Seed-Placed Phosphorus and Sulphur Fertilizers: Effect on Canola Plant Stand and Yield

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Abstract

Hybrid canola has a high requirement for phosphorus (P) and sulphur (S). Conventional P and S fertilizers differ in their risk of ammonia and salt toxicity and can significantly reduce canola plant stands if applied in the seed-row above recommended safe rates. Enhanced efficiency fertilizers such as polymer coated monoammonium phosphate (cMAP), Vitasul, or Microessentials S15 (MES15) could be more seed-safe than conventional sources. Field studies were conducted to determine the effect of various sources and rates of seed-placed P and S fertilizers on plant stand and yield of canola. Soil properties may also affect the toxicity of the fertilizer. The risk of ammonia toxicity from ammonium sulphate (AS) 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. A growth room experiment was conducted to determine the effect of soils from different landscape positions on the toxicity of seed-placed AS and monoammonium phosphate (MAP) with canola. Under controlled environment conditions, canola emergence was reduced and delayed by conventional sources of seed-placed P and S fertilizers due to salt and ammonia toxicity. Ammonium sulphate, in particular, has a high salt index and risk of ammonia toxicity, especially on calcareous soils; therefore, AS has a greater potential to reduce plant stands than MAP. Under field conditions, the highly available sources of P and S may increase the risk and severity of seedling toxicity, but they also increase the frequency and size of yield response in situations where these nutrients are deficient. Enhanced efficiency fertilizers (cMAP, MES15 and Vitasul) were effective in decreasing seedling damage, but may not be as effective as conventional sources in providing sufficient available nutrients to reach yield potential.

Introduction

Hybrid canola has a high requirement for phosphorus (P) and sulphur (S). Farmers across Canada are moving to one pass seeding systems, placing all their P and S in the seed-row. Although P fertilizer is most efficient if placed near or with the seed, canola seedlings are very sensitive to seed-placed fertilizers (Grant et al., 2001). Conventional P and S fertilizers differ in their risk of ammonia and salt toxicity and can significantly reduce plant stands if applied above recommended safe rates. To attain maximum yield potential, adequate nutrition supplied by fertilizers must be balanced with acceptable plant stand. Fertilizer toxicity could be reduced by using enhanced efficiency fertilizers such as polymer coated monoammonium phosphate (cMAP), Vitasul, or Microessentials S15 (MES15). Field studies were conducted to determine the effect of various sources and rates of seed-placed P and S fertilizers on plant stand and yield of canola. The source and rate of fertilizer in addition to soil properties may affect the toxicity of the fertilizer in the band and hence the plant stand. Because soil properties in the landscape can vary considerably, the toxicity of fertilizers within a field needs to be considered. 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. 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

Field Study

The study was conducted in 2010, 2011 and 2012 at six sites across Canada: Lethbridge, AB Normandin, QC, Thunder Bay, ON and Brandon, Carman and Glenlea, MB (Glenlea for 2011 and 2012, only). The experiment had treatments arranged as a randomized complete block design with four replicates. The treatments consisted of various source and rates of seed-placed P and S fertilizers. Rates of P applied were 18 lbs P_2O_5/ac (Low) or 35 lbs P_2O_5/ac (High) and rates of S applied were 8 lbs S/ac (Low) and 16 lbs S/ac (High).

1) Control
2) Low AS (Ammonium sulphate)
3) Low ATS (Ammonium Thiosulphate)
4) High AS
5) High ATS
6) Low MAP (Monoammonium Phosphate)
7) Low APP (Ammonium Polyphosphate)
8) Low Coated MAP
9) Low/Low Microessentials S15
10) Low MAP/Low AS
11) Low Coated MAP/Low AS
12) Low APP/Low ATS
13) Low MAP/High AS
14) Low Coated MAP/High AS
15) Low APP/High ATS
16) High MAP
17) High APP
18) High Coated MAP
19) High MAP/Low AS
20) High Coated MAP/Low AS
21) High APP/Low ATS
22) High/High Microessentials S15
23) High MAP/High AS
24) High Coated MAP/High AS
25) High APP/High ATS
26) High MAP/High Vitasul

Liquid fertilizer treatments were omitted from Normandin (all years), Thunder Bay (all years) and Carman (2011 only). The seeding equipment used at each site varied, but the seed bed utilization at most sites was approximately 12%. Nitrogen was applied as a 75:25 blend of ESN:Urea at a rate appropriate to optimize yield at each location. N rate for each plot was balanced for the N in the P or S fertilizer treatment. N was placed in the mid-row or side-band.

