CLIMATE CHANGE
ADAPTATION PROGRAM

Evaluation of Thrips in Potatoes in a Changing Climate Report

Funding for this project has been provided by the Governments of Canada and British Columbia through Growing Forward 2, a federal-provincial-territorial initiative. The program is delivered by the Investment Agriculture Foundation of BC.

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E. S. Cropconsult Ltd.

Evaluation of Thrips in Potatoes in a Changing Climate

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Executive Summary

Within the Lower Mainland and throughout British Columbia (BC), potatoes are an essential income-generating crop for many growers. With expected climate change within BC, a proactive approach is needed to help deal with pests that are likely to become serious issues. Thrips are a key pest of concern as they thrive under hot dry summer weather and are more likely to survive milder winters (the predicted impact of climate change for BC). Local monitoring has shown higher levels of thrips and more severe foliar damage as summer temperatures have become hotter. While foliar damage has been severe, there is no known threshold for thrips on potatoes and local information is lacking. Thrips are also of concern because they are known to spread viruses such as the tomato spotted wilt virus (TSWV) (known to be present in BC).

In this study, the impact of thrips foliar damage on yield was examined through field trials with eight fields across two study seasons - 2015 and 2016. Thrips numbers and leaf tissue damage varied between fields and seasons. In 2015, increases in thrips damage resulted in a small increase in yield. However, in 2016, although thrips damage on leaves appeared to have an impact on some individual fields, there was no overall effect on yield. The prevalence of transmission of tomato spotted wilt virus (TSWV) was assessed through ELISA testing of leaf tissue from grower fields in 2015 and 2016. No TSWV was found. The third objective of this study was to determine if variety or other field factors impacted the number of thrips found at a field edge. Geographic location was found to have a significant effect, with more thrips likely to be found in Delta than in Abbotsford. Production type significantly impacted thrips numbers with organic fields having a higher likelihood of greater thrips numbers than conventional fields. Variety also had an impact of likelihood of thrips, but only when comparing Satina to AC Peregrine, Imola, Kennebec and Orchestra, where Satina was found to have higher thrips numbers. Geographic orientation (North, South, East or West) was not found to have a significant impact on thrips numbers. Finally, an important component of the project was to evaluate grower knowledge related to thrips and reducing knowledge gaps through surveys, information sheets, and field and grower meeting presentations. Growers were initially found to be concerned with thrips, particularly related to climate change, and knowledge gaps were found in growers' abilities to identify thrips and their damage, awareness of potential virus transmission, and strategies for managing thrips. Project updates were presented at different industry meetings to facilitate knowledge transfer.

Introduction

Potatoes are the biggest field grown vegetable crop in British Columbia, making up one-third of all field vegetable production (BCMAFF 2003) and one of BC's top five-export commodities in the agricultural industry (BCMA 2014). Among the challenges potato producers face, pest management is one of the top contributing factors that affects crop yield. High quality potato production is best achieved through a combination of monitoring techniques and biological, cultural, and chemical control measures – all key components of Integrated Pest Management (IPM).

Western flower thrips (*Frankliniella occidentalis*) have become a rising pest of concern for a wide variety of crops throughout the world. Crops that are affected by thrips include potatoes, onions, strawberries, cucumbers, peppers, eggplants, tomatoes, nectarines, cashews and floral crops (Demorizer 2012; Rhaman 2010; Reitz 2009; Rhainds 2007; Rueda 2007; Hao 2002; Shipp 2000; Pearsall 2000; Igboekwe 1985). Thrips can cause significant damage to crops, affecting both yield and quality. Injury caused by thrips is threefold; through direct feeding, egg laying in leaf tissue, and the transmission of viruses. Thrips have piercing, sucking mouthparts, which they use to penetrate individual plant cells and suck out cell contents. Thrips soften up plant tissues by injecting saliva into the feeding site, which allows for the pre-digestion of plant material (Stafford-Banks 2014). This unique feeding behavior may also play a role in virus transmission, specifically for tomato spotted wilt virus (TSWV) (Stafford-Banks 2014). TSWV is a serious disease which affects a wide host range including potatoes. TSWV symptoms vary greatly, with the most serious being its effect on plant growth and tuber quality. Due to their short lifecycle and capacity to reproduce quickly, thrips can increase exponentially within a field and potentially lead to significant crop damage, early senescence and yield loss.

Thrips reproduce rapidly in hot weather, and under favourable temperatures (25-30°C) their life cycle can be as short as nine days (Reitz 2009). Their populations are highest, and therefore most destructive, in hot, dry weather (Bellotti 2012; Rueda 2007). Locally, milder winter weather may also increase overwintering survival rates, resulting in higher early season population numbers (Bale 2010).

Data summarized from historical E.S. Cropconsult monitoring reports from the Fraser Valley indicate that thrips populations have been increasing in potato fields locally. Over the past 13 years, there has been an increase in the percentage of fields with control recommendations made for thrips (Fig. 1). Prior to 2003, thrips spray recommendations were rarely made with most years having no more than one field being affected. However, in recent years, thrips management recommendations have been implemented in approximately 5% to 35% of monitored fields. Thrips have gone from an occasional pest status to secondary pest status, meaning thrips are now reoccurring every year but not necessarily in every field. When comparing Environment Canada weather data and Farmwest growing degree days with E.S. Cropconsult thrips monitoring data, there appears to be a relationship between years with high thrips numbers and years with hotter conditions when the means of high thrips years (2005, 2009, 2010, 2012-2015) are compared to low thrips years (1998-2003, 2007, 2008, 2016) (Fig. 1).

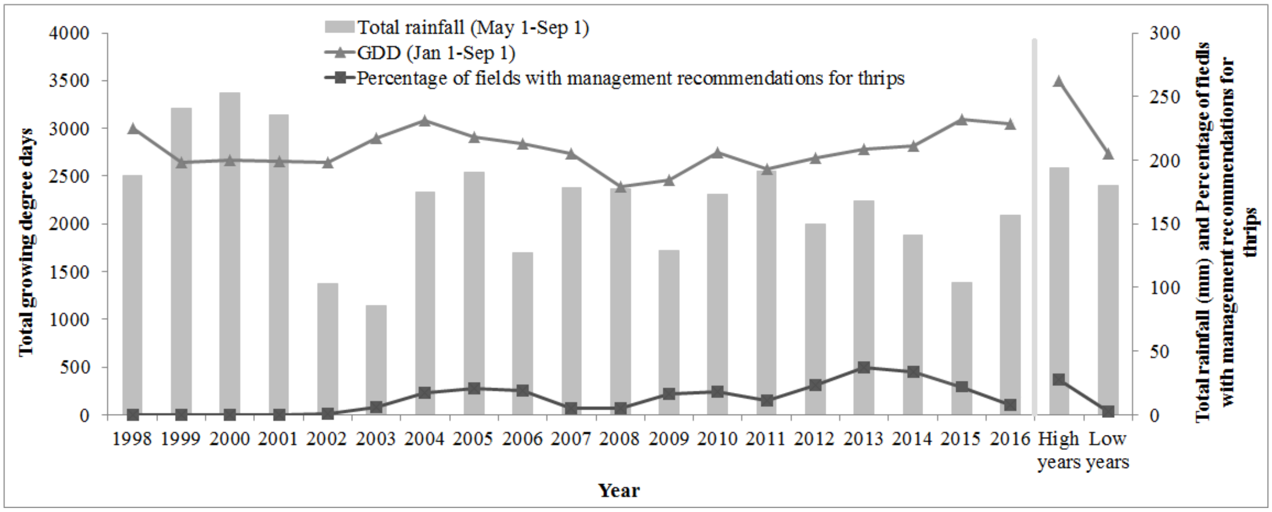

Figure 1. Percentage of fields monitored in the Fraser Valley from 1998 to 2016 that received spray recommendations for thrips, and the total rainfall (mm) (May 1- Sep 1) and growing degree days (Jan 1- Sep 1) per year. The mean percentage of fields with thrips management recommendations in high years (10% or greater of fields monitored) (2005, 2009, 2010, 2012-2015) compared with low years (less than 10% of fields monitored) (1998-2003, 2007, 2008, 2016), and corresponding mean rainfall and mean growing degree days are also shown. Sources: Government of Canada 2014; Farmwest 2017; E.S, Cropconsult Monitoring Reports – unpublished data. Weather data from Vancouver International Airport station with almost all dates having complete data.

Thrips thrive under hot, dry summer conditions. With the potential of the acceleration of climate change affecting the Fraser Valley through hotter, drier summers, a better understanding of potato yield and quality reduction associated with thrips is needed. Thrips are known to cause significant damage to various crops through feeding, egg laying and virus transfer; however, they have only recently become a serious concern for potatoes in the Fraser Valley. As a result, there is a limited understanding of how thrips affect potato yield and quality. This lack of knowledge has left growers and consultants hesitant to make decisions about appropriate timing for thrips pest management to minimize crop damage. There is also minimal knowledge available about risk factors which may affect the likelihood of thrips issues in potato fields, such as locally used varieties, surrounding crops and geographical orientation. Thrips are known to prefer foliage with minimal pubescence and therefore are likely have varietal preferences. While thrips appear to be highest in potato fields next to grain and grass fields as these fields dry out and/or are cut (E.S. Cropconsult, unpublished data), other risky neighbouring crops are not known. Also, thrips can be carried by wind, thus studying orientation of field edges in relation to local wind patterns may be useful in determining if this is an important factor affecting thrips infestation locally.

The BC Agriculture Climate Change Adaptation Risk and Opportunity Assessment: Fraser Valley and Metro Vancouver Snapshot Report, highlights our need for a proactive approach for monitoring, surveillance and management of pests, weeds and diseases (Crawford and MacNair 2012). IPM offers a tactical approach to thrips management based on monitoring, assessment of pest levels compared to thresholds and management of pests using a combination of tools. There has yet to be the development of thresholds for thrips in potatoes in North America. The development of a threshold allows for consultants and growers to take action only when necessary, targeting chemical application to appropriate times and locations within a field. The reduction of pesticide use not only provides environmental and cost benefits, but also reduces the risk of creating resistance in the pest population which is valuable to pest management in other crops in BC. The lack of IPM tools impedes the ability of growers, consultants, and industry specialists to manage thrips outbreaks.

If projections of our regional climate change are accurate, we will be facing hotter and drier summer conditions under which thrips prosper. This project aimed at addressing the uncertainty around whether thrips are causing significant crop yield loss or if they are transmitting TSWV in BC. In addition, this project aimed to find more definitive information on the varietal preferences of thrips so growers would be able to select varieties that are least susceptible to thrips as climate change occurs. This project laid the groundwork for threshold development for thrips in potatoes in BC, which would assist growers and consultants in determining when thrips should be managed. The knowledge gained through this work has been provided to growers and industry specialists, which will help improve farm practices. This work aims to expand new and existing relationships between growers, industry and research professionals through resource sharing and collaboration. The overarching goal of this work is to help minimize the impacts of climate change on pest management.

Objectives

The four central objectives of this project have been to:

1. Evaluate yield loss due to thrips damage to potato crops in relation to growing season conditions (two seasons of study).

2. Assess occurrence of thrips vectoring tomato spotted wilt virus (TSWV) to potatoes within the Fraser Valley (two seasons of study).

3. Evaluate potato varietal difference in thrips attraction (two seasons of study).

4. Increase grower knowledge of the effect of thrips on potato yield and quality, and which varieties can be used to adapt to thrips issues as the climate changes.

Methodology

Objective 1: Evaluate yield loss due to thrips damage to potato crops in relation to growing season conditions (two seasons of study).

Study sites

Field sites were selected based on grower interest in participation, field proximity to grain or grass fields, frequency of potato varietal use, varietal strength and varietal past incidence of thrips. The trial was conducted in four fields each year (2015 and 2016) managed by three different growers (four fields with grower one, three fields with grower two and one field with grower three) within Delta, BC. Goldust was the variety in all eight fields. This variety was selected because it is commonly grown and is described by multiple local growers as a weaker plant than some other commonly grown varieties (R. Swenson, Rod Swenson Farms, personal communication, 2014) and therefore damage to yield would be expected to be more visible. Fields and edges within ftields were selected based on proximity to grass or grain crops. Crop planting and maintenance were completed by the grower (Appendix A). Weather data is from the Vancouver International Airport weather station with almost all dates having complete data.

Trial design

The trial was completed between June 4 and September 11 in 2015 and between May 19 and September 8 in 2016 with flowering periods varying each year (Table 1 and 2). To assess the effect of thrips on yield, the trial aimed to vary thrips incidence across plots using insecticide treatments. In 2015, three treatments were used: 1) Full Season Insecticide (either Ripcord or Delegate), 2) Water and 3) Untreated Control. In addition to these treatments, a fourth treatment was added in 2016: 4) Early Season Insecticide only (either Ripcord or Delegate). Each trial area consisted of the first three potato rows along the selected edge of each field. Where possible, a buffer of 50′ on either end of the trial and 10 rows from the edge of the field inwards was flagged as an area that growers would not treat for thrips. For field A, B and C, ten replicates for each treatment were laid out in plots following a completely randomized design. In field D, five replicates for each treatment were completely randomized within two blocks (ten replicates total) to account for poor emergence along part of the field edge. All 2016 fields had a completely randomized block design, with E, F and G having five replicates for each treatment within two blocks (ten replicates total), and field H having five replicates for each treatment within one block and three replicates for each treatment within the second block due to a shortage of space. All plots were three rows wide by 10′ long with a 3′3″ buffer between plots.

Table 1. 2015 and 2016 trial period for each field.

Field	Year	Triplet assessment period	Card assessment period	Weeks (from initial sampling date per year)	Date of yield assessment
A	2015	June 4 - August 14	June 4 - August 14	1-10	August 26
B	2015	June 4- August 7	June 4- August 7	1-9	August 26
C	2015	June 26 -August 14	June 26 -August 14	3-10	August 26
D	2015	July 3 - August 27	July 3 – September 3	4-12 and week 13 for cards only	September 11
E	2016	May 19- July 26	May 26-July 21	1-10	July 26
F	2016	June 2- August 11	May 26- August 17	2-13	August 30
G	2016	June 16- September 7	June 23- September 1	5-16	September 7
H	2016	June 23- September 8	June 30- September 1	6-16	September 8

Table 2. The dates and corresponding week of flowering for each field.

Field	Year	Before flowering period dates	Before flowering period weeks of trial	During flowering period dates	During flowering period weeks of trial	After flowering period dates	After flowering period weeks of trial
A	2015	June 12- June 19	1-2	June 26- July 17	3-6	July 24- August 14	7-10
B	2015	June 12- June 19	1-2	June 26- July 17	3-6	July 24- August 7	7-9
C	2015	June 26	3	July 3- July 24	4-7	July 31- August 14	8-10
D	2015	July 3- July 10	4-5	July 17- July 31	6-8	August 7- September 3	9-13
E	2016	May 26- June 16	1-4	June 23- July 7	5-7	July 14- July 28	8-10
F	2016	June 2- June 23	2-5	June 30- July 7	6-7	July 14- August 18	8-13
G	2016	June 23- July 14	5-8	July 21- July 28	9-10	August 4- September 8	11-16
H	2016	June 30- July 7	6-7	July 14- July 28	8-10	August 4- September 8	11-16

Treatment of Plots

During the assessments described below, if a single thrips was found within a Full (2015 and 2016) or Early Season (2016 only) Insecticide plot, all plots in that field were treated with the appropriate treatment – insecticide spray, water spray or no spray (Table 3 and Appendix B). All sprays were applied using a backpack sprayer hand-pumped to maintain full pressure. In 2016, the Early Season Insecticide treatment only triggered insecticide sprays until after flowering, after which these plots were not sprayed at all. Field assessments and subsequent treatments began prior to 12:00 pm to allow for early morning spray of one registered product (Ripcord), which is most effective when temperatures do not exceed 25°C. The water ratio was adjusted during the early season to ensure good coverage as plants grew larger. Initially, 4 litres (L) per treatment per field were used which increased to 6 L per treatment per field in all fields but H. In field H, which had eight rather than ten replicates, 3.2 L initially increasing to 4.8 L were used per treatment. Weather conditions, including rain, heat and wind, as well as grower management decisions, such as whether a field was going to be top-killed, affected treatment regimes on three occasions across both years of the study.

Table 3. Treatment products and rates.

Treatment	**Product/active ingredient**	**Rate**	**Treatment area per field**	**Amount of product per treatment**
Insecticide	Ripcord/ Cypermethrin	62.5-125 mL/ha product, 300-500 L/ha water	0.00083613 ha	1 mL
	Delegate/Spinetoram	240 g/ha, sufficient water to ensure thorough coverage (listed for most crops) or 300-500 L/ha as listed for specified crops	0.00083613 ha	2 g
Water	Water	n/a	0.00083613 ha	n/a
Untreated control	None	n/a	0.00083613 ha	n/a

<u>Weekly Assessments</u>

Field information

Observation of plant moisture, wind, temperature, potato crop stage, and neighbouring crop stage were recorded per week.

Triplet Assessments

Triplets (terminal three leaves of a compound leaf) that had three distinct leaves were collected on a weekly basis to assess thrips number and foliar damage. One triplet was collected from within the top six inches of the plant ("upper"), and one triplet from within the bottom six inches of the plant ("lower"), for a total of two triplets per plot. This was done for both the first and third row for a total of four triplets per plot. The only exceptions were due to small plants, a lack of available plants because of poor emergence, or senescent plants, at which point triplets were collected where possible. Upper and lower triplets were assessed for thrips numbers and foliar damage, as described below.

Thrips Numbers on Triplets

Thrips numbers were assessed per plot on a weekly basis prior to treatment application. Thrips were categorized as either dark or light in colour. Numbers of thrips observed were recorded per triplet. For plots that received insecticide treatment, and therefore had very low numbers of thrips, extra triplets were collected if thrips were present on the yellow sticky cards for that plot. These extra triplets were assessed for thrips presence only (and not for foliar damage), to determine if a spray was necessary in that field. Therefore, once a thrips was found in one Full or Early Season Insecticide plot, no further extras were collected for the rest of that field. After flowering, no extra triplets were taken from Early Season Insecticide plots.

Thrips Foliar Damage

Thrips damage was assessed per plot on a weekly basis prior to treatment application. Foliar damage on the top and bottom of each leaf was recorded per triplet using a scale based on the percentage of tissue with damage caused by thrips as this allowed for an easy visualization of damage incurred (Table 4). In 2015, damage assessments on the tops of leaves were not conducted until week four due to a lack of noticeable presence of thrips damage.

Table 4. Leaf tissue damage rating scale.

Fraction of damage	0	$0 < \frac{1}{6}$	$\frac{1}{6} < \frac{1}{3}$	$\frac{1}{3} < \frac{1}{2}$	$\frac{1}{2} < \frac{2}{3}$	$\frac{1}{2} < \frac{2}{3}$	$\frac{2}{3} < \frac{5}{6}$
Percentage of damage	0	0-17%	18-33%	34-50%	51-67%	68-83%	84-100%
Rating	0	1	2	3	4	5	6

Other Pests and Predators

Insects other than thrips, including predators, and foliar damage caused by non-thrips were recorded per plot per week. Diseases that were consistently present were also recorded per plot. In 2016, due to damage caused by *Lepidoptera spp.* in Untreated Control and Water plots in fields F and G, plants in Full and Early Season Insecticide plots were artificially damaged using a stapler and pinching to equally distribute damage in all plots. Non-target pest and predator data were not analyzed as they were not found to accumulate in great numbers or cause great damage to Early or Full Season Insecticide treated plots, where they may have balanced out any impacts of thrips on Untreated Control and Water plots.

Thrips Numbers on Cards

A third method of assessing thrips presence was using yellow sticky cards (Alpha Sents Inc, Oregon, USA). These were held between the top of the canopy to approximately 50 cm above the canopy with a metal wire, which was placed in the centre of each plot (Fig. 2). The 4x6″ grid-marked cards were cut in half and non-sticky sections removed to make two 4x2.5″double-sided sticky cards. A very small label was used to minimize non-sticky card space. Each week, the yellow sticky cards in each plot were collected and replaced with new cards. Large insects were removed and the cards were wrapped in saran wrap for later assessment using a microscope. As with triplets, thrips on cards were counted and categorized as either dark or light in colour. Thrips numbers on the front and back sides of cards were recorded separately but combined for analysis.

For a simple identification of thrips species, four cards from the 2015 season were scanned for thrips species using a microscope at 80-100x.


Figure 2. Card placement for thrips weekly assessment.

Artificial infestation of thrips
In 2015, due to lack of thrips pressure in fields A, C and D, these fields were artificially infested. Field B also had a lack of thrips pressure but no release was made as the field was scheduled for top-killing within a week of release. Thrips for artificial infestations were collected from the barley field next to field D, due to its proximity to two study fields and an abundance of thrips. While walking, a sweep net was swept back and forth 30 times across the top 50 cm of the barley. Visible thrips predators such as ladybird beetles, lacewings and orius bugs were removed and thrips were contained within the nets for transportation to the study fields. The contents of one net were evenly shaken over the three rows of each Water and Untreated control plot. Insecticide plots were not artificially infested. An estimated minimum of 100 thrips (adults and/or nymphs) were released per plot on July 23 in field A, C and D, and again on July 31 in field A (due to persistent lack of pressure).

In 2016, a lack of thrips pressure after flowering in the Early Season Insecticide plots in fields F and H resulted in artificial infestation. A sweep net was used to collect thrips in a barley field near fields E and F, using the same protocol as in 2015. The contents of one net were evenly shaken over the three rows of each Early Insecticide plot in fields F and H. An error also resulted in thrips being released in the Untreated control plots in field F on July 28. An estimated minimum of 100 thrips (adults and/or nymphs) were released per plot on July 28 in field F and H, and in field G on August 12.

Yield Assessment

Yield assessments were conducted approximately two weeks after the field was mowed or top-killed and one week before the grower was planning to harvest the field. A representative 8′ length of the middle row of each plot was harvested, avoiding digging up partial plants at plot edges. The number of plants harvested was recorded per plot. All tubers were dug up using a pitchfork and potatoes were sorted for size by hand. Yield was assessed by weighing (lbs) and counting the number of tubers from three tuber size categories (Western Potato Council Guideline), small (2" diameter and smaller), medium (2" to 3.5") and large (over 3.5").

Objective 2: Assess occurrence of thrips vectoring tomato spotted wilt virus (TSWV) to potatoes within the Fraser Valley (two seasons of study).

