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Full Research Project Final Report

- This report must be a stand-alone report, *i.e.,* must be complete in and of itself. Scientific articles or other publications cannot be substituted for the report.
- One electronic copy and one signed original copy are to be forwarded to the lead funding agency on or before the due date as per the investment agreement.
- A detailed, signed income and expenditure statement incurred during the entire funding period of the project must be submitted along with this report. Revenues should be identified by funder, if applicable. Expenditures should be classified into the following categories: personnel; travel; capital assets; supplies; communication, dissemination and linkage; and overhead (if applicable).
- For any questions regarding the preparation and submission of this report, please contact ACIDF

Section A: Project overview

1. Project number: **2013F017R**
2. Project title: **Toward a strategy for reducing the spore density and dissemination of clubroot of canola in Alberta**
3. Research team leader: Sheau-Fang Hwang
4. Research team leader's organisation: Alberta Agriculture and Forestry
5. Project start date (yyyy/mm/dd): 2013/04/01
6. Project completion date (yyyy/mm/dd): 2017/03/31
7. Project final report date (yyyy/mm/dd): 2017/10/31

Section B: Non-technical summary (max 1 page)

Provide a summary of the project results which could be used by the funders for communication to industry stakeholders (*e.g.*, producers, processors, retailers, extension personnel, etc.) and/or the general public. This summary should give a brief background as to why the project was carried out, what were the principal outcomes and key messages, how these outcomes and key messages will advance the agricultural sector, how they will impact industry stakeholders and/or consumers, and what are the economic benefits for the industry.

Clubroot continues to spread through Alberta and the Prairie Provinces. Prevention of establishment of clubroot in a field can save producers millions of dollars both in control measures and in lost revenue. Fumigation at field entrances reduces spore populations in newly-introduced infestations and reduce the risk of more widespread clubroot establishment in a field. Use of resistant cultivars will further reduce the risk of establishment of clubroot in a field. However, repeated cultivation of resistant cultivars in fields with established infections increases the risk of the development of new strains of clubroot that can defeat resistance resources.

Project 2013F017R was initiated to fully assess the impact of cropping clubroot resistant canola cultivars on soil resting spore populations, to investigate the technical feasibility of using soil fumigation to eliminate clubroot from small-scale infestations and to continue clubroot surveillance and document pathogen spread.

Vapam application was effective at 400-800 L/ha. Some residual toxicity was noted at higher rates. Vapam treatment was most effective when sealed under plastic for 12 days, but sufficient ventilation time (1-2 wk) must be allowed afterwards before seeding to avoid residual toxicity. The biofumigant MustGro was assessed at several rates, but few treatment effects were observed.

Gall mass on clubroot susceptible cultivars was 10-250 times greater than on resistant cultivars, but there were no differences in gall mass or clubroot severity among the clubroot-resistant cultivars. Gall formation and disease severity were reduced to zero after a sequence of fallow or non-host crops, which was lower compared with both susceptible canola and most resistance rotation sequences. All of the 4-year resistance rotation sequences resulted in lower gall formation in susceptible canola grown subsequently. In a study on the interval between canola crops in a rotation sequence, an interval of two years or more between canola crops improved plant growth and yield and reduced clubroot severity and gall mass.

New clubroot infestations were found in 72 of 376 fields surveyed in 2014, plus in 98 fields in surveys conducted by separate counties. Of 70 clubroot-free fields surveyed in Leduc and Sturgeon counties in 2005-9, about half were found infested. In 2015, 65 of 836 fields surveyed were found to be infested with clubroot. Symptoms of the disease were observed in 32 fields sown to clubroot-resistant canola cultivars. In 2016, clubroot was found in 68 of 570 canola crops inspected. Another 221 new cases of the disease were found during surveillance by county and municipal personnel. Symptoms of the disease also were identified in 42 fields that had been planted to clubroot-resistant hybrids. In 2017, clubroot was found in 72 of 554 canola fields surveyed. An additional 229 cases were found in surveys carried out by county and municipal personnel, for a total of 301 new clubroot infestations. This brings the grand total of confirmed cases of clubroot in the province to 2744, representing 36 counties and municipal districts.

Section C: Project details

1. Project team (max ½ page)

Describe the contribution of each member of the R&D team to the functioning of the project. Also describe any changes to the team which occurred over the course of the project.

The composition of the research team did not change over the course of the project. Dr. Hwang served as team leader, coordinating team activities, as well as directing various components of the research related to clubroot pathology. Dr. Strelkov provided pathogen material used in all components of the research, along with expertise and advice on working with the pathogen. The research team enjoyed a good working relationship throughout the project.

2. Background (max 1 page)

Describe the project background and include the related scientific and development work that has been completed to date by your team and/or others.

Clubroot, caused by *Plasmodiophora brassicae*, is an increasingly important disease of canola on the Canadian prairies. The clubroot pathogen increases rapidly under short rotations with susceptible hosts, producing large numbers of resting spores and causing severe yield losses in heavily infested canola crops. Clubroot continues to spread from the original outbreak near Edmonton. It has now been identified in over 2,700 fields in Alberta, with infestations found in 36 counties (Strelkov et al. submitted) and a few cases identified in Saskatchewan and southern Alberta. This has led to concern about clubroot spread across the prairies and the impact of this disease on Canadian canola production.

The research was built on collaboration between the clubroot program at AAF and the U of A. Under the Clubroot Risk Mitigation Initiative (2009-2013), extensive surveys of clubroot-prone areas were undertaken, detailed records of disease spread were compiled, and a clubroot disease nursery was developed. The research continued the clubroot surveillance and added pathotype monitoring. Understanding the rate of clubroot spread, as well as the factors contributing to disease severity, will allow for better risk assessment and the selection of appropriate management strategies.

In addition, studies were conducted to understand the impact of cropping clubroot resistant canola on pathogen resting spore populations in the soil. We hypothesized that resistant cultivars may serve as a 'bait crop', contributing to resting spore germination without subsequent clubroot development, thereby depleting soil inoculum loads. A final component of the project examined the efficacy of soil fumigants and spot treatments to eradicate small-scale clubroot infestations. This would have two likely benefits: (1) eradication of newly established infestations in areas where clubroot is not yet widely dispersed, and (2) elimination of newly established infestations within individual fields. In a study on the distribution of infected plants within clubroot-infested canola crops, it was found that new infestations are most commonly introduced by equipment near the field entrances (Cao *et al.*, 2009). Treatments to reduce clubroot that may not be feasible or economical on a whole-field scale may be effective when targeted to localized spots in a field.

3. Objectives and deliverables (max 1 page)

State what the original objective(s) and expected deliverable(s) of the project were. Also describe any modifications to the objective(s) and deliverable(s) which occurred over the course of the project.

