Production management strategies to improve field pea root health in aphanomyces contaminated soils

Principal Investigators:

Gursahib Singh[1], Garry Hnatowich[1], Jessica Weber[2], Kayla Slind[2] Brianne McInnes[3], Bryan Nybo[4], and Sherrilyn Phelps[5]

[1]Western Applied Research Corporation, Scott, SK

[2]Irrigation Crop Diversification Centre, Outlook, SK

[3]Northeast Agriculture Research Foundation, Melfort, SK

[4]Wheatland Conservation Area, Swift Current, SK

[5]Saskatcheawn Pulse Growers

Project Title: Production management strategies to improve field pea root health in aphanomyces contaminated soils

Project Location(s):

- Scott Saskatchewan
- Melfort Saskatchewan
- Swift Current Saskatchewan
- Outlook Saskatchewan

Project start and end dates (month & year): 2019 and 2021

Project contact person & contact details:

Gursahib Singh (Research Director)

Irrigation Crop Diversification Corporation

Box 1460, Outlook, SK S0L 2N0

Phone: (306) 867-5405

Email: Gursahib.icdc@sasktel.net

Objective:

To demonstrate multiple management strategies to reduce the effect of aphanomyces on field pea root health through root health assessments and overall yield production.

Project Rationale:

Aphanomyces euteiches is an important disease of field peas that is caused by a complex of root pathogens. Cultural and chemical controls are available to reduce the adverse impact of this disease on root development, growth and yield. Still, when used individually, none of these practices are highly effective. Utilizing multiple control strategies, including herbicides, seed treatment, fertilizer rates and foliar nutrient applications to limit the effects of aphanomyces may prove the most effective to improve pea root health. This demonstration will help producers identify which management strategies will result in the greatest increase in plant health and consequentially crop yield. The economics of each strategy will be analyzed to aid producers in determining which practice is most productive and cost-effective.

Methodology:

This trial was initiated in the spring of 2019 and 2021 at four facilities in Saskatchewan- WARC (Scott), ICDC (Outlook), NARF (Melfort) and WCA (Swift Current). Each year, the trials were established in a factorial RCBD design with double wide plots and four replications. The factors evaluated were fertility, herbicide, seed treatment, and foliar nutrients for a total of ten treatments (Table 1). At all locations, each year before seeding, the soil was tested for the presence of Aphanomyces. The land tested positive for

aphanomyces in the spring via soil sample results from Discovery Seed Labs and Agvise for all the sites. Field peas were directly seeded into the previous cereal stubble at all locations. Seeding difficulties occurred due to the compacted soil conditions at Melfort in 2019. Different yellow pea varieties were grown as per the availability but with a seeding rate of 85 seeds/m^2 and target depths of approximately 2- 2.5 inches depending on equipment and spring soil moisture. Times of the various field operations and crop assist products used at each location are shown in Table A1 and Table A2.

Treatment List:

Table 1. Production management strategies to improve field pea root health in aphanomyces contaminated soils treatment list.

TRT	Pre-Seed Herbicide	Fertilizer (lb/ac)	Seed Treatment	Foliar Nutrient
1	Glyphosate	20 P only MAP[1] "Low"	No ST	N/A
2	Glyphosate	20 P only MAP	Vibrance Maxx + Intego	N/A
3	Glyphosate + Trifluralin	20 P only MAP	Vibrance Maxx	N/A
4	Glyphosate + Trifluralin	20 P only MAP	Vibrance Maxx + Intego	N/A
5	Glyphosate + Trifluralin	20 P only MAP	Vibrance Maxx + Intego	Rogue II (Fn)
6	Glyphosate	50 P, 20 K, 10 S[2] "High"	No ST	N/A
7	Glyphosate	50 P, 20 K, 10 S	Vibrance Maxx + Intego	N/A
8	Glyphosate + Trifluralin	50 P, 20 K, 10 S	Vibrance Maxx	N/A
9	Glyphosate + Trifluralin	50 P, 20 K, 10 S	Vibrance Maxx + Intego	N/A
10	Glyphosate + Trifluralin	50 P, 20 K, 10 S	Vibrance Maxx + Intego	Rogue II

Gly= Glyphosate, Tri= Trifluralin, Fertilizer "Low"; "High", ST= Seed Treatment, VM= Vibrance Maxx, I= Intego, Fn= Foliar Nutrient

[1] Low (20P) – application of 20 lb/ac of actual phosphorus (total of 4 lb/ac of nitrogen)

[2] High (50P, 20K, 10S)- application of 50 lb/ac of actual phosphorus, 20 lb/ac of actual potassium, 10 lb/ac of actual sulphur (total of 20lb/ac of nitrogen)

Data Collection:

Plant densities were determined by counting the numbers of emerged plants on 2 x 1meter row lengths per plot approximately four weeks after crop emergence. Disease root rating assessments were done twice between three to five weeks after planting (WAP) and at seven to eight WAP on five plants per plot. The timing of ratings depended on soil moisture levels and crop growth stage at each location. At seven weeks after seeding, the crop stage of the peas was early to mid-flowering. A root disease scale from 0 – 5 was used, where 0 = no symptoms, 1= some clear symptoms observed, 2= symptoms without rot spread more than half of the root; 3= root rot observed on half the root, 4= root rot spread on more than half the root, and 5= root rot spread to the whole root. Yields were determined from cleaned harvested grain samples and corrected to the required moisture content (16% moisture). An economic analysis was conducted to determine which treatment was most economically efficient. Weather data was collected from Environment Canada.

