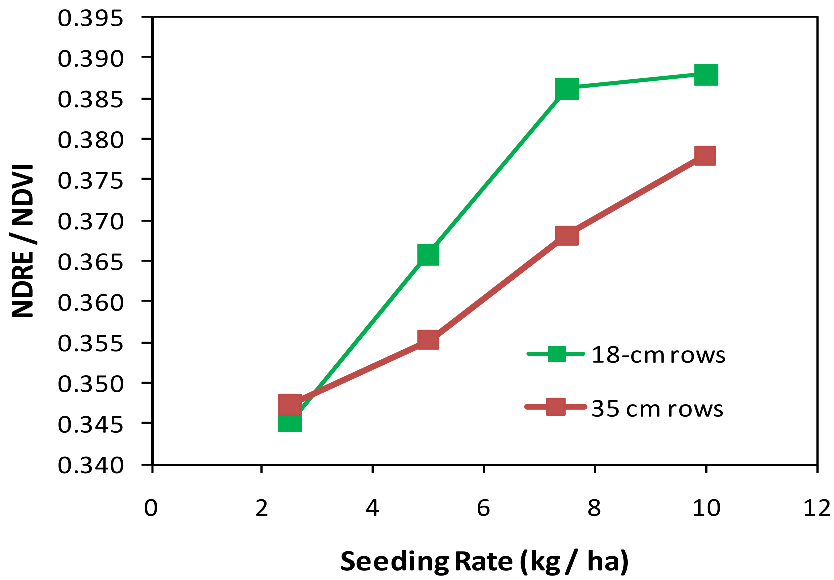



*Fig. 9.* Effect of row width and seeding rate on the NDRE to NDVI ratio. The main effects of both row width and seeding rate were significant, but the interaction was not.

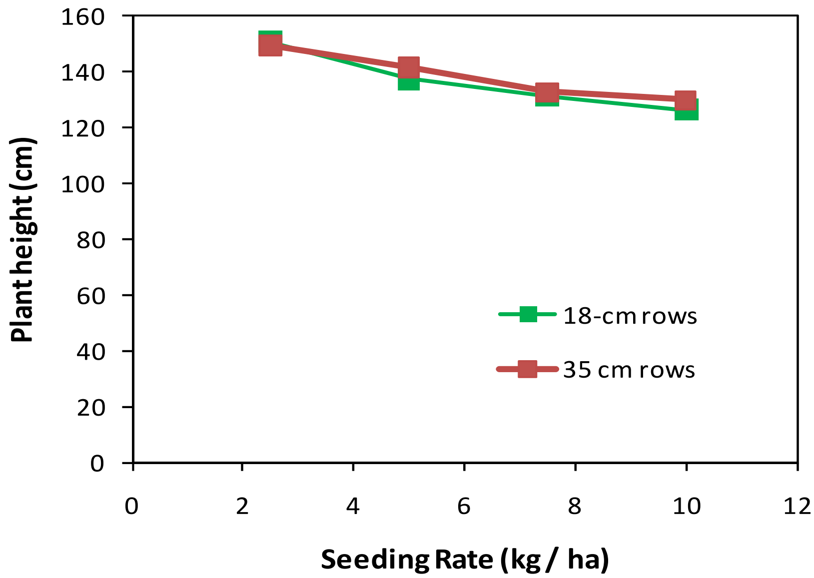



*Fig. 10.* Response of plant height to row width and seeding rate. The seeding rate effect was significant but there was no effect of row width, and no width x rate interaction.

## Canola Fertility Study 2010 (Nova Scotia Agricultural College)

**Management Trials for Spring Canola Fertility (N, S, B) Response / Seeding rate X Row Spacing Response**

**Objective:** The objective of these trials was to evaluate the effect of fertility (nitrogen, sulphur and boron combinations) (Trial 1) and seeding rate by row spacing (Trial 2) on the yield of spring canola under NS conditions in 2010.

**Location**: Truro, NS – Trial 1 - NSAC Field 201
Trial 2 - NSAC Plumdale Range 5
**Crops**: Spring Canola – Invigor 5440

**Previous Crops: Trial 1** - Fertility - Soybeans
**Trial 2** -Seeding Rate X Row spacing – Fallow

**Design**: **Trial 1** - Fertility - Three Factor Factorial, 4 Reps

**Trial 2** - Seeding Rate X Row spacing – Split plot, 4 reps

**Seeding Dates: Trial 1 -** Fertility - May 24
**Trial 2** - Seeding rate X Row spacing – May 24

**Harvest Dates: Trial 1 -** Fertility – September 2
**Trial 2** - Seeding rate X Row spacing – September 3

**Row spacing: Trial 1 -** Fertility –15cm
**Trial 2** - Seeding rate X Row spacing – 15 or 30 cm

**Seeding rates: Trial 1** - Fertility –200 seeds/$m^2$
**Trial 2** - Seeding rate X Row spacing – Variable (See Treatment List Table 2)

**Fertility: Trial 1** - Fertility –220 kg/ha 0-20-20 Preplant incorporated See Treatment List Table 1
**Trial 2** - Seeding rate X Row spacing – 15 or 30 cm
220 kg/ha 0-20-20 Preplant incorporated May 18
85 kg/ha 21-0-0-24S Preplant incorporated May 21
165 kg/ha 27-0-0 Preplant incorporated May 21
150 kg/ha 27-0-0 June 30 Topdressing

**Herbicide: Trial 1** - Fertility –Liberty 200SN 2L/ha June 27
**Trial 2** - Seeding rate X Row spacing – Liberty 200SN 2L/ha June 27

**Plot size: Trial 1** - Fertility – 2 m X 5 m
**Trial 2** - Seeding rate X Row spacing – 1.25 m X 5 m

**Treatments:**

# Table 1. Trial 1 - Fertility treatments

| Trt No. | Nitrogen rate kg/ha | Sulphur rate kg/ha | Boron rate kg/ha |
|---|---|---|---|
| 1 | 17.5 | 0 | 0 |
| 2 | 17.5 | 0 | 2 |
| 3 | 17.5 | 20 | 0 |
| 4 | 17.5 | 20 | 2 |
| 5 | 50 | 0 | 0 |
| 6 | 50 | 0 | 2 |
| 7 | 50 | 20 | 0 |
| 8 | 50 | 20 | 2 |
| 9 | 100 | 0 | 0 |
| 10 | 100 | 0 | 2 |
| 11 | 100 | 20 | 0 |
| 12 | 100 | 20 | 2 |
| 13 | 150 | 0 | 0 |
| 14 | 150 | 0 | 2 |
| 15 | 150 | 20 | 0 |
| 16 | 150 | 20 | 2 |

**Table 2. Trial 2 – Row Spacing X Seeding Rate Treatments**

| Trt No. | Row Spacing cm | Seeding rate kg/ha |
|---|---|---|
| 1 | 15 | 2.5 |
| 2 | 15 | 5 |
| 3 | 15 | 7.5 |
| 4 | 15 | 10 |
| 5 | 30 | 2.5 |
| 6 | 30 | 5 |
| 7 | 30 | 7.5 |
| 8 | 30 | 10 |

**Methods:**
Land was prepared by discing followed by s-tine harrows. Pre-plant fertilizer was applied with a pneumatic fertilizer spreader and incorporated with S-tine harrows. Canola plots were seeded with a small plot drill on the dates indicated. The fertility trial plots were seeded as double plots (two passes of plot seeder) and the seeding rate by row spacing trial was seeded as single plots. The seeding rate by row spacing trial was blocked by row spacing. The various fertility rates for the fertility trial were weighed out for individual plots (2.5 m X 5 m) and broadcast applied by hand after seeding (June 2). The nitrogen source was ammonium nitrate (27-0-0), sulphur source was ammonium sulphate (21-0-0-24S) and the boron source was Borax with filler (3.75% boron). Because the sulphur source was ammonium sulphate at the rate to provide 20 kg/ha S we were still providing 17.5 kg/ha of N so this was the base N rate for all treatments. The 17.5 and 50 kg/ha N rates were both applied immediately after seeding and the 100 and 150 kg/ha N rates were split with half at seeding and the 2nd half at bolting. The herbicide Liberty was applied at 2L/ha with a tractor mounted boom sprayer in approximately 165 L/ha of water. Plots were monitored throughout the growing season for disease and insect pressure. Data collected in the field included plant heights and flowering dates for both trials. In the row spacing X seeding rate trial, stand counts were recorded and plants were collected for branch and pod counts. At harvest, each plot was harvested with a Hege 125C small plot combine. Harvested area was 1.25 m X 5 m for both trials. All seed was collected, dried, cleaned and weighed. Thousand kernel weights (TKW) were measured on a subsample from each treatment.