Overall objective: This project aimed to continue to provide the tools and information necessary to successfully battle clubroot in western Canada, by providing a better understanding of the distribution and dispersal of *P. brassicae*, and the development of methods to eradicate or reduce newly established infestations both in a within-field and a regional basis.
Specific objectives:

a) To continue clubroot surveillance and document pathogen spread and pathotype composition
b) To fully assess the impact of cropping clubroot resistant canola cultivars on soil resting spore populations
c) To appropriately direct attempts at eradication of new infestations by investigating the technical feasibility of using soil fumigation to eliminate clubroot from small-scale infestations.

Deliverables:

1. Annual data from clubroot surveys compiled into maps to document the spread of clubroot and enable epidemiological modelling; pathotype monitoring to allow the detection of shifts in the pathogen population structure as a result of the selection pressure imposed by the cropping of resistant cultivars
2. Characterization of the impact of clubroot resistant canola cultivars on *P. brassicae* resting spore loads in the soil, to determine the utility of these cultivars in reducing disease pressure (and possibly off-setting the selection pressure imposed by resistance)
3. Soil fumigation experiments to compare clubroot severity and seed yield with varying application times, products, water volumes, application rates, soil coverage and soil temperatures; recommendations developed for spot treatments to eradicate clubroot
4. Technology transfer (maps, articles, posters, data, etc.) distributed to stakeholders
5. A demonstration of experiments from this project was displayed at the International Clubroot Workshop to be held in Edmonton in 2013, and annual tours for producers and other stakeholders were hosted in subsequent years
6. Annual reports on experiments and a final report summarizing the data collected from this project (including major conclusions)

4. Research design and methodology (max 4 pages)

Describe and summarise the project design, methodology and methods of laboratory and statistical analysis that were actually used to carry out the project. Please provide sufficient detail to determine the experimental and statistical validity of the work and give reference to relevant literature where appropriate. For ease of evaluation, please structure this section according to the objectives cited above.

a) Surveillance

Clubroot surveillance was coordinated with municipalities and other stakeholders. A total of 376 fields were surveyed in 2014, 836 in 2015, 570 in 2016 and 554 in 2017. Surveys were done either randomly with a fixed sampling pattern ('W'-shaped) including the entrance, or focused on problem areas where the producer had previously identified clubroot. Incidence and severity ratings were done using the scale outlined by Kuginuki et al. (1999), where 0 = no galls, 1 = small/minor galling, 2 = moderate galling, and 3 = severe galling. The ratings were used to calculate an index of disease (ID) using the formula of Strelkov et al., 2006. Populations and single-spore isolates from selected locales were characterized for pathotype designation.

b) Fumigation studies

Effect of Vapam application rate -

2013 - To determine the effective rate of Vapam under field conditions, two trials were conducted at two sites, Henwood and 50th Street in Edmonton. The experiments were set up in a randomized complete block (RCB) design with four replications. Each four-row plot was 6 m x 1.3 m, with 1 m between plots and 2 m between blocks. The treatments consisted of Vapam at 0, 40, 80 and 160 mL m^{-2}, applied on May 17 and 16, 2013 at 50th Street and Henwood, respectively. On May 28, the plots at both sites were seeded with a clubroot susceptible canola cultivar 45H26 at 4 g seed plot^{-1} with a plot seed drill.

2014-15 Post-fumigation treatment effects - Under field conditions, the soil was pre-worked with a rototiller at the site near Henwood. Vapam was applied at 66 mL/m^2 to all plots except the untreated control on June 4, 2014 and May 28, 2015. The soil was rototilled again to incorporate the treatment and then compacted with a land roller. After compaction, the plots were: 1) left open, 2) drenched with water at 2.6 L/m^2, 3) covered with black plastic sheeting for 1 wk, or 4)drenched with water as described in Treatment 2 and then covered with black plastic for 1 wk. On June 12, 2014 and June 16, 2015 the plots were sown with the susceptible canola cultivar 45H31. Emergence was recorded on July 4, plant height was recorded for 10 plants on August 5 and plant vigour was recorded on August 6, 2014. Clubroot severity was assessed for 25 plants/plot on August 10, 2014 and August 21, 2015. At maturity (September 24, 2014; October 2, 2015) the remainder of the plots was harvested to determine yield.

2015-16 Effect of plastic covering on Vapam efficacy -

To assess the effect of soil incorporation on Vapam efficacy, trials were conducted at two sites at Henwood, Edmonton in 2015. Each site was prepared with a rototiller prior to treatment. The treatments consisted of Vapam application followed by incorporation with a rototiller, soil compaction with a land roller and finally, covering with a plastic sheet for 7, 12 or 16 days. Non-treated plots were subjected to the same treatments. Each four-row plot was 6 m x 0.9 m, with 0.6 m between plots and 2 m between blocks.

Vapam application rate was the same as in the previous experiment. The Vapam solution was incorporated into the soil with a rototiller to a depth of 10 cm and rolled with a land roller on May 14, 2015 and June 7, 2016. Plastic sheeting was applied to all plots and removed on May 21, 26 or 30, 2015, and on June 14, 19 or 23, 2016 (7, 12 or 16 days after fumigation in each case). The plots were seeded on at 4 g seed plot^{-1} with a plot seed drill on May 26, May 31 or June 5, 2015 and on June 27, 30 or July 5, 2016. Seedling establishment and plant vigor were assessed on June 29, 2015 and July 21, 2016. On August 20, 2015 and September 23, 2016, a 1-m^2 area of each plot was selected at random, and the plants were uprooted and washed under tap

water. Data on fresh gall weight and clubroot severity using the 0–3 scale as described above six weeks after seeding. On October 1, 2015 and November 18, 2016, the remaining plants in the plots were harvested by small plot combine. Seed was dried and weighed to determine yield.

c) *Biofumigant assessment*

MustGrow (MPT Mustard Products & Technologies Inc., Saskatoon, SK) is a dry granular product derived from the seeds of *B. junceaI.* It contains a mixture of glucosinolates and myrosinases in a concentrated and stable form for treatment (MustGrow 2015). MustGrow is applied to a dry soil surface and water is then added to the treated soil.

Soil infested with *P. brassicae* was collected from a field nursery in Edmonton, AB (the 'Henwood site', 53 38' 48"N, 113 22' 33"W), in 2013. The soil was allowed to air dry and then measured into a large re-sealable plastic bag. The soil was mixed to create a homogenous blend, sampled for the presence and amount of *P. brassicae* resting spores via conventional polymerase chain reaction (PCR) and quantitative PCR analysis, and treated with MustGrow. Briefly, the treatment granules were added to the 1.5 L of infested soil in the plastic bag and incorporated by sealing and shaking the bag. Three MustGrow treatment rates were evaluated: 1.11 g /L, 2.22 g/L and 4.44 g /L soil. The manufacturer's recommended rates consist of a range of 1121-2240 kg/ha. The rates applied in this study were equivalent to approximately 1153 kg/ha, 2313 kg/ha, and 4625kg/ha.

