PROJECT DETAILS

- **Title**: Improving nutrient management in canola and canola-based cropping systems
- **Funders:** Agriculture and Agri-Food Canada, Alberta Canola, Canola Council of Canada, Manitoba Canola Growers and SaskCanola
- **Research program:** Growing Forward
- **Principal investigator:** Cynthia Grant (Agriculture and Agri-Food Canada, Brandon)
- **Collaborators/additional investigators:** Jeff Schoenau, Fran Walley, Jean Lafond, Denis Pageau, Sukhdev Malhi, Brian Beres, Neil Harker, John Heard, Don Flaten, and Tarlok Sahota
- **Year completed:** 2013

Final report

Background

Canola has a high requirement for nutrients, particularly N, P and S (Grant and Bailey 1993), with producers applying an average of 79.5 lbs of N, 25.8 lbs of P, 4.9 lbs of K and 13.6 lbs of S according to the 2009 Canola Council Agronomy Survey.

- Accurate assessment of nutrient supply and demand will be important to optimize nutrient efficiency
- Increases in nutrient use efficiency will be important in canola because of the high rates of nutrient application and the high crop value relative to cereal crops
- Considerable carry-over of nutrients to following crops may occur

Much of the P, S and urea-N is applied either in the seed-row or in a one pass system, however canola is very sensitive to seedling damage (Nyborg and Hennig 1969)

- The average rate of P and S reported by producers may be enough to cause seeding toxicity
- Over 1/3 of producers in the Canola Council 2009 agronomic survey indicate that their fertilizer rate is limited by crop safety

Canola differs substantially from cereal crops in root morphology and exudates, effects on soil microbiological activity, residue amount and form, and nutrient concentration in the residue (Grant et al. 2009).

- Canola may have important effects on soil quality and nutrient dynamics in the following crop.
- Nutrient credits for improved nutrient supply following canola should be assessed when considering the economic benefits of canola in a rotation.

Find more information on this project and many other relevant canola studies on the Canola Research Hub.
The Canola Research Hub is funded through the substantial support of the Canadian Agricultural Partnership and the canola industry, including Alberta Canola, SaskCanola, Manitoba Canola Growers and the Canola Council of Canada.

References

Grant, C.A. and Bailey, L.D. 1993. Fertility management in canola production. Can. J. Plant Sci. 73:651-670.

Grant, C. A., Irvine, R. B., Monreal, M. A., Mohr, R. M., McLaren, D. L. and Khakbazan, M. M. 2009. Crop response to current and previous season applications of phosphorus as affected by crop sequence and tillage. Can. J. Plant. Sci. 89: 49-66.

Nyborg, M. and Hennig, A. M. F. 1969. Field experiments with different placements of fertilizers for barley, flax and rapeseed. Canadian Journal of Soil Science 49:79-88.

Questions

1. What are safe rates of P and S blends that can be seed-placed across a range of environments?
2. Do traditional and enhanced efficiency P and S fertilizers differ in their effect on seedling damage, nutrient use efficiency, crop yield, and canola quality when applied alone and in blends across a range of environments?
3. How does preceding crop (flax, wheat or canola) influence soil quality parameters (aggregation, microbial activity, penetration resistance), microbial activity, canola yield, crop quality and rate of N and S fertilizers needed for optimum crop yield and quality?
4. How do various novel S fertilizer sources influence canola yield and quality for biodiesel production?

Methods

Replicated field studies were conducted at locations in each of the three Prairie Provinces, Ontario and Quebec for three years. A hybrid canola cultivar suitable for each individual location was selected in consultation with Canola Grower Agronomists. In addition, greenhouse studies were conducted at the University of Saskatchewan.

Study 1a: Influence of combinations of seed-placed P and S fertilizer forms and rates on seedling damage and crop yield and quality of hybrid canola

Research sites: Lethbridge, Brandon, Carman, Glenlea, Thunder Bay, Normandin

Objectives:

1) To determine safe rates of combined S and P fertilizers for use in hybrid canola
2) To determine if enhanced efficiency fertilizers can increase the rates of P and S that can be seed-placed with canola
3) To determine if restricting P and S to a standard recommended blend will limit yield potential of hybrid canola

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Study Design: Randomized complete block with 4 replicates. An overall application of N will be applied at a rate designed to optimize crop yield at each individual location, balanced for the N applied in the P and S sources. Data will be analysed using PROC MIXED of SAS with contrast analysis.

Treatments (in kg of P_2O_5 or S per ha):

1) 0 P, 0 S
2) 0 P, 9 S as AS (Ammonium sulphate)
3) 0 P, 9 S as ATS (Ammonium Thiosulphate)
4) 0 P, 18 S as AS
5) 0 P, 18 S as ATS
6) 20 P, 0 S as MAP (Monoammonium Phosphate)
7) 20 P, 0 S as APP (Ammonium Polyphosphate)
8) 20 P, 0 S as Coated MAP
9) 20 P, 9 S as Microessentials S15
10) 20 P, 9 S as MAP and AS
11) 20 P, 9 S as Coated MAP and AS
12) 20 P, 9 S as APP and ATS
13) 20 P, 18 S as MAP and AS
14) 20 P, 18 S as Coated MAP and AS
15) 20 P, 18 S as APP and ATS
16) 40 P, 0 S as MAP
17) 40 P, 0 S as APP
18) 40 P, 0 S as Coated MAP
19) 40 P, 9 S as MAP and AS
20) 40 P, 9 S as Coated MAP and AS
21) 40 P, 9 S as APP and ATS
22) 40 P, 18 S as Microessentials S15
23) 40 P, 18 S as MAP and AS
24) 40 P, 18 S as Coated MAP and AS
25) 40 P, 18 S as APP and ATS
26) 40 P, 18 S as MAP and RRS (rapid release sulfur)

Note: The fluid sources APP and ATS were only used at the locations where fluid application equipment is available. Microessentials S15 is a compound S and P product so it cannot be included in all the rate combinations

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Data Collection

1) Background soil characterization - N, P, K, S, pH, OM, conductance, texture
2) Gravimetric moisture at seeding.
3) Weather data (daily rainfall, minimum and maximum air temperature.)
4) Date of crop emergence
5) Plant density counts at 2 and 4 weeks after emergence
6) Canola biomass and nutrient content at early flowering
7) Swathing date
8) Seed yield and moisture content
9) Green kernels or chlorophyll content of seed
10) Seed oil and protein

Study 1b: Influence of combinations of seed-placed P and S fertilizer rates on seedling damage of several oilseed types under controlled environment conditions

Growth chamber studies were conducted at U. of Saskatoon to evaluate combinations of MAP and AS under more controlled conditions.

A series of controlled environment studies were conducted in which flats of a sulfur and phosphorus deficient soil collected from southern Saskatchewan were prepared. A seeding tool was used that provided a seed-row with approximately one inch spread on a ten inch row spacing for a seed-bed utilization of ~10%, similar to what is currently being used in today's low disturbance direct seeding systems. Treatments included 0, 10, 20, 30, 40 and 50 kg S/ha as ammonium sulfate (21-0-0) alone, and the same rates in combination with 15 and 30 kg P_20_5/ha as monoammonium phosphate (12-51-0). The responses of four different categories of canola were evaluated: Open pollinated Argentine, Hybrid Argentine, Polish, and Mustard Canola (B. juncea), along with Camelina and Carinata to provide information on response of these two new oilseed crops to starter fertilizer. The fertilizers were placed with canola seed in the seed-row. The percentage of planted seeds that emerge over a two week period was measured. Two weeks after emergence, the seedlings were harvested and the dry matter yield determined. The seedling biomass was ground and analyzed for nitrogen, phosphorus and sulfur content using digest and CNS analyzer. The seedling yield multiplied by the tissue concentration was used to calculate early nutrient uptake.

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Timeline for Study 1a and b:
2010-11: Provided questions for canola production survey. Recruited graduate student. Conduct year 1 of field studies. Conduct first run of growth chamber studies. Initiate quality analysis of seed. Analyzed data, prepare reports.
2011-12: Conducted year 2 of field studies. Conducted second run of growth chamber studies. Initiate quality analysis of seed from year 2. Analyzed data, prepare reports. Presented preliminary results at technology transfer meetings.
2012-13: Conducted year 3 of field studies. Initiated quality analysis of seed from year 3. Analyze data combined over years. Prepared final report. Presented results at technology transfer meetings. Initiated preparation of scientific papers.

Study 2: Influence of preceding crop on relative response of canola to N and S fertilization.

Research sites: Lethbridge, Brandon, Carman, Glenlea, Thunder Bay, Normandin

Objectives:
1) To determine if preceding crop will affect the response of canola to N and S fertilizers across a range of environments
2) To determine the impact of canola in comparison to wheat and flax on a range of microbial and soil quality parameters

Study Design: Split plot design with 4 replications. Preceding crop was the main plot and N and S combinations as sub-plots. Data was analysed using PROC MIXED of SAS with contrast analysis.

Treatments: (in kg of N or S per ha):
Flax, canola and wheat were grown as preceding crops in the first year of a two year cropping sequence, fertilized with the recommended rate of N, S and P for the location and crop, based on soil test values. The following year, canola was grown after each of the preceding crop with a standard rate of 20 kg P_5O_5 ha^{-1} as seed-placed MAP in all plots plus the following treatments:

1) Control
2) 50 kg N ha^{-1}
3) 100 kg N ha^{-1}
4) 150 kg N ha^{-1}
5) 50 kg N ha^{-1} + 15 kg S ha^{-1}

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6) 50 kg N ha^{-1} + 30 kg S ha^{-1}
7) 100 kg N ha^{-1}+ 15 kg S ha^{-1}
8) 100 kg N ha^{-1}+ 30 kg S ha^{-1}
9) 150 kg N ha^{-1}+ 15 kg S ha^{-1}
10) 150 kg N ha^{-1}+ 30 kg S ha^{-1}

The source for N in year 2 was 75% ESN and 25% urea side-banded at seeding. The sulphur was side-banded as ammonium sulphate (21-0-0-24). The N treatment rate was balanced for the N in the ammonium sulphate.

As well, preceding crops were established in year 2 as was done in the first year of the study at an adjacent location, Canola with N and S treatments was seeded on these preceding crops in year 3.

Effects on crop establishment and early season growth, crop yield, crop quality, and nutrient accumulation were assessed at all locations. Soil quality factors aggregation, and microbial dynamics were assessed at selected sites.

Data Collection
1) Background soil characterization - N, P, K, S, pH, OM, conductance, texture
2) Gravimetric moisture at seeding.
3) Weather data (daily rainfall, minimum and maximum air temperature.)
4) Date of crop emergence
5) Plant density counts at 2 and 4 weeks after emergence
6) Canola biomass and nutrient content at early flowering
7) Swathing date
8) Seed yield and moisture content
9) Green kernels or chlorophyll content of seed
10) Seed oil and protein

Timeline:
2010-11: Provided questions for canola production survey. Established preceding crops.
2011-12: Conducted year 1 of field studies on canola and prepare preceding crops for second run of study. Initiated quality analysis of seed from year 1. Analyzed data, prepare reports. Presented preliminary results at technology transfer meetings.

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2012-13: Conducted year 2 of field studies on canola. Initiate quality analysis of seed from year 2. Analyze data combined over years. Prepared final report. Presented results at technology transfer meetings. Initiated preparation of scientific papers.

Deliverables:

1) Recommendations for adjustment of rates of N and S for canola based on preceding crop.
2) Determination of impact of canola as compared to wheat or flax on specific microbial and soil quality parameters

Study 3: Feasibility of rapid release micronized elemental S in preventing S deficiency in hybrid canola for diesel

Research site: Melfort

Objectives: To determine the effectiveness of an enhanced elemental S source for supplying available S to hybrid canola used for diesel production.

Activities: Replicated field trials will be conducted on a sulphur deficient site near Star City.

Study Design: Randomized complete block design with four replicates.

Treatments:

1) Control
2) RRMES-G Broadcast Fall
3) RRMES-G Broadcast Spring Pre-Till
4) RRMES-G Broadcast Spring Pre-Emergence
5) RRMES-G Seed-Placed Spring Sideband
6) RRMES-G Seed-Placed Spring Seedrow-Placed
7) Potassium Sulphate Broadcast Spring Fall
8) Potassium Sulphate Broadcast Spring Pre-Till
9) Potassium Sulphate Broadcast Spring Pre-Emergence
10) Potassium Sulphate Spring Sideband
11) Potassium Sulphate Seed-Placed Spring Seedrow-Placed

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Notes: Rate of S at 20 kg S ha^{-1} Rate of N at 150 kg N ha^{-1}

Data to be collected:

1. Seed and straw yield.
2. Protein, oil, biodiesel content in seed.
3. Total S in seed and straw.
4. Residual nitrate-N and sulphate-S in soil at termination after 3 or 4 years.

