Insect Pest and Disease Incidence in Northwestern Ontario canola Fields

By

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While canola has enjoyed a long and lucrative history as a globally successful crop, it has only recently gained popularity in the Thunder Bay District, having been grown locally for just over 10 years. As part of any crop management strategy, it is a vitally important first step to plan mitigation tactics to prevent insect pests and disease infestation. Known insect pests and diseases detrimental to canola in the Manitoba, Saskatchewan and Southern Ontario areas include insect pests such as; Diamondback moth, three species of Flea beetle and the Lygus bug – and diseases such as Aster Yellows, Clubroot and Blackleg. While these insect pests and diseases have begun to migrate to Northwestern Ontario crops, their numbers have not yet proved significantly detrimental to the locally grown canola crops. As part of an Integrated Pest Management plan (IPM), crop rotation is among the recommended measures to prevent pest damage and is recognized as an effective practice for suppressing pests and/or improving biological control, especially with the addition of perennial species. To assist four local farmers with their crop management strategies, this study undertook a net-sweep survey and visual monitoring of eight local privately owned canola fields to determine the effectiveness of crop rotation as a part of their IPM plans. Rotation of canola crops is one such strategy that has been utilized in the prairie provinces and for many generations with a multitude of other crops with success. This study showed that there were significant effects on the incidence of Flea beetles when rotation age was changed but in general the levels of Lygus bugs and Diamondback moths stayed the same. Date of capture had significant effect on the incidence of Diamondback moth and field size had significant differences when divided into above and below 50 acres but no direct effect on insect pest incidence. Diseases existed in such low amounts that it was nearly impossible to attain proper statistical analysis for. Future studies can expand upon this with more rigorous testing measures to ensure proper management of canola in the Thunder Bay District.

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INTRODUCTION

Canola has had a rich history as a crop and has been cultivated for a variety of different purposes. canola species, *Brassica napus* L. is known to be one of the oldest cultured plants having been grown more than 4000 years ago (Hiiesaar et al. 2003). Canola as we know it in the modern world is a cultivar of *B. napus* that is low in erucic acid, less than 2% (Raymer, 2002). The low erucic variety was first licensed in 1968 with the introduction of the Oro seed brand (Bell, 1982). The low erucic acid content allowed the oil to be more safely consumed, where others oils were not. The two main sources of edible rapeseed oil, now referred to collectively as canola oil are *B. napus* and *Brassica rapa* L. (Raymer, 2002).

Figure 1. A typical canola field with distinctive bright Yellow flowers.

Source: Ethan Sahagun, 2018

Farmers produce canola extensively in Europe, Canada, Asia, Australia, and to a more limited extent in the United States (Raymer, 2002). Within Canada, the main canola producing provinces are Saskatchewan, Alberta, and Manitoba, in that order, with British Columbia and Ontario producing to a much lesser extent. A primary reason for Canadian farmers gravitating to canola as a crop is that it is a multi-use crop. The canola is primarily used as oil, with secondary uses being ground meal for feed and stalk-shredding for straw. The utility of the crop allows farmers to be paid for their crop (roughly 1000 dollars per tonne with an average yield of 0.6-1 tonnes per acre) and they can also use the by-products (ground meal or straw) on their own farms. Canadian production first reached 10 million tonnes in 2008; five years later canola production was nearly doubled to 18 million tonnes with the highest recorded tonnage in 2017 at 21.5 million tonnes, as noted in the table below (Canola Council of Canada 2022).

Table 1. Canadian canola harvest in acres for the last 20 years.