Treated soil was poured into 12 cm x 12cm x 12cm pots and seeded 14 days after the biofumigant was applied. Ten seeds of the clubroot susceptible canola cultivar 45H26 were planted in each pot. Six replicates were included for each of the four treatments. Each trial was designed as a randomized complete block, with six blocks. The trial was replicated twice in the same greenhouse, with plant growth conditions maintained at 24°C and approximately 30% relative humidity under natural light supplemented with artificial lighting (16 h day/8 h night). The height of the main stem, fresh above ground plant biomass and seed yield were recorded for each plant, and the plants were carefully dug out from the soil, with the roots washed with tap water and evaluated for clubroot symptom severity and gall fresh and dry weight. All plants in each pot were assessed.

A 250mL soil sample was collected from each pot as a post-treatment sample to assess spore populations via conventional and qPCR analysis.

d) Impact of resistant cultivars on P. brassicae population dynamics

***Analysis of clubroot spore populations in soil*s**

Soil samples were collected from field studies below. Sub-samples were taken from each of the soil samples and composited. Bulked samples were either: **1)** homogenized using a barrel sieve and rolling bars; or **2)** ground using a mortar and pestle. DNA was extracted using a PowerSoil DNA Isolation Kit. The conventional PCR method developed by Cao et al. (2007) was used to amplify *P. brassicae* DNA. The qPCR protocol developed by Rennie et al. (2011) was used to quantify spores per gram soil of the samples that tested positive in the conventional PCR. The inoculum potential of infested soil samples was also assessed via greenhouse clubroot bioassays. Briefly, naturally infested (with *P. brassicae*) soil was combined with a potting medium and thoroughly mixed; susceptible canola cultivars was then grown in each soil sample as a secondary method to verify and corroborate field data.

2013 Field - The clubroot-resistant canola cultivars '45H29' (Pioneer Hi-Bred), '74-47' (Monsanto), '9558C' (Viterra), or '72439-10' (DL Seeds) and the susceptible cultivar '45H26' (Pioneer Hi-Bred) were sown in field soils containing approximately 10^8 spores g^{-1} of soil in a randomized complete block design with four replications. Each plot measured 6 m x 1.5 m, with four rows, 0.3 m spacing between rows and 0.6 m spacing between the plots. The experiment was seeded on May 28, 2013 at two field sites, 10 km apart, near Edmonton AB (50th Street and Henwood Clubroot Nursery, Crop Diversification Centre North), Alberta. Plant counts (plants m^{-2}), clubroot severity and club weight were assessed at the late pod stage on August 27, 2013. Clubroot severity ratings were converted to ID% as described above.

2014 Field - The clubroot-resistant canola cultivars '08N823R', '45H29' (Pioneer Hi-Bred), '73-67', '73-77', '74-47' (Monsanto), '9558C' (Viterra), '72439-10', '72447-10', '72451-10' (DL Seeds), 'L135 C' (Bayer), '6056 CR' (Brett Young) and the susceptible cultivars '45H26', '45H31' (Pioneer Hi-Bred), 73-15RR (Monsanto) and were sown in field soils at Henwood containing approximately 10^8 spores g^{-1} of soil in a randomized complete block design with four replications. Each plot measured 6 m x 0.6 m, with two rows spaced at 0.3 m and a 0.6 m spacing between the plots. The experiment was seeded on June 3, 2014. Plant counts were conducted on July 8. Disease severity was assessed on August 10. The disease index was calculated as described previously. Plant counts were lower compared to all other lines for '73-15RR' and higher compared to all others for '08N823R'.

e) *Effects of crop sequences on clubroot severity*:
Brassica rapa, a Polish canola cultivar 'Reward' highly susceptible to clubroot, and perennial ryegrass cv. 'Russian Wild-Swift' were evaluated for their effectiveness as bait crop in inducing *P. brassicae* resting spore germination and thereby reducing clubroot symptoms on susceptible *B. napus* canola cultivar ('45H26'). Seeds of each crop were surface sterilized with 1% NaOCl for 2 min and rinsed with sdH_2O. The seeds were incubated for 1 week on moistened, sterilized filter paper in 9-cm diameter Petri dishes and allowed to germinate. One hundred 1-week-old seedlings from each crop were transplanted into the plastic tubs of infested soil. The transplants were planted in four rows per container, with each row consisting of 25 seedlings. The containers were placed in a greenhouse and maintained at 20 ± 2 °C/18 ± 2 °C (day/night) with a 16-h photoperiod. The containers were watered daily from the bottom with tap water adjusted to pH 6.4 with HCl. The treatments assessed were *B. rapa* (B), ryegrass (R) and fallow (F), and the sequences were: 1) R–B, 2) B–R, 3) R–F, 4) B–F, and 5) F–F. The trial was arranged as a randomized complete block design with four replicates (containers) per treatment. Each crop was grown for 2 weeks. At the end of each 2-wk cycle, the crops were uprooted and removed, and replanted with the second crop for 2 weeks. When the second crop was removed, each tub was replanted with the clubroot-susceptible *B. napus* (cv. 45H26) for 6 wk to assess the treatment effects on clubroot severity. After each cycle of the bait crop the soil was allowed to dry for one week, and the soil was thoroughly cultivated with a hand shovel. No fertilizer was applied at any stage in the study.
A soil sample was collected from each replicate (tub) and air-dried. Resting spores were extracted from three 500 mg subsamples of the soil from each tub. Total genomic DNA was extracted from the resting spore pellet and analyzed by conventional and quantitative PCR (qPCR) to establish the presence and concentration of *P. brassicae* DNA in the soil.

2014 -17 Field Study (CR4) Effects of resistant cultivar rotation on clubroot severity in the final year

The clubroot-resistant canola cultivars '45H29' (Pioneer Hi-Bred), '74-47' (Monsanto), '9558C' (Viterra), or '72439-10' (DL Seeds) and the susceptible cultivar '45H26' (Pioneer Hi-Bred) were sown in field soils containing approximately 10^8 spores g^{-1} of soil in a randomized complete block design with four replications, beginning May 28, 2013. Each plot measured 6 m x 1.5 m, with four rows, 0.3 m spacing between the rows and 0.6 m spacing between the plots. Before canola seed-set, the plots were cut with a forage harvester to prevent volunteer growth. The experiment was re-seeded on June 3, 2014 at the Henwood disease nursery, on the same site as the 2013 plots. The 50th street site was discontinued in 2014 due to a change of landowner. Plant counts were conducted on July 8. Disease severity was evaluated on August 10. Shoot, root and gall fresh weight and plant height were recorded on August 27. Emergence was similar among all treatments. The plots were re-seeded following the planned rotational sequence on May 29, 2015 and June 15, 2016. The final crop in the sequence was seeded May 31, 2017 and harvested on September 11, 2017.