**Results:**
**Trial 1 – Response of canola to nitrogen, sulphur and boron**
Seed yield responded significantly to nitrogen, sulphur and boron (Table 3). A significant response

was seen to the increase in N from 17.5 kg/ha to 50 kg/ha N and, although there was a trend to higher yields with each increase in N, no significant difference was found between 50, 100 and 150 kg/ha N (Fig. 1). There was a significant yield response with the application of S. Overall treatments receiving the S yielded 246 kg/ha higher than those not receiving S. However, there was also a significant interaction between the nitrogen and sulphur applied. There was a trend towards increased yields with the application of sulphur with each N rate except at the lowest N rate. This increase was only statistically significant for the highest N rate where yields were 614 kg/ha higher with 150 N plus S compared to the 150 N and no S (Fig. 2). There was a slightly significant yield reduction going from 0 kg/ha B to 2 kg/ha B. There was also a significant plant height response from 17.5 kg/ha N to 50 kg/ha N but not beyond this.

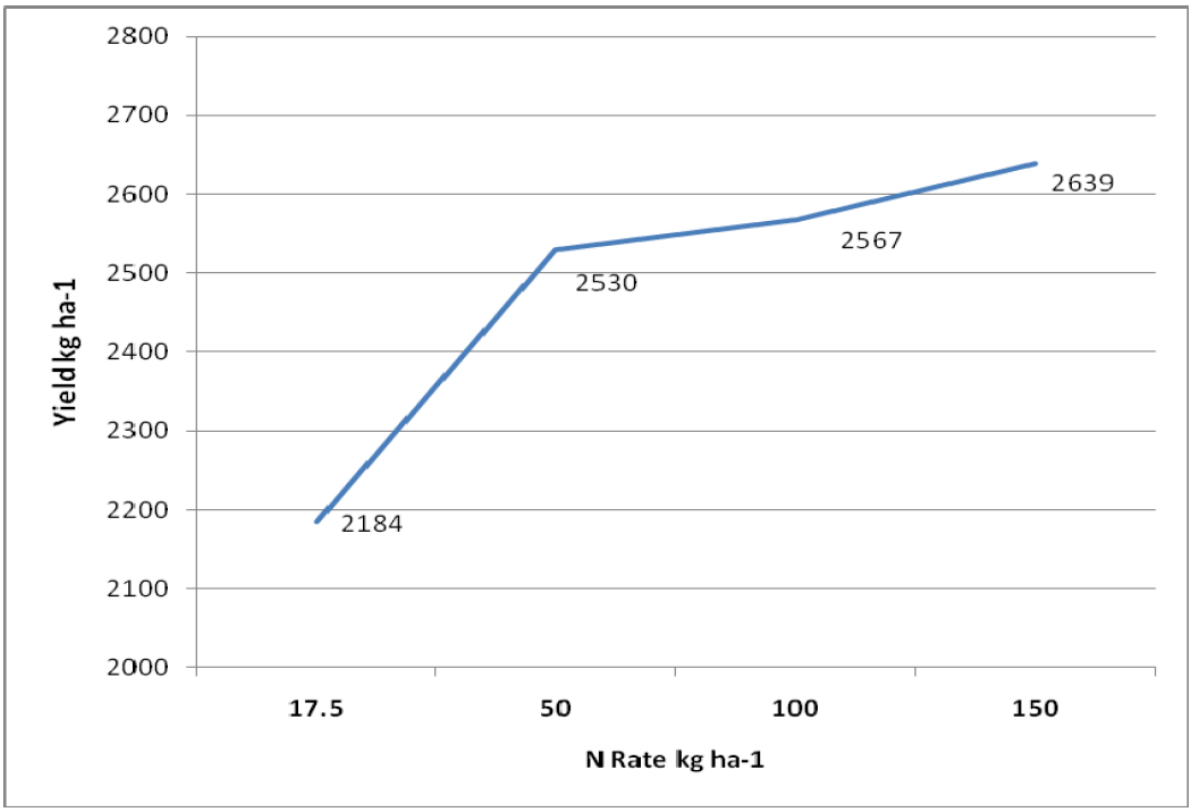



**Figure 1. Canola Yield Response to Increasing N Levels**

Table 3. Factorial ANOVA Table for Trial 1- Response to Nitrogen, Sulphur and Boron

| Rating Data Type<br>Rating Unit | | Yield<br>kg/ha | TKW<br>g | Plant Ht.<br>cm |
|---|---|---|---|---|
| TABLE OF R MEANS | | | | |
| Replicate 1 | | 2432 | 3.85 | 99 |
| Replicate 2 | | 2448 | . | 102 |
| Replicate 3 | | 2276 | . | 104 |
| Replicate 4 | | 2764 | . | 104 |
| | *LSD p <0.05* | *204* | | *ns* |
| TABLE OF A MEANS | | | | |
| 1 | N 17.5 kg/ha | 2184 | 3.73 | 97 |
| 2 | N 50 kg/ha | 2530 | 3.85 | 104 |
| 3 | N 100 kg/ha | 2567 | 3.89 | 104 |
| 4 | N 150 kg/ha | 2639 | 3.93 | 104 |
| | *LSD p <0.05* | *275* | | *4* |
| TABLE OF B MEANS | | | | |
| 1 | S 0 kg/ha | 2357 | 3.83 | 101 |
| 2 | S 20 kg/ha | 2603 | 3.86 | 103 |
| | *LSD p <0.05* | *98* | | *ns* |
| TABLE OF C MEANS | | | | |
| 1 | B 0 kg/ha | 2538 | 3.85 | 103 |
| 2 | B 2 kg/ha | 2423 | 3.84 | 102 |
| | | *83* | | *ns* |
| TABLE OF AB MEANS | | | | |
| 1<br>1 | N 17.5 kg/ha<br>S 0 kg/ha | 2188 | 3.78 | 97 |
| 2<br>1 | N 50 kg/ha<br>S 0 kg/ha | 2436 | 3.85 | 106 |
| 3<br>1 | N 100 kg/ha<br>S 0 kg/ha | 2472 | 3.9 | 100 |
| 4<br>1 | N 150 kg/ha<br>S 0 kg/ha | 2332 | 3.8 | 103 |
| 1<br>2 | N 17.5 kg/ha<br>S 20 kg/ha | 2180 | 3.68 | 96 |
| 2<br>2 | N 50 kg/ha<br>S 20 kg/ha | 2624 | 3.85 | 103 |
| 3<br>2 | N 100 kg/ha<br>S 20 kg/ha | 2662 | 3.88 | 108 |
| 4<br>2 | N 150 kg/ha<br>S 20 kg/ha | 2946 | 4.05 | 106 |
| | | *259* | | *ns* |