Canola was direct seeded into stubble at a recommended rate of 150 seeds m^{-2} at a depth of 12-25 mm. The canola cultivar used was InVigor 5440 (InVigor 5030 at Normandin). Weeds were controlled prior to seeding as well as in-crop with the appropriate herbicide.

At four weeks after emergence, plant stand in each plot was assessed by counting all the seedlings in two one meter rows in two locations. All the plots were swathed and harvested using a plot combine, except for Brandon 2011, which was not harvested because of late planting due to excessive wetness. The grain was weighed, cleaned and weighed again to determine yield.

The Mixed Procedure in SAS 9.3 was used to conduct statistical analysis for the field experiment. A randomized complete block design ANOVA model was used to test the significance of the treatment effect at each site-year. Treatment was considered a fixed effect and replicate as a random effect. Site years with unequal variance among treatments were corrected using the repeated statement. Each treatment was compared to the control using k-1 single degree of freedom estimates to determine if there were significant differences in plant stand and seed yield. Estimates were considered to be significant at $p < 0.05$.

Growth Chamber Study

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 (crest) in the landscape and from a hollow (lower slope) position. A subset of treatments from the field experiment was 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 2.5 cm 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 22.9 cm pail to a depth of 10 cm. 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 NO_3-N, Olsen-P, exchangeable K, water extractable SO_4-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.

The Mixed Procedure in SAS 9.3 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 rate, AS rate, 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. Mean separation was done using a SAS macro (pdmix800) and adjusted using the Tukey method. Means were considered significantly different at $p < 0.05$.

Results

Field Study

AS or MAP applied alone at either rate did not reduce plant stand for most site years (Table 1). Applying a blend of P and S increased the frequency and severity of plant stand reduction. The blends with the high rate of AS were most damaging. The enhanced efficiency fertilizer blends including MES15, Vitasul and cMAP were less toxic than equivalent rates of conventional granular fertilizer. Coated MAP applied alone did not reduce plant stand for any site years.

Some liquid P and S fertilizer treatments were more toxic more often than equivalent rates of conventional granular fertilizers (Table 2). Although liquid and granular sources of P and S are similar in their risk of ammonia and salt toxicity, the close proximity of the liquid fertilizer band with the seed may have made reduced the plant stand to a greater extent than granular fertilizers.

Using conventional granular P or S alone increased yields for approximately half the site years; however, blending P and S increased yield more frequently (Table 3). The most consistent and greatest increase in yield was for the High MAP/Low AS treatment. The high rate blend of MAP/AS did not produce the greatest or most consistent yield probably due to the severe reduction in plant stand that occurred at some of the sites with this treatment.

Coated MAP at the low rate did not increase yields at the same frequency or to the same magnitude or as the equivalent rate of MAP (Table 3), perhaps indicating that P diffusion from the polymer coated granule did not occur at a sufficient rate to meet crop demand. The high rate of cMAP increased yield more frequently than the high rate of MAP (Table 3), indicating that more P was available at higher rate to satisfy crop demand and/or the slightly greater frequency of seedling toxicity from uncoated MAP was limiting P response.

Yield response to MES15 was similar to equivalent blends of MAP/AS (Table 3). The yields may have been similar because, as mentioned previously, the greatest frequency of yield responses and the largest mean yield increase occurred for the High MAP/Low AS treatment, indicating that sulphur deficiency was not severe. Therefore, even though half of the S in the MES15 is in the elemental form, and low rates of sulphate-S supplied by MES15 may have been sufficient to meet crop demand. Also, at the high rate of sulphate-S supplied by the MAP/AS blend, any nutritional benefits from the larger supply of plant available S may have been offset by decreases in plant stand.

Vitasul, an elemental S product, again requires oxidation to be converted into plant available sulphate. However, it is formulated to break down quickly in soil by increasing the surface area for microbes to access it. When compared to the equivalent rate of MAP/AS, it performed similarly (Table 3); however, because the Vitasul was blended with MAP, it is difficult to determine if the yield increase was due to a P or S response at some sites. Some of the elemental S in Vitasul appears to have oxidized in the year of application, because it improved yields at some S-responsive sites. However, the High MAP/Low AS treatment outperformed all other treatments, indicating that S applied in an immediately available form is the most reliable for reducing the risk of S deficiency in the year of application.