Growing Conditions:

Mean monthly temperatures and precipitation amounts for all locations are listed in Tables 2 and 3. The 2019 season was cooler than the long-term average at all sites, whereas 2021 temperatures were above the long-term average. Rainfall was below average for all sites in both growing seasons except Scott and Swift Current (Table 3). Research plots at Outlook were irrigated throughout the growing season to keep up with the crop demand (128.5 mm in 2019 and 213 mm in 2021).

Table 2. Mean monthly temperature from April to September 2019 at Saskatchewan Trial Locations.

Location	Year	May	June	July	August	September	Average
		Mean Temperature (°C)					
Outlook	2019	9.9	16.0	18.0	16.2	NA	15.0
	2021	10.2	18.6	21.6	17.9	NA	17.1
	Long-term	***11.5***	***16.1***	***18.9***	***18***	**NA**	**16.1**
Scott	2019	*9.1*	*14.9*	*16.1*	*14.4*	11.3	11.7
	2021	8.9	17.3	19.6	17.2	NA	13.3
	Long-term	***10.8***	***14.8***	***17.3***	***16.3***	**11.2**	**14.1**
Swift Current	2019	*9.5*	*15.8*	*17.7*	*16.8*	NA	14.9
	2021	9.5	18.4	21.7	18	NA	16.9
	Long-term	***11***	***15.7***	***18.4***	***17.9***	**NA**	**15.8**
Melfort	2019	8.8	15.3	16.9	14.9	11.2	13.4
	2021	9.6	18.2	20.1	16.9	14	15.8
	Long-term	**10.7**	**15.9**	**17.5**	**16.8**	**10.8**	**14.3**

Table 3. Precipitation amounts vs long-term (30 year) means for the 2019 growing seasons at Saskatchewan Trial Locations.

Location	Year	May	June	July	August	September	Total
		Precipitation (mm)					
Outlook	2019	13.2	90.2	43.8	39.6	NA	186.6
	2021	44.5	10.3	13.8	37.7	0.2	106.5
	Long-term	***43.2***	***69.3***	***57.6***	***44.2***	**32.7**	**247.0**
Scott	2019	12.7	97.7	107.8	18	41.8	278
	2021	43.9	43.8	10.4	51.3	NA	150.1
	Long-term	***38.9***	***69.7***	***69.4***	***48.7***	**26.5**	**253.2**
Swift Current	2019	13.3	156	11.1	42.6	NA	223
	2021	35	29.6	38.9	55.8	NA	159.3
	Long-term	***42.1***	***66.1***	***44***	***35.4***	**NA**	***187.6***
Melfort	2019	18.8	87.4	72.7	30.7	43.0	252.6
	2021	31.4	37.6	0.2	69.3	7.5	146
	Long-term	**42.9**	**54.3**	**76.7**	**52.4**	**38.7**	**265.0**

Results & Discussion

Plant Densities

Crop emergence slightly varied among locations with Melfort < Swift Current < Scott < Outlook increasing in average plant densities. In general, all sites had an acceptable level of establishment (Table 4). In 2019 Melfort had stand establishment issues due to soil compaction variability within the study. This resulted in varied emergence throughout the early spring. However, the plants recovered, and maturity between plots was similar, indicating a minimal difference in emergence timing. The crop stand in the second year (2021) was better at all sites, with Melfort < Swift Current < Scott < Outlook increasing in average plant densities (Table 4.).

Disease Root Ratings

The disease pressure at the first (3 to 5 WAP) and second (7 or 8 WAP) disease ratings varied among years (2019 vs 2021) and between the four locations (Scott vs. Outlook vs. Melfort vs. Swift current). Treatment combinations did not affect disease suppression at any of the sites except Melfort at 3 WAP in 2019 (Table 5). Disease pressure at the first disease rating was similar in both growing seasons (2019 and 2021) as the spring environmental conditions were similar in both years (Table 5). However, due to less precipitation in 2021 as compared to2019, the disease pressure in 2019 was higher than in 2021 at the second disease rating. Disease ratings were higher at Scott and Outlook in both years as compared to Melfort and Swift current.

2019

Disease ratings at 3 WAP were relatively low across all sites, with disease levels averaging at less than half the roots infected (< 2 out of 5). Disease ratings were the highest at Scott 3 WAP with disease pressure greatest with Gly + 20 P. Less than a 25% difference was observed from the most infected to the least infected diseased roots. Root disease symptoms did not occur at Outlook, whereas at Swift Current and Melfort the disease was rated as < 2 (disease present on less than half to a quarter of the root) at 3 WAP (Table 5). Disease pressure was limited at 3 WAP mainly due to the dry conditions that persisted at all the sites early in the growing season (Table 3).

Above normal precipitation at Scott (Table 3) contributed to high disease pressure compared to the other three sites. The disease pressure at 8 WAP was 63% more than at 3 WAP. The most diseased plants occurred when low fertilizer (20 P) + Gly was used compared to the higher fertilizer applications (50 P, 20 K, 10 S). The least diseased roots were reported with the combination of Gly + 50 P, 20 K, 10 S + VM + I and Tri+ 50 P, 20 K, 10 S + VM + I + FN.