YEAR	CANADA TOTAL	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
2021	12,594,605	43,882	2,290,642	5,987,419	4,173,050	65,607
2020	19,484,700	33,400	3,190,700	10,967,900	5,212,100	55,900
2019	19,912,300	42,200	3,056,300	11,394,000	5,320,100	72,000
2018	20,723,500	66,700	3,318,400	11,308,000	5,870,600	123,900
2017	21,458,100	45,400	3,147,900	11,311,000	6,826,600	90,600
2016	19,599,200	37,100	2,608,200	10,682,100	6,157,500	81,600
2015	18,376,500	34,000	2,857,600	9,536,800	5,851,300	70,800
2014	16,410,100	31,300	2,510,600	7,971,900	5,796,900	71,900
2013	18,551,000	49,900	3,025,500	9,178,400	6,168,900	88,700
2012	13,868,500	61,200	2,100,100	6,486,400	5,097,200	82,800
2011	14,608,100	73,700	1,746,300	7,348,200	5,347,900	56,000
2010	12,788,600	75,500	2,215,800	5,692,600	4,740,000	39,700
2009	12,898,100	44,700	2,891,700	6,259,600	3,628,700	49,900
2008	12,644,900	49,900	2,576,400	5,629,100	4,322,700	31,800
2007	9,611,100	37,800	1,950,400	4,154,900	3,401,900	47,600
2006	9,000,300	14,200	1,825,700	3,696,800	3,424,600	27,200
2005	9,483,300	24,900	1,261,000	4,456,500	3,651,400	63,500
2004	7,673,600	46,500	1,746,300	2,880,300	2,925,700	43,800
2003	6,771,200	40,800	1,769,000	2,676,200	2,222,600	38,600
2002	4,520,500	44,200	1,451,500	1,769,000	1,224,700	18,100
2001	5,017,100	31,300	1,134,000	2,154,600	1,655,600	34,000

Source: Statistics Canada. Table 32-10-0359-01 – Estimated areas, yield, production and average farm price and total farm value of principal field crops.

As canola is a newer crop in Northwestern Ontario – just over 10 years – a full understanding of the insect pests and diseases that pose potential risk to crop yields in the area is limited. Known insect pests of the canola plant include, but are not limited to, the Diamondback moth (*Plutella xylostella* L.), three species of Flea beetle; the Striped beetle (*Phyllotreta striolata* (F.)), the Crucifer beetle (*Phyllotreta cruciferae* Goeze.) and the Hop beetle (*Psylliodes punctulata* Melsh.) and the Lygus bug (*Miridae* sp). Other known canola pests include the Bertha armyworm, the Swede midge, several species of cutworm and grasshoppers and many terrestrial beetles that are more carnivorous in nature. While these insect pests currently exist as major detriments to canola production in prairie provinces, causing extensive economic losses, they have yet to cause significant damage to most Northwestern Ontario crops. As with insect pests the diseases can be detrimental to canola crops as well. Potential diseases that may be present are Aster Yellows (Candidatus Phytoplasm asteris), Blackleg of canola (*Leptosphaeria maculans* P. Karst), Clubroot (*Plasmodiophora brassicae* Woronin) and others, such as, Powdery mildew (*Erysiphe cruciferarum*) and Alternaria blackspot (*Alternaria brassicae*). With canola growth and production becoming more popular, insect pests that are currently more prolific in crops found near Manitoba, Saskatchewan and Southern Ontario have been able to travel between fields and reach Northwestern Ontario.

Mitigation of insect pests and diseases is always the first step to protection of crops. One such step is choosing the correct seed. With seed selection comes the option to choose genetically modified seeds or seeds treated with insect pesticide (see figure below) to ensure survival of seeds and new sprouts.

Figure 2. Insect pesticide coated seed of canola, roughly 2mm in diameter.
Source: James Thordarson

There are currently three brands of canola in use at the Lakehead University Agricultural Research Station (LUARS) LibertyLink, Roundup ready and Clearfield; LibertyLink is also being used by the surrounding farmers. The first two are considered GMO products that are resistant to herbicides, and the seeds are typically pre-treated with an insect pesticide designed to kill any insect pests that may attempt to feed on the seed or newly emerging seedlings. Clearfield is not considered a GMO seed and, as such, is popular with organic farmers. GMO products are becoming more common as can be seen in Table 2. In 1995, 100% of canola grown commercially in Canada was conventional (non-GMO). Within five years that 100% for conventional had been reduced to 20% with Roundup Ready (RR) canola rising to 40%, LibertyLink canola (L) to 15% and Clearfield canola (CL) to 25%. By 2010, conventional canola was only used 1% of the time for three consecutive years with RR at 47%, L at 46% and CL at 6%.