The impact of cropping resistant cultivars on P. brassicae inoculum levels (resting spore numbers per g soil) was evaluated under greenhouse and field conditions. In the field, plot areas were sampled for pathotype and soil inoculum loads to establish baseline data. Four resistant cultivars were assessed in a 4-year experiment in a combination of treatments: 1) a single cultivar over 4 years; 2) alternating cultivars; or 3) rotational sequences with a different cultivar each year. At the end of the experiment, the soil was sampled at multiple points in each plot. Inoculum loads were measured by quantitative PCR. A subset of samples was also bioassayed to measure disease severity on a susceptible cultivar, in order to get another measure of soil infective potential. The impact of different crop rotation schemes was examined in greenhouse experiments conducted with soils collected from the Bassano area of southern Alberta, and from the Edmonton region of central Alberta. Comparisons were made on the impact of the various rotation schemes on clubroot severity and plant growth parameters in the various canola cultivars, as well as on soil resting spore loads.

f) Non-host interval between canola crops

To determine the effect of the non-host crops barley or pea on spore populations, canola crops were grown in field soils containing approximately 10^8 resting spores g^{-1} of soil at the same site described in the previous experiment, followed by four cropping sequences over five years: 1) continuous canola (C–C–C–C–C), 2) one-year break with canola alternating with barley (C–B–C–B–C), 3) two-year break (C–C–B–B–C), and 4) three-year break (C–B–P–B–C), where C was the susceptible canola 45H31, B was the barley cv. Harrington and P was the pea cultivar Midas. Each plot measured 6 m x 1.5 m, with four rows, 0.3 m spacing between rows and 0.6 m spacing between the plots. The experiment was set up in a randomized complete block design with four replications. The experiment was initiated in 2013 and continued until the end of the sequences in 2017. The experiment was seeded on May 28, 2013, June 3, 2014, on May 29, 2015, June 15, 2016, and May 26, 2017. Where appropriate, seedling emergence per plot was counted three weeks after seeding in every treatment sequence of the experiments. The plants in the final year were harvested on September 11, 2017.

The same experiment was repeated under net-house conditions in mini-plots filled with clubroot infested soil collected from the Henwood Clubroot Nursery. The spore concentration of the soil was adjusted to 0.5 x 10^8 by mixing with Sunshine mix 4 potting mixture at 1:1 ratio. The Mini-plots were consisted of 38-L plastic tubs (50 cm x 35 cm x 22 cm) filled with 30 L of soil mixture. Seeds of the crops mentioned above were seeded in four rows with 7 cm spacing at 10 seeds per row. The experiment was seeded on August 12, 2014, on June 19, 2015, June 20 in 2016, and on May 26, 2017. The other experimental details were the same as described in the previous section. The seedling emergence was counted after 21 days of seeding. After 6 weeks of seeding the plants were uprooted, and washed with running tap water to remove soils. Clubroot severity was assessed as described in the previous section. Data on seedling emergence, plant height, plant biomass, gall weight were also recorded. Before seeding the final year crop soil samples from each experimental unit (replicate) were collected to determine the spore load as mentioned previously.

5. Results, discussion and conclusions (max 8 pages)

Present the project results and discuss their implications. Discuss any variance between expected targets and those achieved. Highlight the innovative, unique nature of the new knowledge generated. Describe implications of this knowledge for the advancement of agricultural science. For ease of evaluation, please structure this section according to the objectives cited above.
NB: Tables, graphs, manuscripts, etc., may be included as appendices to this report.

a) Surveillance

2014 Survey

A total of 376 fields were surveyed in 2014. Of these, 72 were found to be infested with clubroot. Infestation was light in 48 of these fields, moderate in 19 and severe in 5. The counties of Clearwater, Lesser Slave River and Woodlands were added to the list of counties with infested fields. The county of Flagstaff had 2 severely infested fields; Lamont, Minburn and Ponoka each had one. An additional 98 fields infested with clubroot were found in separate surveys conducted in the counties of Athabasca, Clearwater, Lacombe, Lamont, Leduc, Red Deer, and Wetaskiwin. One new clubroot-infested field was identified by the County of Athabasca for a total of 21 cases. One new clubroot-infested field was identified by the County of Clearwater for a total of 2 cases. Four new clubroot-infested fields were identified by the County of Lacombe for a total of 39 cases. One new clubroot-infested field was identified by the County of Lamont for a total of 21 cases. Two new clubroot-infested fields were identified by the County of Red Deer for a total of 18 cases. Six new clubroot-infested fields were identified by the County of Wetaskiwin for a total of 32 cases. Eighty-three new clubroot-infested fields were identified by the County of Lacombe for a total of 143 cases. Clubroot-free fields that were surveyed in 2005-9 in Leduc and Sturgeon counties were re-surveyed. Of approximately 70 fields, about half are now infested. Collectively, surveillance activities in 2014 revealed 383 new records of clubroot in Alberta, representing the second largest single-year increase in the number of new cases since surveys commenced in 2003. While still concentrated mainly in central Alberta, the clubroot outbreak continues to spread. Despite its increasing prevalence in many regions, clubroot remains relatively uncommon in southern Alberta. Aside from three unconfirmed reports of the disease in the County of Newell, no other new cases of clubroot were identified south of the counties of Red Deer and Stettler in 2014.

2015 Survey

A total of 836 commercial canola (*Brassica napus* L.) crops in 38 counties and municipalities in central and southern Alberta were surveyed for the prevalence and severity of clubroot in 2015. These included 604 crops that were located in fields that had either not been surveyed previously for clubroot, or had been inspected in earlier surveys and found to be free of the disease. An additional 232 crops were

surveyed because they were within a 1.6 km radius of fields where clubroot resistance appeared to have become eroded in 2013 or 2014 or because they were in fields confirmed to have been planted to canola in at least three of the last five years. Most fields were surveyed in late August and September shortly after swathing. When inspecting fields, a 20 to 30 m^2 area was selected near the field entrance and a minimum of 50 canola roots were sampled randomly within that area. If no symptoms of clubroot were found, then no more sampling was performed. If clubroot was found, then the crop was surveyed more extensively by examining the roots of all plants within a 1 m^2 area at each of 10 locations along the arms of a 'W' sampling pattern. A total of 65 of the 836 canola crops inspected were found to have symptoms of clubroot, 58 of which represented new records of clubroot infestation. Clubroot severity ranged from mild to moderate, but no severe infestations (ID > 60%) were identified in 2015. Symptoms of the disease were observed in a total of 32 fields that had been sown to clubroot-resistant canola cultivars. All of these fields had been planted to canola for at least three of the past five years, and (or) were in close proximity to fields where clubroot resistance had been eroded or defeated in 2013 or 2014. Many of the *P. brassicae* strains recovered from resistant cultivars in 2013 and 2014 have been confirmed to be highly virulent on these cultivars, suggesting shifts in the virulence of pathogen populations a result of the selection pressure imposed by the planting of resistant hosts in short rotations. Further evaluation of the virulence of the 2015 pathogen collections is underway in order to better understand changes in the pathotype composition of *P. brassicae* populations.