Disease ratings at Outlook were slightly lower as compared to Scott and did not exhibit the same trend noted above. The combination of Tri+ 50 P, 20 K, 10 S + VM + I had slightly more disease than the

other combinations, and the disease pressure was lowest for the low fertility (20 P) treatments (Table 5). Disease pressure among all treatments was relatively low, with less than 8% difference between the most infected and least infected roots. Disease ratings at Swift Current were slightly lower than Outlook, and all treatments had very similar root disease ratings that equaled 2.7 to 3.5 (root disease was marginally less than half to slightly greater than half of the root). As ratings were so similar between treatments, no trend was detected. Disease ratings at Melfort were the lowest regardless of the heavy rainfall that occurred in June (33 mm above the long-term average) and on average precipitation in July (Table 3). The disease ratings fluctuated between 0 and 1 (no symptoms to some apparent symptoms observed). As symptoms were minor, it wasn't easy to detect any trends.

2021

Due to the relatively cool spring, crop development was delayed, and the first disease ratings were done at 5 WAP when the crop was at the six nodes stage. Treatments (Table 1) did not affect disease levels at all sites. Overall disease pressure at 5 WAP was low and varied among all four sites. Outlook being the irrigated site, had readily available soil moisture, which favoured disease and had the highest disease pressure (mean disease rating - 0.7; Figure 1), followed by Scott (mean disease rating - 0.2) and Melfort (mean disease rating - 0.1) (Table 5). At Swift current no damage roots were noticed at 5 WAP due to the dry conditions, and plots were rated as zero for disease incidence and severity. At Outlook treatment- Gly + 20 P +VM +I had the highest disease pressure (disease rating – 1.4) at 5 WAP. At Scott and Melfort, treatment- Gly + 20 P and treatment- Tri + 20P + VM + I + FN respectively resulted in the highest disease ratings (disease rating – 0.4 and 0.4; Table 5).

There were no significant differences between treatments for disease levels across all site years. Across four locations, disease pressure was highest at Outlook (mean disease rating – 3.8), followed by Scott (mean disease rating – 2.1) and Melfort (mean disease rating – 0.5) at 8 WAP. Dry conditions persisted throughout the growing season at Swift current leading to low disease levels. The trend of disease suppression by treatments was different at all sites. At Outlook, treatment- Gly + 20 P +VM +I resulted in the highest disease ratings, whereas the lowest disease was recorded in treatment- Gly + 50 P, 20K, 10S +VM +I (Table 5). The highest disease was recorded for treatment- Gly + 20 P at Scott, whereas at Melfort treatment- Gly + 50P 20K, 10S demonstrated the highest disease ratings (Table 5).

Yield

Yield differed among all sites in both growing seasons and was not significantly influenced by any of the inputs applied, except Scott in 2019 (P =0.0132). Each location demonstrated a slightly different yield response to the input combinations. Overall yields were impacted by both disease pressure and drought conditions; combined yields of 2019 were higher than 2021 (Table 6). Each location demonstrated

a slightly different yield response to the input combinations. In 2019, all five treatment combinations with high fertility had higher yields than low fertility treatments. In contrast, the fertility effect on yield was less apparent in 2021. The use of seed treatment and foliar nutrients were quite variable and did not appear to have a consistent effect on yield, particularly when averaged across all sites.

2019

Yields at Scott were the lowest compared to all four sites. The meagre yields were likely attributed to the intense root disease pressure recorded (Table 5). The highest yields were achieved by adding higher rates of fertilizer (50 P, 20 K, 10 S) to result in a 9 bu/ac yield gain compared to when low fertilizer (20 P) was applied (Table 6). At Outlook, the disease levels were slightly lower than at Scott, however, Outlook had much higher yields (on average 44 bu/ac higher). This could indicate that the disease pressure had less of an influence on overall yields at Outlook than at Scott, and therefore the effects of the inputs were less evident at Outlook. The three highest yielding treatments differed by herbicides applied (Glyphosate vs. trifluralin), fertility (high vs. low), seed treatment used (Untreated vs Vibrance Maxx vs. Vibrance Maxx and Intego) and the absence and presence of a foliar nutrient applied (Table 6). A yield benefit of 6 bu/ ac was achieved when two or more inputs (Gly + high fertility, Tri + low fertility and Tri + high fertility) were used in combination over the lowest yielding treatment (Gly + 20 P). The three highest yielding input combinations reported at Outlook were two of the lowest yielding at Swift Current. The combination of Tri + low fertility + VM and Gly + high fertility had the lowest yields, while the combination of Tri + high fertility + VM, Gly + low fertility + VM + I and Tri + low fertility +VM +I + Fn had the highest yields (Table 6). The common input between the three highest yielding treatments was applying a seed treatment of Vibrance Maxx (VM) with and without Intego (I). The yield trends at Melfort once again varied from the three previous sites in which the three highest yielding treatments were (1) Gly + high fertility, (2) Gly + low fertility+ VM + I, and (3) Tri+ high fertility + VM. The common factor between the three high-yielding treatments was when glyphosate was combined with high fertility or seed treatment (VM + I). The lowest yielding treatments were when glyphosate was used with a low fertility (Table 6).