The seed yield response of canola to liquid P and S fertilizers used alone or as blends was generally lower than the equivalent rates conventional P and S granular fertilizers (Table 4). Although both granular and liquid P and S fertilizers are immediately available sources, the liquid fertilizers caused more severe damage to the plant stand at some of the sites than granular fertilizers which may have caused a reduction in yield potential. Part of the reason for the increased toxicity of the liquid fertilizers may have been due to less scattering compared to granular fertilizer, resulting in a greater concentration of fertilizer next to the seed.

Growth Chamber Study

Increasing rates of MAP alone had a small effect on canola plant stands for soil from the knoll or hollow (Figure 1). However, as the rate of AS increased, the plant stand was reduced substantially on both the soil from the knoll and the hollow (Figure 2). However, the decline in plant stand much more severe on the knoll soils, resulting in a significant interaction (P=<0.001) between AS rate and soils from different landscape positions (Figure 3). The soil properties of the two soils are similar, except for the calcium carbonate content ($CaCO_3$), which was 0.5% $CaCO_3$ for the hollow soil and 21% $CaCO_3$ for the knoll soil. Ammonium sulphate reacts with the $CaCO_3$ in the soil, forming calcium sulphate and unstable ammonium carbonate, which decomposes, releasing ammonia and carbon dioxide (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. Treatments with MAP alone had a much smaller impact on emergence (Figure 1) than AS on both soils, 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, among MAP rate, AS rate, landscape position and days after emergence. The lowest and slowest emergence 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 (Figure 4). These treatments probably have the highest 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.

Conclusions

Canola emergence was reduced and delayed by conventional sources of seed-placed P and S fertilizers due to salt and ammonia toxicity. Risk of seedling damage from seed-place MAP was moderate and polymer coating was effective in reducing salt toxicity of MAP. Conversely, AS has a high salt index and high risk of ammonia toxicity on calcareous soils; therefore, AS was more likely to reduce plant stands than P fertilizers.

Liquid APP/ATS may be more toxic than conventional granular blends perhaps because the delivery increases the proximity and therefore the concentration of the liquid band with the seed. MES15 and Vitasul may be less toxic than equivalent rates of MAP/AS because the elemental S requires time to oxidize and therefore has a low salt index.

The relationship between plant stand and yield is plastic and reaching yield potential depends on balancing optimum plant stand with adequate rates of plant available P and S. Increasing rates of conventional sources of P and S above the recommended rates can cause significant seedling damage, which may reduce the capacity to reach yield potential. Ammonium sulphate applied at high rates can decrease yield compared to low rates even at a S responsive site because of a severe reduction in plant stand. Seed-placed MES15 and Vitasul contain elemental forms of S, which may be as effective as seed-placed AS in the year of application if S deficiencies are not severe; however, their ability to provide adequate S in the year of application for soils with severe S deficiencies was not tested in this experiment.

Highly available sources of P and S increase the risk and severity of seedling toxicity, but they also increase the frequency and size of yield response where P and S are deficient. In order to maximize the benefits and minimize the risks of applying highly available P and S, farmers with single shoot, low SBU seeding equipment, should reserve the limited tolerance of canola for seed-row fertilizer for P. Unlike P, S is relatively mobile in the soil and could be placed away from the seed with substantially less risk of toxicity and no loss in agronomic availability.

References

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Table 1. Frequency and severity of significant reductions in plant stand (plants/m²) with seed-placed granular P and S fertilizer treatments compared to the control at all site years

Treatment	# Site-years (out of 17) with decrease in plant stand compared to control*	Mean difference in plant stand (plants/m²) compared to the control at all 17 sites
Low AS only	1	-5
High AS only	1	-8
Low MAP only	1	-3
High MAP only	1	-7
Low cMAP only	0	1
High cMAP only	0	0
Low MAP/ Low AS	2	-9
Low MAP/ High AS	6	-17
High MAP/ Low AS	4	-11
High MAP/ High AS	7	-20
Low cMAP/ Low AS	1	-4
Low cMAP/ High AS	4	-10
High cMAP/ Low AS	1	-6
High cMAP/ High AS	5	-12
Low MES15	1	-6
High MES15	2	-11
High MAP/High Vitasul	1	-8