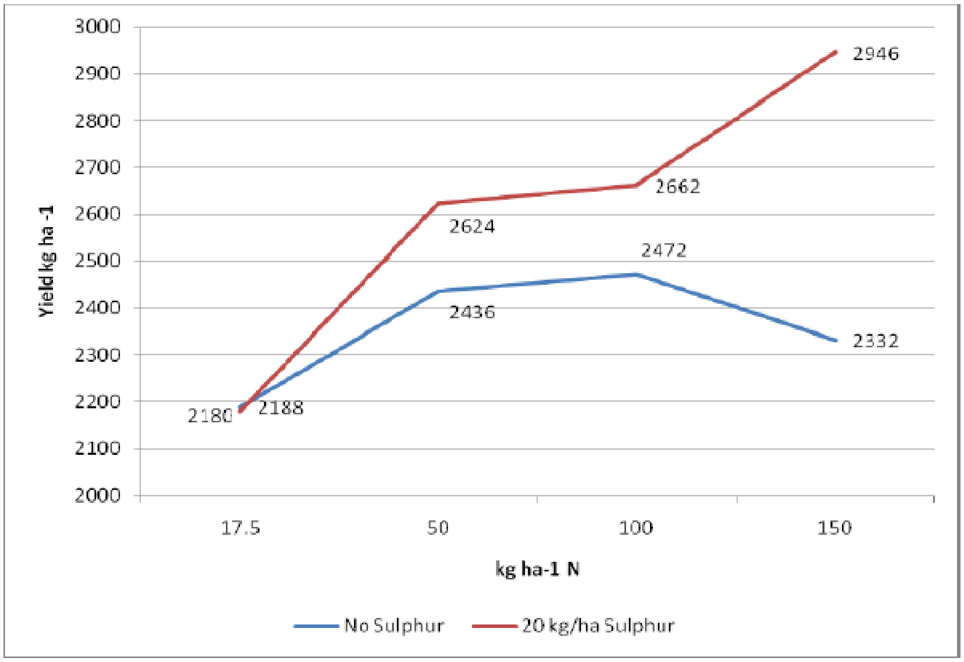



**Fig. 2. Canola Yield response to N and S combinations**

**Trial 2 – Response of canola to row spacing and seeding rate**
Yields were low in this trial due to heavy weed pressure in certain areas despite the use of Liberty. Although yields were low, there were differences seen among treatments. Seed yield responded significantly to seeding rate but no differences were seen between 15 and 30 cm row spacing (Table 4). Yields increased significantly from 2.5 kg/ha to 5 kg/ha N but no significant difference was found between 5, 7.5 and 10 kg/ha. There was a significant plant stand response to seeding rate as the plant stand count increased significantly as expected with each increase in seeding rate up to 7.5 kg/ha but was not significantly higher at 10 kg/ha compared to 7.5 kg/ha.

The plant stands achieved were reasonable, based on the seeding rates. The branch number per plant and the percentage of plants with greater than two branches was significantly affected by seeding rate but not by the row spacing. There was a significantly higher average branch number and the percentage of plants with at least two branches with the 2.5 and 5 kg/ha seeding rate than compared to the 7.5 and 10 kg/ha seeding rate.

**Table 4. Factorial ANOVA Table for Trial 2 – Row Spacing X Seeding Rate**

| Trt No. | Treatment Name | YIELD kg/ha | TKW g | Stand Count M2 | Plant Ht. cm | Average branch# /plant | Average pod# /plant | % Plants with >2 branches |
|---|---|---|---|---|---|---|---|---|
| TABLE OF R MEANS | | | | | | | | |
| Replicate 1 | | 1686 | 4.1 | 167 | 105 | 2.4 | 50.5 | 36.75 |
| Replicate 2 | | 872 | . | 152 | 98 | 2 | 40.8 | 27.19 |
| Replicate 3 | | 828 | . | 127 | 103 | 2.4 | 49.6 | 35.06 |
| Replicate 4 | | . | . | . | . | . | . | . |
| | LSD p <0.05 | 201 | | ns | 4 | ns | ns | ns |
| TABLE OF A MEANS - Row spacing | | | | | | | | |
| 1 | 15 cm | 1157 | 4.1 | 131 | 104 | 2.6 | 52.3 | 45.04 |
| 2 | 30 cm | 1100 | 4.2 | 166 | 99 | 1.9 | 41.7 | 20.96 |
| | LSD p <0.05 | ns | | ns | ns | ns | ns | ns |
| TABLE OF B MEANS - Seeding rate | | | | | | | | |
| 1 | 2.5 kg/ha | 733 | 4.2 | 71 | 102 | 2.5 | 53.2 | 53.17 |
| 2 | 5 kg/ha | 1205 | 4.2 | 128 | 104 | 2.7 | 51.3 | 40.17 |
| 3 | 7.5 kg/ha | 1224 | 4.2 | 190 | 101 | 1.8 | 42.5 | 19.33 |
| 4 | 10 kg/ha | 1352 | 4.1 | 206 | 101 | 2 | 40.8 | 19.33 |
| | LSD p <0.05 | 201 | | 36 | ns | 0.5 | ns | 17 |
| TABLE OF AB MEANS | | | | | | | | |
| 1<br>1 | 15 cm<br>2.5 kg/ha | 795 | 4.1 | 67 | 106 | 3 | 62.3 | 77.33 |
| 2<br>1 | 30 cm<br>2.5 kg/ha | 672 | 4.3 | 76 | 97 | 2 | 44 | 29 |
| 1<br>2 | 15 cm<br>5 kg/ha | 1253 | 4.2 | 120 | 108 | 3.3 | 62.7 | 57.83 |
| 2<br>2 | 30 cm<br>5 kg/ha | 1157 | 4.2 | 136 | 101 | 2 | 40 | 22.5 |
| 1<br>3 | 15 cm<br>7.5 kg/ha | 1301 | 4.0 | 160 | 102 | 2 | 44.7 | 22.67 |
| 2<br>3 | 30 cm<br>7.5 kg/ha | 1147 | 4.3 | 219 | 100 | 1.7 | 40.3 | 16 |
| 1<br>4 | 15 cm<br>10 kg/ha | 1280 | 4.1 | 178 | 101 | 2 | 39.3 | 22.33 |
| 2<br>4 | 30 cm<br>10 kg/ha | 1424 | 4.0 | 233 | 100 | 2 | 42.3 | 16.33 |
| | LSD p <0.05 | ns | | ns | ns | ns | ns | ns |

**Conclusions:**

Although canola responded positively to each increase in nitrogen, yields only significantly increased from 17.5 kg/ha N to 50 kg/ha N and not beyond 50 kg/ha N. Canola also responded positively to sulphur applications and showed a significant effect with the interaction of nitrogen and sulphur. The addition of sulphur with the highest N rate significantly increased yield compared to the highest N rate without S. Results of the seeding rate by row spacing trial indicated yields were significantly affected by seeding rate but not by row spacing with the optimum seeding rate being 5 kg/ha. Based on the results of these trials optimum N rates for canola would be in the 50 to 100 kg/ha range and seeding at a minimum of 5 kg/ha would be recommended. The addition of a sulphur source would be recommended to ensure optimum utilization of applied N. The addition of boron did not enhance crop performance and appeared in fact to cause a yield depression.

## Canola Fertilization Trial 2010 (McGill University)

Effect of fertilizers on canola plants growth was studied in the field conditions.

## Materials and methods

Conventional tillage was used for soil preparation.

Fertilizers Ammonium nitrate (27.5-0-0), Ammonium sulfate (21-0-0-24) and Granubor (14.3% boron) were used in the experiment and obtained from the Agrocenter Belcan Inc. (Ste-Marthe, Quebec, Canada). Soil on experimental plots contained sufficient amount of phosphorus and potash. All fertilizers were distributed on the plots and incorporated into the soil on May 27 before sowing.