2021

At all locations, the yield was not significantly influenced by any of the inputs applied. At Scott, the highest and lowest yielding treatments differed by herbicide application (trifluralin vs. glyphosate), fertility [high (50 P, 20 K, 10 S) vs low (20 P)] and seed treatment (Untreated vs. Vibrance Maxx and Intego) and resulted in a 5.2 bu/ac yield gain (Table 6). At Outlook, yields were higher than Scott, even with higher disease pressure. This could indicate that readily available soil moisture through irrigation overall helped the damaged roots to meet the plants water demand. The highest yielding treatment had a yield advantage of 15.5 bu/ac as compared to the low yielding treatment. Like the 2019 growing season, the highest yields were achieved when high fertility was used compared to low fertility in the lowest

yielding treatment. The yield at Melfort was highest among all four sites, with an average of 53 bu/ac, but the trends once again varied from the other three sites. The common factor between the two high yielding treatments was seed treatment (VM or VM + I), whereas the common factor in the two lowest yielding treatments was low fertility (20 P; Table 6). Yields at Swift current were the lowest compared to all four sites. The very low yields were likely attributed to moisture stress and dry conditions, which prevailed in the 2021 growing season (Table 2). The lowest yielding input combinations reported at Outlook were the highest yielding at Swift Current. The combined analysis of all sites showed that high fertility treatments had slightly higher yields than low fertility treatments.

Out of the four inputs (fertility, herbicide, seed treatment and foliar nutrients) used in the current study, the most common factor that influenced disease severity and field pea yields were the fertilizer rates (20 P vs. 50 P, 20 K, 10S). The effect of foliar nutrients, seed treatment, and herbicide is less clear, and so is the interaction between these inputs and fertility. Higher fertilizer rates (P) resulted in higher yields and marginally reduced disease pressure at Scott in 2019. Although the fertilizer rates effect of yield and disease was not significant at the remaining seven site years, there was a trend of increased yield with high fertility treatments (Table 6.). The current study results correspond with earlier studies focused on the effects of inorganic phosphate fertilizer and arbuscular mycorrhizal fungi (AMF) on aphanomyces in pea roots (Dehne 1982; Linderman 1994; Bodker et al. 1998; Thygesen et al. 2004). These studies reported that AMFs enhance plant phosphate uptake, improve overall plant vigour, and increase field pea roots' tolerance capacity. Moreover, this enhanced plant development may increase phosphorus concentration in the plant, which eventually reduces disease development in peas (Bodker et al. 1998).

The effect of herbicide application (trifluralin vs glyphosate) on yield and disease suppression was less apparent than fertilizer response. Previous studies on chemical management strategy found that application of dinitroaniline herbicide such as trifluralin improved pea yield in aphanomyces contaminated soils (Katan and Eshel 1973; Grau and Reiling 1976; Teasdale et al. 1997; Harvey et al. 1975). Harvey et al. (1975) reported higher yields when peas were grown in aphanomyces infected soils treated with trifluralin. Similarly, Teasdale et al. (1997) stated that applying a dinitroaniline herbicide would inhibit the production of motile zoospores (the infecting propagule of the pathogen), which delayed the root infection by 2- weeks. This delay resulted in additional plant growth that allowed the peas to withstand the effects of subsequent disease development better. The results from this study didn't provide any concrete evidence of delayed infection as stated by previous studies, but overall, trends indicate that infection may have been slightly delayed. The inconsistency in results and efficacy of trifluralin among sites could be attributed to various factors like the application to incorporation timing and environmental and soil conditions. Generally, trifluralin must be applied and incorporated within 24 hours after application due to it's high sensitivity to volatilization. The depth of incorporation, soil temperature and soil moisture may all influence

the rate of degradation and efficacy of trifluralin.

Additionally, the seeding depth and amount of surface plant residue may play a role in its efficacy. In this study, trifluralin application did not affect disease levels, and yield and response varied among all sites. Although, combining high fertilizer with trifluralin resulted in the two highest yields at Scott, the highest at Swift Current and the third and fourth highest yields at Outlook in 2019, the combined effect was less evident in 2021. The possible reason for variable response between growing seasons could be due to drought conditions in 2021 which reduced the efficacy of both fertilizer and herbicide.

Like herbicide application, the effects of seed treatments were quite variable. The efficacy of the seed treatment may have been influenced by the environmental conditions as the spring was quite dry at all locations. Seed treatments are best utilized under wet, moist conditions conducive for disease development within the first few weeks of application. As moisture stressed conditions in 2019 and 2021 likely reduced the efficacy of seed treatments and therefore had a negligible effect on the degree of aphanomyces infection on peas.

The least effective method to managing aphanomyces on field peas was the application of a foliar nutrient. There is little research to support the effects of a foliar nutrient, and this study has provided little evidence of its intended benefits. The application of foliar nutrients may help improve late-season vigour but overall, its effect was minimal and variable amongst all locations.

Economic Analysis

Similar to yield trends which were different for all sites in both years, the most profitable treatment combination differed among locations (Table 7). When combining the yield from all sites, the most profitable combination was the application of Gly + high fertility (50 P, 20 K, 10 S). However, this combination holds less promise to improve field pea tolerance to aphanomyces. The only site where the treatment effect significantly increased yield was Scott in 2019, trifluralin + high fertility (50 P, 20 K, 10 S) + Vibrance Maxx was the most profitable combination, and this combination was equally profitable as the Gly + high fertility (50 P, 20 K, 10 S).

Table 4. Observed field pea plant densities (plants/m^2) influenced by herbicide, fertilizer, and seed treatment in aphanomyces infected soils at Scott, Outlook, Swift Current, and Melfort SK, 2019 and 2021.