Table 2. Estimated acreage, production, and percentage of herbicide-tolerant canola in Canada – 1995 to 2010

YEAR	Total Acres Harvested	Total Production (Metric Tonnes)	Roundup Ready*	Liberty*	Clearfield**	Conventional
2010	16,097,000	11,866,000	47	46	6	1
2009	15,755,000	12,417,000	51	40	7	1
2008	16,048,000	12,643,000	45	41	13	1
2007	15,511,000	9,529,000	47	41	11	2
2006	12,946,000	9,100,000	44	40	11	5
2005	12,980,000	9,660,000	45	34	14	7
2004	12,200,000	7,728,000	45	30	18	7
2003	11,600,000	6,669,000	48	22	19	12
2002	7,060,000	3,577,000	43	21	20	16
2001	9,601,000	5,062,000	45	16	20	19
2000	11,995,000	7,086,000	40	15	25	20
1999	13,700,000	8,798,000	35	18	18	29
1998	13,500,000	7,588,000	23	12	16	49
1997	12,000,000	6,266,000	4	8	14	74
1996	8,800,000	5,056,000	1	3	6	90
1995	13,200,000	6,436,000	0	0	0	100

Source: Provincial databases, seed company information, surveys and Statistics Canada Updated: December 3, 2010 (data sources no longer available)

As choosing the right seed can help to mitigate insect pest problems, so too can crop rotation as it is one of the oldest forms of crop management for weeds and insect pests and diseases. The most important mitigation strategy, to ensure long-term sustainable canola production, is to rotate canola with other crops (Harker et al. 2015a). Rotating the crop yearly and using multiple species of crop as well as different crop types (cereal, feed, oil, etc.) is an easy way to reduce the number of possible pests that persist between different harvests. Crop diversification should always be considered as a strategy to prevent emerging pest problems and improve crop resilience also in the North (Altieri et al. 2015). An insect pests affecting canola is unlikely to affect wheat and will change locations for a better food source or die off once any natural food source has been limited. By increasing the number of crops between each crop, such as canola, you minimize the chances that insect pests and diseases will be in that field in any significantly harmful capacity. This is a cultural mechanism of field management that does not rely on chemicals, nor is it overly expensive. The practice of using crop rotation to mitigate pests and diseases is regarded as healthy for the environment by the public and keeps pesticide treatment costs down for farmers.

Insect pests and diseases have different life cycles, host specifications, modes of attack and methods of sampling. I will discuss three of the main insect pests known to hold the potential to cause economic losses as well as three diseases common to canola crops in Canada. These insect pests and diseases have been identified as being present in Northwestern Ontario in some capacity.

LITERATURE REVIEW

Flea beetles

The three most common species of Flea beetle to affect canola crops are *Phyllotreta cruciferae* (Goeze) the Crucifer Flea beetle (Figure 3), *Phyllotreta striolata* (F.) the Striped Flea beetle (Figure 4) and *Psylliodes punctulata* Melsh the Hop Flea beetle (Figure 5). The Flea beetles' host range is restricted to plants of Brassicaceae, Capparaceae and Tropaeolaceae families (Feeny et al. 1970). Flea beetles measure roughly 3-4mm in length and are best known for their powerful hindlegs that allow them to jump significant distances like Fleas, hence the name Flea beetle.

Figure 3. A Crucifer Flea beetle compared to the tip of a ballpoint pen. Source: James Thordarson

P. cruciferae was introduced into North America in the early 1920s in British Columbia and can now be found across southern Canada and the USA (Wylie, 1979). P. cruciferae has been the most abundant Flea beetle on crops of *Brassica napus* in Manitoba, followed in order by *P. striolata* and *P. punctulata* (Wylie, 1979). Insect pests are drawn to plants based on various factors such as enticing volatiles (chemical mixtures released by plants often due to stress) or the insect pest's specific nutrient needs. The attractiveness of plants in the mustard family for Flea beetles is a result of the presence of volatile mustard oils (mustard plants being part of the Brassica family of plants) (Smith, 2000). Flea beetles of the genus *Phyllotreta* are serious and almost cosmopolitan pests of plants from the Brassicaceae family (Burgess, 1977).

Figure 4. Three Striped Flea beetles on a canola seedling.

Source: James Thordarson

In northern regions the three Flea beetle species have only one generation per year (Lamb, 1983). The adult Flea beetle species overwinter in hedgerows, topsoil, and other available shelter. The adults are active in early spring. They disperse and seek out their hosts, which are typically weeds initially, with a later progression of moving into cultivated crops. Eggs are laid in the soil near the host plants in late May and into June. Larvae hatch after a few days depending on temperature requirement and degree days (^{o}D). A degree day is the amount of heat that has been accumulated in an area over a 24-

hour period where the temperature is higher than the organisms (in this case an insect) developmental threshold (Dara 2011). For eggs to hatch the temperature must be above 11^{o}C and to reach adulthood the accumulation of ^{o}D must be 455.9. (Kinoshita et al. 1979). The larvae feed on the roots of the host plant before pupating in the soil. Adult Flea beetles emerge in July and August and feed on cultivated and wild crucifers (Feeny et al. 1970). The most damaging stage to the canola crop occurs with overwintered adults feeding on newly emerged seedlings in spring (Burgess, 1977). Flea beetle damage at early stages can be detrimental to crops to the extent that some fields may have to be fully replanted after an epidemic.