Timeline:

2010-11: Initiated field studies in fall of 2010.
2011-12: Conducted year 1 of field studies. Initiated quality analysis of seed from year 1. Analyzed data, prepared reports. Presented preliminary results at technology transfer meetings.
2012-13: Dr. Malhi's employment was terminated so final year was not completed.

RESULTS AND DISCUSSION

Study 1A

The 2012 conditions at Brandon were again wet during May, leading to delay in seeding operations. Dry conditions later in the season influenced crop growth and yield production. Both the Carman and Kelburn sites had excellent growing conditions early in the growing season with adequate moisture and heat.
However, in July, the temperatures were high for a number of days during flowering, which may have burned off some flowers. Aster yellows infestations may have also been a factor limiting yield at both sites. Conditions in Manitoba in general were dry at the end of the growing season, but it made for good harvesting conditions. At Lethbridge, weather was very good in early spring and perfect for seeding. After seeding was done, there were timely rains until middle of June and then conditions turned hot and dry and no more rain occurred. Harvest conditions were good but wind right after canola was swathed may have led to some shelling. At Normandin, average summer temperatures were higher than normal with good precipitation in May and June. Conditions turned dry in July possibly leading to drought stress. However, overall crop yield was high. At Thunder Bay, the growing season was good, with early seeding and fairly high temperatures throughout the season. Rainfall was adequate and yields were good.

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Stand Density

Table 1: Stand density (plants m^{-2}) at two weeks of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Brandon in 2012 (SE=5.00).

P Rate	S Rate	MAP[1] + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	49.7	49.7	49.7	49.7	49.7
0	9	34.7	35.0	nd	nd	nd
0	18	40.9	26.3	nd	nd	nd
20	0	40.9	36.3	46.9	nd	nd
20	9	37.2	28.1	59.4	39.7	nd
20	18	27.2	27.8	42.2	nd	nd
40	0	40.6	36.6	45.9	nd	nd
40	9	38.1	36.9	51.3	nd	nd
40	18	39.1	21.6	38.8	49.1	43.1

[1.]MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Stand density at Brandon decreased with applicant of S, with ATS being particularly damaging (Tables 1 and 2). The combination of APP and ATS led to greater damage than the other fertilizer sources. Damage was generally less with the coated P than with uncoated MAP. There was no significant difference in seedling damage between the Microessentials S15 and the MAP.

There was little seedling damage observed at Carman in 2012, even with the higher rates of fertilizer application (Tables 2 and 3). Stand declined when S fertilizes were applied with P, but the effect was small.

Table 2: Contrast analysis for effects of P and S fertilizers on stand density of canola at Brandon, Carman, Kelburn and Lethbridge in 2012.

Label	Brandon	Carman	Carman K Lethbridge	Kelburn
Control vs S Alone	0.0057	ns	ns	0.0500
Control vs P Alone	ns	ns	ns	ns
Control vs S and P	0.0305	ns	ns	0.0949
MicroEssentials vs MAP	ns	ns	ns	ns
APP and ATS vs MAP and AS	0.0515	ns	ns	ns
MAP vs coated P	0.0005	ns	ns	ns

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MAP plus AS vs MAP + RRS	ns	ns	ns	ns
Low MAP vs High MAP - with S	ns	ns	ns	ns
Low S vs High S - with MAP	ns	ns	0.0075	0.0507
Low APP vs High APP - with S	ns	ns	ns	ns
Low coated vs high coated - with S	ns	ns	ns	ns
Low ATS vs High ATS with P	ns	ns	ns	ns
Low vs high MicroEssentials	ns	ns	ns	ns
P with no S vs P + S S RESPONSE	ns	0.0398	0.0088	ns
S with no P vs S + P P RESPONSE	ns	ns	ns	ns

Table 3: Stand density (plants m^{-2}) at two weeks of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Carman in 2012 (SE=8.27).

P Rate	S Rate	MAP1 + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	69.7	69.7	69.7	69.7	69.7
0	9	60.3	73.3	nd	nd	nd
0	18	73.1	64.7	nd	nd	nd
20	0	76.3	71.9	85.0	nd	nd
20	9	59.7	55.9	52.8	82.5	nd
20	18	64.7	66.6	63.4	nd	nd
40	0	63.1	59.4	67.5	nd	nd
40	9	62.2	71.3	61.6	nd	nd
40	18	64.1	60.6	64.6	69.4	64.4

1. MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Stand density at the Kelburn site decreased with high application of S, especially when combined with P application (Tables 2 and 4). Damage at this location tended to be greatest with the highest application rate of MAP plus AS.

Stand density at the Lethbridge location showed a tendency to decrease with application of S fertilizer application (Tables 2 and 5). There was no significant difference among sources in their effect on stand density at this location, although numerically the fluid forms tended to have lower stand density than the granular forms.

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Table 4: Stand density (plants m^{-2}) at two weeks of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Kelburn in 2012 (SE=12.45).

P Rate	S Rate	MAP1 + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	99.1	99.1	99.1	99.1	99.1
0	9	87.8	90.3	nd	nd	nd
0	18	91.3	73.8	nd	nd	nd
20	0	89.1	102.5	141.3	nd	nd
20	9	109.7	90.0	82.5	91.6	nd
20	18	69.1	73.4	72.2	nd	nd
40	0	93.1	82.8	80.6	nd	nd
40	9	95.3	82.8	61.9	nd	nd
40	18	66.3	88.4	80.9	72.2	72.2

1. MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Table 6: Stand density (plants m^{-2}) at two weeks of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Lethbridge in 2012 (SE=4.27).

P Rate	S Rate	MAP[1] + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	50.6	50.6	50.6	50.6	50.6
0	9	45.3	42.2	nd	nd	nd
0	18	43.8	38.4	nd	nd	nd
20	0	51.6	37.8	45.9	nd	nd
20	9	41.6	45.0	45.6	44.1	nd
20	18	50.9	40.0	46.9	nd	nd
40	0	45.6	42.2	49.4	nd	nd
40	9	43.4	37.8	47.5	nd	nd
40	18	48.8	45.0	36.9	42.5	46.6

1. MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

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Stand density was low at Normandin and decreased further with application of S and P with the greatest damage occurring when the MAP and AS were applied together (Tables 7 and 8). Damage was greater with the uncoated MAP than the coated MAP but was did not differ between the MicroEssentials S15 and the MAP + AS combination or the MAP + RRS.

Table 8: Contrast analysis for effects of P and S fertilizers on stand density of canola at Carman B, Normandin and Thunder Bay in 2011.

Label	Normandin	Thunder Bay	Thunder Bay
Control vs S Alone	ns	ns	
Control vs P Alone	ns	ns	
Control vs S and P	0.0200	ns	
MicroEssentials vs MAP	Ns	ns	
MAP vs coated P	0.0032	0.0594	
MAP Plus AS vs Map + RRS	Ns	0.0971	
Low MAP vs High MAP - with S	0.0823	ns	
Low S vs High S - with MAP	0.0106	ns	
Low coated vs high coated- with S	Ns	0.0733	
Low vs high MicroEssentials	Ns	ns	
P with no S vs P + S	Ns	0.0001	
S with no P vs S + P	0.0262	ns	

Table 9: Stand density (plants m^{-2}) at two weeks of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Normandin in 2012 (SE=3.62)

P Rate	S Rate	MAP[1] + AS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	33.8	33.8	33.8	33.8
0	9	25.9	nd	nd	nd
0	18	33.8	nd	nd	nd
20	0	22.8	31.3	nd	nd
20	9	29.4	29.7	19.7	nd
20	18	22.2	29.1	nd	nd
40	0	25.0	32.8	nd	nd
40	9	17.8	31.3	nd	nd
40	18	20.6	23.4	21.6	24.4

1. MAP=monoammonium phosphate, AS=ammonium sulphate, RRS=Ready Release Sulphur.

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Stand density was substantially higher at Thunder Bay than at the other sites and tended to decline with application of MAP and AS (Tables 9 and 10). Stand density tended to be greater with the coated than uncoated MAP and with the Microessentials S15 and RRS than with the MAP and AS, especially at the higher rates of fertilizer application.

Table 10: Stand density (plants m^{-2}) at two weeks of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Thunder Bay in 2012 (SE=8.57).

P Rate	S Rate	MAP[1] + AS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	120.5	120.5	120.5	120.5
0	9	120.5	nd	nd	nd
0	18	104.8	nd	nd	nd
20	0	128.8	127.8	nd	nd
20	9	108.3	110.5	103.3	nd
20	18	98.0	129.5	nd	nd
40	0	126.5	138.8	nd	nd
40	9	106.0	115.8	nd	nd
40	18	89.3	92.5	102.5	110.0

1. MAP=monoammonium phosphate, AS=ammonium sulphate, RRS=Ready Release Sulphur.

Biomass Yield at Flowering

At the Brandon site, biomass yield at flowering increased with P application and when P and S were applied together, with the yield response primarily due to the P component of the fertilizer (Tables 11 and 12). There was no significant different among fertilizer sources. There was no advantage to the use of the Microessentials S15, although at the moderate rate of application, the Microessentials S15 product produced numerically higher yields that the other products.

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Table 11: Contrast analysis for effects of P and S fertilizers on stand density of canola at Brandon, Carman, Kelburn and Lethbridge in 2012.

Label	Brandon	Carman	Carman K Lethbridge	Kelburn
Control vs S Alone	ns	ns	ns	ns
Control vs P Alone	0.0008	ns	ns	ns
Control vs S and P	0.0001	ns	ns	ns
MicroEssentials vs MAP	ns	ns	ns	ns
APP and ATS vs MAP and AS	ns	ns	ns	ns
MAP vs coated P	ns	ns	ns	ns
MAP plus AS vs MAP + RRS	ns	ns	ns	0.0754
Low MAP vs High MAP - with S	ns	ns	ns	ns
Low S vs High S - with MAP	ns	ns	ns	ns
Low APP vs High APP - with S	ns	ns	ns	ns
Low coated vs high coated - with S	ns	ns	ns	ns
Low ATS vs High ATS with P	0.0394	0.0113	ns	ns
Low vs high MicroEssentials	ns	ns	ns	ns
P with no S vs P + S S RESPONSE	ns	ns	ns	ns
S with no P vs S + P P RESPONSE	0.0001	ns	0.0912	ns

Table 12: Biomass yield (Mg ha^{-2}) at flowering of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Brandon in 2012 (SE=0.450).

P Rate	S Rate	MAP1 + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	2.57	2.57	2.57	2.57	2.57
0	9	2.62	3.42	nd	nd	nd
0	18	2.60	2.76	nd	nd	nd
20	0	4.44	3.17	4.63	nd	nd
20	9	4.05	3.39	4.30	4.52	nd
20	18	4.09	4.05	4.95	nd	nd
40	0	4.88	4.07	4.32	nd	nd
40	9	4.17	3.81	5.30	nd	nd
40	18	4.75	5.02	4.84	5.00	5.08

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

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Table 13: Biomass yield (Mg ha-2) at flowering of canola as affected by P2O5 and S rate (kg ha-1) and source at Carman in 2012 (SE=0.3279).

P Rate	S Rate	MAP1 + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	2.26	2.26	2.26	2.26	2.26
0	9	3.21	2.78	nd	nd	nd
0	18	3.21	3.06	nd	nd	nd
20	0	2.97	2.94	2.67	nd	nd
20	9	2.94	2.29	3.13	2.86	nd
20	18	2.97	3.27	3.41	nd	nd
40	0	2.93	2.73	3.19	nd	nd
40	9	2.62	2.65	2.78	nd	nd
40	18	3.02	3.23	3.48	2.80	2.42

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

At the Carman site, there was no statistically significant response of biomass yield at flowering to fertilizer application, although all fertilized treatments produced numerically higher yields than the unfertilized control (Tables 11 and 13). Similarly, there was no significant effect of fertilizer application on biomass yield at flowering at the Kelburn (Tables 11 and 14) or Lethbridge (Tables 11 and 15) sites.

Table 14: Biomass yield (Mg ha^{-2}) at flowering of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Kelburn in 2012(SE=0.28987).

P Rate	S Rate	MAP1 + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	3.78	3.78	3.78	3.78	3.78
0	9	3.62	3.49	nd	nd	nd
0	18	3.13	2.77	nd	nd	nd
20	0	3.51	3.62	3.57	nd	nd
20	9	3.86	3.95	3.77	3.80	nd
20	18	3.01	3.34	3.17	nd	nd
40	0	3.83	3.52	3.94	nd	nd
40	9	3.30	3.28	2.97	nd	nd
40	18	3.60	4.04	3.43	3.20	3.53

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

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Table 15: Biomass yield (Mg ha^{-2}) at flowering of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Lethbridge in 2011 (SE=0.469).