2016 Survey

Symptoms of clubroot were found in 68 of 570 canola crops inspected. Disease severity ranged from mild to severe, with an average ID <10% in 45 crops, 10-60% in 20 crops, and >60% in three crops. The three cases of severe clubroot were found in susceptible hybrids. In addition to the new records of clubroot identified in the province-wide survey, another 221 new cases of the disease were found during surveillance by county and municipal personnel in the counties of Athabasca, Camrose, Lacombe, Lamont, Leduc, Minburn, Parkland, Smoky Lake, Stettler, Strathcona, Sturgeon, Westlock, Wetaskiwin and Woodlands. Since Athabasca, Lacombe, Lamont, Minburn, Parkland, Stettler and Wetaskiwin were not visited as part of the pan-Alberta survey, the only data on clubroot occurrence in those counties came from the municipal personnel. Further monitoring of canola crops in the Peace River Region of Alberta by Ministry of Agriculture and Forestry staff revealed no instances of clubroot there, and the region still appears to be free of the disease. In total, 289 new clubroot infestations were recorded in Alberta in 2016, for a grand total of 2443 fields with confirmed infestations since surveys began in 2003.

While most of the 289 new records of clubroot were found on susceptible canola hybrids or hybrids of unknown resistance, symptoms of the disease also were identified in 42 fields that had been planted to clubroot-resistant hybrids. Galled canola root tissue was collected from each of these fields in order to recover the corresponding pathogen populations and evaluate their virulence under controlled environmental conditions. Novel virulence phenotypes of *P. brassicae*, capable of overcoming the resistance in most clubroot resistant hybrids, have been recently identified in Alberta. As such, it is important to monitor for further shifts in pathogen virulence that could decrease the effectiveness of genetic resistance as a clubroot management tool.

2017 Survey

Clubroot was identified in 72 of the 554 canola crops surveyed in 2017, including the first records of the disease in Big Lakes County, Brazeau County, Lac La Biche County, the County of Paintearth and the Municipal District (M.D.) of Wainwright. The identification of clubroot in Big Lakes County is particularly significant because it represents the first confirmed occurrence of the disease in the Peace Country of northwestern Alberta. The survey results also indicate the continued spread of clubroot into eastern Alberta, with confirmed infestations now recorded along the border with Saskatchewan all the way from Lac La Biche County to the M.D. of

Wainwright (Fig. 1). While the movement of clubroot into southern Alberta has been slower, there is some evidence of its dispersal in this region as well, with the identification of the first cases of clubroot in the County of Paintearth this year and in Mountain View County in 2015 (5). In addition, three new records of the disease were found in the County of Newell, nearly doubling the number of confirmed cases there. In general, clubroot severity ranged from mild to severe, with an average ID <10% in 44 crops, 10-60% in 23 crops, and >60% in 5 crops. All severely infested crops were confirmed to be susceptible canola hybrids. Nonetheless, significant symptoms of the disease were identified in at least 40 fields planted to clubroot resistant canola cultivars, and *P. brassicae* populations recovered from these fields were tested for their ability to overcome host resistance. The emergence of new strains of the pathogen, capable of overcoming clubroot resistance, was first detected in 2013 (6).

In addition to the 72 new cases of clubroot found in the Alberta-wide survey, a further 229 new records of the disease were confirmed in field inspections carried out by municipal and county personnel in Barrhead, Beaver, Bonnyville, Camrose, Clearwater, Flagstaff, Lac Ste. Anne, Lacombe, Lamont, Leduc, Lesser Slave River, Minburn, Newell, Parkland, Red Deer, St. Paul, Strathcona, Two Hills, Vermillion River, Wainwright and Woodlands. Collectively, surveillance activities confirmed 301 new clubroot infestations in Alberta in 2017, for a grand total of 2744 recorded cases of the disease distributed across 36 counties/municipal districts plus two cities and one town.

b) Fumigation studies

2013 - Effect of Vapam application rate:

Vapam application rates had a significant effect on canola stand establishment, plant height, pod number, seed yield and disease severity at both field sites. The stand establishment was greater compared with the non-treated control at all Vapam application rates at both sites. At both sites, the stand establishment increased with increased Vapam application rate up to 80 mL m^{-2} and then stabilized. The stand establishment at the Henwood site was relatively poor compared with the 50th Street site. The plant height was significantly greater for all rates of Vapam treatments compared with the non-treated control at 50th Street, while at Henwood the plant height was significantly greater with 40 mL m^{-2} Vapam compared with the control. At 50th Street, plant height increased with the increased Vapam rates, while at Henwood plant height increased at 40 mL m^{-2} and then declined.

2014-15 Post-fumigation treatment effects -

The number of pods per plant was greater with the application of Vapam compared with the control at both sites. At 50th Street, the increment in pod number for each increased Vapam rate was significant. A similar result was obtained at Henwood, except that the pod number was not different at the 80 and 160 mL m^{-2} Vapam rates. At both sites, the pod number per plant was increased with the increased Vapam rates. The seed yield was significantly greater with Vapam treatments compared with the non-treated control, and the seed yield was increased with the increased rates of Vapam, but the yield increments at increased Vapam rates were not significantly different. Clubroot severity and gall weight were reduced with each increase in Vapam application rates at 50th Street. At Henwood, disease severity and gall weight were reduced compared with the non-treated control, and both disease parameters were lowest at the highest rate of Vapam application. Clubroot severity and gall weight at 40 and 80 mL m^{-2} Vapam were not significantly different. Both disease severity and gall weight decreased as the Vapam rates increased. Among the dose response curves, there was a strong negative and linear relationship between DSI and Vapam application rate at both sites, and between gall weight and Vapam application rate at one of the sites. The remaining curves were explained by second-degree polynomial equations.