Figure 5. Flea beetle damage on young canola seedling. Note the pitting and holes in the leaves.

Source: James Thordarson

Lygus bugs

The Lygus bug is part of the Miridae family. The Lygus bug has four life stages, egg, larva, nymph, and adult. The nymph stage consists of five instars (separate developmental stages between moulting periods). Each of these instar stages, as well as the adults, are harmful to the host plants (Butts and Lamb, 1990). In Western Canada four Lygus species have been observed as destructive to canola crops. The are *Lygus keltoni* (Schwartz and Foottit), *Lygus lineolaris* (Palisot de Beauvois), *Lygus elisus* (Van Duzee), *Lygus borealis* (Kelton), all collectively referred to as Lygus bugs (Cárcamo, 2002). The Lygus bugs feed on flower buds as well as the seeds and will use their piercing sucking mouthparts to digest the plant before sucking in the digested nutrients as seen in Figure 6 (Kelton, 1975 & Young, 1986).

Figure 6. Adult Lygus bug on canola.

Source: Canola Council of Canada

The Lygus bug can have as many as three generation per year depending on the climate of the region and all regions are able to experience an extra generation when an early spring and late fall occur (Wise et al. 2005). The Lygus bug overwinter under plant litter in various locations and are able to survive air temperatures of -30 degrees Celsius under their shelter. Lygus development requires a temperature of 12°C and require 426 °D to complete a full generation (Dara 2011).

Figure 7. Third or fourth instar nymph Lygus bug on a net.

Source: Canola Council of Canada.

Lygus bugs are a generalist species, in that they can, and typically will, attack hundreds of different plant species globally.

> These species include plants such as alfalfa, canola, lentils, potato, strawberries, vegetable crops, flax, hemp, fava beans, tree fruits, and weeds such as redroot pigweed, stinkweed, wild mustard, and lamb's-quarters.
>
> (Young, 1986 & Butts and Lamb, 1991).

Fourth and fifth instar Lygus bugs and adults are typically the most damaging to crops. Reductions to yield of *B. napus* have been recorded at upwards of 20% when plants are flowering and when seed pods are going through the maturation period (Wise and Lamb, 1998). Typical field assessments are conducted at this crucial time when Lygus bugs are most active. Lygus bugs are most damaging during hot dry weather when plants are already stressed. Lygus bug damage causes flower buds and seed pods to abort; these symptoms can be easily monitored and, as such, can be used to help identify the presence of Lygus bugs in the field.

Diamondback moths

The Diamondback moth (DBM), *Plutella xylostella* (L.) belongs to the Lepidopteran family of insect pests. The adult moths (Figure 8) are roughly 8-9mm in length, with wings folded over its back. The markings on the wings form diamond-like shapes giving rise to its common name (Government of Alberta, 2014a). All larval stages will feed on leaves, flower buds and seed pods and this occurs throughout the season because of the multiple generations that overlap. DBM is considered as one of the most destructive pests to cruciferous species in the world and can become resistant to most insect pesticides (Talekar and Shelton, 1993).

Figure 8. Adult Diamondback moth.

Source: canola Council of Canada

The Diamondback moth may overwinter in the prairies, but not frequently or in large numbers, and instead migrates northward from infested regions in the southern or western U.S.A. or northern Mexico with wind currents (Dosdall et al. 2011). Most large infestations occur when there is no heavy rain and temperatures stay warm for extended periods of time. The DBM may have up to four generation per year in the prairies depending upon climate and food availability (Government of Alberta, 2014a). The development threshold temperature for Diamondback moth is 7.3°C with a full generation time (egg to adult) requiring only 283 °D (Harcourt 1954). Diamondback moth is restricted in its host range to plants of the family Brassicaceae (Safraz et al. 2010).