P Rate	S Rate	MAP1 + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	2.05	2.05	2.05	2.05	2.05
0	9	2.26	2.00	nd	nd	nd
0	18	2.27	1.74	nd	nd	nd
20	0	2.65	1.73	2.77	nd	nd
20	9	2.30	2.21	2.54	1.77	nd
20	18	2.51	1.80	2.09	nd	nd
40	0	2.60	3.56	2.34	nd	nd
40	9	2.21	2.32	2.12	nd	nd
40	18	2.90	2.72	2.95	2.50	4.22

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

At the Normandin site, biomass yield at flowering tended to be lower with the high as compared to low rates of NAP + S, possibly reflecting effects of seedling damage (Tables 11 and 16). Biomass yield increased with increasing rates of coated P possibly because the coated P reduced seedling damage at higher application rates. However, biomass yield was still higher with application of S and P together than with application of S alone, indicating that P nutrition increased biomasss yield.

Table 16: Biomass (Mg ha^{-2}) at flowering of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Normandin in 2011 (SE=0.0.370)

P Rate	S Rate	MAP1 + AS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	1.62	1.62	1.62	1.62
0	9	1.67	nd	nd	nd
0	18	1.37	nd	nd	nd
20	0	1.92	1.97	nd	nd
20	9	2.27	1.70	1.95	nd
20	18	1.96	1.58	nd	nd
40	0	1.94	2.47	nd	nd
40	9	1.69	2.57	nd	nd
40	18	1.70	2.19	2.06	2.05

1. MAP=monoammonium phosphate, AS=ammonium sulphate, RRS=Ready Release Sulphur.

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Biomass yield at flowering also increased with application of P and S at the Thunder Bay site (Tables 17 and 18), although yield decreased at the highest rate of combined MAP and AS, presumably reflecting some degree of seeding damage. There were no significant differences among sources in their effects on biomass yield at flowering at this site.

Table 17: Contrast analysis for effects of P and S fertilizers on biomass yield at flowing of canola at Normandin and Thunder Bay in 2012.

Label	Normandin	Thunder Bay
Control vs S Alone	ns	ns
Control vs P Alone	ns	ns
Control vs S and P	ns	ns
MicroEssentials vs MAP	ns	ns
MAP vs coated P	ns	ns
MAP Plus AS vs MAP + RRS	ns	ns
Low MAP vs High MAP - with S	0.0924	ns
Low S vs High S - with MAP	ns	ns
Low coated vs high coated- with S	0.0044	ns
Low vs high MicroEssentials	ns	ns
P with no S vs P + S	ns	ns
S with no P vs S + P	0.0801	ns

There was no significant effect of fertilizer application of biomass yield at flowering at the Thunder Bay site, although again all fertilizer treatments produced numerically higher yields than the unfertilized control (Tables 17 and 18). The high variability in the biomass yield at flowering makes it difficult to detect differences.

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Table 18: Biomass (Mg ha^{-2}) at flowering of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Thunder Bay in 2012 (SE=0.0.377).

P Rate	S Rate	MAP1 + AS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	2.89	2.89	2.89	2.89
0	9	3.16	nd	nd	nd
0	18	3.44	nd	nd	nd
20	0	3.15	3.42	nd	nd
20	9	3.43	3.26	3.74	nd
20	18	3.10	3.88	nd	nd
40	0	3.48	3.08	nd	nd
40	9	3.03	3.50	nd	nd
40	18	3.34	3.96	3.32	3.02

1. MAP=monoammonium phosphate, AS=ammonium sulphate, RRS=Ready Release Sulphur.

Seed Yield

Seed yield at Brandon was relatively low because of the late seeding of the trial, however there was a large increase in seed yield with application of both P and S (Tables 19 and 20). Highest yields were obtained when both P and S were applied together, indicating the need for balanced nutrient application. Seed yield did not increase significantly when the rate of application of either P or S was increased from low to high. Seed yield was higher with the combination of MAP and AS than with APP and ATS, but there were no significant improvements in yield when any of the controlled release products were used, although the Microessentials S15 product did have numerically higher seed yield than the conventional products at the higher rate of application.

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Table 19: Seed yield (t ha^{-1}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Brandon in 2012. (SE=0.166).

P Rate	S Rate	MAP[1] + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	0.79	0.79	0.79	0.79	0.79
0	9	0.85	1.13	nd	nd	nd
0	18	1.15	0.84	nd	nd	nd
20	0	1.50	0.95	1.49	nd	nd
20	9	1.46	1.23	1.67	1.57	nd
20	18	1.83	1.52	1.68	nd	nd
40	0	1.57	1.13	1.61	nd	nd
40	9	1.72	1.40	1.99	nd	nd
40	18	1.66	1.37	1.60	1.84	1.51

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Table 20: Contrast analysis for effects of P and S fertilizers on seed yield of canola at Brandon, Carman, Kelburn and Lethbridge in 2012.

Label	Brandon	Carman	Carman K Lethbridge	Kelburn
Control vs S Alone	ns	ns	ns	ns
Control vs P Alone	0.0014	ns	ns	0.0686
Control vs S and P	0.0001	ns	ns	0.0369
MicroEssentials vs MAP	ns	ns	ns	ns
APP and ATS vs MAP and AS	0.0154	ns	ns	ns
MAP vs coated P	ns	ns	ns	ns
MAP plus AS vs MAP + RRS	ns	ns	ns	ns
Low MAP vs High MAP - with S	ns	ns	ns	ns
Low S vs High S - with MAP	ns	ns	ns	ns
Low APP vs High APP - with S	ns	ns	ns	ns
Low coated vs high coated - with S	ns	ns	ns	ns
Low ATS vs High ATS with P	ns	ns	ns	ns
Low vs high MicroEssentials	ns	ns	ns	ns
P with no S vs P + S S RESPONSE	0.0091	ns	ns	ns
S with no P vs S + P P RESPONSE	0.0001	ns	ns	ns

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Table 21: Seed yield (t ha^{-1}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Carman in 2012. (SE=0.1051).

P Rate	S Rate	MAP1 + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	1.71	1.71	1.71	1.71	1.71
0	9	1.67	1.76	nd	nd	nd
0	18	1.87	1.87	nd	nd	nd
20	0	1.70	1.66	1.64	nd	nd
20	9	1.88	1.57	1.81	1.70	nd
20	18	1.87	1.82	1.66	nd	nd
40	0	1.63	1.67	1.75	nd	nd
40	9	1.82	1.77	1.36	nd	nd
40	18	1.78	1.77	1.92	1.68	1.70

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Seed yield was not significantly affected by P or S applications at either Carman or Kelburn (Tables 20-22). The lack of yield increase with nutrient applcition indications that yields were not limited at these two locations by a P or S deficiency, while the lack of a yield decrease indicates that seedling damage from the seed-placed fertilizers was not enough to reduce seed yield.

Table 22: Seed yield (t ha^{-1}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Kelburn in 2012. (SE=0.0897).

P Rate	S Rate	MAP[1] + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	1.57	1.57	1.57	1.57	1.57
0	9	1.56	1.48	nd	nd	nd
0	18	1.61	1.62	nd	nd	nd
20	0	1.54	1.52	1.65	nd	nd
20	9	1.58	1.58	1.58	1.64	nd
20	18	1.50	1.57	1.59	nd	nd
40	0	1.62	1.52	1.70	nd	nd
40	9	1.51	1.70	1.60	nd	nd
40	18	1.51	1.49	1.58	1.57	1.54

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

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Seed yield at Lethbridge increased with the application of both P and S, with the highest yields occurring when both nutrients were applied together (Tables 20 and 23). There was no significant benefit when rates were increased from low to high. No significant differences occurred among sources, although the combination of MAP + RRS led to the numerically highest seed yield at this site.

Table 23: Seed yield (t ha^{-1}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Lethbridge in 2011. (SE=0.0.327).

P Rate	S Rate	MAP1 + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	1.23	1.23	1.23	1.23	1.23
0	9	1.65	1.58	nd	nd	nd
0	18	1.74	1.76	nd	nd	nd
20	0	1.72	1.66	1.71	nd	nd
20	9	1.58	1.80	1.64	1.82	nd
20	18	1.78	1.50	1.42	nd	nd
40	0	1.61	2.13	1.66	nd	nd
40	9	1.88	2.04	1.76	nd	nd
40	18	2.17	1.90	1.55	1.92	2.41

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Table 24: Contrast analysis for effects of P and S fertilizers on seed yield of canola at Carman B, Normandin and Thunder Bay in 2011.

Label	Normandin	Thunder Bay
Control vs S Alone	0.0075	0.0001
Control vs P Alone	0.0004	0.0038
Control vs S and P	0.0001	0.0001
MicroEssentials vs MAP	ns	ns
MAP vs coated P	ns	ns
MAP Plus AS vs MAP + RRS	ns	0.0221
Low MAP vs High MAP - with S	ns	ns
Low S vs High S - with MAP	ns	ns
Low coated vs high coated- with S	0.0039	ns
Low vs high MicroEssentials	0.0012	ns
P with no S vs P + S	0.0001	0.0001
S with no P vs S + P	0.0001	ns

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Seed yield at Normandin was increased by application of both P and S, with the highest yield occurring when both nutrients were applied together (Tables 24 and 25). There was no significant difference in seed yield among nutrient sources although seed yield increased with increasing rate of the Microessentials S15 but not with the standard MAP + AS, possibly indicating that a slightly higher rate was needed to optimize yield with the enhanced efficiency product or that the slightly lower seeding damage with the product allowed a greater yield response at the higher application rate. Seed yield was also slightly but nonsignificantly lower with the RRS product than with AS, possibly indicating a tendency to limited availability from the RRS product on these soil conditions.

Table 25: Seed yield (t ha^{-1}) of canola of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Normandin in 2012 (SE=0.1808).

P Rate	S Rate	MAP[1] + AS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	3.91	3.91	3.91	3.91
0	9	4.26	nd	nd	nd
0	18	4.21	nd	nd	nd
20	0	4.24	4.31	nd	nd
20	9	4.53	4.46	4.27	nd
20	18	4.47	4.44	nd	nd
40	0	4.43	4.25	nd	nd
40	9	4.63	4.80	nd	nd
40	18	4.64	4.67	4.72	4.42

1. MAP=monoammonium phosphate, AS=ammonium sulphate, RRS=Ready Release Sulphur.

At the Thunder Bay location, seed yield also increased with both P and S application (Tables 24 and 26). The seed response at this site was greater to S application than to P application indicating that S was more limiting than P at this location, although yield was highest when both nutrients were applied. Under the high S deficiency at this site, seed yield was lower with the RRS product than with the AS, indicating that S availability was lower with the elemental than the sulphate product. Seed yield also tended to be lower with the Microessentials S15 than the MAP + As products, although the effect was not statistically significant.

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Table 26: Seed yield (t ha-1) of canola of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Thunder Bay in 2011 (SE=0.203).

P Rate	S Rate	MAP[1] + AS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	1.60	1.60	1.60	1.60
0	9	2.81	nd	nd	nd
0	18	2.74	nd	nd	nd
20	0	2.44	1.93	nd	nd
20	9	2.68	2.79	2.37	nd
20	18	2.68	2.93	nd	nd
40	0	2.22	2.49	nd	nd
40	9	2.69	3.10	nd	nd
40	18	3.04	3.15	2.73	2.38

1. MAP=monoammonium phosphate, AS=ammonium sulphate, RRS=Ready Release Sulphur.

Summary of 2012 results

There were indications of seedling toxicity with excess rates of MAP + AS or APP + ATS in combination. Seed-placed P and S significantly reduced stand density at several of the sites, with effect of S being particularly damaging. Use of the MES-15 or the RRS product occasionally reduced seedling damage but did not generally increase final seed yield as compared to the traditional MAP+AS. Significant increases in seed yield with application of P and S occurred at the majority of sites, with highest yield occurring when both nutrients were applied. Yield response to P and S varied considerably from site to site and was generally not strongly affected by the source of fertilizer. In contrast, where the yield response to S was strong, yield tended to be greater with the AS sources than with the other, possibly more slowly available forms.

2010 to 2012 Results

Significant differences occurred in response of canola to application of seed-placed P and S, depending on the soil characteristics, the environment and the degree of nutrient deficiency.
When data were combined over the three years of the study, stand density was significantly affected by fertilizer application at the Brandon, Carman and Normandin sites (Tables 27-29).

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Table 27. Stand density (plant m^{-2}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Brandon (2010-2012) (SE=0.5.22).