The number of plants per plot and plant height was lower in the untreated control compared to any of the Vapam treatments. Plant vigour was similar among the treatments. Pooled results from 2014 and 2015 showed that emergence was unaffected by any of the plastic covering or water treatments. All of the Vapam treatments resulted in greater shoot weight compared with untreated plots. The disease index was lower for all Vapam-treated plots compared with untreated plots, with no differences among the treatments.

2015-16 Effect of plastic covering on Vapam efficacy -
Vapam fumigation reduced disease severity compared with untreated plots. None of the treatments affected emergence. Plant vigour was greater in Vapam-treated plots that had been covered for 7-12 days compared with untreated plots that had been covered for 12 days. Plant biomass was greater in Vapam-treated plots that had been covered 7-12 days compared with all untreated plots, and greater in Vapam-treated plots that had been covered for 16 days compared with untreated plots that had been covered for 7 days. Gall weight was lower where Vapam-treated plots were covered for 7 days compared with all non-treated plots, and lower in Vapam-treated plots that had been covered for 12-16 days compared with untreated plots that had been covered for 16 days. Yield was greater for Vapam-treated plots that had been covered for 12 days compared with all other treatments.

Vapam is a very effective soil fumigant for the management of various nematodes, soil-borne diseases, insects and weeds (Sinha et al. 1979; Triky-Daton et al. 2010). However, it should be noted that Vapam is a non-selective toxin. It is both volatile and highly soluble in water and as such constitutes a hazard to human health, as well as to non-target organisms in the area surrounding its application. Applicators must follow all regulations regarding its use and adhere to the label recommendations (AMVAC 2005).

c) Biofumigant assessment
The greatest number of surviving plants was observed at the highest treatment rate of MustGro. Seedling mortality appeared to be the result of root rot. Clubroot symptoms were visible on the roots of plants harvested from all of the treatments. None of the treatments showed significantly lower Index of Disease compared with the control. However, plant height was significantly greater compared with the control at the highest rate of MustGrow (74.1 cm v. 49.5 cm). The above-ground biomass exceeded that of the control for the two lower rates of MustGrow, but not for the highest rate. The root weight for the untreated plants was lower compared with the two higher rates of MustGrow, but the gall weight was similar for both treated and control plants. No seed yield was obtained from control plots, and yield was not significantly different among the treated plants.

d) Impact of resistant cultivars on spore populations
2013 Field - There were no differences in seedling emergence among the canola cultivars, although seedling establishment was numerically higher at the 50th Street site compared with the Henwood site. The club mass of the susceptible canola cultivar was 24–250 fold greater compared with the resistant cultivars at the 50th Street site and 13–90 fold greater at the Henwood site, while clubroot severity was 16–98 and 9-75 fold greater at both sites, respectively. However, there were no differences among the clubroot-resistant cultivars in terms of club mass or clubroot severity.

2014 Field -Disease severity and disease index were higher for the susceptible varieties compared to the resistant ones, but there there were no significant difference among either the susceptible varieties or the the resistant varieties.

2014 -17 Field Study - Effects of resistant cultivar rotation on clubroot severity in the final year

Under net house conditions, the rotation of resistant canola in any sequence did not affect the seedling emergence on the susceptible canola grown after completion of the rotation sequence. The plant height was greater following the BCBCS sequence and lower following the SSSSS sequence compared with all other treatments. Plant height for the fallow and non-host treatment was lower compared with the BCBCS and CDCDS sequences and greater only compared with the continuous susceptible treatment. The plant biomass was also greater following the BCBCS sequence compared with all others except the ABABS sequence. Only these two sequences had greater biomass compared with the SSSSS sequence.

As expected, the gall weight and disease index were greater in the SSSSS sequence compared with all other treatments. Interestingly, there was no gall formation following the four year fallow or non-host crop barley rotations, but this was not significantly different from any of the other treatments except the ABABS and ABCDS sequences. The disease severity for the fallow and non-host crop barley rotations was lower compared with all other sequences except BCBCS and BDACS.

The seed yield was the greater with the BCBCS sequence and, as expected, lower with the with SSSSS sequence compared with all other treatments. Among the resistant cultivar rotation sequences, ABCDS had lower seed yield compared with the ABABS, ADADS, BCBCS, BDACS and CADBS sequences.

Under field conditions, the rotation of resistant canola in the CDCDS sequence had greater seedling emergence compared to BCBCS sequence, but the seedling emergence following these two sequences were not significantly different compared with any of the other sequences.

The plant height was similar to that of the continuous susceptible canola for all treatments except continuous fallow and continuous non-host crop as well as the BDACS and CADBS sequences. Among these four treatments plant height was greater with continuous fallow and continuous non-host crop compared with the BDACS, and CADBS sequences. Root biomass was similar to the continuous susceptible sequence for all treatments except for the fallow sequence. The fallow sequence had greater root biomass compared with all other treatments except the non-host sequence, AAAAS and BDACS. Shoot biomass was similar to the continuous susceptible sequence for all other treatments. The continuous fallow treatment had greater shoot biomass compared with ABCDS, BCBCS and CDCDS. Gall weight was similar to the continuous susceptible sequence for all treatments. Gall weight for the fallow treatment was higher compared with the BCBCS sequence. Disease severity was lower for all the treatments compared with the continuous susceptible sequence. Among these treatments disease severity was lower when susceptible canola was grown after ADAD, BDBD, continuous fallow and continuous non-host crop sequences. The effect of rotation sequences on yield was not significant.

e) *Effects of crop sequences on clubroot severity*:

In the case of naturally infested soil, clubroot severity on *B. napus* following *B. rapa*–fallow or *B. rapa*–ryegrass in any sequence was lower than following ryegrass–fallow or fallow–fallow sequences. The index of disease was the highest when *B. napus* was grown after a fallow–fallow sequence. In the potting mix, the index of disease on *B. napus* was lower when grown after *B. rapa* or ryegrass than after continuous fallow, and lower following sequences that included *B. rapa* than those that included ryegrass only. Similarly, ID was lower in treatments where *B. rapa* was followed by either fallow or ryegrass than where ryegrass was followed by fallow or *B. rapa*. The continuous fallow sequence resulted in the greatest number of resting spores in the potting mix. The spore concentration was reduced by 50% in the *B. rapa*–ryegrass sequence

compared with the continuous fallow. The concentrations in the other crop sequences were intermediate between these two sequences.
The potting mix from each rotation sequence was positive for the presence of P. *brassicae* DNA when tested by conventional PCR analysis. Analysis by qPCR resulted in the detection of greater amounts of *P. brassicae* genomic DNA following the continuous fallow sequence compared with the ryegrass–*B. rapa* or *B. rapa*–fallow sequences. There were no differences in the amount of genomic DNA following continuous fallow, *B. rapa*–ryegrass or ryegrass–fallow sequences. However, positive correlations were observed between the amount of *P. brassicae* DNA and Index of Disease on the subsequent canola crop, between DNA and spore count, and between spore count and Index of Disease.