Figure 9. Larval stage of the Diamondback moth and some damage to the leaf.
Source: canola Council of Canada

In most other regions of the world, Diamondback moths attack crops of cabbage (*Brassica oleracea* L. var. capitata), cauliflower (*B. oleracea* var. botrytis), broccoli (*B.*

oleracea var. italica), and kale (*B. oleracea* var. alboglabra) (Dosdall et al. 2011). The Diamondback moth feeds on wild and cultivated brassicas, but only in the absence of cultivated hosts does the pest appear to maintain itself on wild species (Talekar and Shelton, 1993). The costs of preventative measures and damage due to DBM have been estimated at between four and five billion US dollars worldwide (Zalucki et al. 2012a).

Clubroot

Clubroot disease is a major threat to crops belonging to the Brassicaceae family (Diederichsen, 2009). It was first reported in Prairie canola crops (*B. napus*) in 2003 (Strelkov and Hwang 2014) thought it was previously found in 1997 in Quebec where canola crops are much less prevalent (Morasse et al. 1997). Clubroot disease is caused by *Plasmodiophora. brassicae*, an obligate, soilborne parasite. The parasite causes gall structures (Figure 10) to form on the roots of the host plant that will create difficulties with water and nutrient uptake (Wallenhammar, 1996).

Figure 10. Characteristic Clubroot galls on the roots of canola.

Source: Canola Council of Canada

Clubroot is estimated to be present in approximately 10% of all areas where host plants are cultivated (Crete, 1981) and up to 20% in Canada (Landry, 1992). The disease can persist in soils and remains viable for upwards of 20 years, making eradication of the pathogen extremely difficult (Wallenhammar, 1996). Resistant varieties of *B. napus* can be created to provide protection against Clubroot epidemics (Figure 11). Plants that are infected with the disease can become unstable after gall formation, affecting yield, quality, and crop consistency (Dixon 2007).

Figure 11. Healthy roots of a resistant canola plant that are unaffected by Clubroot disease.

Source: James Thordarson

Aster Yellows

The disease known as Aster Yellows is caused by aster leafhoppers (Figure 12), *Macrosteles quadrilineatus*, that carry *Candidatus* Phytoplasma asteris (a phytoplasma disease) (Government of Alberta, 2014b). Leafhoppers have egg, nymph and adult stages with generation times ranging from 27-34 days (Nakajima et al. 2009).

Figure 12. Aster leaf hopper that can be a vector for Aster Yellows.

Source: James Thordarson

The crowns of Aster Yellows diseased plants are subject to bacterial soft rot in wet weather but the disease itself is typically more prevalent in hot dry weather. The Aster Yellows can continue to develop in storage meaning already harvested crops are subject to yield loss. Various degrees of stunting can occur on seed plants, as well as potential malformation, and chlorosis (yellowing of leaves typically caused by nutrient deficiencies). Aster Yellows can also cause sterility of the flowering structures of the canola as seen in Figure 13 (Howard et al. 1994).

Figure 13. An example of Aster Yellows causing flowering bodies to abort and not produce seed pods.

Source: James Thordarson

In Quebec, symptoms of Aster Yellows on carrot are rated on a scale of 0 (no symptoms), 1 (symptoms rarely seen), 2 (symptoms every 10 paces), 3 (symptoms every 5 paces), or 4 (symptoms every pace). At a level of 4, it is usually best to obtain a more accurate measure of the incidence of the disease to predict the potential level of crop losses (Howard et al. 1994). While able to infect at least 191 plant species (Lee et al. 1998), the disease incidence and severity in Prairie canola is typically very low at around 1% (Government of Alberta 2014b).

Blackleg

The fungus *Leptosphaeria maculans* (Desm.) is the causal agent for Blackleg of canola and is among the most economically significant diseases of canola worldwide (Van De Wouw, 2016). Blackleg was initially reported in Saskatchewan and Manitoba in 1975 and 1984, respectively (Markell et al. 2008). Blackleg disease results in 10–20% yield losses annually in Canada and the United Kingdom, with up to 90% yield loss caused by epidemics in Australia (West et al. 2001).

Figure 14. Disease severity rating system that can be used for blackleg.

Source: Canola Council of Canada.

Blackleg disease is stubble-borne ,and it reproduces sexually on infected crop residue left after harvest. The sexual spores are released following rainfall events and land on the leaves of seedlings, germinate and then invade the plant through either open wounds or the stomata (Van De Wouw et al. 2021). Canola can be surveyed during and after the growth period by examining the exterior of stems and also by cutting stems (Figure 15) to check for internal signs of blackleg infection.