P Rate	S Rate	MAP[1] + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	52.2	52.2	52.2	52.2	52.2
0	9	46.8	50.2	nd	nd	nd
0	18	48.2	36.3	nd	nd	nd
20	0	58.6	44.4	56.7	nd	nd
20	9	40.3	41.7	60.8	55.3	nd
20	18	45.5	42.6	56.8	nd	nd
40	0	47.7	43.9	57.2	nd	nd
40	9	45.2	40.2	54.8	nd	nd
40	18	44.5	37.0	50.2	45.9	59.2

[1]MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Stand density at the Brandon site decreased with combined application of MAP + AS and APP + ATS, with the greatest impact being due to the S portion of the fertilizer (Table 27). Stand density was higher with the Microessentials S15 ($p<0.450$) or the RRS ($p<0.0124$) than the MAP + AS combination. Interestingly, stand was also higher with the coated P + AS than with the MAP + AS, with a greater benefit occurring than would be expected since both treatments contained AS.

Table 28. Stand density (plant m^{-2}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Carman (2010-2012) (SE=0.8.90).

P Rate	S Rate	MAP[1] + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	51.0	51.0	51.0	51.0	51.0
0	9	53.6	49.5	nd	nd	nd
0	18	49.9	54.7	nd	nd	nd
20	0	51.6	54.6	53.3	nd	nd
20	9	43.4	48.8	41.9	48.1	nd
20	18	45.8	50.2	40.8	nd	nd
40	0	44.7	43.8	46.3	nd	nd
40	9	37.1	52.5	38.1	nd	nd
40	18	35.4	44.6	44.8	47.6	46.0

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

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Stand density at Carman decreased with the application of MAP + AS to a greater extent than with Microessentials S15 ($p<0.0312$), APP + ATS ($p<0.0037$) or MAP + RRS ($p<0.0645$) (Table 28). Both the AS and the MAP component of the fertilizer led to stand reduction, with the greatest decrease occurring when both nutrients were applied together.

Table 29. Stand density (plant m^{-2}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Normandin (2010-2012) (SE=0.450).

P Rate	S Rate	MAP[1] + AS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	78.3	78.3	78.3	78.3
0	9	73.2	nd	nd	nd
0	18	66.9	nd	nd	nd
20	0	72.2	86.0	nd	nd
20	9	67.3	76.4	64.3	nd
20	18	53.2	62.2	nd	nd
40	0	60.4	83.2	nd	nd
40	9	55.5	78.1	nd	nd
40	18	49.8	59.9	65.5	61.0

1. MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Stand density at the Normandin site decreased with both P and S, with the greatest effect occurring when both nutrients were applied together (Table 29). Use of the coated MAP decreased seedling damage ($p<0.0001$) as compared to MAP + AS and use of the RRS product showed a trend towards less damage ($p<0.0865$). Microessentials S15 produced less damage than the uncoated MAP at the high but not at the low rate of application.

Seed Yield Averaged over Years

Seed yield at Brandon increased with both S and P, with yields more than doubling with balanced application of MAP + AS as compared to the unfertilized control (Table 27). Seed yield was higher with MAP + AS than with APP + ATS ($p<0.0027$) and tended to be higher with MAP + AS than MAP + RRS ($p<0.0788$). There was no significant difference between seed yield with the Microessentials S15 and the MAP + AS.

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Table 30. Seed yield (t ha^{-1}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Brandon (2010-2012) (SE=0.5.22).

P Rate	S Rate	MAP[1] + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	0.96	0.96	0.96	0.96	0.96
0	9	1.43	1.47	nd	nd	nd
0	18	1.48	1.26	nd	nd	nd
20	0	1.60	1.27	1.47	nd	nd
20	9	1.81	1.45	2.01	1.84	nd
20	18	2.15	1.72	2.00	nd	nd
40	0	1.68	1.42	1.80	nd	nd
40	9	2.16	1.74	2.36	nd	nd
40	18	2.14	1.68	1.94	2.14	1.71

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Seed yield at Lethbridge increased with application of both P and S, with the highest yield being obtained when both nutrients were applied (Table 31). Seed yield increased with increasing rates of both MAP and APP. However, there was no significant difference in yield due to fertilizer source.

Table 31. Seed yield (t ha^{-1}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Lethbridge (2010-2012) (SE=0.260).

P Rate	S Rate	MAP[1] + AS	APP + ATS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	0.95	0.95	0.95	0.95	0.95
0	9	1.33	1.19	nd	nd	nd
0	18	1.27	1.27	nd	nd	nd
20	0	1.38	1.30	1.28	nd	nd
20	9	1.27	1.27	1.24	1.20	nd
20	18	1.37	1.07	1.01	nd	nd
40	0	1.18	1.56	1.40	nd	nd
40	9	1.65	1.51	1.40	nd	nd
40	18	1.61	1.64	1.25	1.53	1.41

1. MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

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Seed yield at Normandin increased with both S and P, with the greatest increase being when both nutrients were applied (Table 32). There was no significant difference among sources, although yield increased with increasing rates of coated P+ AS and Microessentials S15, but not with increasing rates of MAP + AS. This may reflect yield constraints due to seedling damage with high rates of application of MAP + AS.

Table 32. Seed yield (t ha^{-1}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Normandin (2010-2012) (SE=0.1639).

P Rate	S Rate	MAP[1] + AS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	1.91	1.91	1.91	1.91
0	9	1.95	nd	nd	nd
0	18	1.83	nd	nd	nd
20	0	2.34	2.12	nd	nd
20	9	2.51	2.44	2.28	nd
20	18	2.44	2.14	nd	nd
40	0	2.32	2.59	nd	nd
40	9	2.31	2.84	nd	nd
40	18	2.51	2.72	2.71	2.36

1.MAP=monoammonium phosphate, AS=ammonium sulphate, APP=ammonium polyphosphate, RRS=Ready Release Sulphur.

Table 33. Seed yield (t ha^{-1}) of canola as affected by P_2O_5 and S rate (kg ha^{-1}) and source at Thunder Bay (2010-2012) (SE=0.5.22).

P Rate	S Rate	MAP[1] + AS	Coated P + AS	Microessentials S15	MAP + RRS
0	0	2.89	2.89	2.89	2.89
0	9	3.16	nd	nd	nd
0	18	3.44	nd	nd	nd
20	0	3.15	3.42	nd	nd
20	9	3.43	3.26	3.74	nd
20	18	3.10	3.88	nd	nd
40	0	3.48	3.08	nd	nd
40	9	3.03	3.50	nd	nd
40	18	3.34	3.96	3.32	3.02

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Seed yield increased with application of S and P at the Thunder Bay site, with the majority of the response attributable to the S portion of the fertilizer, although maximum yield was obtained when both nutrients were applied (Table 33). There was no significant difference among sources.

Overall Summary (2010-2012)

There were indications of seedling toxicity with excess rates of MAP + AS or APP + ATS in combination at about half of the site-years. Seed-placed P and S significantly reduced stand density at several of the sites, with effect of S being particularly damaging. Use of the MES-15 or the RRS product occasionally reduced seedling damage but did not generally increase final seed yield as compared to the traditional MAP+AS. Significant increases in seed yield with application of P and S occurred at two thirds of the sites, with highest yield occurring when both nutrients were applied. Yield response to P and S varied considerably from site to site and was generally not strongly affected by the source of fertilizer. In contrast, where the yield response to S was strong, yield tended to be greater with the AS sources than with the other, possibly more slowly available forms.

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Study 1A: Supplemental. Impact of Soil Characteristics on Seedling Damage from Ammonium Sulphate Fertilizer (Lead - Laryssa Grenkow).

Seedling toxicity of ammonium sulphate fertilizer is due both to the salt effect and due to direct ammonia toxicity. The concentration of ammonia is solution is a function of the rate of fertilizer applied, the solubility of the fertilizer and the proportion of the fertilizer that is in the ammonia form. Ammonia concentration is affected by an equilibrium reaction in the soil between ammonium and ammonia that is affected by soil characteristics that influence ammonium adsorption and the amount of hydrogen ion in the solution. The risk of ammonia toxicity may be especially severe on soils with a high calcium carbonate ($CaCO_3$) content, which can frequently occur on eroded knolls in Canadian Prairie landscapes. Because soil properties in the landscape can vary considerably, the toxicity of fertilizers within a field needs to be considered. A growth room experiment was conducted to determine the effect of soils from different landscape positions on the toxicity of ammonium sulphate (AS) and monoammonium phosphate (MAP) fertilizers placed in the seed-row with canola.

Materials and Methods
Soil from a field south of Brandon, MB was collected in the spring of 2012. Soil was collected from an area of the field with visible erosion on the knoll position in the landscape and from a hollow position. A subset of treatments from the field experiment were applied in a randomized complete block design to each soil, with four replicates. The following treatments were placed in the seed-row:

1) Control
2) Low AS
4) High AS
6) Low MAP
10) Low MAP/Low AS
13) Low MAP/High AS
16) High MAP
19) High MAP/Low AS
23) High MAP/High AS

The fertilizer and seed were applied in a 2.5cm band assuming a row spacing of 20.32 cm to mimic the seedbed utilization of the seeding equipment used in the field study. Nitrogen rates were not balanced. Soil was placed in 22.9 x 22.9cm pail to a depth of 10cm. Soil moisture was maintained at gravimetric moisture content between 70-100% of container capacity.

A composite soil sample was taken from each of the soils and analyzed for N, P, K, S, pH, organic matter content, conductance, texture, cation exchange capacity and calcium carbonate content.
Date of emergence was recorded when at least half of the seedlings had emerged from the control treatments on the hollow soil. Plant stand was assessed every two days until four weeks after emergence.

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The Mixed Procedure in SAS was used to conduct statistical analysis for the growth chamber experiment. A complete factorial, repeated measures design ANOVA model was used to test the significance of the MAP, AS, landscape position and days after emergence for soils at each site. A first order autoregressive variance-covariance structure with heterogeneous variance across periods was used.

Results and Discussion

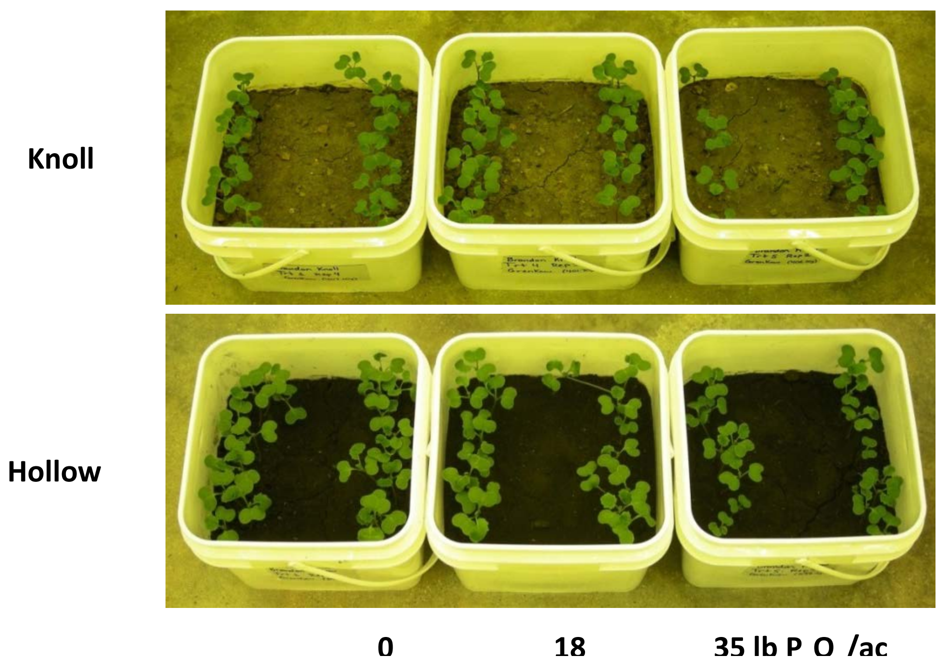

Figure 1. Effect of MAP on seedling emergence of canola applied at low and high rates on soil collected from an eroded knoll and a hollow from a field in Brandon, MB.

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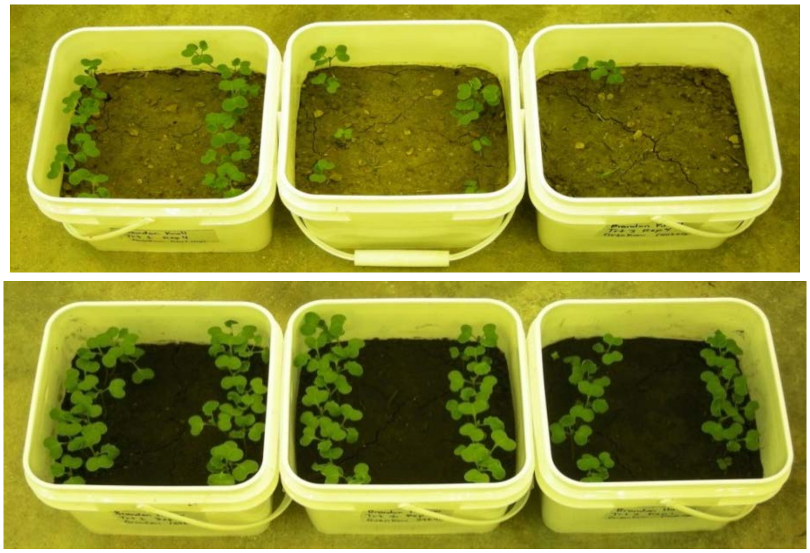
Knoll

Hollow



0 8 16 lb S/ac

Figure 2. Effect of AS on seedling emergence of canola applied at low and high rates on soil collected from an eroded knoll and a hollow from a field in Brandon, MB.