* Estimates significant at $P<0.05$

Table 2. Frequency and severity of significant reductions in plant stand (plants/m²) with seed-placed granular and liquid P and S fertilizer treatments compared to the control at site years with a complete set of treatments

Treatment	# Site-years (out of 10) with decrease in plant stand compared to control*	Mean difference in plant stand (plants/m²) compared to the control at all 10 sites
Low AS only	1	-3
High AS only	0	-4
Low ATS only	1	-1
High ATS only	2	-11
Low MAP only	0	0
High MAP only	1	-4
Low cMAP only	1	0
High cMAP only	0	-2
Low APP only	2	-4
High APP only	0	-9
Low MAP/ Low AS	1	-7
Low MAP/ High AS	1	-10
High MAP/ Low AS	2	-5
High MAP/ High AS	1	-11
Low cMAP/ Low AS	1	-1
Low cMAP/ High AS	2	-8
High cMAP/ Low AS	1	-5
High cMAP/ High AS	1	-7
Low APP/ Low ATS	1	-10
Low APP/ High ATS	2	-11
High APP/ Low ATS	2	-12
High APP/ High ATS	2	-10
Low MES15	0	-3
High MES15	1	-6
MAP/Vitasul	0	-3

* Estimates significant at $P<0.05$

Table 3. Frequency and size of significant increases in seed yield (bu/ac) with seed-placed granular P and S fertilizer treatments compared to the control at all site years

Treatment	# Site-years (out of 16) with increase in seed yield compared to control*	Mean increase in seed yield (bu/ac) compared to the control at all 16 sites
Low AS only	8	8.3
High AS only	7	7.6
Low MAP only	8	7.4
High MAP only	6	7.7
Low cMAP only	4	5.5
High cMAP only	8	8.5
Low MAP/ Low AS	10	10.8
Low MAP/ High AS	10	11.2
High MAP/ Low AS	12	13.2
High MAP/ High AS	10	10.8
Low cMAP/ Low AS	10	9.4
Low cMAP/ High AS	10	9.7
High cMAP/ Low AS	11	12.2
High cMAP/ High AS	9	10.8
Low MES15	9	8.8
High MES15	10	10.6
High MAP/High Vitasul	11	10.3

* Estimates significant at $P<0.05$

Table 4. Frequency and size of significant increases in seed yield (bu/ac) with seed-placed granular and liquid P and S fertilizer treatments compared to the control at site years with a complete treatment set

Treatment	# Site-years (out of 9) with increase in seed yield compared to control*	Mean increase in seed yield (bu/ac) compared to the control at all 9 sites
Low AS only	3	5.8
High AS only	2	5.8
Low ATS only	0	4.3
High ATS only	1	4.8
Low MAP only	3	6.2
High MAP only	2	6.0
Low cMAP only	2	4.8
High cMAP only	3	6.6
Low APP only	1	3.7
High APP only	3	5.9
Low MAP/ Low AS	3	6.3
Low MAP/ High AS	4	8.6
High MAP/ Low AS	5	10.5
High MAP/ High AS	5	9.6
Low cMAP/ Low AS	5	8.2
Low cMAP/ High AS	3	7.0
High cMAP/ Low AS	4	9.0
High cMAP/ High AS	4	8.6
Low APP/ Low ATS	4	8.6
Low APP/ High ATS	2	6.5
High APP/ Low ATS	3	6.9
High APP/ High ATS	4	8.0
Low MES15	3	6.3
High MES15	4	8.7
MAP/Vitasul	5	9.5