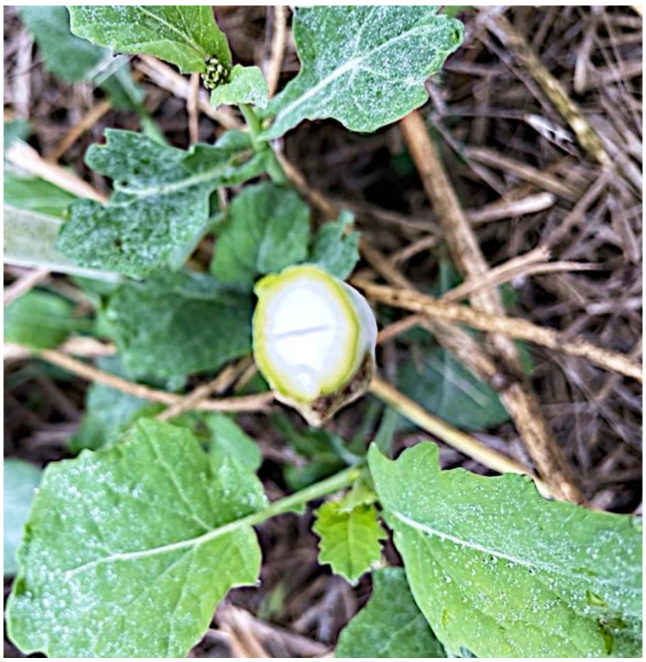

Figure 15. A stem of canola cut to determine whether there are signs of blackleg. This stem was clear of any blackleg, note the bright white core of the stem.

Source: James Thordarson

To manage for blackleg, farmers are advised to not grow canola on a field more frequently than once every four years. There is always a possibility that blackleg could be introduced to a farmer's land by wind-borne spores; longer rotations will increase the probability that low levels of disease infection will disappear when the infected stubble has rotted (Government of Alberta, 1997). Resistant varieties can be used but they have only been used to varying degrees of success worldwide.

Monitoring and Sampling

Management of insect pests and diseases is important to the health and yield received from a crop. To create effective crop management strategies, monitoring and sampling of crops is necessary to determine disease and insect pest abundance. Diseases and insect pests can damage crops at any growth stage and as such should be monitored at all growth stages. Taking pictures and recording observations of unknown pests and diseases will help to guarantee proper future identification (Figures 16 and 17).

Figure 16. Unknown disease or insect pest causing curling of seedpods in canola.
Source: James Thordarson

Figure 17. Dieback of seedpods that will limit oil availability in that plant.
Source: James Thordarson

Sampling methods for insect pests can include net sweeping, pit fall traps, light traps, window-pane traps, and sticky traps. Each technique has advantages targeting certain insect pests; pit fall traps are best for terrestrial insects, while window-pane traps are good for flying insect pests and light traps are used to catch nocturnal insect pests. When discussing diseases, one should look for malformed or different looking specimens as well as soil samples and normal looking specimens to bring in for further testing to determine if fungal, bacterial, or viral diseases are present. For the purposes of this study the only method of sampling used was net sweeping and therefore details of other sampling methods is not given.

An efficient way to sample in fields is the net sweep. A large cloth net is swept back and forth in front of the field Technician and used to catch any insect pests that may be flying or resting on plants. While walking through canola it is easiest to traverse in the early stages (Figure 18) before plants have bolted (begun growing very fast and developing flowering structures). After plants have gained height, they begin to tangle with each other and become incredibly difficult to walk through while minimizing damage to the crop.

Figure 18 Several weeks-old canola that is more easily walkable to observe for signs of damage.

Source: James Thordarson

Walking a field is the most basic form of visual monitoring for farmers to get a general sense of the field. Alternately, potential monitoring could include the use of drones for flyovers to help determine if there is the potential for yield loss or significant dieback in a crop. Monitoring should always be performed to determine whether economic thresholds have not yet been surpassed. Thresholds vary for all insect pests; for flea beetles it is 20% leaf area eaten on young plants, for lygus bugs it is 5 adults (or late-stage nymphs) per sweep and for Diamondback moth the threshold is 100-150 larvae per square metre in immature plants and 200-300 per square metre in mature plants (Canola Council of Canada). Monitoring and sampling should be performed regularly and thoroughly to determine the necessity for insect pesticides, herbicides or even re-seeding of a crop if damage is high.