Treatments	2019				2021				Combined 2019	Combined 2021	Combined 2019+2021
	Scott	*Outlook*	*Swift Current*	*Melfort*	*Scott*	*Outlook*	*Swift Current*	*Melfort*			
Gly + 20 P	70	88	64	63	90	112	82	76	74	90	81
Gly + 20 P+ VM + I	63	81	69	64	83	126	72	79	74	90	80
Tri + 20P + VM	74	80	75	67	79	90	61	69	72	87	74
Tri + 20P + VM + I	74	90	70	55	84	113	64	76	72	85	78
Tri + 20P + VM + I + FN	69	80	68	62	80	113	63	76	71	84	77
Gly + 50 P, 20 K, 10 S	66	96	55	58	84	96	69	66	70	83	74
Gly + 50 P, 20 K, 10 S + VM + I	70	82	66	55	90	117	73	68	70	83	78
Tri+ 50 P, 20 K, 10 S + VM	70	76	78	58	84	94	77	76	69	82	77
Tri+ 50 P, 20 K, 10 S + VM + I	67	71	73	61	88	103	77	71	68	79	76
Tri+ 50 P, 20 K, 10 S + VM + I + FN	75	86	74	60	85	102	68	74	68	75	78
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Gly= Glyphosate, Tri= Trifluralin, Fertilizer “Low”; “High”, ST= Seed Treatment, VM= Vibrance Maxx, I= Intego, Fn= Foliar Nutrient, NS = not significant

Table 5. Observed root rot disease ratings at 3 and 7 weeks after planting (WAP) influenced by herbicide, fertilizer, seed treatment and foliar nutrients applied on field peas seeded in aphanomyces infected soils at Scott, Outlook, Swift Current, and Melfort SK, 2019.

Treatments	**2019**								**2021**								**Combined 2019**		**Combined 2021**		**Combined 2019+2021**	
	Scott		*Outlook*		*Swift Current*		*Melfort*		*Scott*		*Outlook*		*Swift Current*		*Melfort*							
	Disease ratings I (week 3 to 5) and II (week 7 or 8)																					
	I	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*
Gly + 20 P	2.0	4.8	0	4.3	1.8	3.0	1.0	0.3	0.4	2.6	1.0	3.8	0	0	0.2	0.6	0.4	3.3	0.5	2.3	0.4	2.4
Gly + 20 P+ VM + I	1.6	5.0	0	4.1	1.5	3.1	1.0	0.3	0.1	2.1	1.4	4.1	0	0	0.0	0.4	0.4	3.3	0.5	2.2	0.3	2.4
Tri + 20P + VM	1.6	4.5	0	4.2	1.7	3.1	1.2	0.4	0.1	2.3	0.4	3.6	0	0	0.1	1.1	0.4	3.2	0.2	2.3	0.2	2.4
Tri + 20P + VM + I	1.9	4.8	0	4.1	1.4	2.7	1.1	0.1	0.2	1.7	1.2	3.6	0	0	0.1	0.4	0.4	3.1	0.5	1.9	0.3	2.2
Tri + 20P + VM + I + FN	1.6	5.0	0	4.4	1.5	3.5	1.0	0.1	0.2	2.1	0.6	4.0	0	0	0.4	0.4	0.4	3.1	0.4	2.2	0.3	2.4
Gly + 50 P, 20 K, 10 S	1.6	4.5	0	4.2	1.8	3.0	1.1	0.8	0.2	2.4	0.7	3.9	0	0	0.2	0.8	0.3	3.1	0.4	2.3	0.3	2.5
Gly + 50 P, 20 K, 10 S + VM + I	1.5	3.8	0	4.4	1.6	2.9	1.2	0.9	0.4	2.3	0.5	3.3	0	0	0.1	0.4	0.3	3.0	0.3	2.0	0.3	2.2
Tri+ 50 P, 20 K, 10 S + VM	1.8	4.5	0	4.4	1.6	3.1	1.2	0.3	0.2	1.6	0.4	3.7	0	0	0.0	0.5	0.3	3.0	0.2	1.9	0.3	2.3
Tri+ 50 P, 20 K, 10 S + VM + I	1.8	4.5	0	4.5	1.7	3.1	1.1	1.2	0.2	1.6	0.7	3.9	0	0	0.0	0.1	0.3	3.0	0.3	1.8	0.3	2.3
Tri+ 50 P, 20 K, 10 S + VM + I + FN	1.6	3.8	0	4.3	1.6	3.3	1.2	0.7	0.1	1.4	0.6	3.8	0	0	0.1	0.4	0.3	2.9	0.3	1.8	0.3	2.2
LSD (0.05)	NS	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	NS	-	-	NS	NS	NS	NS	NS	NS	NS	NS

Gly= Glyphosate, Tri= Trifluralin, Fertilizer "Low"; "High", ST= Seed Treatment, VM= Vibrance Maxx, I= Intego, Fn= Foliar Nutrient, NS = not significant

Table 6. Field pea yield (bu/ac) grown under different management strategies including pre-seed herbicide, fertilizer, seed treatment and foliar nutrients in aphanomyces infected soils at Scott, Outlook, Swift Current, and Melfort SK, 2019.