Thrips and leaves with thrips damage and TSWV symptoms were collected from 16 fields each year within the Fraser Valley (Table 5). Sampling took place between August 7 and August 13 in 2015 and between August 1 and August 12 in 2016. Fields were chosen based on thrips numbers and feeding damage found in fields, with an aim to maximize the number of growers included, and to cover the largest geographical area possible. Leaves were collected individually per plant from at least 55 plants along field edges. The terminal leaf of a compound leaf was selected from mid-height of the plant. Plants with thrips damage and appearance of TSWV like symptoms were selected when available. In 2015, leaves were placed in individual plastic bags and frozen the day of collection, whereas in 2016 they were placed in paper bags and kept in a fridge until processing. Thrips were also collected from these fields and placed in vials, with an aim to have 50 thrips for virus testing and 25 for identification per field, however not all fields had high enough numbers of thrips for collection. Thrips for virus testing were frozen at -18°C and those for identification were kept in 70% ethanol. Through consultation with Dr. Hanu Pappu (Washington State University), it was decided to test leaf tissue for virus first and only test the thrips directly for virus if TSWV was found within the leaves.

Between 41 and 45 leaves were tested in each field for TSWV with enzyme linked immunosorbent assay (ELISA) using a TSWV-specific kit from Agdia (Elkhart, Indiana, USA) following the manufacturer's directions. Following ELISA, plates were read at 405 and 450 nm on an absorbance microplate reader (model ELx800, BIO-TEK, Winooski, Vermont, USA). Plants were considered positive if their mean absorbance at 405 nm was greater than the mean absorbance plus three times the mean of the negative control samples and they showed a yellowing of cell colour (Vippen Joshi, BC Ministry of Agriculture, personal communication, 2015). Samples with positive values that did not appear yellow in colour were retested as a precaution. Since no positive leaf samples were found, no thrips were tested for virus.

Table 5. Summary of leaf tissues analyzed for detection of TSWV.

Year	Field	Location	Number of leaves assessed
2015	A	Delta (west)	43
2015	B	Delta (west)	45
2015	C	Delta (west)	45
2015	D	Delta (west)	45
2015	E	Delta (central)	45
2015	F	Delta (central)	45
2015	G	Delta (west)	45
2015	H	Delta (east)	45
2015	I	Abbotsford	45
2015	J	Delta (north)	45
2015	K	Delta (west)	45
2015	L	Delta (north)	44
2015	M	Delta (south)	45
2015	N	Abbotsford	45
2015	O	Richmond	45
2015	P	Surrey	45
2016	A	Abbotsford	45
2016	B	Abbotsford	45
2016	C	Delta (west)	45
2016	D	Richmond	45
2016	E	Delta (west)	45
2016	F	Delta (west)	45
2016	G	Delta (west)	45
2016	H	Delta (central)	45
2016	I	Delta (east)	45
2016	J	Delta (west)	45
2016	K	Delta (south)	45
2016	L	Delta (south)	45
2016	M	Delta (west)	45
2016	N	Abbotsford	45
2016	O	Delta (west)	41
2016	P	Delta (west)	41

Objective 3: Evaluate potato varietal difference in thrips attraction (two seasons of study).

A field survey was conducted using E.S. Cropconsult Ltd. client potato fields (conventional, organic and seed) from throughout the Fraser Valley. Information on potential thrips-related risk factors was recorded for 203 potato fields in 2015 and 209 fields in 2016 that had crop monitoring services. Through literature review and consultation with researchers and entomologists, risk factors for thrips presence were established. For both seasons, and using E.S.

Cropconsult's potato pest monitoring protocol, the following information was collected per pass per field:

- total number of thrips on triplets
- total number of samples
- sampling type
- sampling week
- geographic orientation
- surrounding crops/land use (gathered during July and August in both years)
- potato varieties
- grower
- production type
- geographic location

In 2016 the following categories were added:

- date of assessment
- chemical use

Objective 4: Increase grower knowledge of the effect of thrips on potato yield and quality, and which varieties can be used to adapt to thrips issues as the climate changes.

A survey of grower knowledge and concern related to thrips was conducted in the fall of 2015 (Appendix C). Recruitment for participants was performed through use of the BC Potato and Vegetable Growers Association and the BC Seed Potato Growers Association listservs. A total of 34 growers were contacted directly through emails and phone calls. Data received from these surveys were examined for trends in grower knowledge, knowledge gaps and concerns related to thrips.

A thrips info sheet was sent to growers through listservs and available at the BC Potato and Vegetable Growers Association AGM in the spring of 2016 (Appendix D). A field demonstration of thrips and thrips damage was conducted at the BC Potato Industry Variety Trial Field Day on August 24, 2016. A brief project overview was given at the Western Forum on Pest Management (example in Appendix D) on October 22, 2015 and October 19, 2016, at the Potato Minor Use meeting on November 25, 2015 and November 21, 2016 and the Potato Industry Development meeting on December 10, 2015 and December 9, 2016. Presentations outlining project outcomes were given at the Lower Mainland Horticulture Improvement Association Grower's Short Course on January 28, 2016 and January 26, 2017. Conference proceedings, reporting the 2016 and 2017 Short Course presentations were made available to growers online.

A final grower survey was completed in the spring of 2017 to evaluate ongoing grower knowledge gaps and assess the impact of the outreach activities of the project. Recruitment for participants was performed by contacting growers who had completed the original survey in the fall of 2015. Due to some farm changes and lack of contact numbers, a total of 26 growers were contacted directly through emails and phone calls. Data received from these surveys were examined for trends in grower knowledge, knowledge gaps and concerns related to thrips.

Statistical Analyses for Objective 1 and Objective 3

Objective 1:

All statistical analysis and figures were created using R version 3.3.2 (The R Foundation for Statistical Computing https://www.R-project.org/.).

For all variables measured, any missing samples resulted in the entire data point being discarded from the dataset. Data were analysed separately by year, as different fields were used in 2015 and 2016. Data from all fields were combined with 'field' included as a term in models, where appropriate, to account for between field variation.

Correlation between different thrips measurements
Correlations were conducted using the "pacf" package in R, by computing the cross-correlation through time of thrips on triplets, thrips on cards and damage, all compared with each other. All variables were found to be positively and significantly correlated. For this reason, thrips on cards and damage were both analysed with respect to their effect on yield as the two datasets were distributed very differently. The effect of thrips on triplets on yield were not analysed as data were closely correlated with damage and would therefore demonstrate a very similar result. In addition, they are the two most viable ways of measuring thrips presence in a field, and results could therefore directly inform monitoring practices.

Treatments
The effect of treatments on all thrips variables were analysed using ANOVA(for thrips damage) or generalized linear models (for thrips numbers on triplets and cards) with 'treatment' and 'field' as main effects, including an interaction term, and 'week' as a covariate to account for repeated measures through time. In this study, treatments were applied to vary thrips numbers between plots. Thus, 'treatment' is not used when analysing the effects on yield, as the number of thrips or thrips damage on triplets were the focus of the study. Before, during, and after flowering periods were defined specifically for each field (Table 2), which allowed for fields to be combined into one model per year. Each year was analysed separately as fields were not the same between years.

The effect of thrips and thrips damage on potato yield
The effect of thrips on cards and of damage on both potato yield and the proportion of small potatoes were analysed using linear models. The mean value of thrips on cards for each plot was calculated either across the whole season or before, during or after flowering. The maximum damage score observed during each period was used for the damage analysis as this indicated the worst damage a plot received during the time period.

Each maximal model began with the following:
response (yield/proportion of small potatoes) ~ main effect 1 (thrips on cards/thrips damage) + main effect 2 (field) + interaction between main effect 1 and main effect 2
If the interaction term was not significant, this was removed from the model and it was rerun with only the main effects.

Objective 3:

Survey data were analysed using a quasi-Poisson regression, followed by least-squares means to assess the impact of some of the measured factors on thrips presence. Numbers of thrips on triplets was used as the response variable and therefore this analysis focuses on thrips numbers once plants were 1′ tall (when plants were <1′ tall the sampling method did not include counting thrips on triplets, as per E.S. Cropconsult potato monitoring protocol). Two way interactions were tested between all independent variables but none were shown to be significant. Within each factor, pairwise comparisons were then conducted to assess the effect of each category on thrips presence. In all cases, thrips numbers were adjusted for differences in sample number between edge and inner passes and to reduce the over inflation of zeros.

To obtain the final dataset, neighbouring crop was omitted from analysis as the possible number of combinations between it and the other categorical variables was too high, resulting in very low numbers of replicates.

Cultivars and fields that did not have equal pass numbers for each type of pass orientation (North, South, East, West and inner) were removed. Delta and Abbotsford were the only geographic locations analyzed after areas with fewer replicates were removed. To adjust for differences in sample number between edge and inner passes, triplet thrips numbers were summed, for an across season total, to reduce the over inflation of zeros and inner triplet thrips counts were halved, to reduce the majority of samples to having a sample number of ten rather than twenty.

Results

Objective 1: Evaluate yield loss due to thrips damage to potato crops in relation to growing season conditions (two seasons of study)

Thrips numbers on cards and triplets varied between treatments and across the season in both 2015 and 2016. Blocks appeared to respond similarly for all factors; thrips on triplets, thrips on cards and damage on triplets through both years. Thrips species identification resulted in a finding of *Thrips fuscipennis* to be in the majority along with *Thrips tabaci, Frankliniella intonsa, Frankliniella occidentalis* and *Aeolothrips fasciatus* in smaller numbers.

Thrips numbers on triplets

In 2015, the highest mean value was found in field C in week 10 of data collection and the lowest mean values were found in field A (Fig. 3). Fields A and C had peaks in thrips numbers during flowering. After flowering, fields A and B had a reduction in thrips numbers, field C displayed an increase in thrips numbers, and field D showed a late season peak in thrips presence. Thrips numbers on triplets were very low in field A in comparison to other fields, particularly fields C and D.

In 2016, despite having overall different numbers of thrips, fields E, F and G had similar population dynamics with a peak observed at the end of, or one week after, the flowering period. In Field H thrips numbers on triplets steadily increased and ended at much higher levels than any of the other 2016 fields (Fig. 4).

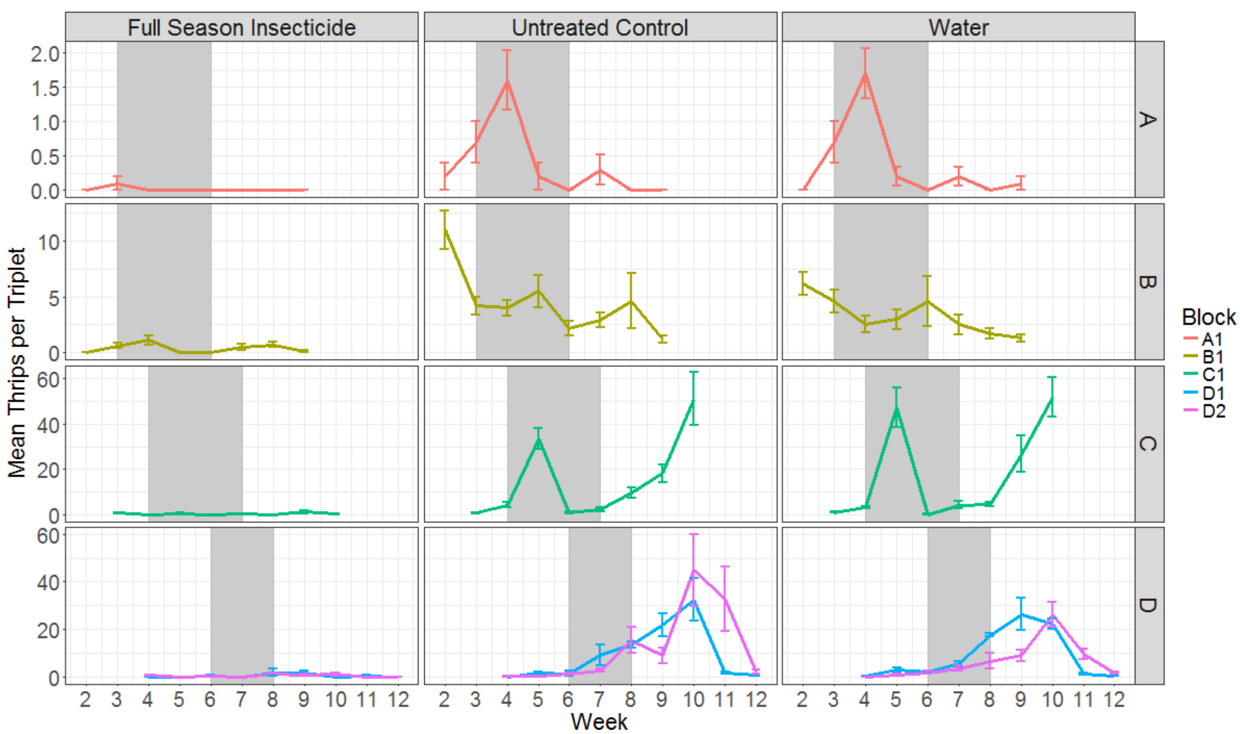

Figure 3. Thrips numbers on triplets in 2015 (fields A-D) across different treatments. Mean values are the mean of all plots in that treatment and block (where applicable) (± s.e.m.). The shaded blocks indicate flowering periods for each field.

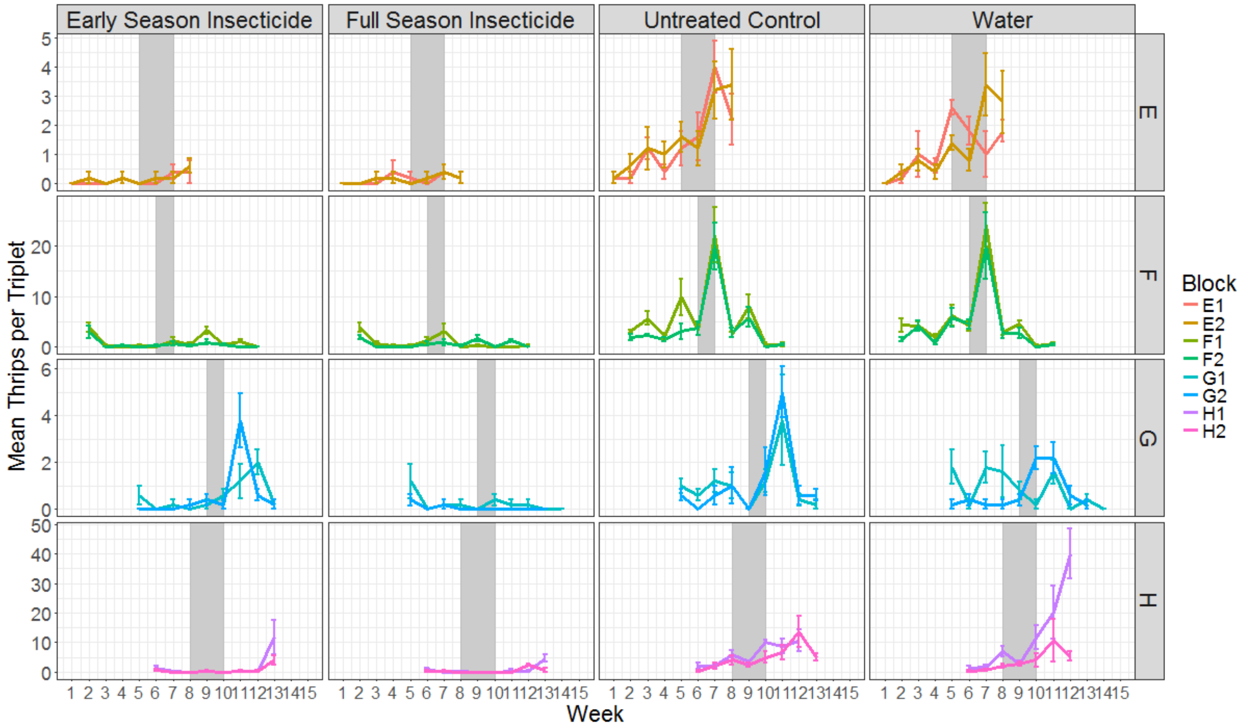

Figure 4. Thrips numbers on triplets in 2016 (fields E-H) across different treatments. Mean values are the mean of all plots in that treatment and block (± s.e.m.). The shaded blocks indicate flowering periods for each field.

As expected, treatment significantly affected the number of thrips observed on triplets in all fields (Figs. 3 and 4; Table 6). Significant field to field differences in thrips numbers were observed across both years of the study (Table 6), but the interaction between field and treatment was not significant (Appendix E).

Table 6. Statistical output for ANOVA conducted on generalized linear models on the effect of treatment on thrips numbers on triplets and on cards in 2015 and 2016. Maximum models are shown in Appendix E.

Year	Response	Model terms	Degrees of Freedom	Deviance	Residual Degrees of Freedom	Residual Deviance	P Value	
2015	Thrips on triplets	Treatment	2	3198.906	1002	12168.871	<0.001	***
		Field	3	3712.338	999	8456.533	<0.001	***
		Week (covariate)	1	856.179	998	7600.354	<0.001	***
	Thrips on cards	Treatment	3	1452.74	1400	6317.773	<0.001	***
		Field	3	1438.513	1397	4879.26	<0.001	***
		Week (covariate)	1	113.42	1396	4765.84	<0.001	***
		Treatment x Field	9	96.966	1387	4668.874	0.022	*
2016	Thrips on triplets	Treatment	2	1297.613	1097	207703.76	0.001	**
		Field	3	44122.95	1094	163580.81	<0.001	***
		Week (covariate)	1	64310.23	1093	99270.58	<0.001	***
	Thrips on cards	Treatment	3	884.66	1708	101098.75	0.009	**
		Field	3	13772.72	1705	87326.025	<0.001	***
		Week (covariate)	1	9252.867	1704	78073.158	<0.001	***

*significant at $P<0.05$; ** significant at $P<0.01$; *** significant at $P<0.001$

Thrips numbers on cards

In 2015, the mean values of thrips numbers on cards were highest in field B (with the highest observed value per treatment being 980 within one week) and the lowest numbers were found in field C (with the highest observed value per treatment being 244 within one week) (Fig. 5). In all fields, numbers increased during the flowering period, with a peak in numbers two to three weeks after flowering. Thrips populations within these fields showed different dynamics, with some fields (A and D) having a single peak, and others (B and C) showing multiple increases and decreases through the season. Surprisingly, the mean value of thrips on cards in fields A and B showed an overall increase over time whereas thrips on triplets in these fields decreased across the season. In 2016, all fields experienced a single thrips population peak followed by a decline (Fig. 6). Thrips numbers on cards varied between fields, with fields E and G having relatively low numbers compared to fields F and H. Similar to 2015, peak numbers on cards were observed two to three weeks after flowering in all fields except H, where a lag was observed.

Treatment significantly affected the number of thrips on cards in all fields (Figs. 5 and 6; Table 6). In 2015, field to field differences were observed and there was a significant interaction between field and treatment (Table 6). For 2016, the interaction was not significant (Appendix E) but there were significant field to field differences in thrips numbers on cards (Table 6).

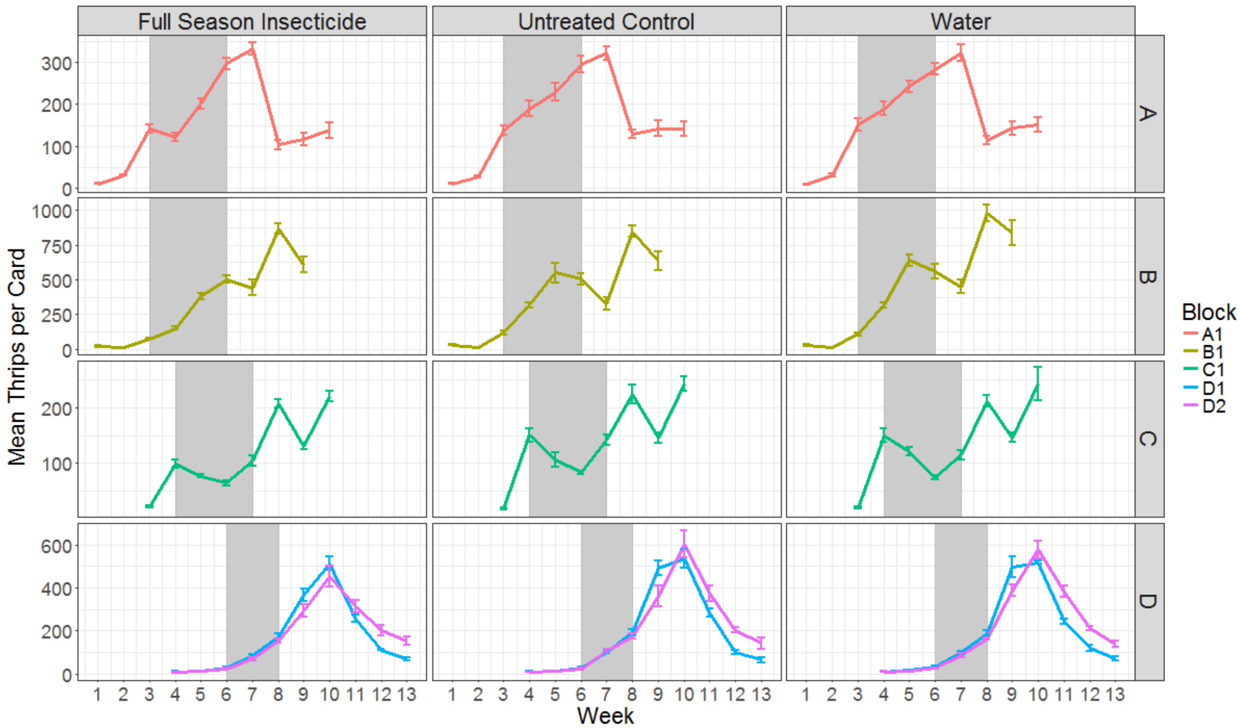

Figure 5. Thrips numbers on cards in 2015 (fields A-D) across different treatments. The mean values shown are the mean of all plots in that treatment and block (where applicable) (± s.e.m.). The shaded blocks indicate flowering periods for each field.