Figure 1. compares the effect of MAP applied alone and figure 2 compares the effects of AS alone on the soils from the knoll and the soil from the hollow. As the rate of AS applied increases plant stand is reduced on both the soil from the knoll and the hollow. However, the decline in plant stand was much more severe on the knoll soils.

There was a significant interaction between AS rate and soils from different landscape positions. The soil properties of the two soils are similar, except for the calcium carbonate content ($CaCO_3$) (0.5% $CaCO_3$ on the hollow soil and 21% $CaCO_3$ on the knoll soil). The AS reacts with the $CaCO_3$ in the soil, forming unstable ammonium carbonate, which decomposes, releasing ammonia and carbon dioxide and decreasing the pH of the surrounding soil (Fenn and Kissel, 1973).

$(NH_4)_2SO_4 + CaCO_3 \leftrightarrow (NH_4)_2CO_3 + CaSO_4$

$(NH_4)_2CO_3 + H_2O \leftrightarrow 2NH_3\uparrow + H_2O + CO_2\uparrow \leftrightarrow 2NH_4OH$

$NH_4^+ + OH^- \leftrightarrow NH_4OH \leftrightarrow NH_3\uparrow + H_2O$

The increased ammonia formed on the knoll soil decreased the seedling emergence compared to the hollow soil. MAP alone treatments had a much smaller impact on emergence (Figures 1 and 2) than AS on both soils, and probably because MAP has a lower salt index and does not have the same capacity to form ammonia as AS.

There was also a significant 4-way interaction, between MAP rate, AS rate, landscape position and days after emergence. The lowest emergence as well as the greatest delays in time to maximum plant stand came from the high rate of MAP or AS applied on the knolls soils, in particular the High MAP or High AS alone treatments and the blends including a High rate of MAP or AS. These treatments probably have the higher salt index and/or ammonia toxicity compared to the other treatments. Also, the knoll soil has a lower moisture holding capacity, so there could be reduced the dilution of the fertilizer salts. Effect of salt and ammonia stress can significantly delay and reduce emergence, which could mean the seedlings will be vulnerable to environmental stress and crop maturity may not be uniform.

A more complete discussion of this portion of the study in combination with information on the field aspects of the study have been uploaded in Soils and Crops Proceedings – Laryssa.

Study 1B: Impact of Fertilizers on Seedling Emergence (Lead – Dr. Jeff Schoenau)
In 2012, studies continued under controlled environment conditions to further seed row placement safety of different sulfur and phosphorus fertilizers for different Brassicae species (Argentine, Polish, Juncea canola, Carinata, Camelina.

Rates of seed-row placed ammonium sulfate above 20–30 kg S ha^{-1} were associated with significant reductions in emergence and biomass of many Brassica species/cultivars. Addition of 15 – 30 kg P_2O_5 ha-1 MAP along with AS often caused further reductions in emergence and biomass, although these were generally not large with B. napus cultivars. Differences in tolerance to seed row placed S and P were observed among cultivars. The cultivar 45H26 RR was the most tolerant of cultivars tested, while the most sensitive to seed-row placed S and S+P were B. rapa, B. juncea cv. Dahinda, and Camelina sativa. Further study is required in the field to establish whether seeds grown under different growing conditions and soil types have similar responses.

Microessentials S15 (MESS15) was also evaluated for its effect on seedling damage in a number of species an cultivars under controlled environment conditions. *Brassica* cultivars and species differed in their sensitivity and responsiveness to seed-placed MES15. All *napus* cultivars could tolerate up to 30 kg S ha^{-1} (66 kg P_2O_5 ha^{-1} and 26 kg N ha^{-1} as MES15™. Rates of seed-row placed S as MES15 above 20–30 kg S ha^{-1} were associated with significant reductions in emergence of many *Brassica* species/cultivars. In general small

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seeded cultivars were more prone to germination damage than larger seeded *B. napus* and *B. carinata* cultivars. Yellow-seeded canola was slightly more prone to reduced emergence with seed-placed MES15 than the black-seeded cultivars. Further research will need to be performed in field trials under a wide range of soil and environmental conditions where yield and quality can be measured under field conditions.

Brassica cultivars and species also differed in their sensitivity and responsiveness to seed-placed ATS and APP. *B. napus* cultivars were most tolerant to seed-placed ATS and APP while *B. rapa and B. juncea* were the most sensitive. With ATS alone, all cultivars and species could tolerate up to 50 kg S/ha placed 10mm away from the seed in the furrow. Combination of APP with ATS at the highest rates (50 kg S/ha) did result in some significant emergence reductions, especially for the more sensitive *Brassica* species. Further research will need to be performed in field trials under a wide range of soil and environmental conditions.

Additional studies were conducted under controlled environment conditions to evaluate the biomass production and nutrient accumulation of canola in response to various fertilizer formulations on several soil types collected from different sites in Saskatchewan. Total biomass and total S uptake of canola was very low in the absence of S fertilization on the soils that were deemed marginal (Black) and S-deficient (Gray). Large biomass yield responses to S fertilization were observed on these soils. Canola grown on the Brown soil responded slightly to S fertilization, in line with high extractable soil sulfate content and a narrow C:S ratio of this soil. Higher available S and greater S mineralization in the Brown soil resulted in more nutrient uptake in the control and less response to S fertilization. Sulfur fertilization significantly increased the concentration of S in canola biomass and reduced the N:S ratio in the plant biomass on all three soils studied. On the Brown and Black soils, there were no significant differences in biomass yield among the three S fertilizers, but was AS>ATS>NPS on the Gray soil.

Among the forms of S, the effectiveness of S form in supplying available S could be considered as ammonium sulfate > ammonium thiosulfate > NPS blend. The response of canola to S was influenced by the source of S fertilization. Partial oxidation of S^o-S in ATS and NPS amended soil over the 42 day time frame of the study may be the reason, and evaluation of S availability over the entire life cycle of the plant and in subsequent cropping would be desirable. Future research should include a greater number of soil types, and evaluation of other application methods apart from seed-row placement to examine the availability of the fertilizers.

More complete descriptions of the work conducted in this section are available in papers Schoenau parts 1, 2, 3, and 4 uploaded with this report.

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Study 2: Effect of preceding crop on relative response of canola to N and S fertilization

2011 Results

Poor weather conditions affected the trials in 2011. Flooding conditions made it impossible to seed the trial at the Brandon location. At both Kelburn and Lethbridge, excess moisture and/or drought reduced crop yields. However, conditions were better at the Carman location and good yields were obtained both at Thunder Bay and at Normandin.

Stand Density at Two Weeks

Crop emergence was not greatly affected by preceding crop or fertilizer application (Tables 2.1 to 2.3). At Carman, stand density was low and erratic. There was an N by S interaction at Carman relating to a decrease in stand density that occurred with S application at the highest rate of N, but this effect may have been unreliable due to the high variability. At Kelburn, stand density tended to be lower after canola than after wheat or flax. No significant effects occurred at Lethbridge, while at Normandin, there was again a tendency towards an N by S interaction related to a decrease in stand density with S at the moderate application rate of N (Tables 2.2 and 2.3).

Table 2.1: Effect of preceding crop and N and S fertilizer on stand of canola at 2 weeks at Carman and Kelburn in 2011.

		Carman				Kelburn			
N Rate	S Rate	Canola	Flax	Wheat	Crop Average	Canola	Flax	Wheat	Crop Average
0	0	14.1	13.1	21.9	16.4	62.2	73.8	93.4	76.5
50	0	14.4	16.9	28.1	19.8	56.9	93.4	89.1	79.8
50	15	33.8	21.6	30.0	28.4	66.3	97.8	72.8	79.0
50	30	15.6	13.4	36.9	22.0	67.8	95.6	78.4	80.6
	50 N Ave	21.3	17.3	31.7	23.4	63.6	95.6	80.1	79.8
100	0	24.1	13.1	37.5	24.9	68.8	83.4	85.9	79.4
100	15	17.8	15.9	29.7	21.1	59.1	83.4	77.8	73.4
100	30	21.9	25.3	46.9	31.4	58.4	76.3	86.6	73.8
	100N Ave	21.3	18.1	38.0	25.8	62.1	81.0	83.4	75.5
150	0	28.1	34.4	28.4	30.3	57.5	79.4	87.5	74.8
150	15	15.9	19.1	35.0	23.3	57.8	77.5	68.4	67.9
150	30	18.4	10.3	27.2	18.6	55.9	85.0	84.7	75.2

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150 N Ave	20.8	21.3	30.2	24.1	57.1	80.6	80.2	72.6
Crop Ave	21.1	18.9	33.3	24.4	60.9	85.8	81.3	76.0
0 S Ave	22.2	21.5	31.4	25.0	61.0	85.4	87.5	78.0
15 S Ave	22.5	18.9	31.6	24.3	61.0	86.3	73.0	73.4
30 S Ave	18.6	16.4	37.0	24.0	60.7	85.6	83.2	76.5

Table 2.2. Analysis of Variance for effects of preceding crop and N and S fertilizer on stand density at 2 weeks of canola.

	Carman		Kelburn		Lethbridge		Normandin	
Effect	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Prec	2.41	ns	4.62	0.0592	0.52	ns	1.12	ns
Nrate	2.21	0.0934	1.24	ns	2.13	ns	0.90	ns
Prec*Nrate	0.58	ns	1.09	ns	0.86	ns	1.22	ns
Srate	0.08	ns	0.76	ns	1.65	ns	2.05	ns
Prec*Srate	1.04	ns	0.92	ns	0.52	ns	0.20	ns
Nrate*Srate	4.09	0.0045	0.29	ns	1.50	ns	2.23	0.0733
Prec*Nrate*Srate	1.54	ns	0.39	ns	0.57	ns	1.55	ns

Table 2.3: Effect of preceding crop and N and S fertilizer on stand of canola at 2 weeks at Lethbridge and Normandin in 2011.

		Lethbridge				Normandin			
N Rate	S Rate	Canola	Flax	Wheat	Crop Average	Canola	Flax	Wheat	Crop Average
0	0	26.6	47.5	45.3	39.8	103.1	86.3	91.9	93.8
50	0	49.1	44.7	44.7	46.1	80.0	97.5	82.5	86.7
50	15	50.9	42.2	43.1	45.4	84.4	78.8	97.5	86.9
50	30	42.2	38.1	46.6	42.3	86.9	88.1	91.3	88.8
	50 N Ave	47.4	41.7	44.8	44.6	83.8	88.1	90.4	87.4
100	0	27.2	31.9	32.2	30.4	100.6	83.8	98.1	94.2
100	15	46.9	34.4	48.1	43.1	88.8	86.3	84.4	86.5
100	30	52.8	34.1	44.1	43.6	77.5	80.6	72.5	76.9
	100N Ave	42.3	33.4	41.5	39.1	89.0	83.5	85.0	85.8
150	0	36.3	30.6	39.1	35.3	80.6	86.9	91.3	86.3
150	15	39.1	34.4	49.4	40.9	79.4	81.9	83.1	81.5
150	30	41.6	29.7	31.9	34.4	84.4	80.6	88.1	84.4

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	150 N Ave	39.0	31.6	40.1	36.9	81.5	83.1	87.5	84.0
Crop Ave		42.9	35.6	42.1	40.2	84.7	84.9	87.6	85.8
0 S Ave		37.5	35.7	38.6	37.3	87.1	89.4	90.6	89.0
15 S Ave		45.6	37.0	46.9	43.2	84.2	82.3	88.3	84.9
30 S Ave		45.5	34.0	40.8	40.1	82.9	83.1	84.0	83.3

Seed Yield

Seed yield at Carman increased with N rate and showed a tendency towards a three way interaction among preceding crop, N rate and S rate (Tables 2.4 and 2.5). The interaction related to reduced crop yields at the highest levels of N and S when canola was grown after canola or flax, but not after wheat. Although average yield of canola was substantially higher when grown after wheat than canola, the effect was not statistically significant due to the high variability.

Table 2.4: Effect of preceding crop on seed yield response of Canola to N and S fertilizer applications at Carman and Kelburn in 2011.