* Estimates significant at $P<0.05$

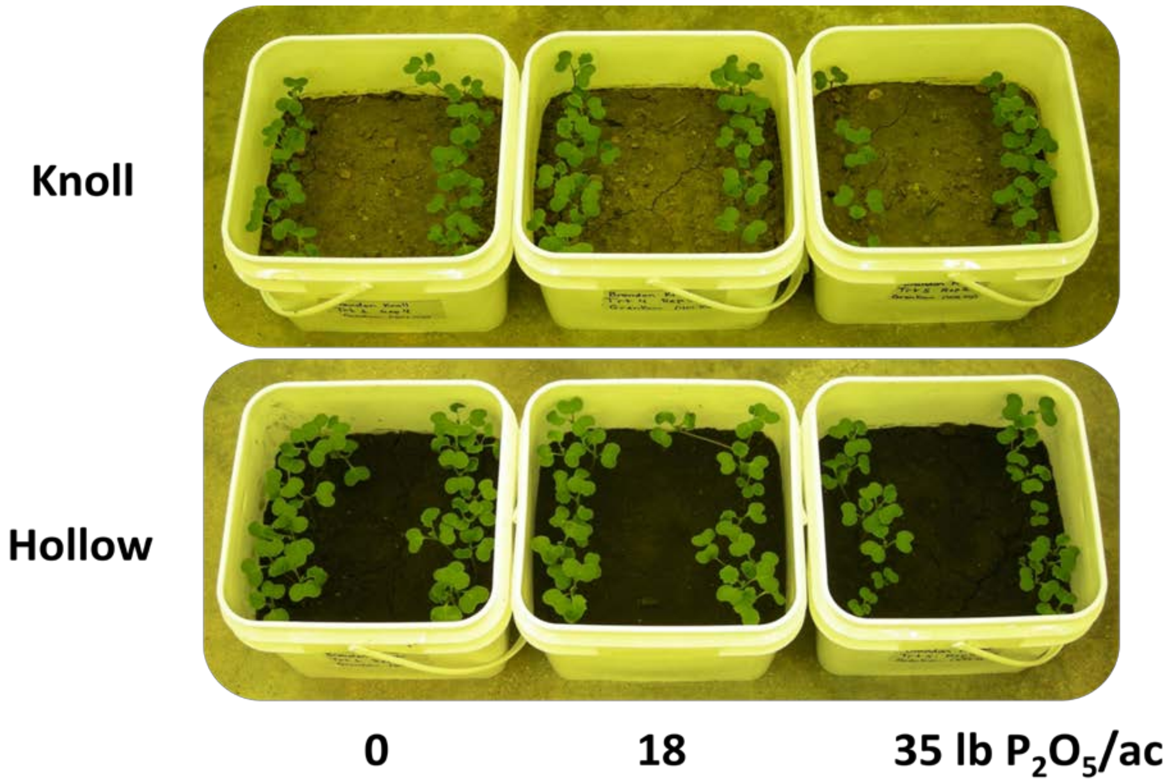

Figure 1. Effect of MAP on seedling emergence of canola applied at low and high rates on soil collected from an eroded knoll and a hollow from a field in Brandon, MB