	2019				2021				Combined 2019	Combined 2021	Combined 2019+2021
	Scott	Outlook	Swift Current	Melfort	Scott	Outlook	Swift Current	Melfort			
Gly + 20 P	17.0	64.0	34.0	40.0	32.7	33.1	30.6	53.5	40.2	36.1	38.1
Gly + 20 P+ VM + I	7.0	64.0	38.0	53.0	34.6	33.8	28.4	53.0	42.6	37.4	40.0
Tri + 20P + VM	19.0	69.0	34.0	47.0	35.9	42.3	27.5	54.5	42.2	39.8	41.0
Tri + 20P + VM + I	17.0	65.0	36.0	45.0	33.9	42.1	27.0	51.7	40.8	38.7	39.8
Tri + 20P + VM + I + FN	20.0	67.0	38.0	48.0	34.4	35.2	26.7	51.5	43.3	36.4	39.8
Gly + 50 P, 20 K, 10 S	27.0	71.0	33.0	55.0	36.6	48.9	26.4	53.2	46.7	40.9	43.8
Gly + 50 P, 20 K, 10 S + VM + I	26.0	66.0	36.0	47.0	33.8	43.8	25.9	54.5	44.2	39.9	42.0
Tri+ 50 P, 20 K, 10 S + VM	30.0	65.0	38.0	49.0	33.7	42.0	25.2	53.7	45.7	39.0	42.3
Tri+ 50 P, 20 K, 10 S + VM + I	25.0	67.0	35.0	47.0	37.9	42.2	24.7	52.3	43.9	40.7	42.3
Tri+ 50 P, 20 K, 10 S + VM + I + FN	27.0	68.0	37.0	49.0	36.2	38.1	24.5	53.0	45.3	38.3	41.8
LSD (0.05)	S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Gly= Glyphosate, Tri= Trifluralin, Fertilizer "Low"; "High", ST= Seed Treatment, VM= Vibrance Maxx, I= Intego, Fn= Foliar Nutrient, NS = not significant

Table 7. Economic analysis (net profit) of field pea yield grown under different management strategies including pre-seed herbicide, fertilizer, seed treatment and foliar nutrients in aphanomyces infected soils at Scott, Outlook, Swift Current, and Melfort SK.

Treatments	Scott	Outlook	Swift current	Melfort	Scott	Outlook	Swift current	Melfort	All sites combined
	2019				*2021*				
	Net Profit ($/ ac)								
Gly + 20 P	178.24	742.24	382.24	454.24	366.64	371.44	341.44	616.24	431.44
Gly + 20 P+ VM + I	144.24	708.24	396.24	576.24	355.44	345.84	281.04	576.24	420.24
Tri + 20P + VM	175.17	775.17	355.17	511.17	377.97	454.77	277.17	601.17	439.17
Tri + 20P + VM + I	135.17	711.17	363.17	471.17	337.97	436.37	255.17	551.57	408.77
Tri + 20P + VM + I + FN	155.52	719.52	371.52	491.52	328.32	337.92	235.92	533.52	393.12
Gly + 50 P, 20 K, 10 S	273.34	801.34	345.34	609.34	388.54	536.14	266.14	587.74	474.94
Gly + 50 P, 20 K, 10 S + VM + I	227.34	707.34	347.34	479.34	320.94	440.94	226.14	569.34	419.34
Tri+ 50 P, 20 K, 10 S + VM	282.27	702.27	378.27	510.27	326.67	426.27	224.67	566.67	429.87
Tri+ 50 P, 20 K, 10 S + VM + I	206.27	710.27	326.27	470.27	361.07	412.67	202.67	533.87	413.87
Tri+ 50 P, 20 K, 10 S + VM + I + FN	214.62	706.62	334.62	478.62	325.02	347.82	184.62	526.62	392.22

Gly= Glyphosate, Tri= Trifluralin, Fertilizer “Low”; “High”, ST= Seed Treatment, VM= Vibrance Maxx, I= Intego, Fn= Foliar Nutrient

Conclusions and Recommendations

In general, plant densities were acceptable at all locations and were higher in 2021 than in 2019. Disease pressure was limited at 3 WAP primarily due to cool and dry spring conditions that persisted at all the sites. Disease ratings were relatively low across all sites in both years, with disease levels less than half of the roots infected, whereas no root disease symptoms were detected at the time of first disease rating at Outlook in 2019 and Swift current in 2021. Disease pressure at Scott in 2019 at 3 WAP was the highest among all sites, and the greatest disease symptoms were observed with Glyphosate + 20 P. Similarly, at 8 WAP, disease ratings were highest at Scott and increased by 63% compared to 3 WAP. Disease ratings at the three remaining sites ranged from very low (0-1) to moderate (2-4), with Outlook exhibiting the second highest disease ratings.

On the other hand, Outlook had the highest disease pressure at 5 WAP in 2021, with the highest disease ratings for glyphosate + 20 P+ VM + I treatment. Disease ratings at 8 WAP were also highest for Outlook and increased by 81% compared to 5 WAP. In both years the most diseased plants occurred when low fertilizer (20 P) + Gly was used compared to the higher fertilizer applications (50 P, 20 K, 10 S). The trends observed in both years at all locations varied, and it is difficult to confirm a treatment effect based on the disease ratings alone.

The yield was not significantly influenced by any of the inputs applied in both years, except at Scott ($P = 0.0132$). The highest yields at Scott were achieved by adding higher rates of fertilizer (50 P, 20 K, 10 S) to result in a 9 bu/ac yield gain compared to when low fertilizer (20 P) was applied. The trend of yield gain varied among all sites in both years except Outlook, where the combination of Gly+ 50 P, 20 K, 10 S increased yield by 7 bu/ac and 15.5 bu/ac in 2019 and 2021, respectively, compared to the lowest yielding treatment (Gly + 20P) in both years. Usually, the higher fertility treatments provided the greatest yield at all sites irrespective of herbicide, seed, or foliar nutrient application. In contrast, the use of seed treatment and foliar nutrients were quite variable and did not appear to have a consistent effect on yield, especially when averaged across all eight sites. The yield response of all sites was combined to determine the most profitable combination: Gly+ high fertility (50 P, 20 K, 10 S) followed by trifluralin + high fertility (50 P, 20 K, 10 S) + Vibrance Maxx or Intego. With the variable response of yield to the combination of fertilizer and herbicide at all sites, it's hard to make assumptions about the effect of foliar nutrients and seed treatment.