		Carman				Kelburn			
N Rate	S Rate	Canola	Flax	Wheat	Crop Average	Canola	Flax	Wheat	Crop Average
0	0	0.88	1.31	1.47	1.22	0.12	0.17	0.40	0.23
50	0	1.08	1.68	1.92	1.56	0.23	0.36	0.27	0.29
50	15	1.26	1.82	1.53	1.53	0.28	0.26	0.27	0.27
50	30	1.37	1.94	1.87	1.73	0.26	0.31	0.57	0.38
	50 N Ave	1.24	1.81	1.78	1.61	0.25	0.31	0.37	0.31
100	0	1.43	1.76	2.20	1.79	0.29	0.71	0.59	0.53
100	15	1.35	1.91	1.82	1.70	0.29	0.45	0.41	0.38
100	30	1.33	1.88	2.43	1.88	0.20	0.47	0.59	0.42
	100N Ave	1.37	1.85	2.15	1.79	0.26	0.55	0.53	0.44
150	0	1.22	2.27	1.89	1.79	0.49	0.78	1.90	1.06
150	15	1.72	1.49	2.51	1.91	0.37	0.66	0.75	0.59
150	30	1.23	1.23	2.29	1.58	0.31	0.61	0.49	0.47
	150 N Ave	1.39	1.67	2.23	1.76	0.39	0.68	1.05	0.71

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Crop Ave	1.33	1.78	2.05	1.72	0.30	0.51	0.65	0.49
0 S Ave	1.25	1.90	2.00	1.72	0.34	0.62	0.92	0.62
15 S Ave	1.44	1.74	1.96	1.71	0.31	0.46	0.48	0.41
30 S Ave	1.31	1.68	2.20	1.73	0.25	0.47	0.55	0.42

Seed yield was very low at Kelburn, reflecting excessive moisture early in the spring that limited crop rooting, followed by drought conditions in July and August. In spite of this there was a significant increase in yield with N application, but yield was not affected by S fertilization. Adverse weather also led to poor yields at Lethbridge (Tables 2.5 and 2.6). Again yield increased with N application, but was not affected by preceding crop or S application. At the Normandin site, canola yields were very high and increased with both N and S application. Canola yield was highest when grown after wheat and lowest when grown after canola. An interaction between preceding crop and S was related to the much larger increase in seed yield that occurred when S was applied canola grown after wheat than after canola. An interaction also occurred between N and S application with the greatest response occurring when both nutrients were applied together. In fact, application of N fertilizer in the absence of S led to only minor increases in crop yield, indicating that the site was highly S deficient.

Table 2.5. Analysis of Variance for effects of preceding crop and N and S fertilizer on seed yield of canola.

	Carman		Kelburn		Lethbridge		Normandin		Thunder Bay	
Effect	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Prec	3.33	ns	2.75	ns	0.42	ns	15.23	0.0035	25.25	0.0007
Nrate	4.77	0.0041	6.14	0.0008	5.06	0.0032	11.46	<.0001	0.2	ns
Prec*Nrate	0.97	ns	0.81	ns	0.27	ns	0.91	ns	0.99	ns
Srate	0.02	ns	2.22	ns	1.48	ns	84.09	<.0001	1.61	ns
Prec*Srate	1.15	ns	0.55	ns	0.86	ns	2.53	0.0468	0.28	ns
Nrate*Srate	1.35	ns	1.55	ns	0.63	ns	2.76	0.0331	0.4	ns
Prec*Nrate*Srate	1.99	0.0579	1.11	ns	0.45	ns	0.41	ns	1.56	ns

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Table 2.6: Effect of preceding crop on seed yield response of Canola to N and S fertilizer applications at Lethbridge and Normandin in 2011.

		Lethbridge				Normandin			
N Rate	S Rate	Canola	Flax	Wheat	Crop Average	Canola	Flax	Wheat	Crop Average
0	0	0.22	0.35	0.28	0.29	3.61	3.82	4.13	3.85
50	0	0.38	0.43	0.32	0.38	3.77	4.06	4.17	4.00
50	15	0.31	0.49	0.44	0.41	4.08	4.27	4.83	4.39
50	30	0.39	0.32	0.37	0.36	4.33	4.65	4.81	4.60
	50 N Ave	0.36	0.41	0.37	0.38	4.06	4.33	4.60	4.33
100	0	0.48	0.51	0.31	0.44	3.82	4.32	3.99	4.04
100	15	0.42	0.39	0.66	0.49	4.44	4.81	5.09	4.78
100	30	0.53	0.56	0.60	0.57	4.59	5.08	5.25	4.97
	100N Ave	0.48	0.49	0.52	0.50	4.28	4.74	4.78	4.60
150	0	0.59	0.39	0.51	0.50	3.85	4.22	4.13	4.07
150	15	0.68	0.72	0.78	0.73	4.76	4.92	5.23	4.97
150	30	0.59	0.63	0.72	0.64	4.73	5.02	5.48	5.07
	150 N Ave	0.62	0.58	0.67	0.62	4.45	4.72	4.95	4.70
Crop Ave		0.49	0.49	0.52	0.50	4.26	4.59	4.78	4.54
0 S Ave		0.48	0.44	0.38	0.44	3.81	4.20	4.10	4.04
15 S Ave		0.47	0.53	0.63	0.54	4.43	4.67	5.05	4.72
30 S Ave		0.50	0.50	0.56	0.52	4.55	4.92	5.18	4.88

Seed yield was also relatively high at the Thunder Bay location, however yield did not respond significantly to application of either N or S indicating a relatively high background nutrient supply at the site (Tables 2.5 and 2.7). Although canola seed yield was substantially higher after wheat than after flax or canola, the effect was not statistically significant.

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Table 2.7: Effect of preceding crop on seed yield response of Canola to N and S fertilizer applications at Thunder Bay in 2011.

		Thunder Bay			
N Rate	S Rate	Canola	Flax	Wheat	Crop Average
0	0	2.84	2.54	3.56	2.98
50	0	3.36	2.68	3.33	3.12
50	15	2.85	2.69	3.41	2.98
50	30	3.27	1.94	3.63	2.95
	50 N Ave	3.16	2.44	3.45	3.02
100	0	3.01	2.41	3.96	3.13
100	15	2.92	2.78	3.58	3.09
100	30	2.45	2.32	3.49	2.75
	100N Ave	2.80	2.50	3.67	2.99
150	0	2.77	2.67	3.83	3.09
150	15	2.58	2.29	3.83	2.90
150	30	2.80	2.80	3.21	2.94
	150 N Ave	2.72	2.59	3.62	2.98
Crop Ave		2.89	2.51	3.58	2.99
0 S Ave		3.05	2.59	3.71	3.11
15 S Ave		2.78	2.59	3.60	2.99
30 S Ave		2.84	2.35	3.44	2.88

Summary of 2011 Results

Seed yield consistently tended to be higher after wheat than after either oilseed crop, with seed yield of canola tending to be lowest when grown after canola; however the effects were not generally statistically significant. Yield generally increased with N application and often with S application, with the highest yields generally occurring when both nutrients were applied at moderate to high levels. At one location, application of N in the absence of S led to no increase or a slight decrease in seed yield, indicating a severe S deficiency. There was an occasional tendency to an interaction between preceding crop and nutrient application, relating to a higher response to nutrient application with the higher yield potential that occurred when canola was seeded after wheat rather than canola or flax.

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2012 Results

The 2012 conditions at Brandon were again wet during May, leading to delay in seeding operations. Dry conditions later in the season influenced crop growth and yield production. At Lethbridge, Last year weather was very good in early spring and perfect for seeding. After seeding was done, there were timely rains until middle of June and then conditions turned hot and dry and no more rain occurred. Harvest conditions were good but wind right after canola was swathed may have led to some shelling. At Normandin, average summer temperatures were higher than normal with good precipitation in May and June. Conditions turned dry in July possibly leading to drought stress. However, overall crop yield was high. Weather conditions at the other locations were relatively good, although late season drought stress at the Carman and Kelburn sites likely affected final crop yield.

Stand Density at Two Weeks

Crop emergence was not greatly affected by preceding crop or fertilizer application (Tables 2.8 to 2.10). At Brandon and Carman, there was no significant effect of treatments on stand density. At Kelburn, stand density was lowest after canola and highest after flax, but was not affected by fertilizer treatment. At Lethbridge, there was also a tendency for stand density to be lower after canola and higher after flax, but there was also a preceding crop by fertilizer intereaction, with canola stand density being relatively higher with moderate to high applications of N and low to moderate applications of S. At Normandin, there was a tendency towards a preceding crop by S interaction, where stand density decreased with S applications after canola but not after flax or wheat. However, differences in stand density were generally fairly small and stand was still within the recommended range for optimum yield.

Table 2.8: Effect of preceding crop and N and S fertilizer on stand of canola at 2 weeks at Brandon, Carman and Kelburn in 2012.

		Brandon				Carman				Kelburn			
N Rate	S Rate	Canola	Flax	Wheat	Crop Ave	Canola	Flax	Wheat	Crop Ave.	Canola	Flax	Wheat	Crop Ave
0	0	94.1	97.8	104.6	98.8	41.3	49.1	58.8	49.7	97.5	96.6	97.5	97.2
50	0	70.1	95.3	87.4	84.3	43.4	50.0	52.2	48.5	90.3	95.6	100.6	95.5
50	15	84.9	97.8	83.7	88.8	40.0	60.3	56.9	52.4	86.6	108.8	70.6	88.6
50	30	99.7	89.2	91.7	93.5	47.8	45.6	63.4	52.3	87.5	114.1	75.9	92.5
	50 N Ave	84.9	94.1	87.6	88.9	43.8	52.0	57.5	51.1	88.1	106.1	82.4	92.2
100	0	91.0	94.7	98.4	94.7	41.6	50.9	60.3	50.9	104.4	119.4	92.5	105.4
100	15	88.0	93.5	107.7	96.4	58.1	64.4	63.8	62.1	76.3	121.9	100.3	99.5
100	30	94.1	87.4	88.0	89.8	37.8	54.4	57.5	49.9	95.9	99.4	79.7	91.7

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	100N Ave	91.0	91.9	98.0	93.6	45.8	56.6	60.5	54.3	92.2	113.5	90.8	98.9
150	0	76.9	85.5	100.9	87.8	40.3	52.2	67.8	53.4	80.9	106.9	78.4	88.8
150	15	87.4	84.3	80.0	83.9	26.9	57.2	67.8	50.6	86.9	116.6	98.4	100.6
150	30	94.1	96.0	81.8	90.6	51.3	53.8	60.3	55.1	98.4	110.3	93.1	100.6
	150 N Ave	86.1	88.6	87.6	87.4	39.5	54.4	65.3	53.1	88.8	111.3	90.0	96.7
Crop Ave		87.4	91.5	91.0	90.0	43.0	54.3	61.1	52.8	89.7	110.3	87.7	95.9
0S Ave		79.4	91.9	95.6	88.9	41.8	51.0	60.1	51.0	91.9	107.3	90.5	96.6
15S Ave		86.7	91.9	90.4	89.7	41.7	60.6	62.8	55.0	83.2	115.7	89.8	96.3
30S Ave		96.0	90.8	87.1	91.3	45.6	51.3	60.4	52.4	94.0	107.9	82.9	94.9

Table 2.9. Analysis of Variance for effects of preceding crop and N and S fertilizer on stand density at 2 weeks of canola in 2012.

	Brandon		Carman		Kelburn		Lethbridge		Normandin	
Effect	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F	F Value	Pr > F
Prec	0.24	ns	2.44	ns	18.88	0.0008	3.49	0.0682	1.47	ns
Nrate	1.12	ns	0.24	ns	0.71	ns	0.91	ns	1.84	ns
Prec*Nrate	0.23	ns	0.33	ns	0.32	ns	1.59	ns	0.50	ns
Srate	0.11	ns	0.53	ns	0.70	ns	1.36	ns	1.05	ns
Prec*Srate	1.02	ns	0.51	ns	1.07	ns	0.90	ns	2.03	0.0981
Nrate*Srate	0.49	ns	0.89	ns	1.60	ns	0.25	ns	0.62	ns
Prec*Nrate*Srate	0.50	ns	0.74	ns	0.28	ns	3.01	0.0052	0.78	ns

Table 2.10: Effect of preceding crop and N and S fertilizer on stand of canola at 2 weeks at Lethbridge and Normandin in 2012.