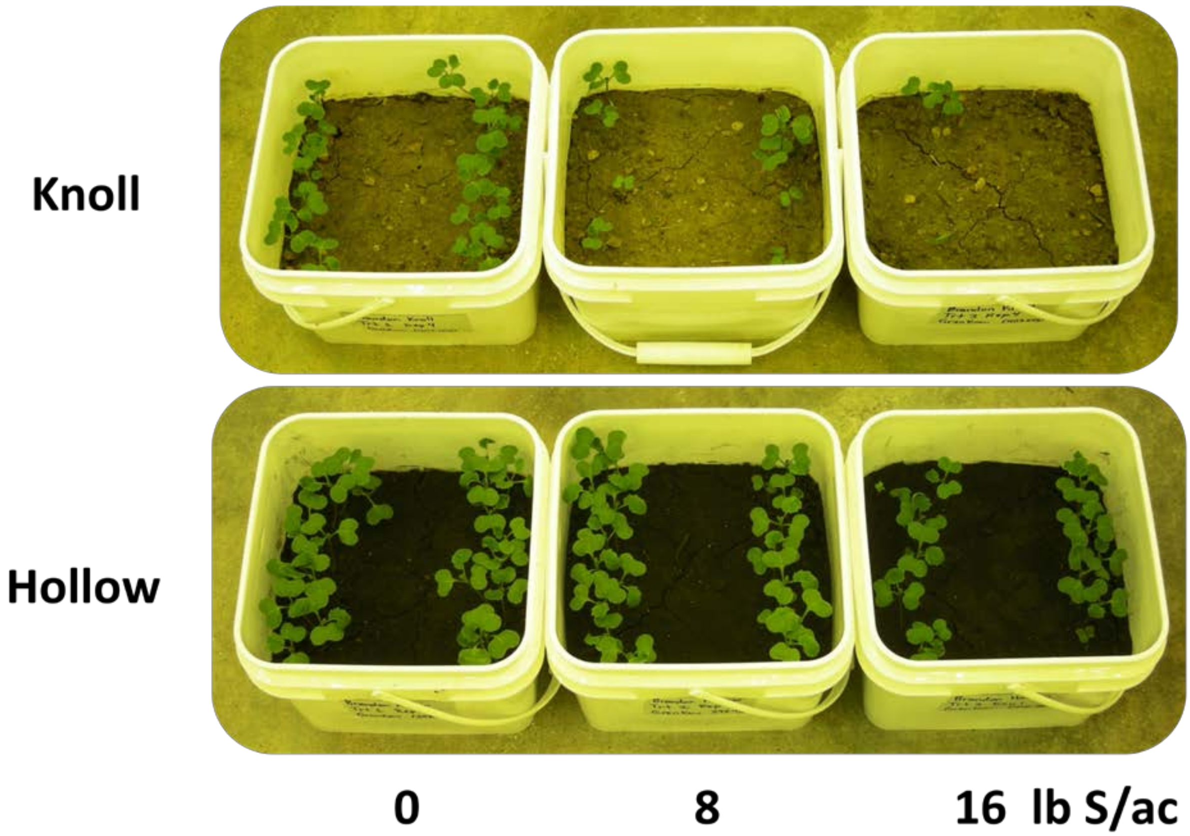

Figure 2. Effect of AS on seedling emergence of canola applied at low and high rates on soil collected from an eroded knoll and a hollow from a field in Brandon, MB