Canola seeds were supplied by TRT company (Quebec, Canada). Seeds were seeded May 28 into 2.0 cm soil depth at 5 kg/ha$^{-1}$ seed rate and 7.5 inches (19.5cm) row width.

Herbicide Liberty was applied on canola seedlings at 2-3 leaf growth stage.

## Experimental design, treatments

The experiments were conducted as a completely randomized blocks design with three plots - replications for each treatment. Plot size was 1.8m x 5m.

The experiments included sixteen treatments comprised of factorial combination of application rates: nitrogen (N ha$^{-1}$); sulfur (S ha $^{-1}$) and Boron (B ha$^{-1}$).

**Treatments:**

| Treatment | Fertilizers application rate, kg/ha$^{-1}$ | | |
|---|---|---|---|
| | Nitrogen (N) | Sulfur (S) | Boron (B) |

| | | | |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2 | 0 | 0 | 2 |
| 3 | 0 | 20 | 0 |
| 4 | 0 | 20 | 2 |
| 5 | 50 | 0 | 0 |
| 6 | 50 | 0 | 2 |
| 7 | 50 | 20 | 0 |
| 8 | 50 | 20 | 2 |
| 9 | 100 | 0 | 0 |
| 10 | 100 | 0 | 2 |
| 11 | 100 | 20 | 0 |
| 12 | 100 | 20 | 2 |
| 13 | 150 | 0 | 0 |
| 14 | 150 | 0 | 2 |
| 15 | 150 | 20 | 0 |
| 16 | 150 | 20 | 2 |

**Data collection**

Canola plants were grown in the field for three month. Data were collected on following variables: plant emergence (number of plants in two rows per plot); plant growths stages (BBCH identification keys, Monograph, 2001); stand count (plant density per 1 meter row, 4 sub samplings per plot); plants dry weight, g/50cm (leaf, stem and seedless pods) 4 sub samplings per plot; seeds dry weight per plant and seeds from plants on 50cm row at plant maturity - 4 sub samplings per plot and seeds yield (g) per the plot. Data presented in tables was calculated per one meter plants row. Samples of shoots (leaves, stems) and seeds were dried at 65$^{o}$C in the oven for the dry biomass assessment.

Canola plots were regularly observed for the presence of pests and diseases.

Pictures and Meteorological data are attached at the end of this section.

## Statistical analysis

Data were analyzed using ANOVA combined with multiple comparison LSD (protected least significant difference) procedures (P<0.05). SAS Statistical Analysis System (v.9.2, SAS Institute Inc., Cary, NC, USA) was used.

Multiple regression analysis general linear statistical model was used to relate the variable to two predictive factors (Statgraphics Plus, v.4.0). There was a statistically significant relationship between variable and the two factors based on ANOVA P-value (P<0.05).

## Results

Canola was seeded May 28 and plants emergence was registered on June 4, June 7, June 9 and June 21 (Table 3). Plants emerged at the same time within all trial and number of seedlings was not significantly different between the treatments.

During the plant growth observations on plant growth stages were regularly recorded, however no visual differences in plant developing stages were determined.

Time to principal growth stages of canola plants development.

Leaf development: Code 10 Cotyledons completely unfolded June 4;

13 Three leaves unfolded June 11.

Stem elongation: Code 30 Beginning of stem elongation “rosette” June 20.

Flowering: Code 60 First flowers open July 5

69 End of flowering August 1.

Development of fruit: Code 71-79 from July to August.

Ripening: Code 80-89 to the end of August

Senescence: Code 97 Plant dead and dry First week of September

99 Harvest September 8

Number of plants per one meter row, dry plants biomass per one meter row and plant$^{-1}$ dry weight were determined at flowering stage (Table 4).The fertilizers did not greatly affect the number of plants in 1m row, however with the increase of N ha$^{-1}$ the dry plant biomass per m$^{-1}$ row increased, as well as the plant$^{-1}$ dry biomass.

The nitrogen is an important element affecting canola plant growth; sulfur and boron had no effect

on canola plant biomass (Fig. 4 and Fig. 5; Table 4) at flowering stage in our fertilization trial. The nitrogen rate increase from 50 to 150 kg/ha$^{-1}$ resulted in canola plants dry biomass increase from 170 g/m$^{-1}$ to 216 g/m$^{-1}$ and resulted in greater plant$^{-1}$ dry weight in treatments with N application above 100 kg/ha$^{-1}$. Increase in plant$^{-1}$ dry weigh was observed also on treatment 6 and 7.
Samples of plants were harvested at senescent growth stage for the determination of final stand count, plants dry biomass and seeds production (Table 5). No significant difference was recorded between the treatments in stand count, although the plants dry biomass increased with an increase of N rate. Sulfur and Boron did not have an effect on dry plants biomass (Fig. 8 and Fig. 9).
Similar effect of nitrogen was observed on canola seeds production (Fig. 6 and Fig. 7). The N rate increase from 50 to 150 kg/ha $^{-1}$ cause significant increase in canola seeds production, but application of boron (Fig. 6) and sulfur (Fig. 7) did not affect the seeds production. The nitrogen application rate increase from 50 to 150 kg/ha$^{-1}$ resulted in canola yield increase from 1315g up to 1771 g/plot$^{-1}$ (Table 5). Application of sulfur and boron had no effect on canola yield (Fig. 10 and Fig. 11) most likely due to sufficient amount of these microelements present in our soil.
During the experiment canola was observed for the presence of insects and diseases. Casual damage (pictures, p.27) from flea beetle was observed on canola seedlings and tarnished plant bug and cabbage moth were observed at flowering stage of canola plants, however the insect pressure was neglectful. No diseases were recorded on canola.

**Conclusions**

1. Nitrogen application rate affect canola plants productivity, but no effect of sulfur or boron applied in fertilization trial (experiment 2) on canola was determined.

2. No pests and disease pressure was observed on canola plants during the summer trials in 2010.

McGill 2010 Fertilization Trial.

Differences in plants color on low and high rates of nitrogen


Treatment 1. Nitrogen 0 kg/ha$^{-1}$. Minor leaf damage from flea beetle

Treatment 9.  Nitrogen 100kg/ha$^{-1}$

Table 1. Meteorological data (June, 2010) Ste-Anne-de-Bellevue

| **Date** | **Temperature ($^{o}$C)** | | | **Total precipitation (mm)** |
|---|---|---|---|---|
| | **max** | **min** | **average** | |
| 1 | 22.4 | 12.8 | 17.6 | 11.6 |
| 2 | 27 | 16.1 | 21.6 | 3 |
| 3 | 18.8 | 15 | 16.9 | 19 |

| | | | | |
|---|---|---|---|---|
| 4 | 24 | 15.2 | 19.6 | 0.2 |
| 5 | 21.9 | 11.8 | 16.9 | 4.8 |
| 6 | 12.9 | 10.4 | 11.7 | 13.4 |
| 7 | 18.9 | 9.7 | 14.3 | 0 |
| 8 | 19.7 | 9.1 | 14.4 | 0 |
| 9 | 21.6 | 11 | 16.3 | 0.4 |
| 10 | 15.3 | 12.1 | 13.7 | 3 |
| 11 | 21.5 | 10.2 | 15.9 | 0 |
| 12 | 20.9 | 12.4 | 16.7 | 0.6 |
| 13 | 26 | 11.8 | 18.9 | 0 |
| 14 | 18.5 | 13 | 15.8 | 1.8 |
| 15 | 22 | 10.9 | 16.5 | 0.2 |
| 16 | 19 | 9.4 | 14.2 | 34.2 |
| 17 | 25.6 | 14.2 | 19.9 | 5.2 |
| 18 | 27.5 | 15.2 | 21.4 | 0 |
| 19 | 29.4 | 14.9 | 22.2 | 8.8 |
| 20 | 26.9 | 19 | 23 | 0.4 |
| 21 | 25 | 13.4 | 19.2 | 0 |
| 22 | 25.7 | 13.2 | 19.5 | 3 |
| 23 | 26.1 | 18.7 | 22.4 | 5.8 |
| 24 | 23.8 | 15.9 | 19.9 | 24.2 |
| 25 | 22.1 | 13.9 | 18 | 0.2 |
| 26 | 20.1 | 16.6 | 18.4 | 0 |
| 27 | 24.5 | 16.3 | 20.4 | 0 |
| 28 | 27.3 | 17.5 | 22.4 | 19.4 |
| 29 | 20.1 | 14.2 | 17.2 | 0.4 |
| 30 | 19.1 | 11.3 | 15.2 | 0.8 |