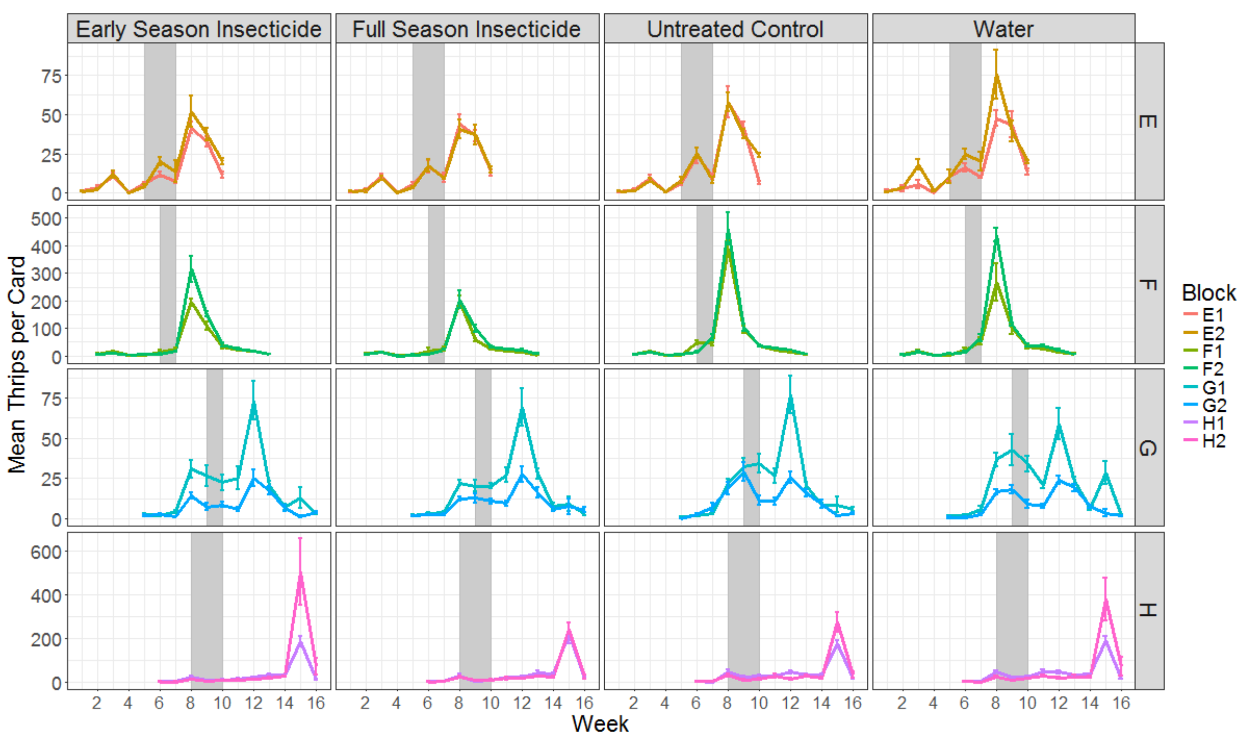

Figure 6. Thrips numbers on cards in 2016 (fields E-H) across different treatments. The mean values shown are the mean of all plots in that treatment and block (± s.e.m.). The shaded blocks indicate flowering periods for each field.

Thrips damage on triplets
In both years, abaxial (underside) leaf damage accumulated over the season in all fields in the Untreated Control and Water treatments and in 2016 damage additionally accumulated in the Early Season Insecticide treatment (Figs. 7 and 8). Damage patterns and levels varied between fields. Highest mean values of damage were seen in fields D and F and lowest overall damage occurred in fields A, B, E and G. As with thrips numbers on cards and triplets, damage increased during and just after flowering.

Treatment significantly affected damage caused by thrips, in both 2015 (Fig. 7; Table 7) and 2016 (Fig. 8; Table 7). In both years, there was a significant interaction between treatment and field, indicating that different fields responded differently to treatments (Table 7).

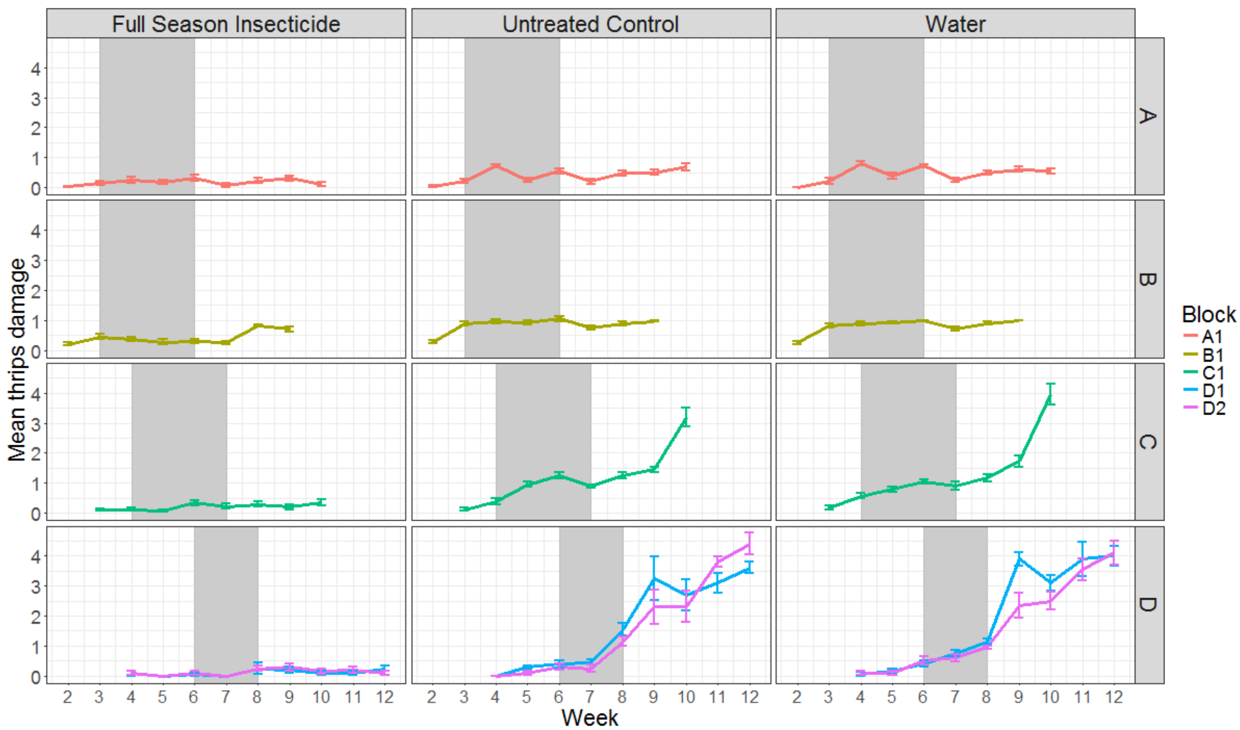

Figure 7. Thrips damage on the abaxial leaf surface of triplets in 2015 (fields A-D) across different treatments. Values are the mean value for all plots in that treatment and block (where applicable) (± s.e.m.).

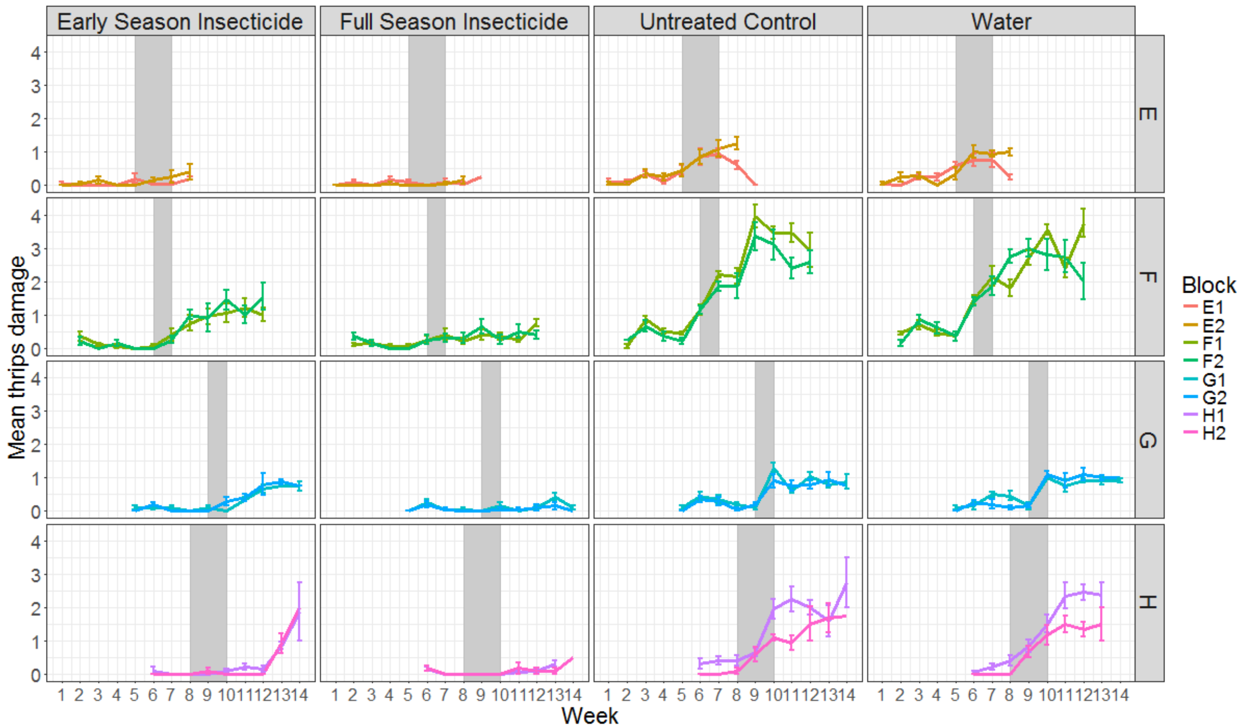

Figure 8. Thrips damage on the abaxial leaf surface of triplets in 2016 (fields E-H) across different treatments. Values are the mean value of all plots in that treatment and block (± s.e.m.).

Table 7. ANOVA output looking at the effect of treatment on damage on triplets caused by thrips across both years of the study.

Year	**Response**	**Model terms**	**Degrees of Freedom**	**Sum of Squares**	**Mean Sum of Squares**	**Test statistic**	**P Value**	
2015	Damage - minimal model	Treatment	2	155.41	77.705	154.21	<0.001	***
		Field	3	105.201	35.067	69.592	<0.001	***
		Week (covariate)	1	206.412	206.412	409.634	<0.001	***
		Treatment x Field	6	70.829	11.805	23.427	<0.001	***
		Residuals	986	496.838	0.504			
2016	Damage - minimal model	Treatment	4	207.346	51.837	177.871	<0.001	***
		Field	3	147.077	49.026	168.226	<0.001	***
		Week (covariate)	1	216.595	216.595	743.218	<0.001	***
		Treatment x Field	9	62.983	6.998	24.013	<0.001	***
		Residuals	1379	401.88	0.291			

*significant at $P<0.05$; ** significant at $P<0.01$; *** significant at $P<0.001$

Correlation between different thrips variables

Higher numbers of thrips on triplets significantly corresponded with higher numbers of thrips on cards (Fig. 9a). Damage caused by thrips was significantly correlated with thrips numbers on cards (Fig. 9b) and thrips on triplets (Fig. 9c) with increasing thrips numbers in both monitoring methods resulting in higher levels of damage.

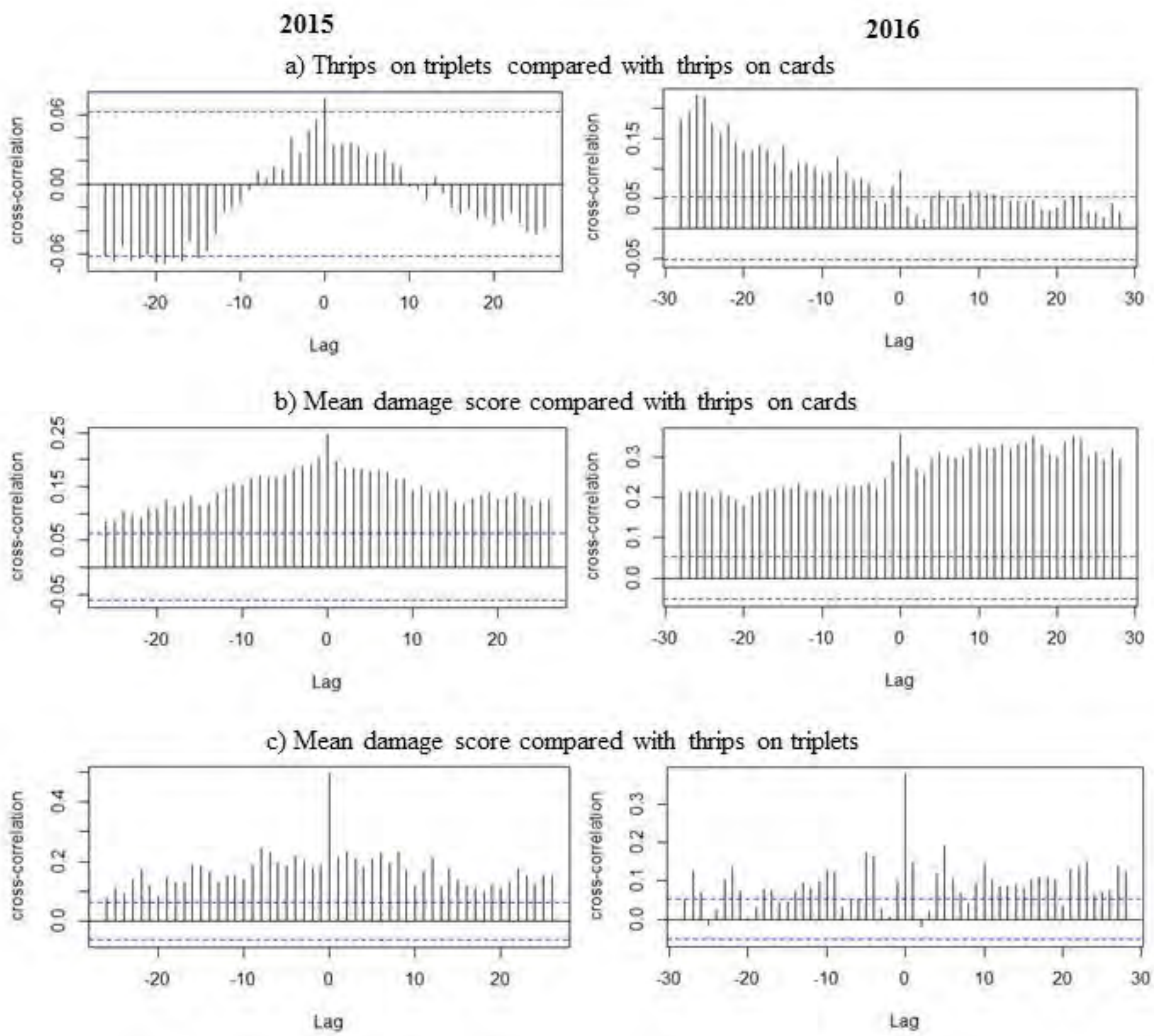

Figure 9. Cross-correlation of thrips on triplets compared to cards (a), mean damage score compared with thrips on cards (b), and mean damage score compared with thrips on triplets (c). When the cross-correlations on the y axis cross the horizontal dashed blue line there is a significant correlation between the two variables, and when this line is positive an increase in one variable will also have an increase in the other variable.

The effect of thrips on cards on potato yield

As expected, yield varied between fields across both years of study (Fig. 10). Field D had a low yield compared to other 2015 fields, and field E and F had slightly higher yields than fields G and H. Combining fields for each year into a single model and including a factor for field in the model accounts for this field to field variation.

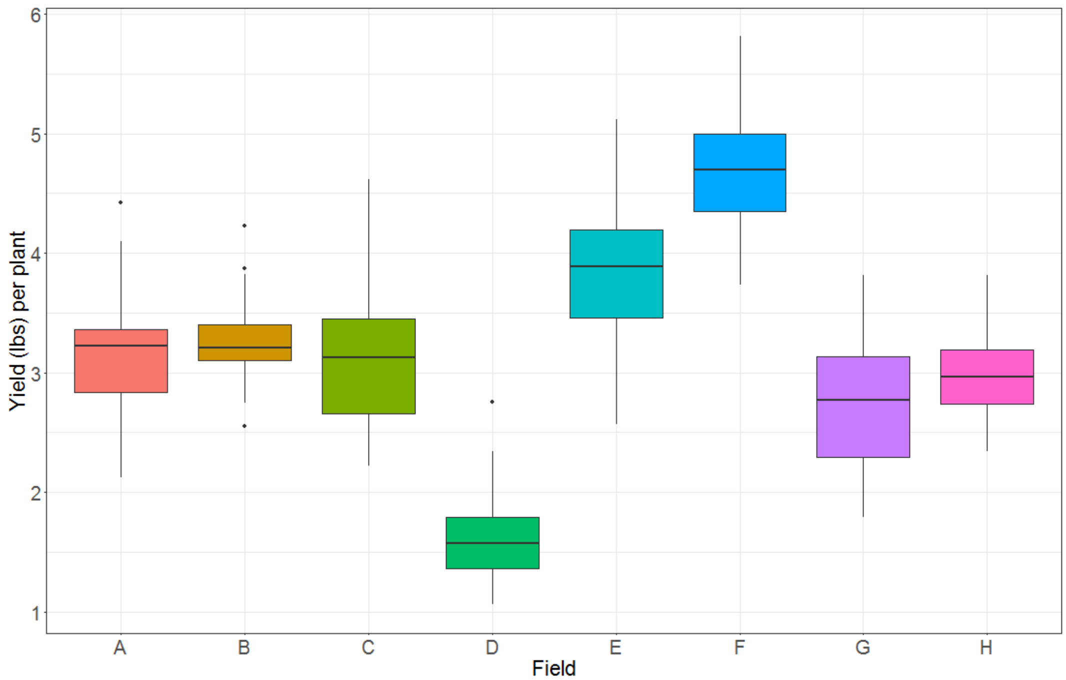

Figure 10. Boxplot showing potato yield in lbs per plant for all fields in 2015 (A-D) and 2016 (E-H). The middle line of each box depicts the median and the top and bottom edge of the boxes show the first and third quartile of the data. Whiskers are the 95% range of the data and points indicate data that fall outside of the 95% range.

2015

In 2015, thrips numbers on cards had a significant and positive effect on yield across the whole season (ie. yield increased as thrips increased) (Fig. 11; Table 8). There were significant interactions between fields and thrips for most time periods. This can be interpreted as field having a slightly different effect on the relationship between thrips and yield. Across the whole season, the relationship between yield and thrips numbers responded differently in all fields (Fig. 11); before flowering, only field B behaved differently from other fields (Fig. 12); and after flowering, all fields showed a different relationship between thrips numbers and yield (Fig. 13; Table 8).

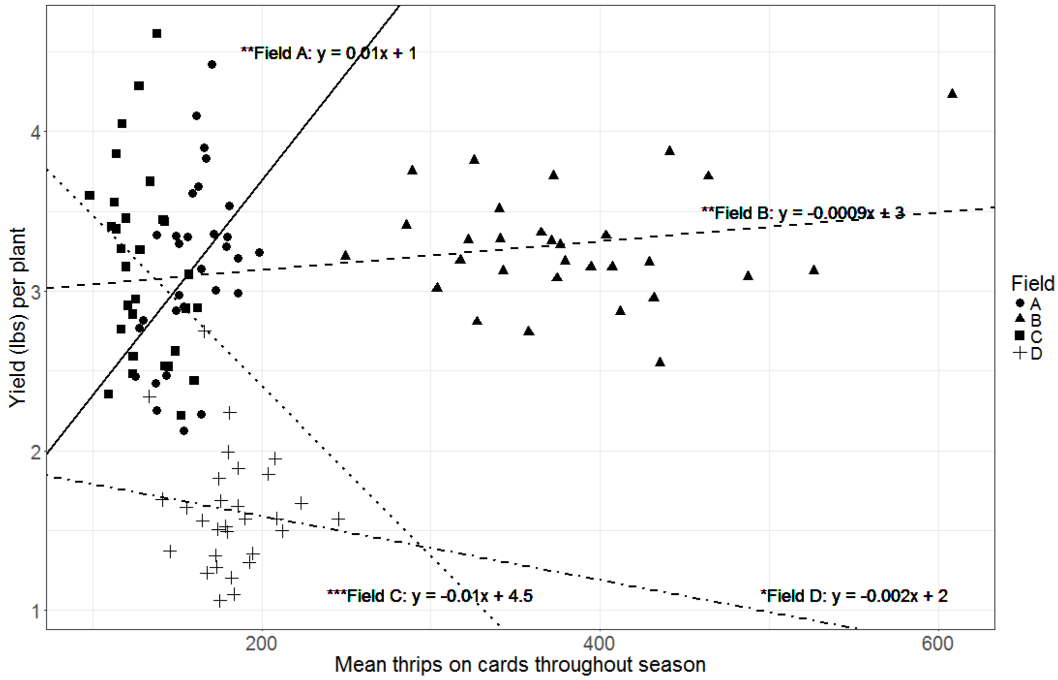

Figure 11. The effect of the mean value of thrips on cards across the season on potato yield in all 2015 fields. Model lines display results and equations from Table 8 and significance levels are depicted as follows: *** (p<0.001); ** (p<0.01); *(p<0.05).