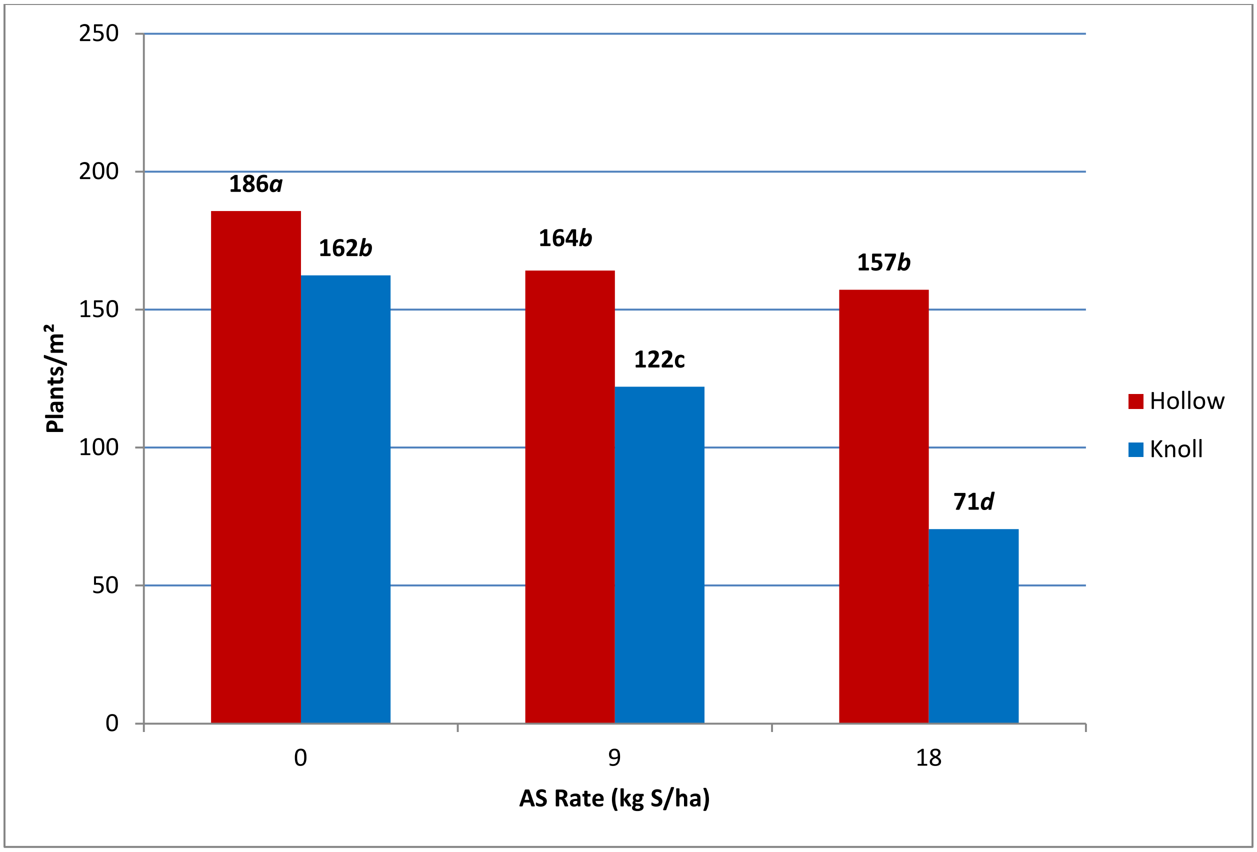

Figure 3. Interaction between AS rate and landscape position on seedling emergence of canola

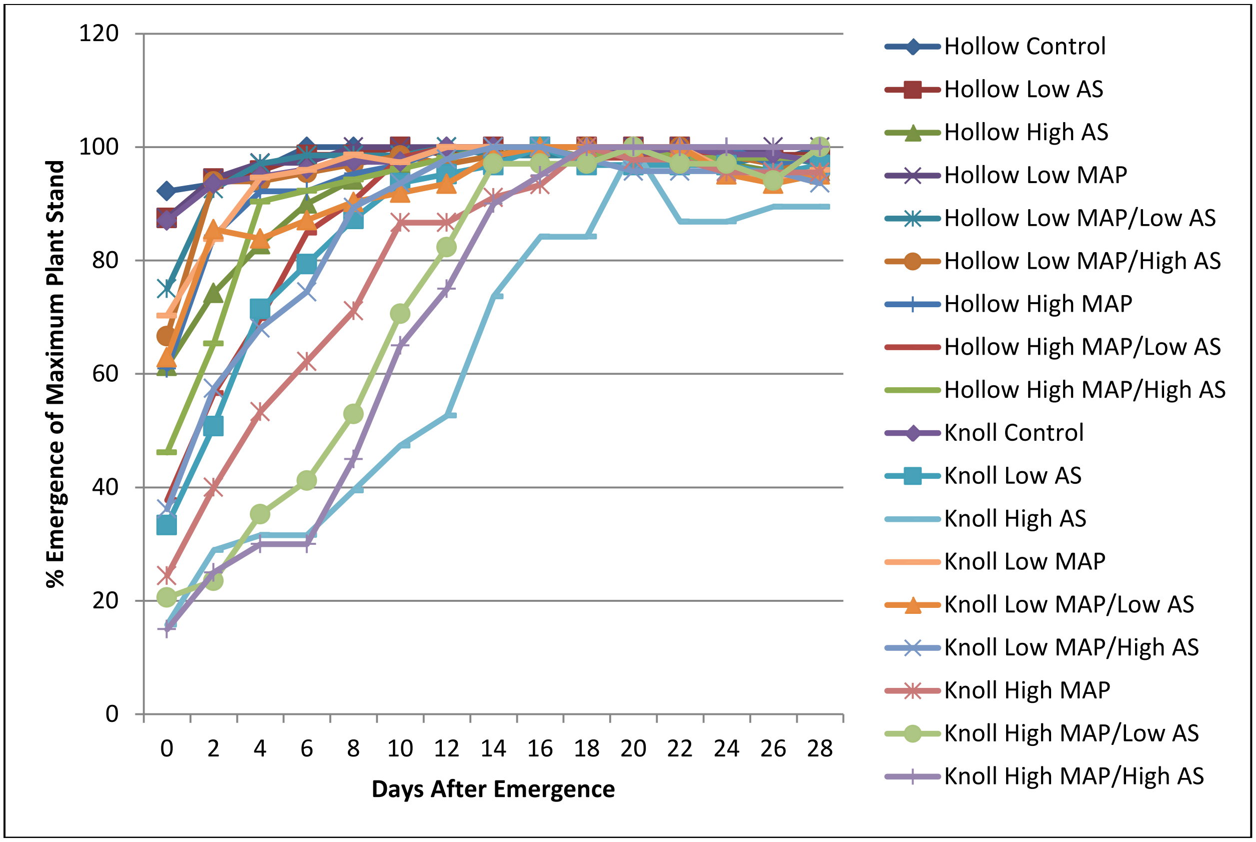

Figure 4. Interaction between MAP rate, AS rate, landscape position and days after emergence on seedling emergence of canola