Table 2. Meteorological data (July, 2010) Ste-Anne-de-Bellevue

| **Date** | **Temperature (°C)** | | | **Total precipitation (mm)** |
|---|---|---|---|---|
| | **max** | **min** | **average** | |

| | | | | |
|---|---|---|---|---|
| 1 | 20 | 11.9 | 16 | 0.8 |
| 2 | 24.5 | 13.2 | 18.9 | 0 |
| 3 | 27.9 | 15.1 | 21.5 | 0 |
| 4 | 29.6 | 18.7 | 24.2 | 0 |
| 5 | 32.5 | 19.8 | 26.2 | 0 |
| 6 | 33.2 | 23.8 | 28.5 | 0 |
| 7 | 33.7 | 23.3 | 28.5 | 0 |
| 8 | 33.9 | 23.1 | 28.5 | 0 |
| 9 | 30.6 | 20.7 | 25.7 | 30.2 |
| 10 | 28.7 | 19.3 | 24 | 0.4 |
| 11 | 30 | 19.2 | 24.6 | 0 |
| 12 | 29.5 | 17.9 | 23.7 | 0 |
| 13 | 26.8 | 20.1 | 23.5 | 6 |
| 14 | 28.3 | 18.9 | 23.6 | 0 |
| 15 | 29.8 | 16.7 | 23.3 | 0 |
| 16 | 27.6 | 22.7 | 25.2 | 0 |
| 17 | 28.8 | 19.9 | 24.4 | 17 |
| 18 | 25.4 | 18.3 | 21.9 | 0.2 |
| 19 | 23.7 | 18.3 | 21 | M |
| 20 | 27 | 16 | 21.5 | M |
| 21 | 26.4 | 15.7 | 21.1 | 5.4 |
| 22 | 26.7 | 15.5 | 21.1 | 0.2 |
| 23 | 25.4 | 14.4 | 19.9 | 0 |
| 24 | 26.9 | 17.4 | 22.2 | 0.4 |
| 25 | 23.2 | 18.5 | 20.9 | 0 |
| 26 | 25.8 | 16.2 | 21 | 0 |
| 27 | 29.3 | 16 | 22.7 | 0 |
| 28 | 27.9 | 18 | 23 | 0 |
| 29 | 23.1 | 13.5 | 18.3 | 0 |
| 30 | 20.6 | 10 | 15.3 | 0 |
| 31 | 22.8 | 8.9 | 15.9 | 0 |

Table 3. Meteorological data (August, 2010) Ste-Anne-de-Bellevue

| Date | Temperature (°C) | | | Total precipitation (mm) |
|---|---|---|---|---|
| | max | min | average | |
| 1 | 26.2 | 10 | 18.1 | 0 |
| 2 | 27.6 | 14.3 | 21 | 6.2 |
| 3 | 25.9 | 19.9 | 22.9 | 71.8 |
| 4 | 28.4 | 20 | 24.2 | 19 |
| 5 | 28.6 | 17.9 | 23.3 | 16.6 |
| 6 | 20 | 10.8 | 15.4 | 0.4 |
| 7 | 20.5 | 10.8 | 15.7 | 0 |
| 8 | 23.7 | 14.4 | 19.1 | 16.4 |
| 9 | 26.4 | 18.5 | 22.5 | 0.4 |
| 10 | 28.1 | 16 | 22.1 | 0.2 |
| 11 | 26.2 | 14.8 | 20.5 | 0.2 |
| 12 | 24.8 | 14.1 | 19.5 | 0 |
| 13 | 26 | 13.2 | 19.6 | 0 |
| 14 | 27.2 | 16.9 | 22.1 | 0 |
| 15 | 25.6 | 20 | 22.8 | 14.8 |
| 16 | 27.6 | 19.6 | 23.6 | 6.2 |
| 17 | 25.7 | 16.1 | 20.9 | 0 |
| 18 | 22.7 | 13.8 | 18.3 | 0 |
| 19 | 26.5 | 11.1 | 18.8 | 0 |
| 20 | 22.2 | 10.1 | 16.2 | 0 |
| 21 | 20.3 | 11 | 15.7 | 1.6 |
| 22 | 18.4 | 15.1 | 16.8 | 7 |
| 23 | 24.2 | 14.7 | 19.5 | 1.6 |
| 24 | 24.6 | 13.7 | 19.2 | 0 |
| 25 | 22.1 | 12.9 | 17.5 | 0 |
| 26 | 23.2 | 14.2 | 18.7 | 0.2 |
| 27 | 21.8 | 12.3 | 17.1 | 0 |
| 28 | 25.8 | 15 | 20.4 | 0 |
| 29 | 29.4 | 18.5 | 24 | 0 |
| 30 | 29.8 | 17.2 | 23.5 | 0 |
| 31 | 31.5 | 21.2 | 26.4 | 0 |

Similarly, experiment conducted at Laval University also showed a linear response of canola yield to fertilizer N (Fig. 8).

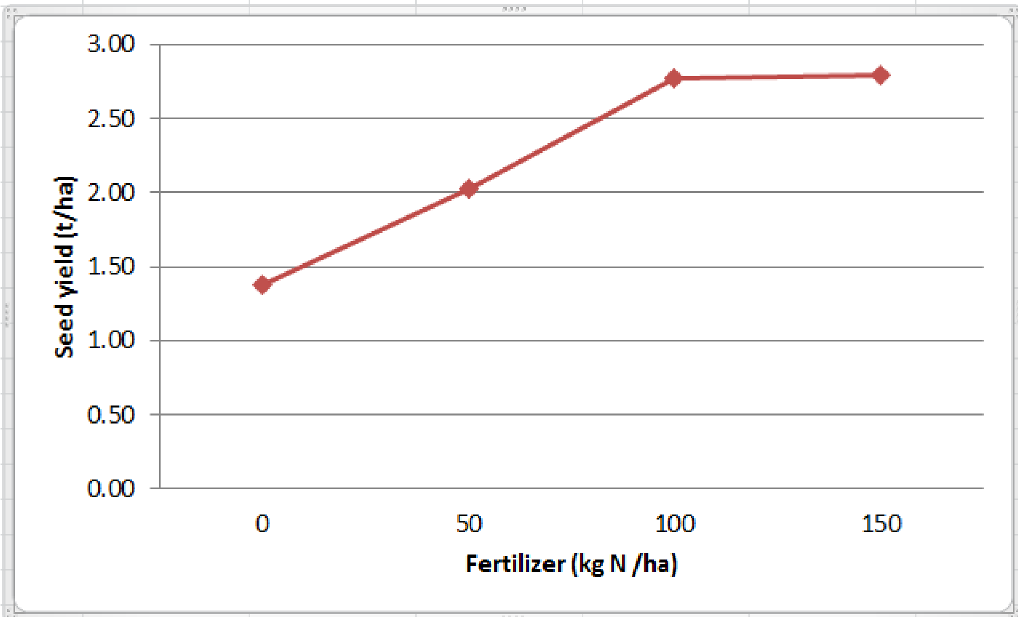



Fig. 8. Canola seed yield response to preplant applied N fertilizer rates at Laval University in 2010.