When looking at disease management options in terms of effectiveness and profitability, the three most essential strategies should include (1) proper fertilization (higher than the current standard of 20 lb/ac of P_2O_5), (2) applications of herbicide (glyphosate or trifluralin) to reduce weed pressure and (3) the application of seed treatments in a wet, cold spring. Both years when this study was undertaken were typically drier and the effects of a seed treatment may not have been reported to their fullest potential. Of

all the treatment combinations, fertility had the highest impact on yield and disease ratings, whereas other treatment combinations provided less disease tolerance/ suppression evidence. At this point, it's hard to justify that either of the other treatments had any role in delaying infection and improving disease tolerance. Additional research is required to confirm the most effective and profitable combination of field peas grown under aphanomyces infected soils.

Figure 1. Arial view of Outlook research site, the dark brown area showing hot spots of aphanomyces in the research plots. Aphanomyces symptoms were detected at 5 WAP and 8 WAP in Outlook 2021.

Supporting Information

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Appendices

Appendix A

Table A1. Times of operations and crop input products utilized by all locations in 2019.

Activity	Location			
	Scott	**Outlook**	**Swift Current**	**Melfort**
Stubble Selection	Canola	Wheat	Durum	Wheat
Pre-seed Herbicide Application	May 24 (Glyphosate 540 @ 1L/ac + Trifuralin 480 EC @ 0.65 L/ac)	May 6 (Glyphosate 540 @ 1L/ac + Trifuralin 480 EC @ 0.65 L/ac)	May 16 (Trifluralin 480 EC @ 690 ml/ac)	May 23 (Trifuralin 480 EC @ 930 ml/ac) + May 30 (Glyphosate 540 1 L/ac)
Seed Treatment	May 28 (Vibrance Maxx @ 325ml/100kg & Vibrance Maxx + Intego @ 325ml/100kg	May 9 (Vibrance Maxx RFC @100 ml/100 kg + INTEGO Solo @ 19.6 ml/100 kg	May 17 (Vibrance Maxx @ 325ml/100kg & Vibrance Maxx + Intego @ 325ml/100kg	May 27 (Vibrance Maxx @ 325ml/100kg & Vibrance Maxx + Intego @ 325ml/100kg
Variety	Arbarth	CDC Inca	CDC Inca	AC Carver
Seeding date	May 28	May 9	May 17	May 27
In-crop Herbicide Application	June 27 (Viper ADV @ 400 ml/ac + UAN @ 0.81 L/ac)	Viper ADV @ 400 ml/ac + UAN @ 0.81 L/ac	June 12 (Viper ADV @ 400 ml/ac + UAN @ 0.81 L/ac)	June 27 (Viper ADV @ 400 ml/ac) + July 5 (Assure II 300 ml/ac)
In-crop Fungicide Application	N/A	Priaxor @ 180 ml/ac	N/A	July 12 (Acapella @ 325 ml/ac)
Desiccation	Aug 20 (Roundup 540 @ 1 L/ac + Aug 28 Reglone Ion @ 0.83 L/ac)	Aug 15 (Reglone Ion @ 0.83 L/ac @ 20gpa	N/C	Sept 16 (Glyphosate 540 @ 0.67 L/ac + Heat LQ @ 59 ml/ac)
Harvest	Sept 5	Aug 21	Aug 20	Sept 23

NA = Not applied
NC = Observation not captured

Table A2. Times of operations and crop input products utilized by all locations in 2021.

Activity	Location			
	Scott	**Outlook**	**Swift Current**	**Melfort**
Stubble Selection	Canola	Wheat	Durum	Wheat
Pre-seed Herbicide Application	May 11 (Glyphosate 540 @ 1L/ac + Trifuralin 480 EC @ 0.65 L/ac)	May 10 (Glyphosate 540 @ 1L/ac + Trifuralin 480 EC @ 0.65 L/ac)	May 17 (Glyphosate 540 @ 670ml/ac + Trifluralin 480 EC @ 690 ml/ac)	May 14 (Trifuralin 480 EC @ 930 ml/ac) + May 30 (Glyphosate 540 1 L/ac)
Seed Treatment	April 30 (Vibrance Maxx @ 325ml/100kg & Vibrance Maxx + Intego @ 325ml/100kg	May 7 (Vibrance Maxx RFC @100 ml/100 kg + INTEGO Solo @ 19.6 ml/100 kg	May 14 (Vibrance Maxx @ 325ml/100kg & Vibrance Maxx + Intego @ 325ml/100kg	May 10 (Vibrance Maxx @ 325ml/100kg & Vibrance Maxx + Intego @ 325ml/100kg
Variety	Arbarth	CDC Inca	CDC Inca	CDC Spectrum
Seeding date	May 12	May 18	May 17	May 27
In-crop Herbicide Application	June 12 (Viper ADV @ 400 ml/ac + UAN @ 0.81 L/ac)	June 09 (Viper ADV @ 400 ml/ac + UAN @ 0.81 L/ac)	June 08 (Viper ADV @ 400 ml/ac + UAN @ 0.81 L/ac)	June 8 (Viper ADV @ 400 ml/ac) + July 5 (Assure II 300 ml/ac)
In-crop Fungicide Application	Dyax @ 160 mL/ac	N/A	N/A	July 09 (Priaxor @180ml/ac)
Desiccation	July 30 (Reglone Ion @ 0.83 L/ac)	Aug 6 (Reglone Ion @ 0.83 L/ac @ 20gpa	Aug 12 (Reglone Ion @ 0.83 L/ac @ 20gpa	Aug 05 (Glyphosate 540 @ 0.67 L/ac)
Harvest	Aug 5	Aug 13	Aug 20	Aug 17