		Lethbridge				Normandin			
N Rate	S Rate	Canola	Flax	Wheat	Crop Ave	Canola	Flax	Wheat	Crop Ave
0	0	60.7	70.5	73.3	68.2	81.3	76.9	78.1	78.8
50	0	68.9	80.4	84.2	77.8	75.6	78.1	83.8	79.2
50	15	68.4	79.3	86.4	78.0	67.5	79.4	71.9	72.9
50	30	74.9	60.7	74.9	70.2	75.0	76.9	78.1	76.7
	50 N Ave	70.7	73.5	81.8	75.3	72.7	78.1	77.9	76.3

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100	0	86.9	78.2	71.1	78.7	80.0	81.3	77.5	79.6
100	15	66.7	76.6	79.3	74.2	69.4	85.6	88.1	81.0
100	30	58.5	61.8	76.0	65.4	56.9	73.8	90.0	73.5
	100N Ave	70.7	72.2	75.5	72.8	68.8	80.2	85.2	78.1
150	0	85.3	70.5	77.6	77.8	98.8	84.4	80.6	87.9
150	15	91.9	77.6	60.7	76.7	70.6	83.8	86.3	80.2
150	30	52.5	117.6	56.9	75.6	76.3	84.4	88.1	82.9
	150 N Ave	76.6	88.6	65.1	76.7	81.9	84.2	85.0	83.7
Crop Ave		72.7	78.1	74.1	75.0	74.4	80.8	82.7	79.3
0 S Ave		80.4	76.4	77.6	78.1	84.8	81.3	80.6	82.2
15 S Ave		75.6	77.8	75.5	76.3	69.2	82.9	82.1	78.1
30 S Ave		62.0	80.0	69.3	70.4	69.4	78.3	85.4	77.7

Seed Yield

Seed yield at Brandon was higher when canola was seeded after wheat than after canola, with canola seeded after flax being intermediate (Tables 2.11 and 2.12). In spite of relatively high seed yield, there was no significant increase in seed yield with N application, possibly reflecting the effect of residual N due to poor growing conditions in 2011. In contrast, seed yield increased with S rate. Wet conditions in 2011 likely led to leaching, reducing the plant available sulphate. At Carman, there was also a tendency towards higher canola seed yields following flax or wheat as compared to canola. At Carman, seed yield increased with N application, with the optimal yield occurring at the 100 kg N ha^{-1} rate. Seed yield at Carman also increased with S application with yield being optimized at the 15 kg S ha^{-1} rate.

Table 2.11. Analysis of Variance for effects of preceding crop and N and S fertilizer on seed yield of canola in 2012.

	Brandon	Carman	Kelburn	Lethbridge	Normandin	Thunder Bay
Prec	0.0180	0.0944	0.0291	ns	ns	0.0001
Nrate	ns	0.0006	0.0001	0.0003	0.0001	ns
Prec*Nrate	ns	ns	0.0969	ns	0.0108	0.0937
Srate	0.0001	0.0001	ns	0.0001	0.0001	ns
Prec*Srate	nd	ns	ns	ns	0.0007	ns
Nrate*Srate	nd	ns	ns	0.0022	0.0001	ns
Prec*Nrate*Srate	nd	ns	ns	0.0640	ns	ns

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Table 2.12: Effect of preceding crop on seed yield response of Canola to N and S fertilizer applications at Brandon and Carman in 2012.

		Brandon				Carman			
N Rate	S Rate	Canola	Flax	Wheat	Crop Ave	Canola	Flax	Wheat	Crop Ave
0	0	2.05	2.41	2.56	2.34	0.75	1.10	1.02	0.96
50	0	2.10	2.47	2.49	2.35	0.77	1.32	1.17	1.09
50	15	2.22	2.58	2.59	2.47	0.82	1.53	1.56	1.30
50	30	2.28	2.58	2.80	2.55	1.03	1.34	1.66	1.34
	50 N Ave	2.20	2.54	2.63	2.46	0.87	1.40	1.46	1.24
100	0	2.23	2.34	2.54	2.37	1.17	1.48	1.48	1.38
100	15	2.22	2.57	2.76	2.52	1.22	1.73	1.79	1.58
100	30	2.25	2.55	2.70	2.50	1.11	1.60	1.35	1.35
-	100N Ave	2.23	2.49	2.67	2.46	1.17	1.60	1.54	1.44
150	0	2.11	2.35	2.59	2.35	0.88	1.23	1.33	1.15
150	15	2.15	2.40	2.82	2.46	1.31	1.68	1.82	1.60
150	30	2.24	2.59	2.83	2.55	1.17	1.72	1.76	1.55
	150 N Ave	2.17	2.45	2.74	2.45	1.12	1.54	1.64	1.43
Crop Ave		2.20	2.49	2.68	2.46	1.05	1.51	1.55	1.37
0 S Ave		2.15	2.39	2.54	2.36	0.94	1.34	1.33	1.20
15 S Ave		2.20	2.52	2.72	2.48	1.12	1.65	1.72	1.50
30 S Ave		2.26	2.57	2.77	2.54	1.10	1.55	1.59	1.42

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Table 2.13: Effect of preceding crop on seed yield response of Canola to N and S fertilizer applications at Kelburn and Lethbridge in 2012.

		Kelburn				Lethbridge			
N Rate	S Rate	Canola	Flax	Wheat	Crop Ave	Canola	Flax	Wheat	Crop Ave
0	0	1.33	1.82	1.85	1.67	1.23	0.55	0.72	0.83
50	0	1.56	1.79	1.83	1.72	1.29	0.91	0.94	1.04
50	15	1.34	1.79	1.79	1.64	0.96	1.01	1.30	1.09
50	30	1.48	1.73	1.94	1.72	1.07	1.01	1.53	1.20
	50 N Ave	1.46	1.77	1.85	1.69	1.11	0.97	1.25	1.11
100	0	1.59	1.82	2.04	1.81	1.62	1.21	1.64	1.49
100	15	1.57	1.91	2.09	1.86	1.13	1.00	0.88	1.01
100	30	1.55	1.92	1.96	1.81	1.26	1.01	1.56	1.28
	100N Ave	1.57	1.88	2.03	1.83	1.34	1.07	1.36	1.26
150	0	1.62	2.00	2.02	1.88	1.52	1.76	1.84	1.71
150	15	1.75	1.92	1.83	1.83	0.87	0.68	0.92	0.82
150	30	1.72	1.99	1.94	1.88	1.56	1.51	1.09	1.39
	150 N Ave	1.69	1.97	1.93	1.86	1.31	1.32	1.28	1.31
Crop Ave		1.57	1.87	1.94	1.80	1.25	1.12	1.30	1.22
0 S Ave		1.59	1.87	1.96	1.81	1.47	1.29	1.47	1.41
15 S Ave		1.55	1.87	1.90	1.78	0.99	0.90	1.03	0.97
30 S Ave		1.58	1.88	1.95	1.80	1.30	1.18	1.39	1.29

At the Kelburn site, as at the other locations, canola seed yield was lower when grown after canola than after flax or wheat (Tables 2.11 and 2.13). Seed yield increased with N application rate, but there was also a tendency to a preceding crop by N interaction, reflecting a greater difference in yield between the canola seeded on canola than on flax or wheat in the untreated control than in the N fertilized treatments. In fact, the N response was in the canola seeded on flax or wheat stubble, with yields being quite high in the absence of N application. This may reflect higher depletion of N by the preceding canola crop as compared to the wheat or flax crops.

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At Lethbridge, there was no significant effect of preceding crop on canola seed yield (Tables 2.11 and 2.13). Seed yield was relatively low in most of the plots but increased with N application. There was an unexpected pattern of response to S, with yield being lower with moderate than either nil or higher S applications, particularly at the higher N application rate and after wheat. The reason for this is unclear.

Seed yield was not significantly affected by preceding crop at the Normandin site, although there were interactions between preceding crop and the two nutrients. (Tables 2.11 and 2.14). Seed yield increased with application of N and S, with the major impact occurring with the first increments. Response to N application in particular was greater after canola than after flax or wheat, possibly indicting that the preceding canola crop depleted the soil N supply, increasing the requirement for applied N. An interaction between N and S occurred, primarily due to higher seed yield occurring when both N and S were applied together. Highest yields at this site occurred with the highest application rate of N and S in canola grown after wheat, indicating the importance of balanced nutrition and a diversified crop sequence in supporting canola yield.

Table 2.14. Effect of preceding crop on seed yield response of Canola to N and S fertilizer applications at Normandin andThunder Bay in 2012.

Seed		Normandin				Thunder Bay			
N Rate	S Rate	Canola	Flax	Wheat	Crop Ave	Canola	Flax	Wheat	Crop Ave
0	0	2.87	3.57	3.39	3.28	1.04	1.26	3.42	1.91
50	0	3.45	3.92	3.75	3.71	0.89	1.16	3.92	1.99
50	15	3.59	4.08	4.10	3.92	0.73	1.13	3.40	1.75
50	30	3.61	4.28	4.14	4.01	0.94	1.31	2.93	1.73
	50 N Ave	3.55	4.09	4.00	3.88	0.85	1.20	3.42	1.82
100	0	3.65	3.98	3.52	3.72	1.13	1.11	3.13	1.79
100	15	4.19	4.36	4.62	4.39	1.13	1.11	3.59	1.94
100	30	4.14	4.32	4.45	4.30	1.64	1.06	3.33	2.01
-	100N Ave	3.99	4.22	4.20	4.14	1.30	1.10	3.35	1.92
150	0	3.51	3.86	3.13	3.50	0.89	1.19	3.62	1.90
150	15	4.35	4.32	4.63	4.43	1.07	1.08	3.52	1.89
150	30	4.53	4.63	4.71	4.62	0.90	1.14	3.82	1.95
	150 N Ave	4.13	4.27	4.16	4.19	0.95	1.13	3.65	1.91
Crop Ave		3.89	4.20	4.12	4.07	1.04	1.14	3.47	1.88
0 S Ave		3.53	3.92	3.47	3.64	0.97	1.15	3.56	1.89
15 S Ave		4.04	4.26	4.45	4.25	0.98	1.10	3.50	1.86
30 S Ave		4.10	4.41	4.43	4.31	1.16	1.17	3.36	1.90

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At Thunder Bay, canola seed yield was substantially higher after wheat than after either canola or flax (Tables 2.11 and 2.14). There was no significant response to either N or S, but there was a tendency to a preceding crop N interaction, reflecting a small tendency to an increase in yield with N application in canola grown after canola or wheat, but a tendency to a small decrease in canola grown after flax.

Summary Over Years

Throughout the study, seed yield consistently tended to be higher after wheat than after either oilseed crop, with seed yield of canola tending to be lowest when grown after canola. Yield generally increased with N application and often with S application, with the highest yields generally occurring when both nutrients were applied at moderate to high levels. On S-deficient sites, low S supply prevented the crop from responding efficiently to N applications. At one location, application of N in the absence of S led to no increase or a slight decrease in seed yield, indicating a severe S deficiency. There was an occasional tendency to an interaction between preceding crop and nutrient application, sometimes relating to a higher response to nutrient application with the higher yield potential that occurred when canola was seeded after wheat rather than canola or flax. However, in a few cases, N deficiency and response was higher in canola seeded after canola. In these situations, it appeared that the preceding canola crop had depleted the N supply, leading to very low yields in the unfertilized control and a higher response to n than in the less deficient canola grown on flax or wheat. This confirms the importance of

These results confirm the benefit of having a diversified rotation, with canola following canola yielding substantially lower than canola following the cereal crop, wheat. It also demonstrates the importance of balance nutrition, with optimum yield being obtained when both N and S were supplied in adequate amounts. Nitrogen management was influenced by preceding crop, with N depletion by canola sometimes leading to reduced yields when canola followed without adequate N. While low canola yields following a canola crop were not solely due to enhanced N depletion, it appeared to be a factor at several sites.

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Study 2b: Impact of canola as compared to wheat or flax on specific microbial and soil quality parameters
Scientist(s): Fran Walley, Ph.D.

Location: University of Saskatchewan

Introduction

The quantity and quality of soil organic N and C are strongly influenced by management practices such as crop rotation (Shrestha et al. 2013). In this study, we assessed the impact of canola as compared to wheat and flax on various soil quality parameters, including microbial biomass, glomalin production, and water stable aggregation. Glomalin, a glycoprotein associated with arbuscular mycorrhizal fungi, was assessed because it is thought to contribute to soil aggregation (Wright and Upadhyaya, 1998). Moreover, since canola is a non-mycorrhizal crop, we wanted to assess the impact of canola on this important soil organic fraction and consequent impact on water stable aggregation. Additionally, we used synchrotron-based C and N K-edge x-ray absorption near-edge structure (XANES) spectroscopy to explore C and N chemistry among soils obtained from four different sites (Kelburn, Phillips, Carmen and Thunder Bay) under different phases of a crop rotation study (canola, wheat or flax). We examined both micro and macroaggregate size classes using synchrotron techniques. Synchrotron-based methods have been explored as a sensitive method to assess the complex nature of C and N in soils (Leinweber et al., 2007 and 2009; Gillespie et al., 2011a, b).