## Appendix II

## Results of Canola Greenhouse Experiment

**Activities, outputs, deliverables and performance indicators:**

Experiment 1: a greenhouse experiment was conducted to investigate different combinations of fertilizer-N (0, 75, 150 and 300 kg $ha^{-1}$), S (0, 20, 40 kg $ha^{-1}$) and B (0, 2kg $ha^{-1}$ soil applied, 500 g $ha^{-1}$ dissolved in 200 L $ha^{-1}$ foliar applied at 20% flowering stage) in a completely randomized design with four replicates. The greenhouse study was conducted on soils collected from three field sites (Ste.- Anne- de- Bellevue, Ottawa, St- Augustin). Laboratory grades of $NH_4NO_3$, $K_2SO_4$, $H_3BO_3$ were used as fertilizers. For foliar application, 10% Alphine Boron and Agral 90 used in both the 2011 and 2012 field trial are also used in the greenhouse experiment. InVigor 5440 seed was used. Five seeds were planted and then thinned to two at tri-foliar stage. Basal P, K fertilizer was applied at the rate 50 kg $ha^{-1}$. Straw and seed yield, and oil content were measured at harvest. Total N and S accumulation at crop maturity was determined on the seeds and aboveground shoots. Mineral-N ($NO_3^-$ and $NH4^+$), available-S ($SO_4^{2-}$) and total B were also determined prior to seeding and after harvesting.

Experiment 2: a concurrent greenhouse experiment was conducted to determine the interactions between fertilizer-P (0, 25 and 50 kg $ha^{-1}$) and Zn (0, 1, 2 kg $ha^{-1}$). Experimental design, soil and seed source were the same as described in experiment 1. N (75 kg $ha^{-1}$), S (20 kg $ha^{-1}$) B (2 kg $ha^{-1}$) were applied as basal fertilizer. $NaH_2PO_3$ and $ZnCl_2$ used as P and Zn sources. Total P and Zn accumulated in plant tissue and soil P and Zn extracted by Mehlich 3 are used as the main indicators.

**Deliverables:**

- Site-specific optimum rates of N, S and B application to canola at controlled environment determined for the three site established.
- Impact of application of N, S and B on main soil quality indicators determined.
- Interactions between P and Zn on canola yield better understood

**Timeline:**

February –May 2012: 1st greenhouse study on soil from St Anne de Bellevue
June -September 2012: 2nd greenhouse study on soil from Ottawa
July-October 2012: 3rd greenhouse study on soil from St Augustin
Samples collected on MacDonald Campus or delivered from other site (numbers in the parentheses denote sample amount)
Source 1: Macdonald Campus, 2011 field trial
Post-harvest soil samples (106)
Stem samples from harvesting (106)
Air dried leaf samples from harvesting (106)
Air dried seed (106)
Source 2: Canning research center
Pre-plant soil samples (16)
Whole canola from early flowering stage (102: two samples are missing)

**Major accomplishments:**

1) MacDonald Campus:
Post-harvest soil: KCl extraction ($NH_3$-N and $NH_4$-N)
Stems after harvest (leaves are separated): wet acid digestion (only P, Ca data are obtained)
2) Canning research center:

Pre-plant soil: pH, OM,

Whole above-ground tissue at early flowering stage: total P, Ca, K, Mg (96 out of 102 samples) from wet digestion and total C and N accumulation

3) Greenhouse study: 1st greenhouse is undergoing

4) Preliminary statistical analysis:

Total N accumulation from above-ground tissue from Canning site at early flowering stage is used in a project for Experimental Design (STATS based course). Considering the complexity of 26 treatments (field trial) as factional design and progress of the course, 24 treatments out of 26, which meet the requirement of randomized complete block design, were first tried. Both original and transformation (arcsin) data were used. Preliminary SAS results show there are only significant differences between N treatments from both data sets. It is suggested to use contrast or orthogonal design for further investigation.

## Appendix III

### Canola Biofertilizer Experiment

Initial work was done at McGill University. In 2011 treatment of canola with microbe-to-plant signals resulted in generally higher numerical values for many of the variables measured. However, as a result of the very difficult growth conditions for the 2011 experiment the data was very noisy and there were no statistically significant differences in those variables. In 2012 treatment with thuricin 17 resulted in little difference. However, in 2012 treatment plants grown from seeds primed with the LCO solutions produced more branches, more pods, and more dry biomass than controls and the higher LCO concentration ($10^{-6}$ M) gave a greater result. The final seed yield was also generally numerically greater for plants treated with LCOs, but these increases were relatively smaller than those of some other the other variables and there was no statistical difference among treatments for yield. There is work to be done, but this is a hopeful start with regard to the application of these signal compounds to canola production.

The signal compounds evaluated here constitute a new type of plant growth regulators. While they have already been applied commercially to a number of crops, there are still some key crops, such as canola, the need to be much better understood with regard to the applicability of these compounds during crop production. We have shown here that these compounds can have effects on a range of aspects of canola development, including, in some cases, negative effects. (We have also seen negative effects in some other related work.) Like all plant growth regulators the positive effects can be concentration, crop development and timing dependant. These compounds constitute low-input, low-cost management techniques that could be important to crop production in the near future. Given that they can help overcome stressful conditions and that the developing increase in frequency of extreme weather events as climate continues to change. Detailed report can be found in Section B of the overall report.

In 2012, field test was extended to Ottawa site. The experiment was a randomized complete block design with 3 seed treatments and 4 replications planted in Field 1 of the Central Experimental Farm in Ottawa. The 3 seed treatments were 1) no seed treatment (control), 2) seed treated with nitrogen fixing rhizobacteria (mixed culture of 8 strains), and 3) seed treated with phosphate solubilizing rhizobacteria. According to preplant soil tests, the experiment was planted on Grandby sandy loam soil with a pH of 6.8, OM of 2.7%.

Before planting the seed was treated with the two types of rhizobacteria by mixing 100 gm of seed with 50 ml of each solution of rhizobateria for a few minutes. Then the seed was spread over meshed trays and air dried.

The plots were 10 m long by 3.0 m wide. The spring canola variety, Bayer InVigor 5440 (LL) was planted May 18 using an 8 row hoe drill planter at 5 kg $ha^{-1}$ with 16 rows per plot. No nitrogen was applied beforehand.

Weeds were controlled by spraying the crop once in early June with Liberty 200 SN at 2.5 l $ha^{-1}$.

Stand counts after emergence and at harvest, insect pressure and general phenology were all recorded. Just before flowering when the flower buds were visible from above (GS 51), plant biomass was sampled from a 1 m x 1 row area in each plot. The samples were dried and weighed. At physiological maturity, plants were collected from a 2 m x 1 row area of each plot. These plants were put in the oven at 50°C and later weighed and thrashed in order to determine harvest index. Five canola plants per plot were also collected to determine number of branches and pods per plant, seeds/pod (by counting total number of seeds from 10 pods) and 1000-seed weight. Grain yield and moisture were determined by combining an area 1.5 m wide by the length of the plots using a Wintersteiger Classic combine. Canola is calculated at 10% moisture. Later 200 g of canola seed was saved for oil and protein analysis.

**Results**

There wasn't any insect pressure. Growth in some of the plots was very uneven. Phenology was recorded regularly and results are in Table 1.