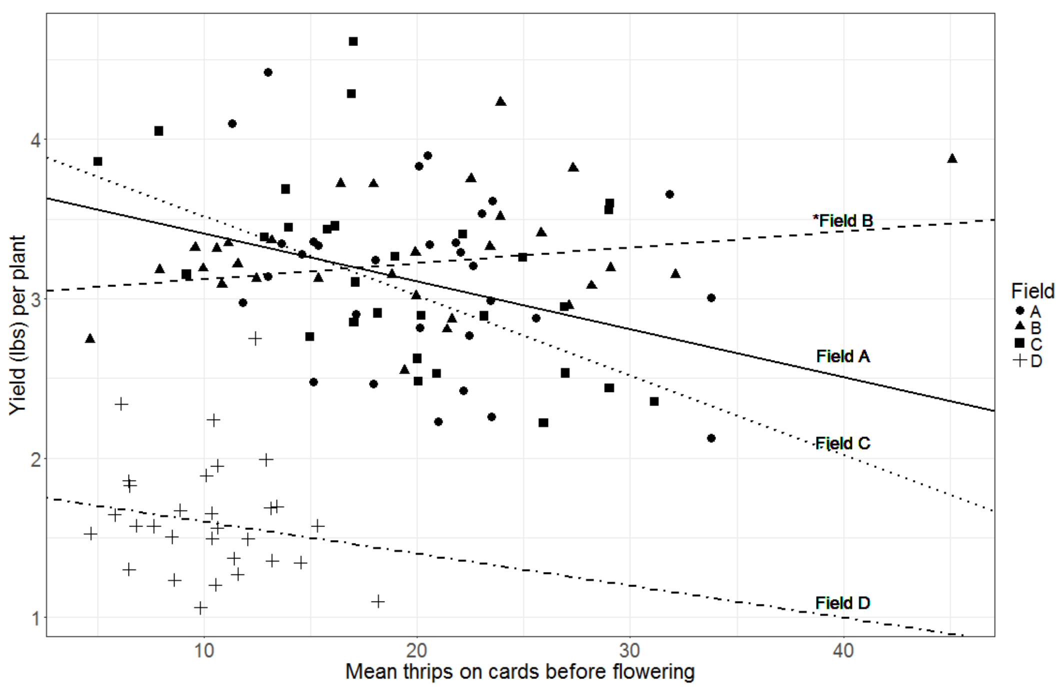

Figure 12. The effect of the mean value of thrips on cards before flowering on potato yield in all 2015 fields. Model lines display results from Table 8 and significance levels are depicted as follows: *** (p<0.001); ** (p<0.01); *(p<0.05).

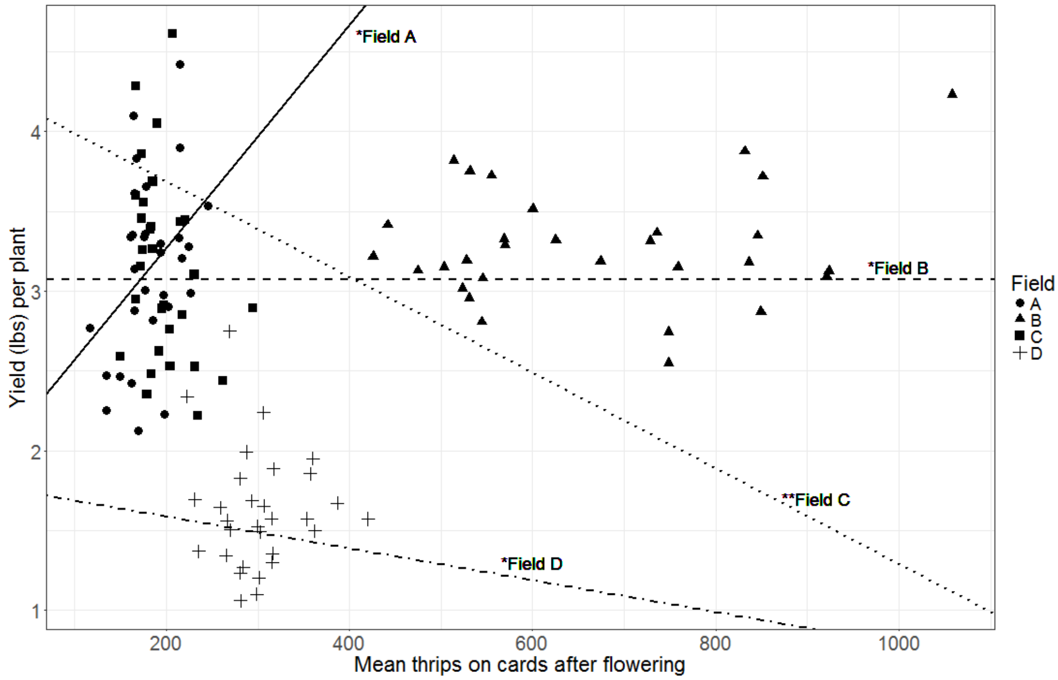

Figure 13. The effect of the mean value of thrips on cards after flowering on potato yield in all 2015 fields. Model lines display results from Table 8 and significance levels are depicted as follows: *** (p<0.001); ** (p<0.01); *(p<0.05).

Table 8. Linear model output on the effect on potato yield of thrips numbers on cards across the season, and before, during, and after flowering in 2015 and 2016. Maximum models are in Appendix E.

Year	Response	Model term	Estimate	Standard error	Test statistic	P value	
2015	Yield	(Intercept)	0.996	0.745	1.337	0.1840	
		Mean number of thrips on cards across whole season	0.013	0.005	2.900	0.0045	**
		Field B	1.956	0.868	2.255	0.0261	*
		Field C	3.550	0.997	3.562	<0.001	***
		Field D	0.994	1.001	0.992	0.3232	
		Mean number of thrips on cards x Field B	-0.013	0.005	-2.636	0.0096	**
		Mean number of thrips on cards x Field C	-0.024	0.007	-3.525	<0.001	***
		Mean number of thrips on cards x Field D	-0.015	0.006	-2.620	0.0100	*
	Yield	(Intercept)	3.708	0.299	12.388	<0.001	***
		Mean number of thrips on cards before flowering	-0.028	0.014	-1.968	0.0516	
		Field B	-0.686	0.364	-1.884	0.0622	
		Field C	0.310	0.400	0.775	0.4401	

Year	Response	Model term	Estimate	Standard error	Test statistic	P value	
		Field D	-1.907	0.415	-4.596	<0.001	***
		Mean number of thrips on cards x Field B	0.041	0.017	2.396	0.0182	*
		Mean number of thrips on cards x Field C	-0.016	0.019	-0.812	0.4187	
		Mean number of thrips on cards x Field D	0.011	0.030	0.352	0.7256	
	Yield	(Intercept)	2.996	0.206	14.521	<0.001	***
		Mean number of thrips on cards during flowering	0.001	0.001	0.782	0.4355	
		Field B	0.037	0.181	0.203	0.8392	
		Field C	0.081	0.154	0.524	0.6012	
		Field D	-1.440	0.159	-9.059	<0.001	***
	Yield	(Intercept)	1.866	0.534	3.496	<0.001	***
		Mean number of thrips on cards after flowering	0.007	0.003	2.421	0.0171	*
		Field B	1.195	0.643	1.859	0.0656	
		Field C	2.421	0.773	3.132	0.0022	**
		Field D	-0.083	0.794	-0.105	0.9168	
		Mean number of thrips on cards x Field B	-0.007	0.003	-2.271	0.0251	*
		Mean number of thrips on cards x Field C	-0.013	0.004	-3.169	0.0020	**
		Mean number of thrips on cards x Field D	-0.008	0.003	-2.167	0.0323	*
2016	Yield	(Intercept)	3.970	0.284	13.960	<0.001	***
		Mean number of thrips on cards across whole season	-0.010	0.017	-0.581	0.5624	
		Field F	1.225	0.386	3.173	0.0018	**
		Field G	-2.311	0.346	-6.689	<0.001	***
		Field H	-1.021	0.376	-2.713	0.0075	**
		Mean number of thrips on cards x Field F	0.000	0.018	0.018	0.9854	
		Mean number of thrips on cards x Field G	0.082	0.021	3.820	<0.001	***
		Mean number of thrips on cards x Field H	0.012	0.018	0.634	0.5270	
	Yield	(Intercept)	3.651	0.107	33.984	<0.001	***
		Mean number of thrips on cards before flowering	0.045	0.020	2.275	0.0244	*
		Field F	0.775	0.130	5.958	<0.001	***

Year	Response	Model term	Estimate	Standard error	Test statistic	P value	
		Field G	-1.273	0.139	-9.166	<0.001	***
		Field H	-0.721	0.127	-5.663	<0.001	***
	Yield	(Intercept)	3.778	0.093	40.479	<0.001	***
		Mean number of thrips on cards during flowering	0.003	0.003	0.753	0.4529	
		Field F	0.868	0.130	6.656	<0.001	***
		Field G	-1.121	0.121	-9.245	<0.001	***
		Field H	-0.819	0.127	-6.457	<0.001	***
	Yield	(Intercept)	4.128	0.302	13.666	<0.001	***
		Mean number of thrips on cards after flowering	-0.009	0.008	-1.084	0.2803	
		Field F	1.029	0.393	2.621	0.0097	**
		Field G	-2.444	0.354	-6.908	<0.001	***
		Field H	-1.204	0.370	-3.250	0.0014	**
		Mean number of thrips on cards x Field F	0.004	0.009	0.425	0.6717	
		Mean number of thrips on cards x Field G	0.068	0.013	5.329	<0.001	***
		Mean number of thrips on cards x Field H	0.010	0.009	1.167	0.2450	

***significant at *P*<0.05; ** significant at *P*<0.01; *** significant at *P*<0.001**

2016

In 2016, overall for the whole season, there was no effect of thrips numbers on cards on potato yield. There were significant interactions between fields, driven by field G (Fig. 14). In field G, thrips numbers on cards caused a marked increase in yield while other fields either had a decrease (E and F) or a slight increase (H) but these three fields are not significantly different from each other. Before flowering, there was a significant increase in yield when thrips numbers increased (Fig. 15; Table 8). There were no significant interactions between fields during this time period, and fields had significantly different yields, as expected. Thrips numbers on cards during and after flowering did not have a significant impact on yield but there were significant differences between the relationship in field G compared with other fields. For the two final time windows (during and after flowering), if there was an impact of thrips on yield it wasn't strong enough to stand out against field to field differences.

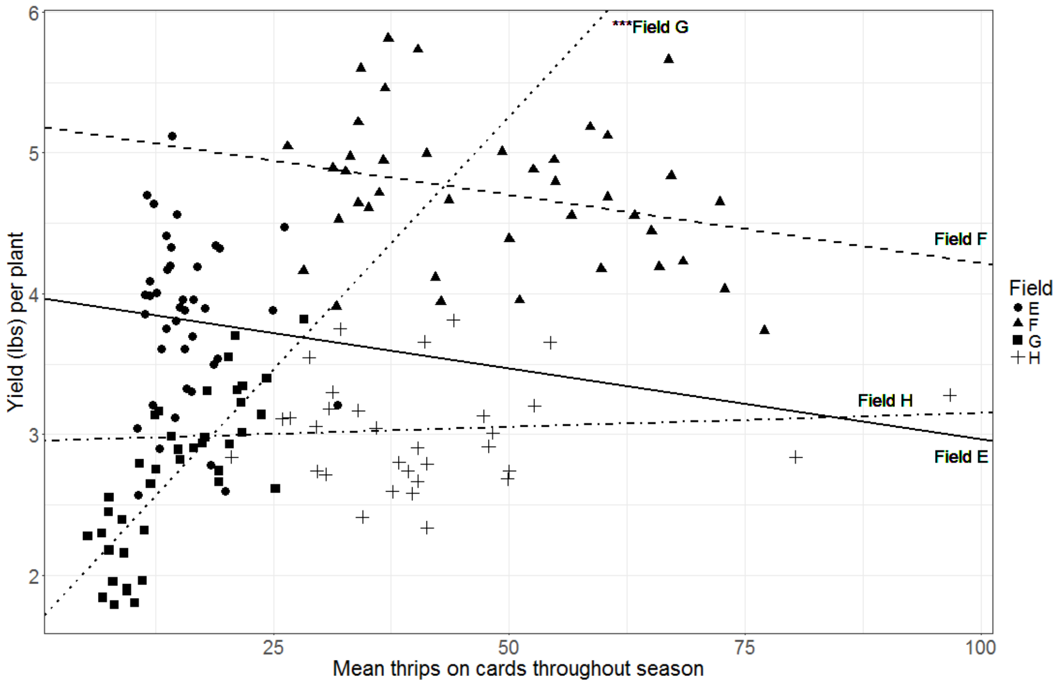

Figure 14. The effect of the mean value of thrips on cards throughout the season on potato yield in all 2016 fields. Model lines display results from Table 8 and significance levels are depicted as follows: *** (p<0.001); ** (p<0.01); *(p<0.05).

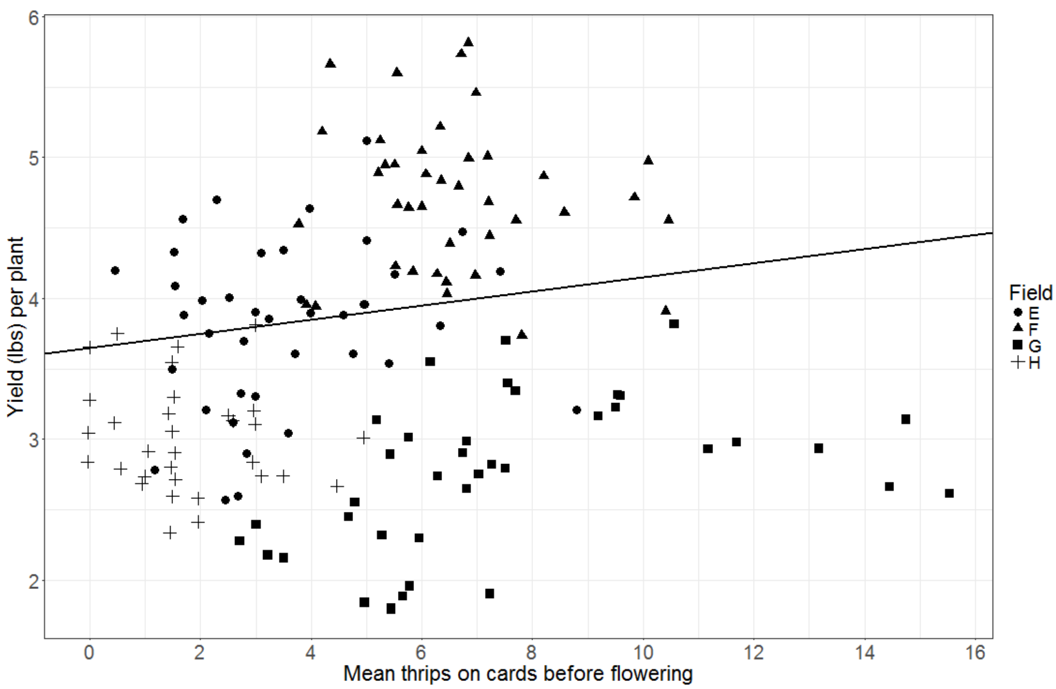

Figure 15. The effect of the mean value of thrips on cards before flowering on potato yield in all 2016 fields. Model line shown is y = 0.05x + 3.65.

The effect of thrips damage on potato yield

There were no significant impacts on yield due to thrips damage on triplets throughout the season or within specific timeframes in 2015 and 2016 (Figs. 16 and 17; Table 9). There were no significant interactions between fields, indicating that damage caused by thrips did not affect yield differently per field.

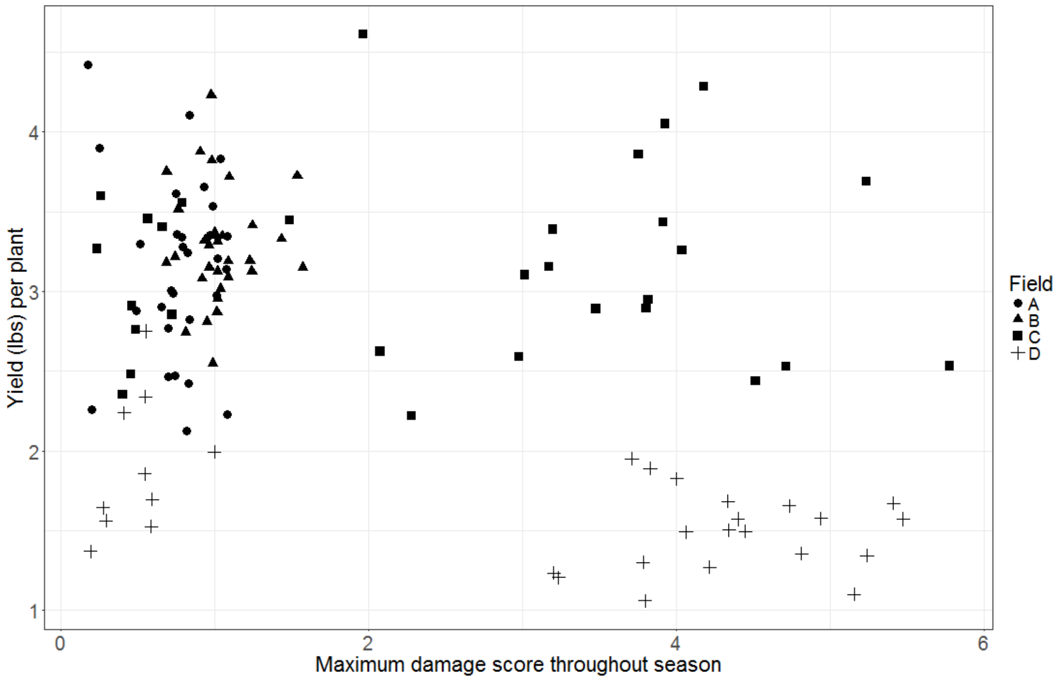

Figure 16. The effect on potato yield of thrips damage on triplets across the season in all fields in 2015.

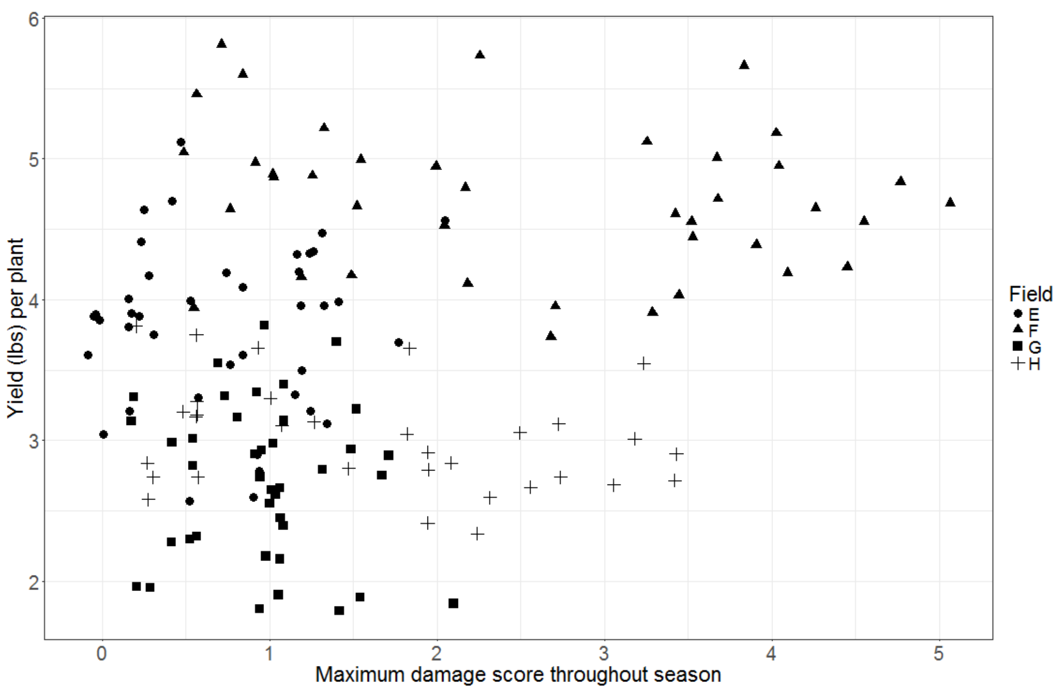

Figure 17. The effect on potato yield of thrips damage on triplets across the season in all fields in 2016.

Table 9. Minimal linear model output on the effect on potato yield of thrips damage on triplets across the season, and before, during, and after flowering. Maximum models are in Appendix E.

Year	Model terms	Estimate	Standard error	Test statistic	P value	
2015	(Intercept)	3.170	0.090	34.660	<0.001	***
	Maximum damage score throughout season	-0.040	0.030	-1.260	0.2116	
	Field B	0.150	0.120	1.210	0.2273	
	Field C	0.090	0.140	0.630	0.5302	
	Field D	-1.420	0.150	-9.660	<0.001	***
	(Intercept)	3.160	0.090	36.150	<0.001	***
	Maximum damage score before flowering	-0.580	0.300	-1.930	0.0563	.
	Field B	0.270	0.140	1.900	0.0593	.
	Field C	0.070	0.130	0.540	0.5917	
	Field D	-1.450	0.130	-11.240	<0.001	***
	(Intercept)	3.150	0.110	27.800	<0.001	***
	Maximum damage score during flowering	-0.010	0.110	-0.050	0.9596	
	Field B	0.140	0.130	1.100	0.2721	
	Field C	0.010	0.130	0.090	0.9266	
	Field D	-1.520	0.130	-11.850	<0.001	***
	(Intercept)	3.170	0.090	35.130	<0.001	***
	Maximum damage score after flowering	-0.040	0.030	-1.300	0.1962	
	Field B	0.150	0.120	1.240	0.2184	
	Field C	0.090	0.140	0.670	0.5049	
	Field D	-1.410	0.150	-9.540	<0.001	***
2016	(Intercept)	3.870	0.090	43.580	<0.001	***
	Maximum damage score throughout season	-0.080	0.050	-1.790	0.0757	.
	Field F	1.060	0.140	7.440	<0.001	***
	Field G	-1.080	0.120	-9.260	<0.001	***
	Field H	-0.730	0.130	-5.600	<0.001	***
	(Intercept)	3.810	0.090	40.600	<0.001	***
	Maximum damage score before flowering	0.000	0.170	0.010	0.9885	
	Field F	0.910	0.130	7.130	<0.001	***
	Field G	-1.100	0.120	-9.250	<0.001	***
	Field H	-0.800	0.130	-6.370	<0.001	***
	(Intercept)	3.870	0.090	42.350	<0.001	***
	Maximum damage score during flowering	-0.090	0.060	-1.500	0.1351	
	Field F	0.960	0.120	7.920	<0.001	***
	Field G	-1.100	0.120	-9.450	<0.001	***
	Field H	-0.790	0.120	-6.380	<0.001	***

Year	Model terms	Estimate	Standard error	Test statistic	P value	
	(Intercept)	3.850	0.090	45.290	<0.001	***
	Maximum damage score after flowering	-0.090	0.050	-1.940	0.0546	.
	Field F	1.090	0.150	7.320	<0.001	***
	Field G	-1.060	0.120	-9.020	<0.001	***
	Field H	-0.700	0.130	-5.230	<0.001	***

*significant at *P*<0.05; ** significant at *P*<0.01; *** significant at *P*<0.001

The effect of thrips on the proportion of small potatoes

The effect of thrips on small size potato yield was analyzed for the whole season in both years, and when significant effects of thrips on yield were found in more specific time periods. In 2015, the proportion (in weight) of small potatoes was not significantly affected by thrips numbers on cards or thrips damage on triplets (Table 10), although damage had marginally non-significant effects both across the season and after flowering. In 2016 before flowering, the proportion (in weight) of small potatoes decreased as thrips numbers on cards increased (Fig. 18; Table 10). This indicates that the proportion of medium or large potatoes increased as thrips numbers on cards increased.