NA = Not applied

Abstract

A study was initiated in Saskatchewan, Canada, to demonstrate multiple management strategies to reduce the effect of aphanomyces on field pea root health through root health assessments and overall yield production. The demonstration was arranged as a randomized complete block design, doubled wide, with four replicates at Scott, Outlook, Swift Current and Melfort in 2019 and 2021. The factors evaluated were herbicide (Glyphosate vs. trifluralin), seed treatment (none vs. Vibrance Maxx vs. Vibrance Maxx + Intego), fertility (20 P_2O5 vs. 50 P_2O5, 20 K, 10S) and foliar nutrient application for a total of 10 treatments. Disease ratings 3 to 5 WAP were relatively low across all sites. Disease ratings were higher at Scott and Outlook in both years than Melfort and Swift Current. At all sites, disease pressure was higher at the second disease rating (7 WAP or 8 WAP) than the first disease rating (3 to 5 WAP). The disease suppression trends with respect to applied inputs varied amongst all locations. The most diseased plants occurred when low fertilizer (20 P) + Gly was used compared to the higher fertilizer applications (50 P, 20 K, 10 S). In general, it is difficult to confirm a treatment effect based on the disease ratings alone. The applied inputs did not influence the yield at any site, except Scott in 2019 (P =0.0132). The highest yields at Scott were achieved by adding higher fertilizer rates (50 P, 20 K, 10 S) than when low fertilizer (20 P) was applied. Similar to the disease suppression response, the average yield of the remaining seven sites increased when high fertilizer rates were used as compared to low. When averaged across all sites, the two most profitable combinations were Gly+ high fertility (50 P, 20 K, 10 S) and Tri + high fertility (50 P, 20 K, 10 S) + Vibrance Maxx or Intego. The most profitable input to utilize was high fertilizer rates, whereas herbicide application, seed treatments, and foliar nutrient response were less promising in the current study. Additional research is required to confirm the most effective and profitable combination of field peas grown under aphanomyces infected soils.

Extension Activities:

The preliminary results of this study were presented at the Australian Seminar in Horsham, October 2019 with approximately 50 people in attendance. The results were also shared by Sherrilyn Phelps, Saskatchewan Pulse Growers at various grower extension events (+200 to date) as well as at the Agronomy Research Update 2019 (250 attendees), and at CropSphere (150 attendees). A fact sheet will also be generated and distributed on the WARC website as well as all Agri-ARM and WARC events to ensure the information will be transferred to producers.The trial at Swift Current was promoted on a CKSW radio program called "Walk the Plots" that was broadcasted on a weekly basis throughout the summer and may also be highlighted by Bryan Nybo, Wheatland Conservation Area at the Swift Current Winter Pulse Meetings on February 27, 2020. The research trails were highlighted at CSIDC field day (100+ attendees) in the summer and the results were later presented at the Irrigation conference (150+ attendees) held at the Dakota Dunes resort in the fall of 2021.

References

Abbott LK, Robson AD (1984) The effect of mycorrhizas on plant growth. In: Powell CL, Bagyaraj DJ (eds) VA mycorrhizae. CRC, Boca Raton Fla, pp 113–130

Bødker, L., Kjøller, R. and Rosendahl, S., 1998. Effect of phosphate and the arbuscular mycorrhizal fungus Glomus intraradices on disease severity of root rot of peas *(Pisum sativum)* caused by *Aphanomyces euteiches*. *Mycorrhiza*, *8*(3), pp.169-174.

Dehne HW .1982. Interaction between vesicular-arbuscular mycorrhizal fungi and plant pathogens. Phytopathology 72:1115–1119

Garbaye J .1991. Biological interactions in the mycorrhizosphere. Experientia 47:370–375

Harvey, R.G., Hagedorn, D.J. and DeLoughery, R.L., 1975. Influence of Herbicides on Root Rot in Processing Peas 1. Crop Science, 15(1), pp.67-71.

Katan, J and Y Eshel. 1973. Interaction sbetween herbicides andplant pathogens. Residue Rev. 45; 145-177

Linderman RG. 1994. Role of VAM fungi in biocontrol. In: Pfleger FL, Linderman RG (eds) Mycorrhizae and plant health. APS, St. Paul, Minne, pp 1–25

Sharma AK, Johri BN, Gianinazzi S. 1992. Vesicular-arbuscular mycorrhizae in relation to plant disease. World J Microbiol Biotechnol 8: 559–563

Teasdale, J., Harvey, R., & Hagedorn, D. (1979). Mechanism for the Suppression of pea (Pisum sativum) Root Rot by Dinitroaniline Herbicides. Weed Science, 27(2), 195-201.

Thygesen, K., Larsen, J. and Bødker, L., 2004. Arbuscular mycorrhizal fungi reduce development of pea root-rot caused by *Aphanomyces euteiches* using oospores as pathogen inoculum. *European Journal of Plant Pathology*, *110*(4), pp.411-419.