Table 1. Phenology from planting to maturity in 2012.

| | |
|---|---|
| Planting | May 18 |
| Emergence | May 25 |
| 2 cotyledans | May 28 |
| 2-3 leaves (rosette) | June 6 |
| 3 leaves | June 9 |
| 6 leaves (rosette | June 18 |
| GS 51 (flower heads visible from above) | June 22 |
| GS 62 (20% Flowering) | June 28 |
| GS 63 (30% Flowering | July 3 |
| GS 64 | July 9 |
| GS 69 (Flowering ending; pods all formed) | July 16 |
| GS 83 (seeds turning brown | August 8 |
| Physiological Maturity | Aug 22 |

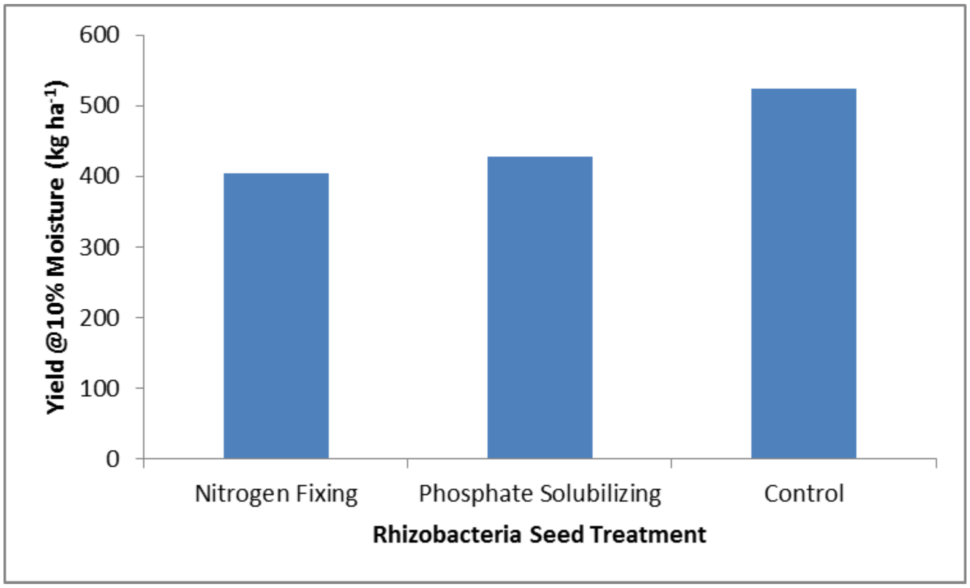
There are no significant differences between treatments for stand count, harvest Index and seeds/pods (Table 2). The results are low compared to other canola experiments. The control had the most stems and pods per plant, but even these results are very low. The plants whose seeds were treated with nitrogen fixing rhizobacteria had the lowest biomass just before flowering, and the lowest number of seeds/pod, stems and pods per plant.

Table 2. Rhizobacteria treatment effect on stand count, plant biomass just before flowering, harvest index, seeds/pod, stems and pods per plant in Ottawa in 2012.

| **Treatment** | **Plants $m^{-2}$** | **Biomass ($g\ m^{-2}$)** | **HI** | **Seed/Pod** | **Stems/Plant** | **Pods/Plant** |
|---|---|---|---|---|---|---|
| **N rhizobacteria** | 72 | 81.13 | 0.18 | 19 | 3 | 35 |
| **P rhizobacteria** | 72 | 93.22 | 0.17 | 20 | 4 | 45 |
| **Control** | 73 | 93.08 | 0.17 | 20 | 5 | 56 |

At the time of combine harvesting there was a lot of green regrowth. The plants were short (only waist high) compared to canola in other experiments. Yields were extremely low with the control having the higher yields (Fig. 1). There was no significant difference in yields between the two rhizobacteria treatments. However plants treated with nitrogen fixing rhizobacteria had the lowest yields.

Fig. 1. Rhizobacteria treatment effect on yields in 2012.




**Summary**

The late planting of this experiment and the extreme drought conditions in Ottawa during flowering and the grain filling period had a very negative effect on plant growth and the final grain yield. Full grown plants were very short with very few pods. The yields were extremely low. The control plots had slightly higher yields and number of pods per plant and the plots treated with nitrogen fixing rhizobacteria had the lowest yields and lowest number of pods per plant. There were no significant differences in planting densities, biomass just before flowering, harvest index and number of seeds per pod. If this experiment is to be repeated again, planting at the recommended date for canola would improve the final results.

## Overall Summary and Concluding Remarks

1) Canola yields are highly dependent on weather, soil N and S fertility. There is also a definite yield advantage when the application of N was split between planting and the rosette stage. The addition of N fertilizer significantly increased canola yields. Canola yield was strongly correlated ($r^2 = 0.99$) with preplant N application.
2) The nitrogen that is sidedressed appeared to be better utilized by the crop and, therefore, producing even greater yields than the crop that received equivalent amounts of N all at preplant. For every kg of preplant N, yields increased by 9.7 kg $ha^{-1}$. However when additional N was applied later in June, yield increased by 13.7 kg $ha^{-1}$ for every kg of N.
3) In 2012, Ottawa and Saint Anne-de-Bellevue did not have a yield response to N like the other sites. This was due to the extremely dry conditions that summer during flowering and the grain filling period.
4) Preplant sulphur at 20 kg $ha^{-1}$ in the form of ammonium sulphate significantly increased yields over plots that received no sulphur.
5) The lack of difference in yields between plots with boron and plots that received no boron may indicate that our soils were sufficient in boron or soil boron was unavailable to the crop when it was needed. However, there appears to be a yield advantage when boron is applied foliarly at the 20% flowering stage, suggesting that the plants are very efficient at boron uptake through their leaves.
6) CropScan, Greenseeker and the UniSpec-DC are tools that can be used to look at the status of the crop health and help determine the amount of nitrogen to be applied at sidedress. NDVI values from these instruments were strongly correlated with the amounts of nitrogen added to the soil before seeding. The addition of nitrogen at sidedressing did not immediately improve the greenness of the plants by the 20% flowering stage and had similar NDVI readings to the plots that received only 50 kg N/ha. NDVI readings at the rosette and 20% flowering stage are also strongly correlated to final yields.
7) These instruments do not detect any differences in greenness between plots that received different amounts of boron or sulphur.
8) Aboveground biomass at the 20% flowering stage and leaf area index (LAI) significantly increased with increasing amounts of preplant urea applied to the soil, with the 0 N plots having the lowest LAI readings and the plots that received 150 (2011) and 200 kg N $ha^{-1}$ (2012) having the highest LAI readings The plots that received additional urea at sidedressing (50+50, 50+100, 50+150), had similar LAI and biomass readings to the plots that received 50 kg $ha^{-1}$ preplant urea.
9) There were no significant LAI differences between plots that received different amounts of sulphur and boron.

10) Plant heights, number of branches per plant, number of pods per plant, number of seeds/pod and number of seeds per plant all significantly increased with increasing amounts of preplant nitrogen applied to the soil.
11) The seed from all sites is grade No. 1 Canola seed as there was less than 2% distinctly green seed and less than 5% damaged seed (which includes the green seed).
12) Nitrogen fertilizer significantly affects the protein and oil content of the seed. Increasing amounts of nitrogen actually suppress oil concentration of seed at all sites, even though the protein content of the seed increases. Sulphur has no effect on either seed oil or seed protein levels. However, seed oil levels appear to be lower in plots that received foliar boron compared to plots that receive no B and preplant B at 2 kg $ha^{-1}$.
13) The drought conditions in Ottawa and Montreal in 2012 also affected the seed oil content by causing it to be lower than the oil content of 2011.
14) The Unity Scientific SpectraStar 2500x NIR spectrometer was calibrated to give lower values for oil content than those values from the Foss Infratec™ 1241 Grain Analyzer.
15) Two greenhouse experiments are underway to illustrate the role of micronutrients B and Zn and to determine the interaction of micronutrients and macronutrients on plant growth, yield and oil concentration of canola seeds.
16) Nitrogen concentrations in plant and seed material increase significantly with increasing amounts of urea added to the soil ($p \leq 0.001$) with the highest N concentrations found in plants from plots that have received sidedressed nitrogen. At harvest the grain has higher concentrations of N than the straw indicating that nitrogen has been translocated from the plant material to the grain during the grain filling period.
17) Plant samples from the 20% flowering stage and final harvest still need to be analyzed for B and S.
18) Work on testing the effects of biofertilizers on the growth and yield of canola is preliminary and inconclusive due to interaction of late seeding and severe drought.