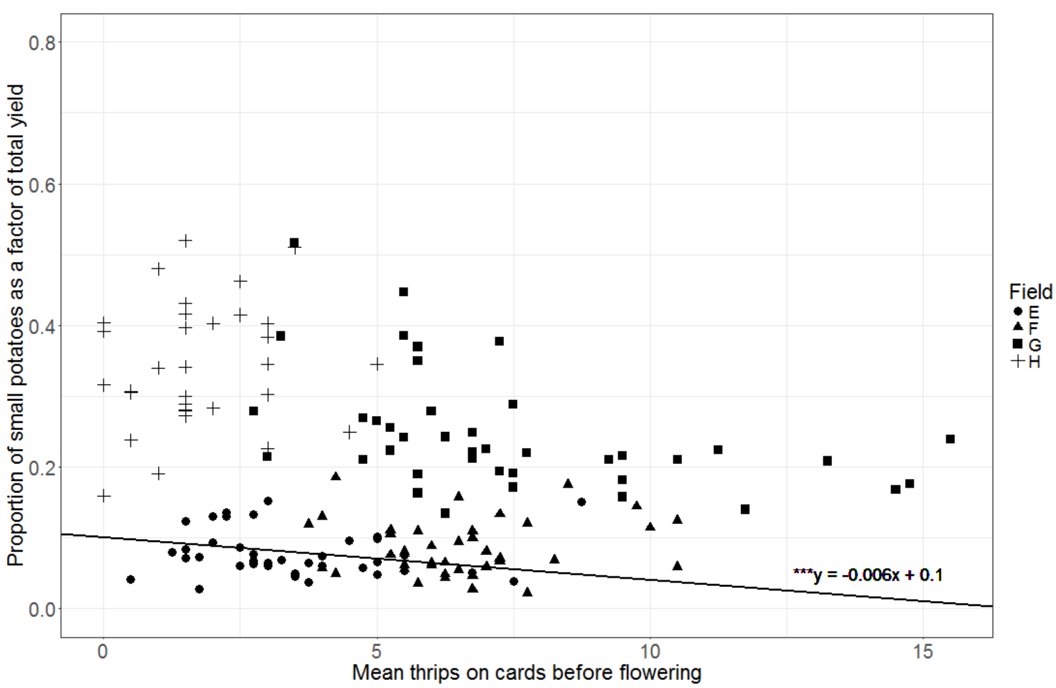

Figure 18. The effect of the mean value of thrips on cards before flowering on the proportion of small potatoes (measuring weight) in 2016.

Table 10. Linear model output on the effect on the proportion of small potatoes of thrips number on cards and damage on triplets across the season, and at time periods where thrips were previously shown to significantly affect yield. Maximum models are in Appendix E.

Year	**Response**	**Model terms**	**Estimate**	**Standard error**	**Test statistic**	**P Value**	
2015	Proportion of small potatoes as a factor of total yield	(Intercept)	0.078	0.023	3.352	0.0011	**
		Mean number of thrips on cards across whole season	0.000	0.000	-0.048	0.9615	
		Field B	-0.014	0.033	-0.430	0.6679	
		Field C	0.136	0.015	8.751	<0.001	***
		Field D	0.108	0.015	7.049	<0.001	***
	Proportion of small potatoes as a factor of total yield	(Intercept)	0.082	0.015	5.356	<0.001	***
		Mean number of thrips on cards after flowering	0.000	0.000	-0.425	0.6715	
		Field B	-0.003	0.033	-0.092	0.9267	
		Field C	0.136	0.015	9.051	<0.001	***
		Field D	0.111	0.017	6.651	<0.001	***
	Proportion of small potatoes as a factor of total yield	(Intercept)	0.071	0.011	6.542	<0.001	***
		Maximum damage score throughout the season	0.007	0.004	1.816	0.0720	
		Field B	-0.017	0.015	-1.178	0.2410	
		Field C	0.122	0.017	7.416	<0.001	***
		Field D	0.078	0.018	3.556	0.1205	***
	Proportion of small potatoes as a factor of total yield	(Intercept)	0.073	0.011	6.754	<0.001	***
		Maximum damage score after flowering	0.007	0.004	1.745	0.0836	.
		Field B	-0.018	0.015	-1.199	0.2330	
		Field C	0.122	0.017	7.338	<0.001	***
		Field D	0.091	0.018	5.143	<0.001	***
2016	Proportion of small potatoes as a factor of total yield	(Intercept)	0.101	0.013	7.566	<0.001	***
		Mean number of thrips on cards before flowering	-0.006	0.002	-2.371	0.0191	*
		Field F	0.024	0.016	1.458	0.1471	
		Field G	0.190	0.017	11.011	<0.001	***
		Field H	0.253	0.016	15.987	<0.001	***
	Proportion of small potatoes as a factor of total yield	(Intercept)	0.078	0.012	6.664	<0.001	***
		Maximum damage score before flowering	0.010	0.021	0.496	0.6206	
		Field F	0.003	0.016	0.182	0.8555	
		Field G	0.166	0.015	11.268	<0.001	***
		Field H	0.264	0.016	16.925	<0.001	***

*significant at P<0.05; ** significant at P<0.01; *** significant at P<0.001

Objective 2: Assess occurrence of thrips vectoring tomato spotted wilt virus (TSWV) to potatoes within the Fraser Valley (two seasons of study).

For 2015 field data, values for sample 14 in field A and sample 36 in field G were found to be positive with initial ELISA testing according to absorbance calculations, but were not indicative of a positive result given colour. After retesting these samples, they were found to be negative. All other samples in 2015 were negative. For 2016 field data, values for sample 15 and 18 in field A were found to be near positive with initial ELISA testing according to absorbance calculations, but were not indicative of a positive result given colour. After retesting these samples, they were found to be negative. All other samples in 2016 were found to be negative. Due to issues with the positive control, fields C-L were retested and all samples were found to be negative after secondary testing.

Objective 3: Evaluate potato varietal difference in thrips attraction (two seasons of study).

Raw R outputs can be found in Appendix F. There was a significant difference in the probability of a field pass having higher thrips values based on geographic location, with Delta having more thrips than Abbotsford (Fig. 19; Table 11). Production type was found to significantly impact thrips numbers with organic fields having more than conventional fields (Fig. 20; Table 11). Variety was also found to be a significant factor in thrips numbers with the variety Satina having more thrips than Kennebec, Orchestra, Imola and AC Peregrine (Fig. 21; Table 11). Pass orientation was not found to have a significant impact on thrips numbers (Fig. 22; Appendix F). Neighbouring crop analyses were attempted but no clear patterns were seen.

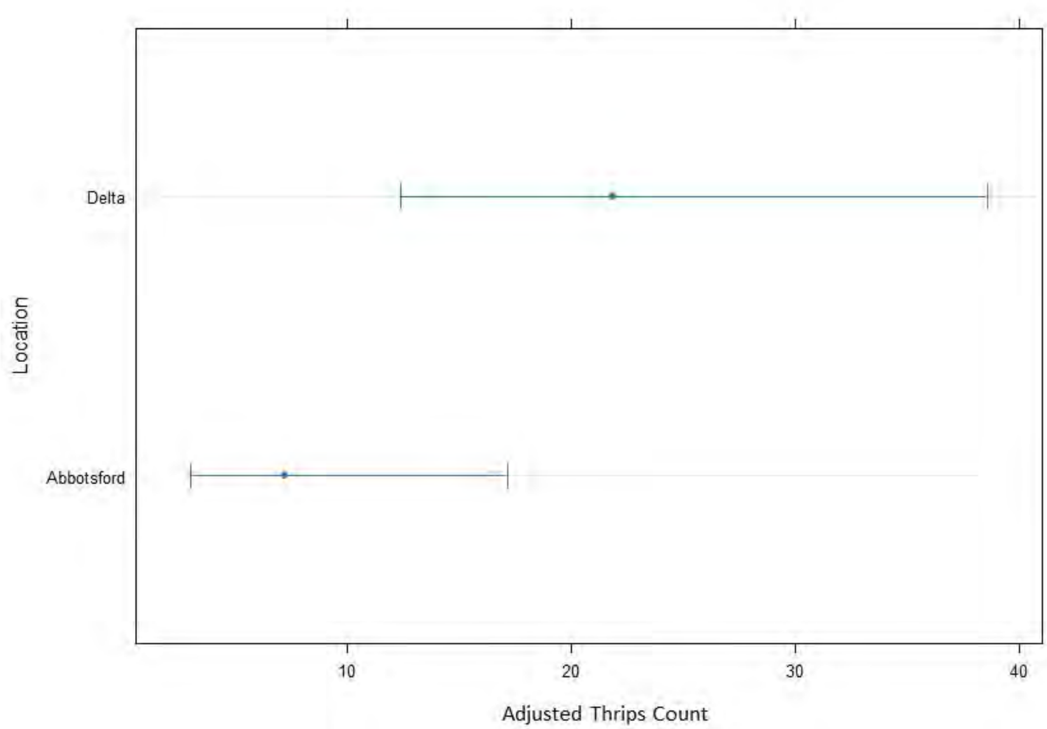

Figure 19. The mean values and 95% confidence intervals of thrips numbers on triplets grouped into the two geographic regions, Delta and Abbostford.

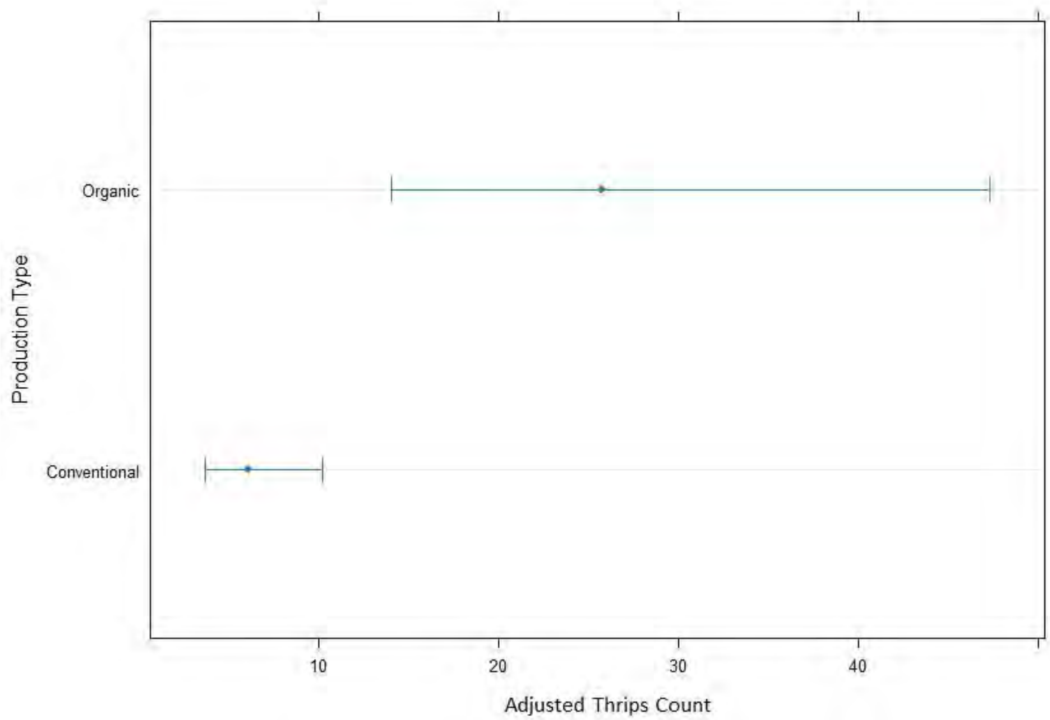

Figure 20. The mean values and 95% confidence intervals of thrips numbers on triplets grouped into the two production types, organic and conventional.

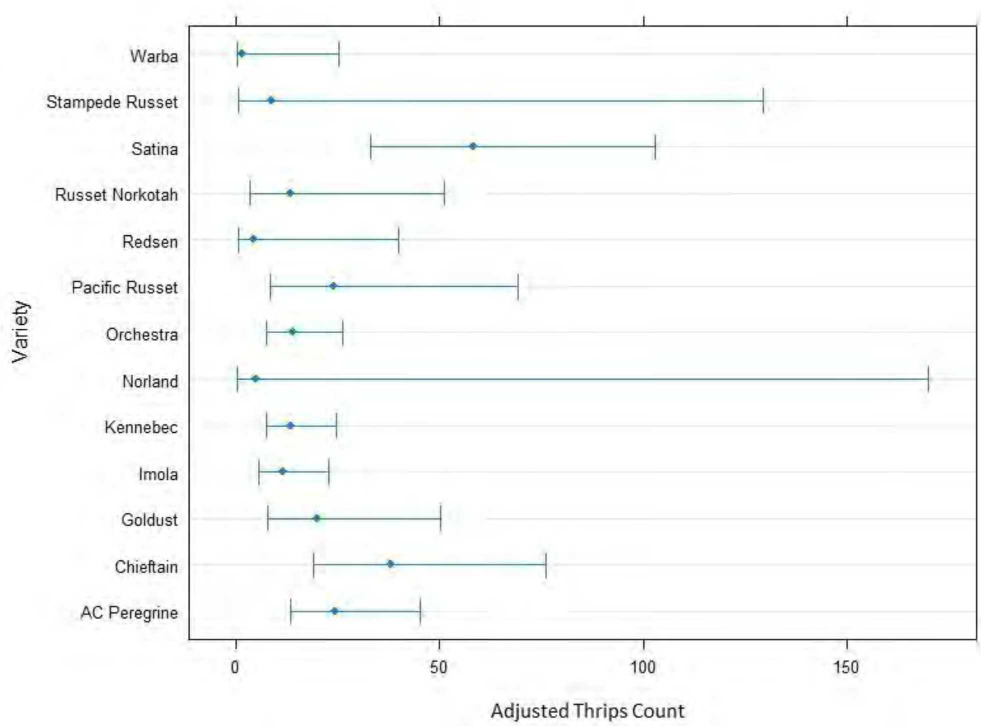

Figure 21. The mean values and 95% confidence intervals of thrips numbers on triplets grouped by potato variety.

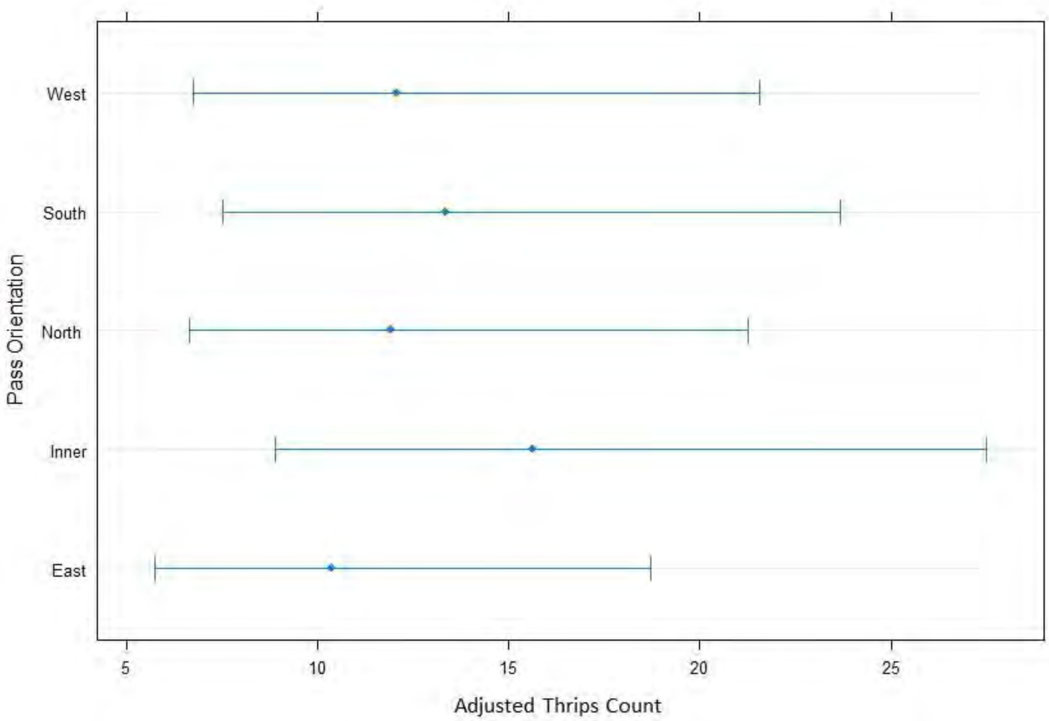

Figure 22. The mean values and 95% confidence intervals of thrips numbers on triplets by pass orientation. Inner refers to samples collected in the middle of the field, rather than along a field edge.

Table 11. Statistical output of pairwise comparisons generated from a generalized linear model, run using a quasi-poisson distribution, on the effect of geographic location, production type, pass orientation, and variety on thrips numbers. Only significant results are shown; full model output is in Appendix E.

Response	**Model terms**		**Rate ratio**	**Standard error**	**Degrees of freedom**	**Z ratio**	**P Value**	
Location as a factor of adjusted thrips numbers	Abbotsford	Delta	0.329	0.169	n/a	-2.1660	0.03	*
Production type as a factor of adjusted thrips numbers	Conventional	Organic	0.238	0.050	n/a	-6.8846	<0.001	***
Variety as a factor of adjusted thrips numbers	AC Peregrine	Satina	0.418	0.081	n/a	-4.5148	<0.001	***
	Imola	Satina	0.193	0.070	n/a	-4.5194	<0.001	***
	Kennebec	Satina	0.230	0.052	n/a	-%6.5451	<0.001	***
	Orchestra	Satina	0.236	0.049	n/a	-6.9748	<0.001	***

*significant at $P<0.05$; ** significant at $P<0.01$; *** significant at $P<0.001$

Objective 4: Increase grower knowledge of the effect of thrips on potato yield and quality, and which varieties can be used to adapt to thrips issues as the climate changes.

Survey of grower knowledge

Of the 34 growers contacted directly to complete the initial thrips questionnaire, 27 responded (79% response rate). An additional three surveys were submitted as a result of the BC Potato Growers Association listserv request. The responses showed that growers had varying degrees of knowledge and concern about thrips in potatoes (Table 12). The majority (93%) of growers had heard of thrips but close to half did not know how to identify them or their feeding damage on leaves. About 70% of growers considered thrips a pest of slight-severe concern with about 50% noting the frequency of concern to often be weather dependent. Thrips specific sprays had been made by 43% of the growers surveyed, with this ranging from part of one or two fields to multiple whole fields. The majority of growers did not consider adjacent crops for managing thrips in potatoes, however 60% did try to preserve beneficial insects which may help manage thrips in fields. There was a large gap in knowledge of thrips virus vectoring, TSWV and potato varieties that may be more susceptible to thrips damage. Furthermore, 50% of the growers did not know what climate thrips thrive under or, aside from spraying, what management practices could be implemented to minimize thrips damage.

Some additional comments were recorded by growers. Complications which affect grower ability to make management decisions related to thrips include land pressure and lack of market for alternative varieties. A few growers reported that while they may have gaps in knowledge, they hire consultants to help them manage thrips, among other pests. Those growers who knew more about thrips listed hot dry weather as the climate thrips thrive under and associate the increased frequency of thrips issues in the past few years to hotter, drier summers. Those who mentioned susceptible varieties listed Russet Norkotah, Goldust and Yukon Gold, and generally noted that plants with weaker tops are more likely to have issues with thrips. In addition, a handful of growers listed spraying for thrips, irrigating and managing field edges as tactics for minimizing thrips and their damage. Finally, thrips were also reported to be a concern in onions, parsnips and cabbage.

Of the 26 growers contacted directly to complete the final thrips questionnaire, 18 responded (69% response rate). As was the case with the initial survey, grower concerns and knowledge about thrips was mixed (Table 13). The most notable changes since the 2015 survey were increases in growers' awareness of thrips, ability to recognize thrips and their damage, knowledge about variety susceptibility, knowledge about virus transmission and climate thrips thrive under and a decrease in the number of growers adjusting neighbouring crop management for thrips in potatoes. There was a slight increase in the percentage of growers who reported to have specifically sprayed for thrips in the 2017 survey compared the 2015 survey. All methods of knowledge transfer were found to be useful, with the most popular option being emailed or faxed factsheets.

Table 12. Summary of 2015 thrips grower questionnaire.

Q#	**Question**	**Response percentage**				
1	Have you heard of thrips?	**93** yes	**3** once or twice	**3** No	n/a	n/a
2	Do you know how to recognize thrips?	**23** yes	**23** maybe	**53** No	n/a	n/a
3	Do you know how to recognize thrips damage?	**3** yes when damage is light and heavy	**33** yes when damage is heavy	**20** no but I have seen my plants die down early	**43** no	n/a
4	Do you consider thrips a pest of concern?	**17** serious	**27** moderate	**27** Slight	**30** no	n/a
5	How often are thrips a pest of concern?	**3** often	**43** sometimes	**23** Rarely	**30** never	n/a
6	Have you sprayed specifically for thrips?	**43** yes	**57** No	n/a	n/a	n/a
7	In an average year, how much have you sprayed for thrips?	**3** multiple whole fields	**13** one whole field	**3** one part of multiple fields	**20** part of one to two fields	**60** no fields
8	When planning where to plant potatoes, do you consider adjacent crops	**20** yes	**80** no	n/a	n/a	n/a

Q#	Question	Response percentage				
	which might harbour thrips?					
9	Have you adjusted your management of adjacent crops due to thrips pressure?	**3** yes	**17** sometimes	**80** No	n/a	n/a
10	Have you preserved beneficial insects which may manage thrips in your fields?	**47** yes	**13** sometimes	**40** No	n/a	n/a
11	Do you know what management practices you could implement to minimize thrips damage?	**48** yes	**52** no	n/a	n/a	n/a
12	Do you know if there are some varieties more susceptible to thrips?	**17** yes	**83** no	n/a	n/a	n/a
13	Have you selected varietiesthat are less susceptible to thrips?	**3** yes	**97** no	n/a	n/a	n/a
14	Do you know if thrips can transmit virus to potatoes?	**20** yes	**80** no	n/a	n/a	n/a
15	Have you heard of TSWV?	**13** yes	**3** yes but not related to potatoes	**83** No	n/a	n/a
16	Do you know what climate thrips thrive under?	**50** yes	**50** no	n/a	n/a	n/a

Table 13. Summary of 2017 thrips grower questionnaire.