Methods and materials

Soil samples were collected from Study #2 ("Influence of preceding crop on relative response of canola to N and S fertilization") sites in both the spring (preseeding) and fall (post harvest). Although every effort was made to collect soils from all sites (Lethbridge, Phillips, Carman, Kelburn, Thunder Bay, and Normandin) in each of the study years and from both phases in each of the study, not all sites or phases were available. For example, because the Brandon site experienced excessive rainfall levels in 2011, the Phase 2 of the 2010 study could not be seeded and Phase 1 of the 2011 test was hit by frost and no final harvest taken. Nonetheless, samples were taken and analysed wherever possible.

Soil microbial biomass C and N was determined using a chloroform fumigation-extraction method, according to Voroney et al. (2008) using field moist samples. Where soil samples were particularly dry, soil moisture content was adjusted to 50% water holding capacity and allowed to incubate at room temperature for 10 d to permit re-establishment of a functioning microbial community.

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Glomalin was extracted according to Wright and Upadhyaya (1998) and estimated using both the Bradford protein analyses (Wright et al., 1996; Rosier et al., 2006) or an indirect enzyme linked immunosorbent assay (ELISA) with monoclonal antibody MAb32B11 developed against crushed spores of G. intraradices according to Rillig (2004). Water-stable aggregates were isolated using a modified procedure from Elliott (1986). Briefly, field moist samples passed through a 9 mm sieve, air dried, and subsequently wet sieved on a 250 µm and 53 µm screen to isolate water-stable macro- and microaggregates, respectively. Five gram samples were placed on the sieve and mechanically oscillated 3 cm vertically for 50 repetitions, and subsequently dried and weighed for each of the size fractions (i.e., > 250 µm, 53 to 250 µm, and <53 µm).

Synchrotron-based x-ray absorption near edge structure (XANES) was used to further assess soil quality. For the soft x-ray analysis the aggregates were slurried in water and deposited onto Au coated Si wafer, and air-dried. The total electron yield (TEY) and total fluorescent yield (TFY) C and N K-edge spectra were collected on the samples using slew scanning (i.e., fast scanning) using the Spherical Grating Monochromator (SGM) beamline 11ID-1 at the Canadian Light Source (CLS), Saskatoon, SK. Calibration at the N K-edge was based on absorption spectrum for N2 measured using ammonium sulfate, as described in Gillespie et al. (2008). Previously published reference compounds (Leinweber et al., 2007) were used to assign N spectral features to N functions. For calibration at the C K-edge, a solid-state absorption spectrum for glutaric acid (dicarboxylic acid) was measured.

Results

Soil quality parameters:

Although MB-C and MB-N differed between sites and were apparently influenced by the sampling date (i.e., spring versus fall), little evidence exists to suggest that crop rotation or fertilizer application affected the microbial biomass in a consistent and predictable manner (data not shown). Others have reported that although microbial biomass is sensitive to inclusion of fallow, microbial biomass is typically consistent over time irrespective of “minor” changes over time associated with specific crop rotations (Biederbeck et al., 1994).

Evidence suggests that water stable aggregation was influenced by crop (i.e, wheat, flax and canola); however, differences between cropping treatments typically did not persist from fall to the next spring (data not shown). Thus any impacts of the crop apparently were relatively short-lived. These observations are consistent with observations regarding the impact of crop on glomalin levels. Specifically, although some variations in glomalin were observed between sites and crops in rotation, these differences were not consistent or predictable.

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Synchrotron assessment of soil quality:

The C K-edge spectra were relatively similar for all the soils and typically contained two distinct peaks, centered at 285 eV and 288.4 eV, attributed to aromatic functional groups (e.g., C=C) and carboxylates (e.g., COO-), respectively (Fig. 1). The Phillips soil also contained a peak at 290.2 eV, which was attributed to carbonate. All soils contained peaks at 297.2 and 300 eV due to the K L-edge.

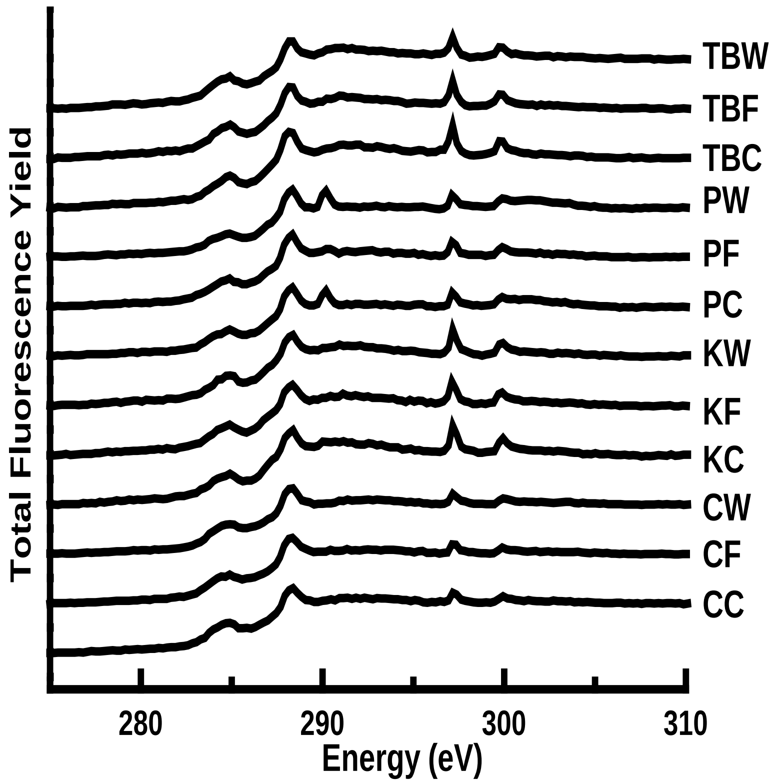

Figure 1. Normalized fluorescence yield of C K-edge x-ray absorption near-edge structure (XANES) spectra of soils obtained from Thunder Bay (TB), Phillips (P), Kelburn (K), and Carmen (C). Samples were collected in the fall, post harvest, and the stubble type includes wheat (W), flax (F) and canola (C). Units for total fluorescence yield are arbitrary units.

The N K-edge spectra also were similar, with one exception, for all the soils and aggregate sizes, generally containing three distinct peaks at 398.6, 401.0 and 405.7 eV (Fig. 2). Protein and amide N frequently are reported to dominate soil organic N and the peak at 401.0 eV corresponds to this functionality (Gillespie et al. 2009). Although subtle, data analyses suggest the appearance of a peak at 400 eV [corresponding to 5-membered rings (pyrazolic)], with a concomitant disappearance of a peak at 402.7 eV [corresponding to N with

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unpaired electrons in 5-membered rings (pyrrolic)] at Carmen where wheat was grown as compared to either of the oilseed crops (flax or canola). Leinweber et al. (2009) speculated that enrichment in pyrazolic N might be associated with more intensive microbial decomposition.

Carbon and N spectral features were unaffected by aggregate size class (data not shown), suggesting that changes in speciation associated with aggregate stabilization were minimal following a single cropping season. Earlier investigations had revealed distinct N functionality differences between bulk and rhizosphere soil, and thus we had anticipated that aggregate classes similarly might have different N functionalities reflecting different mechanisms of stabilization (i.e, physical versus microbial).

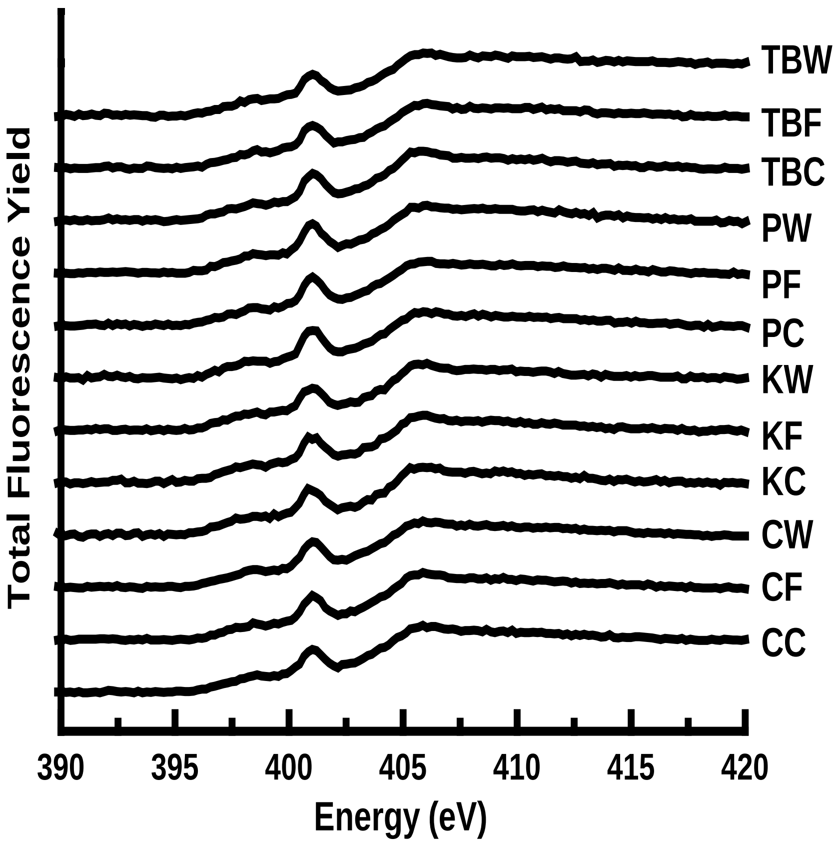

Figure 2. Normalized fluorescence yield of nitrogen (N) K-edge x-ray absorption near-edge structure (N-XANES) spectra of soils obtained from Thunder Bay (TB), Phillips (P), Kelburn (K), and Carmen (C). Samples were collected in the fall, post harvest, and the stubble type includes wheat (W), flax (F) and canola (C). Units for total fluorescence yield are arbitrary units.

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The similarity in spectral features (particularly between sites) was unexpected, as variations between soils have been reported associated with differences in management (i.e., cultivation) (Leinweber et al. 2007, Gillespie et al. 2011) and degree of humification (Leinweber et al. 2007). Thus it was anticipated that site differences would be detected. The similarity in the spectral features revealed in this study suggest that inclusion of canola had little impact on soil N and C functionality after a single year in rotation. Further analyses of the spectra, using linear combination fitting will be used to investigate specific N speciation within the spectra and may reveal more subtle changes in the functionality of the organic C and N species.

Conclusions

The goal of this study was to determine the impact of canola in comparison to wheat and flax on a range of microbial and soil quality parameters. Initially, it was hypothesized that inclusion of canola might have a negative impact on various soil quality parameters, in part because canola is a non-mycorrhizal crop and typically is grown using relatively high fertilizer inputs. To date, our results have not revealed any observations that suggest that inclusion of canola in the crop rotation negatively impacts important soil parameters such as microbial biomass, glomalin production, or associated physical characteristics such as water stable aggregation.

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Study 3: Feasibility of rapid release micronized elemental S in preventing S deficiency in hybrid canola for diesel (Malhi)

Our previous research has indicated that granular elemental S fertilizers were not effective in the year of application and also not as effective as sulphate-S in increasing seed yield of canola, especially when applied in spring, due to poor dispersion of elemental S particles from granules for subsequent oxidation to sulphate-S. A field experiment was established in autumn 2010 to compare the relative effectiveness of rapid release elemental S (RRES) and sulphate-S fertilizers on seed yield, straw yield, oil and protein concentration in seed, and N and S uptake of canola on S-deficient Gray Luvisol loam soil at Star City, Saskatchewan. The 11 treatments included two granular S sources (RRES and potassium sulphate) and five application time/placement method combinations (broadcast in autumn, broadcast in spring pre-tillage, broadcast in spring pre-emergence, sidebanded in spring and seedrow-placed in spring), plus a zero-S control. In 2011, there was a significant seed yield response of canola to applied sulphate-S. Seed yield increased considerably with all sulphate-S treatments compared to the zero-S control, although seed yield tended to be slightly lower in the sideband spring and autumn broadcast treatments than the other sulphate-S treatments. Compared to zero-S control, seed yield also increased significantly with all RRES treatments, but the increase was much greater with autumn applied RRES than spring applied RRES. Autumn applied RRES produced only slightly lower and spring applied RRES produced much lower seed yield than the highest yielding spring applied sulphate-S broadcast pre-till or seedrow-placed S treatments. In conclusion, the findings suggest the potential of autumn broadcast RRES in preventing S deficiency in hybrid canola, but seed yield was still slightly lower than the spring broadcast/incorporated sulphate-S.

No report was provided on this section for 2012-2013 due to the termination of employment of Dr. Malhi.

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