f) Interval between canola crops

Field study- In the final year of the study, where all plots were seeded with susceptible canola cv. 45H31, there was no difference in emergence among the treatments. However, plant height was significantly lower where canola had been grown continuously over the previous four years, compared with all other treatments. Plant height was also significantly lower where canola had been grown in alternating years compared with plots where canola had been grown after a two- or three-year interval with non-host crops. Similarly, plant biomass was lower where canola was grown in alternating years, or continuously, compared with plots where canola had been grown after a two- or three-year interval with non-host crops.
Gall weight was higher where canola had been grown continuously or in alternating years compared with plots where canola had been grown after a two- or three-year interval with non-host crops, while disease severity was highest where canola had been grown continuously compared with all other treatments, and was higher where canola had been grown in alternating years compared with plots where canola had been grown after a two- or three-year interval with non-host crops.
Yield was significantly higher where canola had been grown after a three-year break, compared with a two year break. Yield for canola grown after a two-year break was greater compared to plots where canola had been grown in alternate years or continuously.

Net-house study - In the assessment of the effect of the interval between canola crops under net-house conditions, there were no differences in seedling emergence among the treaments. The plant height, plant biomass and yield were greater with two- and three-year break treatments compared with continuous canola and a one-year break between canola crops. Gall mass, disease severity and quantities of *P. brassicae* DNA were greater with the continuous canola and one-year break compared with the two-year and three-year breaks.

6. Benefits to the industry (max 1 page; respond to sections *a)* and *b)* separately)

a) Describe the impact of the project results on Alberta's agriculture and food industry (results achieved and potential short-term, medium-term and long-term outcomes).

Clubroot continues to spread from the original outbreak near Edmonton. Clubroot occurrence expanded from 1064 fields in 24 counties at the beginning of the project to 2744 fields in 36 counties by 2017.

The canola industry contributes an average of $15.4 billion per year to the Canadian economy, including $8.9 billion in farm cash receipts alone (Rempel et al. 2014, Can. J. Plant Pathol. 36 (S1):19-26). Clubroot represents a very significant threat to this industry, as a consequence of potential yield and quality losses (Pageau et al. 2006) and the costs associated with disease management, including forced rotations out of canola and efforts to exclude the pathogen from non-infested fields and regions. Hard numbers are lacking with respect to the total dollar value for losses associated with clubroot in Alberta, but working on the (conservative) assumption that approximately one-quarter of the traditional canola growing area in this province is at risk for the disease, and using a moderate estimate of 25% yield losses, then 25% of one-quarter of the provincial canola cash receipts could be lost, totaling about $44 million per year (M. Hartman, Alberta Agriculture and Forestry, personal communication).

The research project has monitored the spread of clubroot throughout and has provided tools to slow down the spread of clubroot on the Canadian prairies. The information from the disease surveys will be valuable for future epidemiological work.

Soil fumigation methods have given producers the option to eliminate new clubroot infection foci before they become firmly established, thereby slowing the spread of the disease and minimizing its impact. Application of Vapam reduced clubroot severity and increased stand establishment, plant growth and yield. The application was most effective when the treated area was covered by plastic for a week immediately after application, then ventilated for at least 10 days before seeding. Insufficient ventilation led to losses in viability for the canola seed.

The studies on the impact of cultivar resistant cultivars provide important information on clubroot resistance stewardship. Resistant cultivars may serve as a 'bait crop', contributing to resting spore germination without subsequent clubroot development, thereby depleting soil inoculum loads. However, repeated cultivation of resistant cultivars should be avoided, to prevent selection for clubroot strains with the capability of overcoming resistance traits incorporated into canola.

b) Quantify the potential economic impact of the project results (*e.g.,* cost-benefit analysis, potential size of market, improvement in efficiency, etc.).

Prevention of even a 1% decline in yields for canola producers would outweigh the cost of this project by a ratio of more than 150 to 1. This figure does not include losses in quality (such as seed oil content), losses that could occur if clubroot becomes widespread in Saskatchewan and Manitoba, losses to the value of the land on which the infestation occurs, or losses due to forced rotation out of canola. As such, research to understand and manage the disease, through genetic and pathology approaches, is an important investment in mitigating the impact of clubroot.

In addition, the project enabled an increase in provincial research capacity and expertise, including the training of numerous highly qualified personnel.

7. Contribution to training of highly qualified personnel (max ½ page)

Specify the number of highly qualified personnel (*e.g.*, students, post-doctoral fellows, technicians, research associates, etc.) who were involved in the project.

In addition to the deliverables achieved and information obtained, this project played a very important role in the training of 16 highly qualified personnel at the University of Alberta, and Alberta Agriculture and Forestry. These included 2 research associates, 2 post-doctoral fellows, 4 technicians, 4 graduate students, and 4 summer students. Personnel received training in the areas of genetics, host-pathogen interactions, plant pathology, agricultural biotechnology, and communication with producers, industry and extension personnel, and scientific colleagues.

8. Knowledge transfer/technology transfer/commercialisation (max 1 page)

Describe how the project results were communicated to the scientific community, to industry stakeholders, and to the general public. Organise according to the following categories as applicable:

Scientific publications (*e.g.*, scientific journals); attach copies of any publications as an appendix to this final report.