Q#	Question	Response percentage					
1	Have you heard of thrips?	**100** yes	**0** once or twice	**0** no	n/a	n/a	n/a
2	Do you know how to recognize thrips?	**22** yes	**61** maybe	**17** no	n/a	n/a	n/a
3	Do you know how to recognize thrips damage?	**6** yes when damage is light and heavy	**44** yes when damage is heavy	**11** no but I have seen my plants die down early	**39** No	n/a	n/a

Q#	Question	Response percentage					
4	Do you consider thrips a pest of concern?	**11** serious	**27** moderate	**33** slight	**27** No	n/a	n/a
5	How often are thrips a pest of concern?	**11** often	**22** sometimes	**56** rarely	**11** Never	n/a	n/a
6	Have you sprayed specifically for thrips?	**61** yes	**39** no	n/a	n/a	n/a	n/a
7	In an average year, how much have you sprayed for thrips?	**0** multiple whole fields	**6** one whole field	**11** one part of multiple fields	**33** part of one to two fields	**50** no fields	n/a
8	When planning where to plant potatoes, do you consider adjacent crops which might harbour thrips?	**22** yes	**78** no	n/a	n/a	n/a	n/a
9	Have you adjusted your management of adjacent crops due to thrips pressure?	**0** yes	**11** sometimes	**89** no	n/a	n/a	n/a
10	Have you preserved beneficial insects which may manage thrips in your fields?	**67** yes	**22** sometimes	**11** no	n/a	n/a	n/a
11	Do you know what management practices you	**39** yes	**61** no	n/a	n/a	n/a	n/a

Q#	Question	Response percentage					
	could implement to minimize thrips damage?						
12	Do you know if there are some varieties more susceptible to thrips?	**50** yes	**50** no	n/a	n/a	n/a	n/a
13	Have you selected varieties that are less susceptible to thrips?	**6** yes	**94** no	n/a	n/a	n/a	n/a
14	Do you know if thrips can transmit virus to potatoes?	**33** yes	**67** no	n/a	n/a	n/a	n/a
15	Have you heard of TSWV?	**33** yes	**0** yes but not related to potatoes	**67** no	n/a	n/a	n/a
16	Do you know what climate thrips thrive under?	**61** yes	**39** no	n/a	n/a	n/a	n/a
17	Has your knowledge of thips improved because of this project's outreach in the following categories?	**44** thrips identification	**50** thrips damage identification	**44** weather thrips thrive under	**22** virus transmission and TSWV	**44** variety selection based on thrips risk	**33** management tools for thrips
18	What are the best ways to continue outreach?	**61** grower meetings	**61** LMHIA Short Course Presentation	**89** emailed or faxed info sheets	**61** field days	n/a	n/a

Communication and outreach

A number of growers, industry and government members and researchers received project updates and information transfer in a variety of forms over the course of the project (Table 14). During the 2016 LMHIA Short Course presentation, the audience was surveyed to determine if they had learned anything useful about thrips and of the 36 respondents (approximately 80% of attendees), 100% stated that they learned something useful.

Table 14. Summary of knowledge transfer activities and parties involved.

Number of project collaborators (Institutions)	6
Number of producer cooperators	30
Estimated number of potato growers receiving information on thrips management	30
Number of articles published	1
Number of field days completed	1
Number of fact sheets and project summaries	7
Number of individual reports (Objective 2 on TSWV)	32
Number of presentations	2
Number of grower surveys	3

Discussion

Objective 1:

Thrips numbers on cards

Between the two years, overall, more thrips appear to have been found in 2015 than 2016, although fields F and H had similar or higher peak thrips numbers as found in A, B and D. While there are no great differences in weather between 2015 and 2016 found with local weather station data, 2015 was found to be slightly hotter (having about 50 more growing degree days) and slightly drier (about 50 fewer mm of rainfall) than 2016. While these small differences can be found between these two years in this trial, pest associations with differing weather and climate are best completed with many years of data due to the complexity of factors that affect both pests and the weather. While caution should be taken in interpreting results from this two year study, the pattern of increased thrips with hotter, drier summers is recognizable over nearly two decades worth of local weather data and monitoring observations (Fig. 1).

The mean number of thrips on cards varied within and between years, with the highest found in field B. While fields B, G and H were all next to grass rather than grain fields, the grass field next to field B had longer establishment, which may have impacted thrips build up over time. Local effects, such as proximity to water and field orientation, in B may have also created unique field characteristics. Due to technical difficulties, fields A and C received a thrips effective insecticide on all trial plots, and this may have repressed numbers in these fields making field B appear to have much higher levels. Despite fields A and C being artificially re-infested, reestablishment was difficult and slow. The lowest thrips numbers on cards were seen in fields E and G. No patterns are clear between these two fields as they had different orientations and one was neighboured by a grass field (G) while the other was by a grain field (E). Also, field E was planted early while G was planted late and they were in different parts of Delta. Regardless of variation between fields, no negative impact of thrips on yield was found, indicating that numbers found in the trial were not high enough to cause a negative impact in yield.

In all fields except H for both 2015 and 2016 thrips numbers appeared to greatly increase within the flowering period and peak at the end, or within two weeks of the end, of flowering. In field H, there appeared to be a lag in thrips population peak of about four weeks after flowering. This may have been due to its neighbouring grass crop being newly established, perhaps causing a later establishment of thrips than other fields. Field H also had just under half of its edge next to a potato field, which may not have attracted thrips until later in the season.

The growing period and number of weeks of the trial were longer in 2016 than in 2015. Flowering periods between years were relatively similar with flowering occurring between June 26 and July 31 in 2015 and between June 23 and July 28 in 2016. Thus, despite variability from year to year, flowering and subsequent peaks in thrips numbers are likely to occur between the end of June and end of July, as has been noticed observationally over several years (E.S. Cropconsult, unpublished data). Further work would be needed to determine optimal timing for thrips management as treatment before population peaks may be more effective than during peaks. There does not appear to be a pattern in thrips numbers on cards increasing or decreasing based on planting date, indicating that changes to planting dates may not be an effective tool for managing thrips.

The dynamics of thrips numbers on cards throughout the growing season are varied in 2016 fields compared to 2015. Fields A, D, E and F appear to have a pattern of a relatively steady increase in numbers followed by a population spike which is followed by a steep decline. Fields B and C are different in that the thrips numbers appear to increase and then decrease at least twice within the trial period. There does not appear to be a relationship between the increases or decreases in numbers related to grain or grass cutting. Irrigation of these potato fields may have caused numbers to drop between weeks four to six but wouldn't explain the later drop in week nine.

Not surprisingly, treatment has an impact on thrips numbers on cards, which indicates that cards reflect changes in thrips numbers and therefore could be used both for monitoring and developing a threshold. While there is a correlation between thrips numbers on cards and triplets, there do appear to be some differences between cards and triplets counts in some fields. For example, fields A and C appear to have similar cards and triplet thrips patterns except that the thrips numbers on triplets seem to have been noticeably affected by grower insecticide treatments with a sharp drop in numbers post-spray, while thrips numbers on cards did not have the same sharp drop in numbers. There are important management considerations relevant to this finding as thrips numbers on cards are just a proxy for damage. Caution should be taken if a grower was to use cards alone in determining spray recommendations, as they may be treating for thrips when they are not actually present and causing damage to leaf tissue. The threshold for spraying based on thrips on cards would be much higher than that of thrips on triplets, as numbers on cards are generally much higher than those on triplets. The relationship between thrips numbers on cards and triplets and thrips damage should be looked at more closely before adoption of any management tool that is solely reliant on sticky cards. Future work would benefit from determining a threshold for both triplets and card values so that growers and consultants could use what was appropriate for their operation. Efficiency of evaluations should also be taken into account – cards are more time consuming to assess than triplets, although accuracy of card counts is potentially higher than triplet assessments. Another important consideration regarding card efficacy is the mode of action of insecticides used. Those which require contact will not be effective in preventing thrips from re-infesting by flying or blowing in (thrips most likely caught on cards), although local experience has been that re-establishment to previous levels is uncommon in potato fields. Only one spray is usually recommended and needed per season to target thrips (E.S. Cropconsult, unpublished data).

Although thrips numbers on triplets increased in the Early Season Insecticide plots, they did not reach the same maximum mean values as found in the Untreated Control and Water plots, indicating that early season control of thrips may be an effective method to minimize numbers and damage. The use of water/irrigation is a potential thrips management strategy, especially in organic systems where chemical options may be limited (Palumbo *et al.* 2002). In this study, water sprayed in Water plots does not appear to have an impact on thrips numbers on both cards and triplets. However, this does not necessarily negate the opportunity to use water as a management tool. The amount of water put on plants in this study was applied in a minimal fine mist form and would not have much strength in removing thrips. Also, the sprayed water did not remain but evaporated relatively quickly from the plants and thus was unlikely to slow down reproduction.

Thrips numbers on triplets

In 2015, the field with the highest mean value was found in field C in week 11 of data collection, and the lowest mean values were found in field A. Uniquely, mean numbers of thrips on triplets in field B show an overall reduction over time, whereas the mean value of thrips on cards in this field gradually increase through the season. There is a noticeable drop in the numbers of thrips on triplets in fields A and C earlier in the flowering period compared with thrips on cards. This could be due to predation, as more beneficial insects would likely be on the plants during bloom to access pollen and nectar sources. Alternatively, although an influx of thrips continued flying or blowing in, vegetative growth may not have been preferential food sources at that time as thrips may have primarily fed on pollen/flowers during bloom. In 2016, the population dynamics observed between thrips on triplets and cards are similar with peaks occurring at the end of, or just following, flowering in all fields other than H, where there was no drop in thrips numbers before the field was harvested. As expected, insecticide treatments had a negative effect on thrips numbers on triplets in both years.

Thrips damage on triplets

In both years, abaxial leaf damage generally appears to increase from the beginning to the end of the trial period in the Early Season Insecticide, Untreated Control and Water plots, with damage remaining relatively low in the Full Season Insecticide plots, demonstrating the effect of treatment on thrips. The slightest increase in thrips damage in Full Season Insecticide plots at the end of the season may be attributed to these plants being greener and more attractive to thrips than the other treatment plots where damage had caused early senescence. Highest mean values of damage were seen in fields C, D and F. Field A appears to have the lowest damage overall, though fields B, E and G had similarly low levels. These results are interesting, as the fields with highest or lowest thrips damage do not match up exactly with highest or lowest thrips numbers on cards or triplets, although there is a correlation between these three thrips indicators. It is possible that thrips found on triplets were mostly causing damage to leaf tissue, whereas thrips caught on cards may have just blown in, may only have been passing through the field or may have spent time in the potato flowers rather than on leaves. Damage appears to increase in all fields during and/or after flowering, except in fields A and B where damage remains fairly level throughout the season. Thrips are known to be attracted to and cause damage to flowers in other locally grown crops, such as strawberries. Potato flowers were not assessed for damage in this study, however future work may benefit from adding this evaluation as it might help explain thrips impacts on yield.

As damage is cumulative, and assessed leaves were removed each week, a general increase in damage over time with minor fluctuations from week to week were expected. For most fields damage did not drop greatly below what the previous week's score was. Field E and F are stand out, as damage scores drop by about one score value at the end of the season. One reason for this is that there were very few thrips on triplets and cards found at this time and the leaves being selected may have been new enough not to have received damage. It is important to note that while damage values were recorded in field E, triplets were only available for assessment for two out of ten plots in the Untreated Control, where the drop is noticeable. While every effort was made to maintain consistency, damage assessments are subjective and consistent measurements can be a challenge. Damage is most easily visible when plants are dry and the sun is shining. In periods of heavy dew and rain, accurate damage assessments are difficult. For this reason, assessments were delayed at some points in the season when dew was heavy. The difficulties in measuring damage need to be kept in mind for future studies and when training others (i.e. growers) on how to measure thrips damage. As expected, insecticide treatments had a negative effect on thrips damage on triplets in both years, showing that when necessary, insecticide sprays can be effective in controlling or minimizing thrips and their damage.

The effect of thrips on yield

Between 2015 and 2016 there were no negative impacts on yield due to thrips numbers on cards or thrips damage on triplets. These results appear to be positive for growers as damage and thrips numbers were as high in a few fields as has been found locally over the past 10 years, indicating that the highest thrips numbers and most severe damage currently observed are not likely to cause a negative impact on yield. The main driver of concern related to thrips is their ability to reproduce quickly. It is reassuring that, in this study, despite surges found in thrips populations around flowering, yield was not negatively affected.

A significant increase in yield as thrips numbers on cards increased was found in 2015 overall for the whole season and after flowering, and in 2016 before flowering. As was expected, the impact of thrips numbers and damage on yield varied per field and between years. Although there was an increase in total yield found in 2015 and 2016, the size distribution (in weight) of harvested potatoes was only affected by thrips in 2016 in the 'before flowering' period, with medium or large potatoes found to increase as thrips numbers on cards increase. While pest damage is sometimes assumed to have a direct negative impact on yield, some plants have stress responses which allow them to compensate, and even thrive, under feeding damage pressure. In fact, overcompensation to the point of an increase in potato tuber biomass was observed in response to the Guatemalan potato moth (*Tecia solanivora)* (Poveda *et al.* 2010). This ability to compensate and increase yield is dependent on the level of damage incurred, and this may be the explanation behind this result. The threshold beyond which damage would be too much for compensation by the plant is unknown for thrips in potatoes and was not reached within this study.

While this study was extensive over a two year period, there are some limitations in applying these results to other areas. Mainly, thrips impacts on plants in the Fraser Valley may not relate directly to impacts in other areas, as plant interactions with weather and other stresses may complicate results. Also, for trial consistency, a single potato variety, Goldust, was used in all fields and thus findings from this study may not directly apply to other varieties. Additionally, very high damage was not found in all fields and effects may have been larger had damage been consistent across all fields in both years.

Further work may benefit from additional or supplementary treatments such as only allowing damage to occur in the early season by applying a Late Season Insecticide treatment. Similarly, for analysis purposes, the time periods (before, during and after flowering) were selected due to their relevance to critical potato damage timeframes as summarized from a number of studies in the Insect Pests of Potato (Giordanengo *et al.* 2013). However, it is possible that other time periods than those selected for analysis would be useful and show additional results.

Finally, scientific and statistically relevant work is critical in developing a better understanding of pest damage and crop yield relationships. However, using linear models to analyse complex biologicals systems requires careful interpretation. Certainly, it is not advised that growers infest their fields with thrips to attempt increasing their yield. Rather, from this study, growers should take away that the risk to yield of the damage levels observed here was not negative, and other unmeasured factors may be key in explaining the effect of thrips on yield. From an integrated pest management perspective, this study indicates that thrips may currently not be a top concern for growers in terms of yield loss and growers could consider reducing or eliminating pesticide application for thrips. However, as conditions develop with climate change, this pest may yet become a substantial issue in potatoes and other field vegetables. It will always be important for growers to consider their own operations and tolerance levels for risk.

Objective 2:

The negative results of testing for tomato spotted wilt virus detection are not surprising given that TSWV has not been reported on potatoes in the Fraser Valley in the past. Also, although a variety of locations were sampled and a diversity of growers and potato varieties were included in sampling, the breadth of the survey by no means encompasses all potato fields and was not designed to detect low levels of TSWV. Finally, though it had previously been expected that western flower thrips, *Frankinelli occidentalis*, a known important vector of TSWV, were the most common species in potato fields in the Fraser Valley, a mix of species were found on cards collected for Objective 1. Few species of thrips can transmit TSWV. *Thrips fuscipennis*, the most common species found in this study, may not actually transmit the virus or, if it can transmit, is certainly not among the most efficient vectors (Ebratt E. *et al.* 2013). Growers and consultants should continue to pay close attention for signs of TSWV on potatoes.

Objective 3:

Varietal differences in attraction of thrips do not appear to be so overwhelming that they are the most critical factors in the risk of having high thrips numbers in a field. There are many other variables which likely affect thrips distribution such as geographic location, production type and other factors which were not measured in this study such as predation and other pest levels. There were some differences in thrips numbers between specific varieties yet other factors including geographic location and production type also appeared to influence thrips.

Delta having more thrips than Abbotsford might be due to general production differences in these regions. Delta has more fields used for grass and grain production than in Abbotsford. It is also possible that environmental factors in these two areas affect the dispersal of thrips. While wind is known to assist in the movement of thrips, geographic orientation of a field edge did not have an impact on thrips numbers in this study. This might be due to the complexity of agricultural systems and interactions between multiple factors, of which geographic orientation is just one. Geographic location will be important when taking into consideration the results of this study for management decisions in different geographic areas in BC. It is also important to note that thrips also vary between fields within regions.

Due to the relationship between neighbouring crop and pass orientation (every neighbouring crop type was associated with a field edge), these two variables were confounded and no clear effects of neighbouring crop on thrips numbers were observed. While it's possible that neighbouring crop does not have an effect on thrips numbers, it is also possible that other variables in this analysis, including pass orientation, masked the effects of neighbouring crop in this study. However, while not found within this study, there is anecdotal evidence from observations over time and a previous local study that thrips move from grass and grain fields into potato fields (E.S. Cropconsult, unpublished data; AAFC, unpublished data). Future work should focus on increasing the sample size of fields with different neighbouring crops of interest, and combining with other relevant factors already shown here (geographic region and production type) in order to tease apart these complex factors.

It is not surprising that fields in organic production are likely to have higher thrips numbers than conventional fields. While organic fields tend to have more pests, they also tend to have more beneficial insects, which are seen to manage many pests as a season progresses (E.S. Cropconsult, unpublished data).

Limited statistical differences were found between varieties. If a grower was concerned about thrips and was choosing between Satina, Kennebec, Orchestra, Imola or AC Peregrine, they could choose to not plant Satina, as these are more likely to have higher thrips numbers. However, Satina is not more likely to have thrips than many other varieties such as Goldust, Chieftain and Russet Norkotah. Different plant characteristics may be causing thrips to be more readily attracted to Satina than the four varieties listed above. These include foliage colour, leaf pubescence, flower shape or colour, and plant compounds. While such characteristics have been identified and evaluated in other studies, noted in the variety screening work by Seyed Ali Asghar Fathi (2014), it was not within the scope of this project to determine the exact characteristics attracting thrips to a specific variety.

The finding that there are few statistical differences between varietal attraction of thrips demonstrates that there are other complicating factors affecting thrips numbers in potato fields. This finding has both positive and negative implications. As there are not great differences between many varieties, growers are free to pick which varieties to grow based on the myriad of other important factors for their operations, such as disease resistance and market preferences. Luckily, here, thrips were not found to have a negative impact on yield even when pressure was high, and TSWV was not found in potato fields, so the risk of damage due to thrips is currently low.

The observational survey data aimed to be as standardised as possible between years and fields, however small numbers of replicates for certain characteristics resulted in the exclusion of several points from the dataset. For example, many field edges had more than one potato variety, or multiple neighbouring crop types. In addition, the sampling techniques used to gather thrips numbers changed throughout each season, as per monitoring protocol. This reduced the ability to make comparisons between numbers observed in the early season, before plants reached 1′ in height, and number observed after this point. Future work in this area will benefit from this information, and continuing with consistent sampling techniques as well as improving sample numbers both within a season and across years, will enable further conclusions to be drawn from these data.

Objective 4:

In 2015, the questionnaire received a high response rate and valuable information was gathered about the varying degrees of grower knowledge and concern about thrips in potatoes. While most growers had heard of and were concerned about thrips, a lack of knowledge was found regarding how to identify thrips and their damage, susceptible varieties, thrips virus vectoring, climates thrips thrive under and thrips management practices. These findings demonstrate the importance of this outreach, as growers are concerned and yet have meaningful knowledge gaps related to thrips. Also, clear concern was raised about climate change and subsequent thrips issues. As our summers are expected to get hotter and drier with further thrips outbreaks, growers will benefit from knowledge gained and shared through this project.

Different methods were used to share information about thrips and project updates with growers, industry and researchers and the ability to evaluate grower knowledge transfer varied depending on the method. Between the yield, virus and varietal work, approximately 30 growers were participants in trial work or data collection. Direct grower collaborators for Objective 1 appeared to learn about thrips through personal interest and shared conversation throughout the trial period. While growers tend to appreciate field days where results can be clearly demonstrated, Objectives 1-3 did not provide opportunity for field days. In addition, scheduling field days during the busy growing period is a challenge. For these reasons, a field demonstration was made at the well-attended BC Potato Industry Variety Trial Field Day, where thrips and thrips damage identification were the focus. Although it was an addition to the main event of the variety trial itself, growers displayed an interest and increased their thrips knowledge.

Presenting at the LMHIA short course appeared to be a very effective way of transferring knowledge. The distribution of sticky cards with thrips on them, and high quality photos of damage were the main tools provided to engage growers with identifying thrips and their damage. In 2016, the follow up survey of whether or not the participants had learned something about thrips during the presentation was an effective way of quickly receiving feedback. Unofficial feedback was also highly positive both years. Although grower knowledge improvement could not be ascertained from emailed or faxed thrips info sheets, many growers who would have received these forms of communication were included in the final survey of grower knowledge.

Grower knowledge about thrips improved considerably through the outreach of this project. Gaps in ability to identify thrips and their damage were addressed, as well as the weather conditions that thrips thrive under and variety susceptibility to thrips. Although thrips have been identified within this study as a minimal risk currently, some growers are still concerned about thrips in potatoes and other crops, and the risk of thrips injury may increase as climate change occurs. The outreach from this project has increased growers' abilities to be continually aware of thrips and self-reliant in identification. While knowledge improved in the areas of virus transmission and management tools, these areas have the most room for future outreach. Though the use of various methods to share information with growers proved successful in reducing grower gaps in knowledge, there is room for further work in this area. The final grower information sheet from this project will help address some of these areas.

Finally, though it is more time effective to send emails or faxes for growers to receive and complete a survey, more growers were involved and thus impacted when growers were called, or repeat calls were made if the grower was unable to answer the survey the first time.