## Future Research Needs

Future experimental work could be done to look at:

a) Investigation drought and heat stress on growth, development, yield and grain quality. Identification of traits for selection of genotypes tolerant to drought and heat stress and agronomic measures to mitigate these stresses on canola production.
b) The effect of fertilizer treatments on different canola varieties.
c) The effect of different rates of sulphur greater than 20 kg $ha^{-1}$ on yields and oil content.
d) Different rates of foliar B applied at different stages and its effect on oil content and final yields.

e) On-farm demonstration of nutrient best management practices will also be needed and served as direct technology transfer.

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**B (I). Funded Collaborators (Co-PI, AAFC, other federal scientists)**

- Include the name of scientist / organization.

**B (II). Acknowledgement of non-funded collaborators (who provide support, e.g. access to other laboratory or other facilities and equipment input / advice / guidance / assistance, etc).**

- For research supported by targeted funding programs (e.g. DIAP, Clusters, etc.) please list any collaborators who are receiving Contribution Vote 10 funds (e.g., university and industry collaborators). In addition, please list separately the participants who support your project but are not receiving any funding through the program.
- Include name of scientist / organization.

Don Smith, McGill University;
Peter Scott, New Brunswick Provincial government;
Claude Caldwell, Nova Scotia Agricultural College;
Joann Whalen, McGill University;
Hugh Earl, University of Guelph;
Anne Vanasse, Laval University.

**C. Variance Report** (if applicable, describe how the work differs from the proposed research)

- Include changes to objectives and project work plan / budget, changes to the team, other constraints.

In 2012, severe and extended drought that occurred in eastern Ontario and southern Quebec has increased the variability and lowered the yield potential that inhibited detection of any yield response to N fertilizer rates, either preplant or sidedress application, indicating devastating drought effect on canola production.

**D. Impact Assessment** (if applicable, describe how the variance factors above will impact project continuation)

| |
|---|
| • Include changes to the objectives, changes to the project work plan / budget, changes to performance (i.e. meeting targets). |
| Work has been carried out as planned, but we are unable to get the maximum economic rate of nitrogen for some of the tested sites. Additional site-year data collection is needed. Hope the on-going Growing Forward II project allows expanding the activities. |

**E. Achievements** (include only those related to this project)

- Include innovations, publications / conferences, technology transfer, capacity building, success stories, media, recognition and other outputs.

**Innovations:**

A rapid microplate method was developed for boron analysis in soil and plant. The method was validated by standard methods and also using peach leaves standard reference material (SRM 1547) which resulted in 98% correlation with the expected reference amount.

**Oral Presentations:**

Ma, B.L. 2012. Implementing best management practices for sustainable canola crop production in eastern Canada. Invited field presentation to students and professors from ITA St-Hyacinthe, QC. Oct. 4.

Ma, B.L. 2012. Mitigating abiotic stresses to maximize yield, quality and nutrient use efficiency in field crop production. Invited oral presentation at the Canada-Mexico Partnership – Agri-Business Working Group. K.W. Neatby Bldg., Ottawa, Ontario, August 7, 2012.

Vanasse, A. 2013. Essais de régie sur le canola. Journée d'information INPACQ sur le canola. Bécancour, Québec. 26 février 2013

Ma, B.L. 2012. Responses of crop plants to abiotic stresses. Invited lectures to Lanzhou University and Qinghai University, China, June 26 and 29, 2012.

Ma, B.L. 2011. Development of Nutrient Best management Practices for Canola Production in Eastern Canada. Oral presentation at the Eastern Canada Oilseed Development Canola Workshop. Sheraton Hotel, Dorval Airport, QC, Canada. December 14, 2011.

Ma, B.L. 2011. Improvement of field crop production efficiency with the application of optical sensing technologies. Invited lectures to Dow AgroSciences. Indianapolis, IN, Feb. 27 – Mar 2, 2011. The trip was fully sponsored by the company, but the reimbursement was declined due to a perceivable ethical concern.

ECODA Workshop presentations 2012 (Dr. Joann Whalen), 2013 (Mr. Hicham Benslim)

**Scientific Posters:**

Su, J.-H., J.K. Whalen, B.L. Ma, and D. Poon. 2012. Fertilization with nitrogen, sulfur and boron to optimize canola nutrition in Quebec. Poster presentation to the Joint Conference of the Canadian Society of Agronomy (CSA), Canadian Society for Horticultural Science (CSHS) and Certified Crop Advisors – Prairie Board: Adapting Crops to Change: Technology Transfer in the 21st Century, University of Saskatchewan Saskatoon, SK, Canada, July 16-19.

**Scientific Publications:**

Gao, Y., and B.L. Ma*. 2013. Nitrogen, phosphorus, and zinc supply on yield and metal accumulation in canola grain. J. Plant Nutr. (*in press*). AAFC - ECORC contribution #12-375.

**Graduate Student Thesis:**

M.Sc. Thesis – Jinghan Su, McGill University, 2012: Nitrogen fertilization and soil mineral nitrogen dynamics to optimize canola nutrition and yield in Quebec

**Field Days:**

Ma, B.L. 2012. Optimizing nitrogen use efficiency with remote sensing technology. An invited oral presentation given to North Eastern Soil and Crop Improvement Association and graduate students at Nipissing University. Library, Nipissing University, North Bay, ON. March 22, 2012.

Scott, P. 2012. Demonstration of canola production technologies. Field Day organized by New Brunswick Soil & Crop Improvement Association/New Brunswick Department of Agriculture, Aquaculture and Fisheries. Potato Research Centre, Fredericton, NB. July 19, 2012.

**Scientific Presentations:**

Ma, B.L., and J. Shang.* 2012. Optimizing crop nitrogen use efficiency with optical sensing technology. Given as lecture at the summer school organized by the 1st International Conference on Agro-Geoinformatics, Shanghai, China, August 2-8, 2012.

Biswas, D.K., and Ma, B.L. 2012. Assessing agronomic and nutrient managements on yield and quality of canola in eastern Canada. Oral presentation at the Western Society of Crop Science Annual Meetings, Western Wheat Workers, and Western Education/Extension Research Activities. Joint Annual Meetings. Washington State University, Pullman, WA. July 11-13, 2012.

Biswas, D.K., B.L. Ma, G.M. Jiang, and M.A.K. Jansen. 2011. UV-B adaptation in Arabidopsis thaliana ecotypes. Oral presentation. Proceedings of the Canadian Society of Plant Physiologists Eastern Regional Meeting & Plant Development Workshop. Carleton University, Ottawa, ON, Canada. December 2-3, 2011.

## F. Lessons learned (self-evaluation of project)

We have had an excellent research team which allowed collaborative research activities being carried out with the same standard procedures and on time across sites. It is very much important for such a large scale outcome oriented study to be successfully executed. Building on this collaboration, several projects are proposed under the Growing Forward II program. Hope we can receive the full funding as planned we that we will be able to advance knowledge required to explain canola production in eastern Canada to meet industry demand for more and high quality canola seed stock, to maximize producers profit and to maximize negative impact of agricultural nutrient use on the environment.

| Bao-Luo Ma | 2013-05-30 | |
|---|---|---|
| PI Name | Date | Signature |

**AAFC RESEARCH BRANCH**
**Research Project Final Report**

**Note: After completion and signature, this report must be provided to the appropriate Science Director for assessment. A PDF copy of this report will be sent to Science Operations by the Science Director's office along with the project assessment.**