- Hwang, S.F., H.U. Ahmed, Q. Zhou, A. Rashid, S.E. Strelkov, B.D. Gossen, G. Peng and G.D. Turnbull. 2013. Effect of susceptible and resistant canola plants on *Plasmodiophora brassicae* resting spore populations in the soil. Plant Pathology. 62 (2), p. 404-412. http://Doi: 10.1111/j.1365-3059.2012.02636.x
- Hwang, S.F., H.U. Ahmed, Q. Zhou, S.E. Strelkov, B.D. Gossen, G. Peng and G.D. Turnbull. 2014. Efficacy of Vapam fumigant against clubroot (*Plasmodiophora brassicae*) of canola. Plant Pathology 63: 1374-1383. http://Doi: 10.1111/ppa.12207
- Hwang, S. F., R.J. Howard, S. E. Strelkov and B.D. Gossen. 2014. Management of clubroot (*Plasmodiophora brassicae*) on canola (*Brassica napus*) in western Canada. Can. J. Plant Pathology 36: 49- 65. http://dx.doi.org./10.1080/07060661.2013.863806
- Hwang, S.F., H.U. Ahmed, Q. Zhou, S.E. Strelkov, B.D. Gossen, G. Peng and G.D. Turnbull. 2014. Efficacy of Vapam fumigant against clubroot (*Plasmodiophora brassicae*) of canola. Plant Pathology 63: 1374-1383. http://Doi: 10.1111/ppa.12207
- Hwang, S.F., H.U. Ahmed, Q. Zhou, G.D. Turnbull, S.E. Strelkov and B.D. Gossen. 2015. Effect of host and non-host crops on *Plasmodiophora brassicae* resting spore concentrations in soil and potting mixtures. Plant Pathology 64: 1198-1206. http://Doi: 10.1111/ppa.12347
- Hwang, S.F., H.U. Ahmed, S.E. Strelkov, Q. Zhou, G.D. Turnbull, and B.D. Gossen. 2016. Effects of land preparation on the efficacy of Vapam to control clubroot (*Plasmodiophora brassicae*) and seedling blight of canola. Plant Pathology (prepared)
- Hwang, S.F., S.E. Strelkov, H.U. Ahmed, V.P. Manolii, Q. Zhou, H. Fu, D. Feindel, and G.D. Turnbull. 2017. Virulence and inoculum density-dependent interactions of CR canola with *Plasmodiophora brassicae* Woronin in Alberta. Plant Pathology 66: 1318-1328. Doi: 10.1111/ppa.12688.
- Hwang, S.F., H.U. Ahmed, S.E. Strelkov, Q. Zhou, B.D. Gossen, G. Peng, G.D. Turnbull. 2017. Effects of rate and application method on the efficacy of metam sodium to reduce clubroot (*Plasmodiophora brassicae*) of canola. European Journal of Plant Pathology doi.org/10.1007/s10658-017-1281-y
- Hwang, S.F., H.U. Ahmed, S.E. Strelkov, Q. Zhou, G.D. Turnbull, and B.D. Gossen. 2017. Effects of Basamid on suppression of clubroot and growth of canola in clubroot-infested soils. Can. J. Plant Sci. (in press)
- Hwang, S.F., H.U. Ahmed, Q. Zhou, H. Fu, G.D. Turnbull and S.E. Strelkov. 2018. Rotation of resistant canola, interval between canola crops, and $CaCN_2$ influence *Plasmodiophora brassicae* resting spore populations and clubroot of canola. (prepared)

Industry-oriented publications (*e.g.*, agribusiness trade press, popular press, etc.) attach copies of any publications as an appendix to this final report

Dr. Hwang and the members of the research team were regular contributors of information and data to industry websites, such as the Canola Council of Canada's *clubroot.ca*; information also was disseminated in industry newspapers and magazines, including *The Western Producer*, *Top Crop Manager* and the *Canola Digest*; research updates were provided to the Pathology Sub-Committee of the Western Canadian Canola/Rapeseed Recommending Committee.

Scientific presentations (*e.g.*, posters, talks, seminars, workshops, etc.)

There were a total of 61 scientific presentations over the course of the project. These included: 3 conference proceedings, 54 abstracts, and 4 disease survey reports.

Industry-oriented presentations (*e.g.*, posters, talks, seminars, workshops, etc.)

A total of 36 oral industry-oriented presentations were made. The venues for these presentations included grower meetings, canola industry meetings, and broader agricultural industry meetings such as FarmTech. In addition, slides and other relevant information were widely distributed to other scientists, Canola Council agronomists, as well as provincial government and industry research personnel.

Media activities (*e.g.*, radio, television, internet, etc.)

Four articles appeared in *Top Crop Manager*. Information was posted on the *clubroot.ca* website hosted by the Canola Council of Canada, which is billed as "your comprehensive source for clubroot information." In addition, research team members were occasionally interviewed for radio programs such as "Call of the Land", where they provided updates on findings and recommendations.

Any commercialisation activities or patents

No commercialization activities were undertaken; rather, the choice was made to make all information publicly available as described above.

N.B.: Any publications and/or presentations should acknowledge the contribution of each of the funders of the project.

Section D: Project resources

1. **Statement of revenues and expenditures:**
   a) **In a separate document certified by the organisation's accountant or other senior executive officer, provide a detailed listing of all cash revenues to the project and expenditures of project cash funds.** Revenues should be identified by funder, if applicable. Expenditures should be classified into the following categories: personnel; travel; capital assets; supplies; communication, dissemination and linkage; and overhead (if applicable). A statement of award and expenditures will be prepared and forwarded by the Research Services Office of the University of Alberta.
   b) **Provide a justification of project expenditures and discuss any major variance (*i.e.*, ± 10%) from the budget approved by the funder(s).**

2. **Resources:**

Provide a list of all external cash and in-kind resources which were contributed to the project.

Total resources contributed to the project		
Source	**Amount**	**Percentage of total project cost**
Funders		%
Other government sources: Cash		%
Other government sources: In-kind		%
Industry: Cash		%
Industry: In-kind		%
Total Project Cost		**100%**

External resources (additional rows may be added if necessary)		
Government sources		
Name (only approved abbreviations please)	Amount cash	Amount in-kind
Industry sources		
Name (only approved abbreviations please)	Amount cash	Amount in-kind

Section E: The next steps (max 2 pages)

Describe what further work if any needs to be done.

a) Is new research required to deal with issues and opportunities that the project raised or discovered but were not dealt with within the current project?
b) Is there related work that needs to be undertaken to continue advancement of the project technology or practice?
c) Did the project identify any new technology or practice that needs to be developed?
d) What suggestions do you have that increase commercial use of results by farmers and/or companies. These may be:
   1. commercial uptake.
   2. further research toward commercial use.
   3. extension and information disbursement.

Section F: Research Team Signatures and Employers' Approval

The team leader and an authorised representative from his/her organisation of employment MUST sign this form.

Research team members and an authorised representative from their organisation(s) of employment MUST also sign this form.

By signing as representatives of the research team leader's employing organisation and/or the research team member's(s') employing organisation(s), the undersigned hereby acknowledge submission of the information contained in this final report to the funder(s).

Team Leader's Organisation

Team Leader	
Name: **Sheau-Fang Hwang**	**Title/Organisation:** **Research Scientist**
Signature:	**Date:** **Dec. 1, 2017**
Team Leader's Employer's Approval	
Name: **David Feindel**	**Title/Organisation:** **Director, Pest Surveillance Section**
Signature:	**Date:**

Research Team Members (add more lines as needed)

1. Team Member	
Name:	**Title/Organisation:**
Signature:	**Date:**
Team Member's Employer's Approval	
Name:	**Title/Organisation:**
Signature:	**Date:**

2. Team Member	
Name:	**Title/Organisation:**
Signature:	**Date:**
Team Member's Employer's Approval	
Name:	**Title/Organisation:**
Signature:	**Date:**