Recommendations and Conclusions

Thrips are a pest of increasing concern within the Lower Mainland and throughout British Columbia in a number of crops, including potatoes, as numbers and frequency of damage have been increasing over the past decade. Thrips can cause damage through feeding, egg laying and virus transmission. However, in this study, when thrips numbers had an impact on yield it was positive (resulting in an increase in yield). In other words, thrips damage did not appear to negatively impact yield for the variety tested (Goldust). In addition, no tomato spotted wilt virus was found. A few factors impacting thrips numbers included geographic location (higher in Delta compared to Abbostford), production type (higher in organic compared to conventional) and variety (high in Satina compared to AC Peregrine, Imola, Kennebec and Orchestra).

Growers are encouraged to monitor their fields for thrips and their damage throughout the season. While no negative impact of damage on yield was found within this study, damage was generally highest at the end of the season and growers should be aware that heavy damage early in the growing season may impact potato yield. As a reduction in yield was not found related to thrips damage, growers could consider minimizing or eliminating the pesticide applications they use for thrips control. General management tools for reducing thrips numbers include removing them from plants by using water (through irrigation), attracting predators with diverse plants that ensure season long pollen and nectar availability, conserving predators by minimizing chemical treatments, avoiding dust creation (as this impacts predators) and using appropriately timed, and full coverage, chemical applications. Growers could also purchase and release predators, but this method is expensive and efficacy is not well understood in field settings.

While no tomato spotted wilt virus has been found in potatoes locally, this study was by no means exhaustive. Growers and consultants should continue to look for tomato spotted wilt virus symptoms on plants and tubers and send material in for laboratory confirmation if strong suspicion is aroused.

Although no clear patterns were seen related to neighbouring crop type and thrips numbers, the complexity of these data likely impacted the ability to produce transparent results. Anecdotal evidence from a decade of field monitoring has demonstrated that thrips often, although not always, enter potato fields in high numbers after neighbouring grass or grain fields dry out, are cut, are harvested or are disked (E.S. Cropconsult, unpublished data). Thus, caution could be used when planting a late potato field next to a grass or grain field that is reaching maturity. Also, special attention to thrips monitoring could be made when grass or grain fields that neighbour potatoes are reaching maturity.

Only the variety Satina was determined to have a higher likelihood of increased thrips numbers over AC Peregrine, Imola, Kennebec and Orchestra. However, varieties which are known to be weak plants in any given area could be monitored more closely for thrips. Other biological and abiotic factors may result in varieties responding differently to thrips damage; further study on the plant physiology in response to thrips damage would be beneficial. Future work would benefit from studying thrips impacts on different varieties, in variety specific trials, over more seasons and in different geographic locations.

A key consideration for growers to keep in mind not only for thrips issues but for all pests, is that climate change will likely affect the population size and dynamics of both pests and beneficial organisms, frequency of pest issues, and the geographic spread of pests. While this study demonstrates that the risks of thrips issues are minimal at this time, this could alter with a changing climate.

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Appendix A. Field Conditions and Management Details.

Table 15. Summary of 2015 and 2016 potato field management details.

Grower	Year	Field	Variety	Planting Date	Cultivation	Irrigation	Top kill	Harvest
1	2015	A	Goldust	May 6	June 10 Rotary tilling / Hill	June 13, June 24, July 6, July 16	August 14	September 6
1	2015	B	Goldust	May 4	June 7 Rotary tilling / Hill	June 18, June 26, July 11	August 14	September 9
1	2015	C	Goldust	May 17	June 22 Rotary tilling / Hill	June 27, July 4, July 10	August 17	September 9
2	2015	D	Goldust	May 25	July 10 Rotary tilling / Hill	August 5	September 6	September 22
3	2016	E	Goldust	April 18	Last week of May	First week of July	July 14	July 26
1	2016	F	Goldust	April 27	May 28 Rotary tilling / Hill	July 1, July 27	August 19	September 7
2	2016	G	Goldust	May 17	July 1 Rotary tilling / Hill	First week of August	September 1	October 3
2	2016	H	Goldust	May 26	July 4 Rotary tilling / Hill	na	September 1	September 24

Table 16. Summary of 2015 and 2016 potato field chemical treatment (numbers representing number of sprays).

Field	Year	Seed Piece Treatment	Insecticide	Herbicide	Fungicide	Foliar Fertilizer	Sprout Inhibitor	Desicant
A	2015	1	2 broad spectrum (July 5, 13)	1	5	1	1	1
B	2015	1	0	1	4	0	1	1
C	2015	1	1 broad spectrum (July 11 3 specific-not to thrips (July 18, 24, August 2)	2	2	0	0	1

Field	Year	Seed Piece Treatment	Insecticide	Herbicide	Fungicide	Foliar Fertilizer	Sprout Inhibitor	Desicant
D	2015	1	0	1	5	0	1	2
E	2016	1	0	2	3	0	0	1
F	2016	1	3 broad spectrum (August 5, 15 and 22)	1	6	2	0	1
G	2016	1	0	1	5	1	1	1
H	2016	1	0	1	5	1	0	1

Table 17. Summary of 2015 and 2016 grain field details.

Field	Year	Crop	Variety	Planting Date	Irrigation	Cut/mowed	Harvested	Cultivated
A	2015	Wheat	n/a	May 4	n/a	n/a	August 7	n/a
B	2015	Grass	Fescue blend	n/a	n/a	Cut June 18	June 19	n/a
C	2015	Barley	n/a	n/a	n/a	n/a	n/a	n/a
D	2015	Barley	AC Lacombe	June 4	n/a	September 16	September 16	n/a
E	2016	Wheat	Hard red spring	Last week of April	n/a	Cut August 8	August 11	Last week of August
F	2016	Wheat	Hard red spring	Last week of April	n/a	Cut August 8	August 11	Last week of August
G	2016	Grass	Delta Farmland and Wildlife Trust set aside mix, mostly fescue with some vetch	n/a	August 15	Cut June 25 and the end of August	June 29	n/a
H	2016	Grass/potato	3 Fescue blend	May 1	The beginning and end of June	Mowed July 7	By July 14	n/a

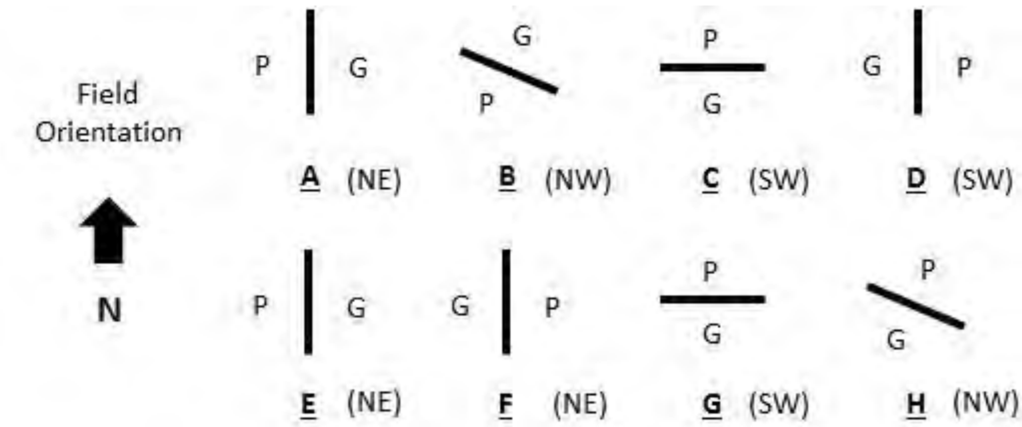

Figure 23. Field orientation per field (A-H) with P signifying the potato field trial edge and G signifying the neighbouring grass or grain field and the relative geographic orientation within Delta indicated by either north east (NE), north west (NW), or south west (SW).

Appendix B. Summary of Trial Treatment Details.

Table 18. Summary of spray schedule and rate used for each product within thrips damage and yield trial.

Field	Year	Date	Week	Product	Treatment sprayed	Rate of water used per treatment	Rate of insecticide used per treatment
A	2015	June 12	1	Ripcord	Full Season Insecticide and Water Control	4 L	1 mL of Ripcord, 4 L of water
	2015	June 26	3	Delegate	Full Season Insecticide and Water Control	4 L	2 g of Delegate, 4 L of water
B	2015	June 12	1	Ripcord	Full Season Insecticide and Water Control	4 L	1 mL of Ripcord, 4 L of water
	2015	June 26	3	Delegate	Full Season Insecticide and Water Control	4 L	2 g of Delegate, 4 L of water
	2015	July 3	4	Ripcord	Full Season Insecticide and Water Control	6 L	1 mL of Ripcord, 6 L of water
	2015	July 31	8	Delegate	Full Season Insecticide and Water Control	6 L	2 g of Delegate, 6 L of water
	2015	Aug 7	9	Ripcord	Full Season Insecticide and Water Control	6 L	1 mL of Ripcord, 6 L of water
C	2015	June 26	3	Delegate	Full Season Insecticide and Water Control	4 L	2 g of Delegate, 4 L of water
	2015	July 3	4	Ripcord	Full Season Insecticide and Water Control	6 L	1 mL of Ripcord, 6 L of water
	2015	July 10	5	Delegate	Full Season Insecticide and Water Control	6 L	2 g of Delegate, 6 L of water
	2015	July 25	7	Ripcord	Full Season Insecticide and Water Control	6 L	1 mL of Ripcord, 6 L of water
	2015	July 31	8	Delegate	Full Season Insecticide and Water Control	6 L	2 g of Delegate, 6 L of water
	2015	August 6	9	Ripcord	Full Season Insecticide and Water Control	6 L	1 mL of Ripcord, 6 L of water
	2015	August 13	10	Delegate	Full Season Insecticide and Water Control	6 L	2 g of Delegate, 6 L of water
D	2015	July 3	4	Ripcord	Full Season Insecticide and Water Control	6 L	1 mL of Ripcord, 6 L of water
	2015	July 10	5	Delegate	Full Season Insecticide and Water Control	6 L	2 g of Delegate, 6 L of water
	2015	July 17	6	Ripcord	Full Season Insecticide and Water Control	6 L	1 mL of Ripcord, 6 L of water
	2015	July 31	8	Delegate	Full Season Insecticide and Water Control	6 L	2 g of Delegate, 6 L of water
	2015	August 7	9	Ripcord	Full Season Insecticide and Water Control	6 L	1 mL of Ripcord, 6 L of water
	2015	August 13	10	Delegate	Full Season Insecticide and Water Control	6 L	2 g of Delegate, 6 L of water
	2015	August 21	11	Ripcord	Full Season Insecticide and Water Control	6 L	1 mL of Ripcord, 6 L of water
E	2016	May 26	1	Ripcord	Full Season Insecticide, Early Season Insecticide and Water Control	4L	1 mL of Ripcord, 4 L of water

Field	Year	Date	Week	Product	Treatment sprayed	Rate of water used per treatment	Rate of insecticide used per treatment
	2016	June 9	3	Delegate	Full Season Insecticide, Early Season Insecticide and Water Control	6L	2 g of Delegate, 6 L of water
	2016	June 16	4	Ripcord	Full Season Insecticide, Early Season Insecticide and Water Control	6L	1 mL of Ripcord, 6 L of water
	2016	June 30	6	Delegate	Full Season Insecticide, Early Season Insecticide and Water Control	6L	2 g of Delegate, 6 L of water
	2016	July 7	7	Ripcord	Full Season Insecticide, and Water Control	6L	1 mL of Ripcord, 6 L of water
	2016	July 14	8	Delegate	Full Season Insecticide, and Water Control	6L	2 g of Delegate, 6 L of water
	2016	July 21	9	Ripcord	Full Season Insecticide, and Water Control	6L	1 mL of Ripcord, 6 L of water
F	2016	June 2	2	Ripcord	Full Season Insecticide, Early Season Insecticide and Water Control	4L	1 mL of Ripcord, 4 L of water
	2016	June 9	3	Delegate	Full Season Insecticide, Early Season Insecticide and Water Control	6L	2 g of Delegate, 6 L of water
	2016	June 16	4	Ripcord	Full Season Insecticide, Early Season Insecticide and Water Control	6L	1 mL of Ripcord, 6 L of water
	2016	June 30	6	Delegate	Full Season Insecticide, Early Season Insecticide and Water Control	6L	2 g of Delegate, 6 L of water
	2016	July 7	7	Ripcord	Full Season Insecticide, and Water Control	6L	1 mL of Ripcord, 6 L of water
	2016	July 14	8	Delegate	Full Season Insecticide, and Water Control	6L	2 g of Delegate, 6 L of water
	2016	July 21	9	Ripcord	Full Season Insecticide, and Water Control	6L	1 mL of Ripcord, 6 L of water
	2016	August 4	11	Delegate	Full Season Insecticide, and Water Control	6L	2 g of Delegate, 6 L of water
	2016	August 11	12	Ripcord	Full Season Insecticide, and Water Control	6L	1 mL of Ripcord, 6 L of water
G	2016	June 23	5	Delegate	Full Season Insecticide, Early Season Insecticide and Water Control	4L	2 g of Delegate, 4L of water

Field	Year	Date	Week	Product	Treatment sprayed	Rate of water used per treatment	Rate of insecticide used per treatment
	2016	July 7	7	Ripcord	Full Season Insecticide, Early Season Insecticide and Water Control	6L	1 mL of Ripcord, 6 L of water
	2016	July 14	8	Delegate	Full Season Insecticide, Early Season Insecticide and Water Control	6L	2 g of Delegate, 6 L of water
	2016	July 28	10	Ripcord	Full Season Insecticide, and Water Control	6L	1 mL of Ripcord, 6 L of water
	2016	August 4	11	Delegate	Full Season Insecticide, and Water Control	6L	2 g of Delegate, 6 L of water
	2016	August 11	12	Ripcord	Full Season Insecticide, and Water Control	6L	1 mL of Ripcord, 6 L of water
	2016	August 18	13	Delegate	Full Season Insecticide, and Water Control	6L	2 g of Delegate, 6 L of water
	2016	August 25	14	Ripcord	Full Season Insecticide, and Water Control	6L	1 mL of Ripcord, 6 L of water
H	2016	June 30	6	Delegate	Full Season Insecticide, Early Season Insecticide and Water Control	6L	2 g of Delegate, 6L of water
	2016	July 7	7	Ripcord	Full Season Insecticide, Early Season Insecticide and Water Control	4.8L	0.8 mL of Ripcord, 4.8 L of water
	2016	July 14	8	Delegate	Full Season Insecticide, Early Season Insecticide and Water Control	4.8L	1.6 g of Delegate, 4.8 L of water
	2016	July 21	9	Ripcord	Full Season Insecticide, Early Season Insecticide and Water Control	4.8L	0.8 mL of Ripcord, 4.8 L of water
	2016	August 4	11	Delegate	Full Season Insecticide, and Water Control	4.8L	1.6 g of Delegate, 4.8 L of water
	2016	August 12	12	Ripcord	Full Season Insecticide, and Water Control	4.8L	0.8 mL of Ripcord, 4.8 L of water
	2016	August 18	13	Delegate	Full Season Insecticide, and Water Control	4.8L	1.6 g of Delegate, 4.8 L of water
	2016	August 25	14	Ripcord	Full Season Insecticide, and Water Control	4.8L	0.8 mL of Ripcord, 4.8 L of water

Appendix C. Grower Survey Example (2015)

Thrips Questionnaire

Dear Grower,

This short survey is designed to identify barriers and gaps in knowledge related to thrips and potato production. Thank you for your time in helping us to collect this information. Funding for this project has been provided by Agriculture and Agri-Food Canada and the BC Ministry of Agriculture through the Investment Agriculture Foundation of BC under Growing Forward 2, a federal-provincial-territorial initiative. The program is delivered by the BC Agriculture & Food Climate Action Initiative. Funding is also provided by the Lower Mainland Horticulture Improvement Association, the Potato Industry Development Fund and E.S. Cropconsult Ltd.

Kiara Jack (E.S. Cropconsult Ltd.)

1. Have you heard of thrips?
   A) Yes
   B) No
2. Do you know how to recognize thrips?
   A) Yes
   B) Maybe
   C) No
3. Do you know how to recognize thrips damage?
   A) Yes, when damage is heavy
   B) Yes, when damage is light
   C) Yes, when damage is heavy or light
   D) No, but I have seen my plants die down early
   E) No
4. Do you consider thrips a pest of concern?
   A) Serious concern
   B) Moderate concern
   C) Slight concern
   D) No concern
5. How often are thrips a pest of concern?
   A) Often
   B) Sometimes
   C) Rarely
   D) Never
6. Have you sprayed specifically for thrips in the past?
   A) Yes
   B) No
7. In an average year how many fields have you sprayed for thrips?
   A) Multiple whole fields
   B) A whole field
   C) Part of multiple fields
   D) Part of one or two fields
   E) No fields

8. When planning where to plant potatoes, do you ever consider adjacent crops which might harbour thrips?
   A) Yes
   B) No
9. Have you adjusted your management of adjacent crops to reduce thrips pressure in potatoes?
   A) Yes
   B) Sometimes
   C) No
10. Do you select pesticides that conserve beneficial insects which may help manage thrips in your fields?
   A) Yes
   B) Sometimes
   C) No
11. Do you know what management practices you could implement to minimize thrips damage?
   A) Yes
   B) No
12. Do you know which varieties are most susceptible to thrips?
   A) Yes
   B) No
13. Have you ever selected varieties that are less susceptible to thrips?
   A) Yes
   B) Sometimes
   C) No
14. Do you know if thrips can transmit viruses in potatoes?
   A) Yes
   B) No
15. Have you heard of tomato spotted wilt virus?
   A) Yes
   B) Yes but not related to potatoes
   C) No
16. Do you know what climate thrips thrive under?
   A) Yes
   B) No

Thank you! Please return by September 18th to kiara@escrop.com or 1-888-813-6228 (fax)

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Appendix D. Example of Thrips Grower Information Sheet and Project Update Summary

2017 Thrips in Potatoes Info Sheet

Kiara Jack and Dru Yates, E.S. Cropconsult Ltd.
Cell: 604-835-2876 kiara@escrop.com

WHAT ARE THRIPS?

Photo: Szent Istvan University

- Adults: 1-1.5 mm long, antennae, can be yellowish or dark depending on species, winged

- Juvenile: translucent, yellowish body, reddish eyes

- Have piercing/sucking mouthparts, used to penetrate plant cells

- Short life cycle (egg to adult in as little as two weeks) under hot dry conditions

Image above: Thrips at various points of the life cycle – translucent juveniles to the left and winged adult to the right.

WHY ARE THRIPS A CONCERN?

Thrips cause damage through:

- Feeding
- Egg laying
- Virus transfer

How to identify thrips damage:

- Shiny
- Speckled
- White or silvery scarring
- Hairspray-like
- Frass → dark specks
- Easier to see if moved in sunlight
- Rough lines
- Running along the veins
- Juvenile and adult thrips
- Predators of thrips

Photos: K. Jack, ES Cropconsult Ltd.

Image above: Varying levels of thrips feeding damage on potato leaves – underside (left), topside (right).

Project Title: Evaluation of thrips damage to potatoes in a changing climate.

Author and Associates: Kiara Jack, Marjolaine Dessureault, Heather Meberg (E.S. Cropconsult), Wim van Herk, Bob Vernon (AAFC, Agassiz), Robert McGregor (Douglas College). Funding for this project has been provided by the governments of Canada and British Columbia through the Investment Agriculture Foundation of BC under *Growing Forward 2*, a federal-provincial-territorial initiative. The program is delivered by the BC Agriculture & Food Climate Action Initiative. Funding is also provided by the Lower Mainland Horticulture Improvement Association, the Potato Industry Development Fund and E.S. Cropconsult Ltd.

Problem: Over the last decade, thrips have become an increasing problem in potatoes, most likely due to reduced use of broad spectrum insecticides and climate change. Climate change predictions for the Lower Mainland and BC in general include hotter, drier summers; conditions which thrips thrive under. Thrips cause economic damage to crops through feeding, oviposition and vectoring of tomato spotted wilt virus (TSWV) in other parts of the world but it is unknown whether or not this is true locally. Also, there is no known threshold for thrips in potatoes.

Objective of research: There are four objectives: 1) Evaluate yield loss due to thrips damage to potato crops in relation to growing season conditions. 2) Assess occurrence of thrips vectoring tomato spotted wilt virus (TSWV) to potatoes within the Fraser Valley. 3) Evaluate potato varietal difference in thrips attraction. 4) Increase grower knowledge of the effect of thrips on potato yield and quality, and which varieties can be used to adapt to thrips issues as the climate changes.

Methodology:

Objective 1: The trials consisted of three to four treatments (untreated control, water control, full season insecticide and early season insecticide) replicated within four potato fields in Delta, BC. Thrips numbers on sticky cards, foliage and foliar feeding damage were assessed per week. Yield measurements included plant number, number of tubers and weight of unwashed tubers.

Objective 2: Leaves and thrips were collected from selected fields and tested for TSWV using ELISA.

Objective 3: Field variety, surrounding crop type, and thrips numbers within fields were recorded for many fields within the Fraser Valley. Spray record data was also added in 2016.

Objective 4: A survey of grower knowledge on thrips was completed. Project finding have been disseminated through handouts, posters or presentations at meetings which potato growers attend or via mail or articles.

Preliminary Findings:

Objective 1: Early season feeding damage may have an impact on yield.

Objective 2: No TSWV was found.

Objective 3: Variety, surrounding crop and geographic orientation all appear to play a role in risk of thrips issues

Objective 4: Most growers are aware of thrips, many are concerned about climate and thrips and there are gaps in knowledge related to thrips identification and management

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Appendix E. Summary of Insignificant and Maximal Model Values for Objective 1

Table 19. ANOVA output on generalized linear models on the effect of treatment on thrips on triplets and cards in 2015 and 2016. Interaction terms were included in the maximum model and were excluded if they were found to be not significant.

Year	Response	Model terms	Degrees of Freedom	Deviance	Residual Degrees of Freedom	Residual Deviance	P Value	
2015	Thrips on triplets - maximum model	Treatment	2	3198.906	1002	12168.871	<0.001	***
		Field	3	3712.338	999	8456.533	<0.001	***
		Week (covariate)	1	856.179	998	7600.354	<0.001	***
		Treatment x Field	6	90.848	992	7509.506	0.170	
2016	Thrips on triplets - maximum model	Treatment	2	1297.613	1097	207703.76	0.001	**
		Field	3	44122.95	1094	163580.81	<0.001	***
		Week (covariate)	1	64310.23	1093	99270.58	<0.001	***
		Treatment x Field	6	377.002	1087	98893.578	0.655	
	Thrips on cards - maximum model	Treatment	3	884.66	1708	101098.75	0.008	**
		Field	3	13772.72	1705	87326.025	<0.001	***
		Week (covariate)	1	9252.867	1704	78073.158	<0.001	***
		Treatment x Field	9	363.572	1695	77709.586	0.850	

Table 20. Linear maximal model output on the effect on potato yield of thrips numbers on cards across the season, and before, during, and after flowering in 2015 and 2016.

Year	Response	Model term	Estimate	Standard error	Test statistic	P value	
2015	Yield - Maximal model	(Intercept)	1.886	0.574	3.286	0.0014	**
		Mean number of thrips on cards during flowering	0.006	0.003	2.212	0.0290	*
		Field B	1.240	0.675	1.838	0.0687	.
		Field C	1.503	0.721	2.083	0.0395	*
		Field D	0.696	0.859	0.810	0.4196	
		Mean number of thrips on cards x Field B	-0.006	0.003	-1.934	0.0557	.
		Mean number of thrips on cards x Field C	-0.008	0.005	-1.710	0.0900	.
		Mean number of thrips on cards x Field D	-0.016	0.007	-2.255	0.0261	*
2016	Yield - Maximal model	(Intercept)	3.635	0.179	20.318	< 2e-16	***
		Mean number of thrips on cards before flowering	0.050	0.045	1.096	0.2751	
		Field F	1.318	0.377	3.498	<0.001	***
		Field G	-1.495	0.274	-5.455	<0.001	***
		Field H	-0.545	0.238	-2.288	0.0236	*
		Mean number of thrips on cards x Field F	-0.085	0.067	-1.274	0.2047	
		Mean number of thrips on cards x Field G	0.028	0.052	0.528	0.5984	
		Mean number of thrips on cards x Field H	-0.095	0.086	-1.114	0.2672	
	Yield - Maximal model	(Intercept)	3.864	0.204	18.975	<0.001	***
		Mean number of thrips on cards during flowering	-0.004	0.015	-0.284	0.7766	
		Field F	1.017	0.253	4.019	<0.001	***
		Field G	-1.694	0.257	-6.595	<0.001	***
		Field H	-0.710	0.284	-2.496	0.0137	*
		Mean number of thrips on cards x Field F	-0.001	0.016	-0.079	0.9373	
		Mean number of thrips on cards x Field G	0.030	0.016	1.818	0.0711	.
		Mean number of thrips on cards x Field H	-0.003	0.018	-0.173	0.8631	

Table 21. Linear maximal model output on the effect on potato yield of thrips damage on triplets across the season, and before, during, and after flowering.

Year	Response variable	Model terms	Estimate	Standard error	Test statistic	P value	
2015	Yield - maximal model	(Intercept)	3.270	0.315	10.393	<0.001	***
		Maximum damage score throughout season	-0.167	0.394	-0.425	0.6720	
		Field B	-0.116	0.557	-0.208	0.8358	
		Field C	-0.167	0.353	-0.475	0.6360	
		Field D	-1.367	0.356	-3.843	<0.001	***
		Maximum damage score throughout season x Field B	0.290	0.588	0.494	0.6225	
		Maximum damage score throughout season x Field C	0.187	0.398	0.470	0.6396	
		Maximum damage score throughout season x Field D	0.076	0.397	0.192	0.8479	
	Yield - maximal model	(Intercept)	3.169	0.092	34.370	<0.001	***
		Maximum damage score before flowering	-1.100	1.166	-0.943	0.3478	
		Field B	0.269	0.175	1.541	0.1262	
		Field C	-0.018	0.145	-0.120	0.9044	
		Field D	-1.402	0.153	-9.137	<0.001	***
		Maximum damage score before flowering x Field B	0.451	1.267	0.356	0.7228	
		Maximum damage score before flowering x Field C	1.102	1.296	0.850	0.3970	
		Maximum damage score before flowering x Field D	0.145	1.299	0.112	0.9113	
	Yield - maximal model	(Intercept)	3.139	0.224	13.990	<0.001	***
		Maximum damage score during flowering	0.005	0.322	0.016	0.9871	
		Field B	-0.027	0.386	-0.070	0.9441	
		Field C	-0.278	0.302	-0.920	0.3597	
		Field D	-1.280	0.279	-4.583	<0.001	***
		Maximum damage score during flowering x Field B	0.187	0.469	0.399	0.6905	
		Maximum damage score during flowering x Field C	0.304	0.376	0.810	0.4197	
		Maximum damage score during flowering x Field D	-0.268	0.359	-0.745	0.4577	

Year	Response variable	Model terms	Estimate	Standard error	Test statistic	P value	
	Yield - maximal model	(Intercept)	3.249	0.238	13.644	<0.001	***
		Maximum damage score after flowering	-0.172	0.354	-0.485	0.6286	
		Field B	0.030	0.938	0.032	0.9742	
		Field C	-0.150	0.285	-0.525	0.6006	
		Field D	-1.349	0.288	-4.687	<0.001	***
		Maximum damage score after flowering x Field B	0.174	1.007	0.173	0.8632	
		Maximum damage score after flowering x Field C	0.193	0.358	0.538	0.5916	
		Maximum damage score after flowering x Field D	0.081	0.357	0.227	0.8210	
	Yield - maximal model	(Intercept)	3.794	0.142	26.713	<0.001	***
		Maximum damage score throughout season	0.022	0.155	0.139	0.8898	
		Field F	1.145	0.224	5.117	<0.001	***
		Field G	-1.013	0.249	-4.072	<0.001	***
		Field H	-0.613	0.222	-2.756	0.0066	
		Maximum damage score throughout season x Field F	-0.107	0.166	-0.647	0.5186	
		Maximum damage score throughout season x Field G	-0.093	0.248	-0.375	0.7085	
		Maximum damage score throughout season x Field H	-0.126	0.178	-0.706	0.4812	
2016	Yield - maximal model	(Intercept)	3.744	0.129	29.124	<0.001	
		Maximum damage score before flowering	0.254	0.373	0.680	0.4973	
		Field F	0.994	0.209	4.756	<0.001	***
		Field G	-1.102	0.199	-5.530	<0.001	***
		Field H	-0.639	0.176	-3.633	<0.001	***
		Maximum damage score before flowering x Field F	-0.284	0.451	-0.630	0.5296	
		Maximum damage score before flowering x Field G	-0.058	0.513	-0.114	0.9098	
		Maximum damage score before flowering x Field H	-0.806	0.577	-1.397	0.1645	

Year	Response variable	Model terms	Estimate	Standard error	Test statistic	P value	
	Yield - maximal model	(Intercept)	3.735	0.129	28.945	<0.001	***
		Maximum damage score during flowering	0.113	0.149	0.758	0.4498	
		Field F	1.145	0.189	6.048	<0.001	***
		Field G	-1.061	0.180	-5.896	<0.001	***
		Field H	-0.560	0.180	-3.113	0.0022	**
		Maximum damage score during flowering x Field F	-0.243	0.175	-1.392	0.1661	
		Maximum damage score during flowering x Field G	-0.049	0.215	-0.229	0.8193	
		Maximum damage score during flowering x Field H	-0.325	0.184	-1.760	0.0806	.
	Yield - maximal model	(Intercept)	3.864	0.119	32.363	<0.001	***
		Maximum damage score after flowering	-0.108	0.174	-0.621	0.5357	
		Field F	1.076	0.210	5.122	<0.001	***
		Field G	-1.139	0.232	-4.898	<0.001	***
		Field H	-0.684	0.209	-3.275	0.0013	**
		Maximum damage score after flowering x Field F	0.022	0.184	0.120	0.9045	
		Maximum damage score after flowering x Field G	0.095	0.264	0.358	0.7209	
		Maximum damage score after flowering x Field H	0.004	0.195	0.023	0.9820	

Table 22. Linear maximal model output on the effect on the proportion of small potatoes of thrips number on cards and damage on triplets across the season, and at time periods where thrips were previously shown to significantly affect yield.

Year	Response	Model terms	Estimate	Standard error	Test statistic	P Value	
2015	Proportion of small potatoes as a factor of total yield - maximal model	(Intercept)	0.224	0.093	2.399	0.0181	*
		Mean number of thrips on cards across whole season	-0.001	0.001	-1.582	0.1164	
		Field B	-0.158	0.109	-1.456	0.1483	
		Field C	-0.071	0.125	-0.571	0.5689	
		Field D	-0.103	0.125	-0.825	0.4113	
		Mean number of thrips on cards x Field B	0.001	0.001	1.519	0.1315	
		Mean number of thrips on cards x Field C	0.001	0.001	1.611	0.1100	
		Mean number of thrips on cards x Field D	0.001	0.001	1.723	0.0876	.
	Proportion of small potatoes as a factor of total yield - maximal model	(Intercept)	0.177	0.065	2.716	0.0077	**
		Mean number of thrips on cards after flowering	-0.001	0.000	-1.555	0.1228	
		Field B	-0.118	0.079	-1.507	0.1346	
		Field C	0.165	0.095	1.745	0.0837	.
		Field D	-0.022	0.097	-0.222	0.8243	
		Mean number of thrips on cards x Field B	0.001	0.000	1.542	0.1260	
		Mean number of thrips on cards x Field C	0.000	0.000	-0.214	0.8311	
		Mean number of thrips on cards x Field D	0.001	0.000	1.522	0.1309	
	Proportion of small potatoes as a factor of total yield - maximal model	(Intercept)	0.080	0.038	2.121	0.0361	*
		Maximum damage score throughout the season	-0.004	0.047	-0.083	0.9339	
		Field B	-0.020	0.067	-0.303	0.7621	
		Field C	0.126	0.042	2.979	0.0035	**
		Field D	0.070	0.043	1.635	0.1049	
		Maximum damage score x Field B	0.006	0.071	0.080	0.9365	
		Maximum damage score x Field C	0.006	0.048	0.135	0.8930	
		Maximum damage score x Field D	0.015	0.048	0.322	0.7484	

Year	Response	Model terms	Estimate	Standard error	Test statistic	P Value	
	Proportion of small potatoes as a factor of total yield - maximal model	(Intercept)	0.070	0.029	2.432	0.0166	*
		Maximum damage score after flowering	0.012	0.043	0.279	0.7808	
		Field B	-0.014	0.113	-0.122	0.9030	
		Field C	0.138	0.034	4.022	<0.001	**
		Field D	0.083	0.035	2.388	0.0186	
		Maximum damage score x Field B	-0.006	0.121	-0.049	0.9610	
		Maximum damage score x Field C	-0.010	0.043	-0.229	0.8195	
		Maximum damage score x Field D	-0.001	0.043	-0.028	0.9778	
	Proportion of small potatoes as a factor of total yield - maximal model	(Intercept)	0.079	0.022	3.619	<0.001	***
		Mean number of thrips on cards before flowering	0.000	0.006	0.059	0.9533	
		Field F	-0.008	0.046	-0.164	0.8696	
		Field G	0.258	0.034	7.687	<0.001	***
		Field H	0.246	0.029	8.446	<0.001	***
		Mean number of thrips on cards x Field F	0.002	0.008	0.235	0.8145	
2016		Mean number of thrips on cards x Field G	-0.012	0.006	-1.942	0.0541	.
		Mean number of thrips on cards x Field H	0.010	0.010	0.948	0.3449	
	Proportion of small potatoes as a factor of total yield - maximal model	(Intercept)	0.077	0.016	4.890	<0.001	***
		Maximum damage score before flowering	0.014	0.045	0.314	0.7541	
		Field F	0.005	0.025	0.190	0.8496	
		Field G	0.195	0.024	8.013	<0.001	***
		Field H	0.245	0.021	11.416	<0.001	***

Year	Response	Model terms	Estimate	Standard error	Test statistic	P Value
		Maximum damage score x Field F	-0.006	0.055	-0.102	0.9187
		Maximum damage score x Field F	-0.080	0.062	-1.277	0.2038
		Maximum damage score x Field H	0.114	0.070	1.620	0.1074

Appendix F. Statistical output for Objective 3

Table 23. Pairwise comparisons of potato varieties extracted from quasi-poisson regression analysis.

Response	Model terms		Rate ratio	Standard error	Degrees of freedom	Z ratio	P Value
Variety as a factor of adjusted thrips numbers	AC Peregrine	Chieftain	0.64212	0.20294	na	-1.4016	0.982
	AC Peregrine	Goldust	1.22858	0.62686	na	0.4035	1
	AC Peregrine	Imola	2.16157	0.85039	na	1.9594	0.793
	AC Peregrine	Kennebec	1.81503	0.4903	na	2.2067	0.625
	AC Peregrine	Norland	4.91105	8.99033	na	0.8694	1
	AC Peregrine	Orchestra	1.76866	0.38739	na	2.6034	0.338
	AC Peregrine	Pacific Russet	1.02404	0.52661	na	0.0462	1
	AC Peregrine	Redsen	5.80287	6.44966	na	1.582	0.951
	AC Peregrine	Russet Norkotah	1.84164	1.53928	na	0.7306	1
	AC Peregrine	Stampede Russet	2.86478	4.13964	na	0.7284	1
	AC Peregrine	Warba	15.746	22.4184	na	1.9361	0.807
	Chieftain	Goldust	1.91331	0.95171	na	1.3044	0.991
	Chieftain	Imola	3.3663	1.26788	na	3.2228	0.074
	Chieftain	Kennebec	2.82662	0.69271	na	4.24	0.002
	Chieftain	Norland	7.64818	13.974	na	1.1135	0.998
	Chieftain	Orchestra	2.75441	0.90219	na	3.0933	0.108
	Chieftain	Pacific Russet	1.59477	0.79983	na	0.9306	1
	Chieftain	Redsen	9.03704	9.99166	na	1.991	0.774
	Chieftain	Russet Norkotah	2.86807	2.37492	na	1.2724	0.992
	Chieftain	Satina	0.65133	0.18098	na	-1.543	0.96

Response	Model terms		Rate ratio	Standard error	Degrees of freedom	Z ratio	P Value
	Chieftain	Stampede Russet	4.46144	6.42686	na	1.0381	0.999
	Chieftain	Warba	24.5219	34.8016	na	2.2545	0.589
	Goldust	Imola	1.75941	0.92515	na	1.0745	0.999
	Goldust	Kennebec	1.47735	0.69071	na	0.8347	1
	Goldust	Norland	3.99736	7.3364	na	0.755	1
	Goldust	Orchestra	1.43961	0.7449	na	0.7042	1
	Goldust	Pacific Russet	0.83351	0.535	na	-0.2837	1
	Goldust	Redsen	4.72325	5.55435	na	1.3202	0.989
	Goldust	Russet Norkotah	1.49901	1.2682	na	0.4785	1
	Goldust	Satina	0.34042	0.16596	na	-2.2104	0.622
	Goldust	Stampede Russet	2.33179	3.38329	na	0.5835	1
	Goldust	Warba	12.8165	18.6736	na	1.7507	0.898
	Imola	Kennebec	0.83968	0.28277	na	-0.5189	1
	Imola	Norland	2.27198	4.12035	na	0.4525	1
	Imola	Orchestra	0.81823	0.3295	na	-0.4982	1
	Imola	Pacific Russet	0.47375	0.26224	na	-1.3496	0.987
	Imola	Redsen	2.68456	3.03405	na	0.8738	1
	Imola	Russet Norkotah	0.85199	0.67964	na	-0.2008	1
	Imola	Stampede Russet	1.32532	1.88634	na	0.1979	1
	Imola	Warba	7.28453	10.3729	na	1.3945	0.983
	Kennebec	Norland	2.70577	4.91797	na	0.5476	1
	Kennebec	Orchestra	0.97445	0.27625	na	-0.0913	1

Response	Model terms		Rate ratio	Standard error	Degrees of freedom	Z ratio	P Value
	Kennebec	Pacific Russet	0.5642	0.2674	na	-1.2076	0.995
	Kennebec	Redsen	3.19712	3.49572	na	1.063	0.999
	Kennebec	Russet Norkotah	1.01466	0.81868	na	0.018	1
	Kennebec	Stampede Russet	1.57837	2.25462	na	0.3195	1
	Kennebec	Warba	8.67536	12.2201	na	1.5338	0.962
	Norland	Orchestra	0.36014	0.66001	na	-0.5573	1
	Norland	Pacific Russet	0.20852	0.39026	na	-0.8376	1
	Norland	Redsen	1.18159	2.49922	na	0.0789	1
	Norland	Russet Norkotah	0.375	0.69253	na	-0.5311	1
	Norland	Satina	0.08516	0.15537	na	-1.3501	0.987
	Norland	Stampede Russet	0.58333	1.27802	na	-0.246	1
	Norland	Warba	3.20624	7.20976	na	0.5181	1
	Orchestra	Pacific Russet	0.57899	0.30188	na	-1.0481	0.999
	Orchestra	Redsen	3.28093	3.65753	na	1.0658	0.999
	Orchestra	Russet Norkotah	1.04126	0.8749	na	0.0481	1
	Orchestra	Stampede Russet	1.61974	2.34469	na	0.3332	1
	Orchestra	Warba	8.90278	12.6984	na	1.5328	0.962
	Pacific Russet	Redsen	5.66667	6.67367	na	1.4729	0.972
	Pacific Russet	Russet Norkotah	1.79842	1.65829	na	0.6365	1
	Pacific Russet	Satina	0.40842	0.20082	na	-1.8212	0.867
	Pacific Russet	Stampede Russet	2.79754	4.1867	na	0.6874	1

Response	Model terms		Rate ratio	Standard error	Degrees of freedom	Z ratio	P Value
	Pacific Russet	Warba	15.3765	22.6963	na	1.8515	0.852
	Redsen	Russet Norkotah	0.31737	0.42829	na	-0.8505	1
	Redsen	Satina	0.07207	0.07937	na	-2.3883	0.489
	Redsen	Stampede Russet	0.49368	0.88459	na	-0.3939	1
	Redsen	Warba	2.71349	4.81566	na	0.5625	1
	Russet Norkotah	Satina	0.2271	0.18671	na	-1.8031	0.875
	Russet Norkotah	Stampede Russet	1.55556	2.27949	na	0.3015	1
	Russet Norkotah	Warba	8.54998	13.2562	na	1.3841	0.984
	Satina	Stampede Russet	6.84974	9.84406	na	1.3389	0.988
	Satina	Warba	37.6491	53.3021	na	2.5628	0.365
Geographic orientation as a factor of adjusted thrips numbers	East	Inner	0.66126	0.12826	na	-2.1324	0.206
	East	North	0.87652	0.1807	na	-0.6393	0.969
	East	South	0.77246	0.15477	na	-1.2886	0.698
	East	West	0.86439	0.17762	na	-0.7092	0.954
	Inner	North	1.32554	0.24737	na	1.5101	0.556
	Inner	South	1.16818	0.2105	na	0.8626	0.911
	Inner	West	1.3072	0.24299	na	1.4411	0.601
	North	South	0.88129	0.17031	na	-0.6539	0.966
	North	West	0.98616	0.19582	na	-0.0702	1
	South	West	1.119	0.21545	na	0.584	0.977

Table 24. Statistical output for a generalized linear model using a quasi-poisson distribution on the effect of location, production type, row type, and variety on thrips numbers.

Model term	**Estimate**	**Standard error**	**Statistic**	**P Value**	
(Intercept)	1.72836	0.58188	2.9703	0.003	**
LocationDelta	1.11133	0.51307	2.16602	0.031	*
Production.typeOrganic	1.43754	0.20881	6.88457	<0.001	***
Row.LabelsInner	0.41361	0.19397	2.13238	0.034	*
Row.LabelsNorth	0.1318	0.20615	0.63931	0.523	
Row.LabelsSouth	0.25817	0.20036	1.28855	0.199	
Row.LabelsWest	0.14573	0.20549	0.7092	0.479	
VarietyChieftain	0.44298	0.31605	1.40162	0.162	
VarietyGoldust	-0.2059	0.51023	-0.4035	0.687	
VarietyImola	-0.7708	0.39341	-1.9594	0.051	*
VarietyKennebec	-0.5961	0.27013	-2.2067	0.028	*
VarietyNorland	-1.5915	1.83063	-0.8694	0.385	
VarietyOrchestra	-0.5702	0.21903	-2.6034	0.01	**
VarietyPacific Russet	-0.0238	0.51425	-0.0462	0.963	
VarietyRedsen	-1.7584	1.11146	-1.582	0.115	
VarietyRusset Norkotah	-0.6107	0.83582	-0.7306	0.466	
VarietySatina	0.87172	0.19308	4.51478	<0.001	***
VarietyStampede Russet	-1.0525	1.44501	-0.7284	0.467	
VarietyWarba	-2.7566	1.42375	-1.9362	0.054	*

Table 25. Least squared means output from generalized linear model on the effect of location, pass orientation, production type, and variety on thrips numbers.

Model term	Rate	Standard error	Degrees of freedom	asymp.LCL	asymp.UCL
Abbotsford	7.14	2.89407	NA	3.22212	15.8
Delta	21.7	6.281	NA	12.2864	38.25
East	10.3	2.85965	NA	5.96523	17.74
Inner	15.6	4.10433	NA	9.2749	26.09
North	11.7	3.20294	NA	6.87363	20.04
South	13.3	3.57644	NA	7.86636	22.54
West	11.9	3.24189	NA	6.97697	20.3
Conventional	6.06	1.42537	NA	3.8229	9.61
Organic	25.5	7.36717	NA	14.4927	44.94
AC Peregrine	24.4	7.47488	NA	13.3439	44.44
Chieftain	37.9	13.1526	NA	19.2194	74.84
Goldust	19.8	9.20254	NA	7.97944	49.24
Imola	11.3	3.95187	NA	5.66508	22.41
Kennebec	13.4	4.01344	NA	7.4654	24.11
Norland	4.96	8.74261	NA	0.15655	157.1
Orchestra	13.8	4.3581	NA	7.40438	25.6
Pacific Russet	23.8	12.692	NA	8.35512	67.69
Redsen	4.2	4.70279	NA	0.46672	37.74
Russet Norkotah	13.2	8.92685	NA	3.52142	49.66
Satina	58.2	16.5665	NA	33.3394	101.7
Stampede Russet	8.5	11.5473	NA	0.5932	121.8
Warba	1.55	2.15581	NA	0.10067	23.76