Crop Rotation

As part of an Integrated Pest Management plan (IPM), crop rotation is among the recommended measures to prevent pest damage and is recognized as an effective practice for suppressing pests and/or improving biological control, especially with the addition of perennial species. Crop rotation is very common and can lead to the establishment and continuation of multiple ecosystem services. The maintenance of soil structures and the microbial activity within, the improvement of nutrient use within soils and crops, and the provision of pest management are all potential benefits inherent in crop rotation practices (Barbieri et al. 2017). Crop rotation is a vital mechanism in breaking the life cycle of specialist feeders to ensure there is no build up of insect pests and diseases in crops (Barzman et al. 2015). Pest management is based on the primary objective of prevention, with the secondary management strategy of extermination. The goal of crop rotation is to create an unfavorable environment for the possible pests while also creating more favorable conditions for the crop to grow (EU, 2009). The Canola Council of Canada recommends a three year rotation to lower levels of both clubroot and blackleg but states that in areas with vast amounts of canola a single field rotation plan will not limit insects such as flea beetle, lygus bug and diamondback moth. However, in an area of very little canola and spread over a large region it may still be effective.

To secure the highest potential benefits of an IPM with canola as part of the rotation, keep in mind that canola best follows cereal grains or fallow in rotation. A preferred crop rotation would have canola planted at least two cropping years between plantings. (Berglund et al. 2021). Not only can crop rotation be used as an effective method for pest control but intercropping has also proven to be beneficial. Intercropping is the practice of planting multiple crops in the same field to maximize yield of resources if space may be a limiting factor.

Intercropped plants repel pest insect pests by:

1. Releasing volatiles that repel pests;
2. Masking volatiles released by crop plants;
3. Altering crop volatiles when crop plants absorb root exudates from intercropped plants; and
4. Providing an alternative resource for pests to consume instead of the crop plants

(Lopes et al. 2016).

Adding the perennial crop alfalfa (*Medicago sativa* L.) into a crop rotation can increase the number of predatory arthropods in a preceding soybean crop, as alfalfa provides excellent habitat for diverse arthropod communities (Schipanski et al. 2017). While a crop rotation can be any number of years, the minimum recommendation is at least two years between successive canola crops. Not only should farmers consider what crops to rotate to maintain pest control, while, replenishing the most favourable nutrients for the incoming crop, but they must also consider how the changes in climate are affecting insect pest proliferation.

Figure 19. Newly emerging canola in a rich soil. Previously hay crops were on the field, which allows for nutrients in deeper soils to be more abundant to the new canola crop as it roots more deeply

Source: James Thordarson

Attempting to control insect pests should be considered equally important when discussing the potential adverse effects of local weather phenomena. These extended periods of potentially adverse weather can increase outbreak frequencies and geographical distributions of insect pests (Lamichane et al. 2015). Crop maintenance practices can improve the resilience of crops to insect pest herbivory and increase a crop’s potential for natural enemy diversity, both of which can help to buffer probable disruptions of biological control that may occur under increasing climate change conditions (Sentis et al. 2013). Sustainable agricultural practices that are promoted for mitigating climate change have the potential to also improve pest management practices (Murrell, 2017). Steps can be taken to mitigate the effects of insect pest outbreaks and disease epidemics in fields; however, climate and weather are major factors that can disrupt mitigation plans as certain conditions make it more optimal for insect pests and diseases to thrive.

OBJECTIVES

The prime objective of the study was to determine whether different rotation ages, specifically if the number of years between subsequent canola crops, has any significant effect on insect pest and disease incidence in Northwestern Ontario canola crops; however, it should be noted that the primary objective takes a more focussed look at the insect pest incidence and to a lesser extent the incidence of disease. Secondary objectives, with insect pest incidence as focus, include measuring the effects of field size, date of capture on the insect pest incidence. Measure the occurrence rates of diseases and insect pests in Northwestern Ontario that pose a risk to the growing of canola crops. There are three hypotheses that go with the objectives, as they pertain to insect pest incidence, as follows;

1. The incidence of the three insect pests (Flea beetles, Lygus bug and Diamondback moth) will be significantly affected by the rotation age of the field.
2. The incidence of the three insect pests will be significantly affected by the size of the field and
3. The incidence of the three insect pests will be significantly affected by the date of capture

METHODS

Four local farmers within the Thunder Bay District provided access to eight privately owned canola fields for surveying purposes in 2021. Surveys for insect pests incidence consisted of four net sweeps in transects across fields from a randomly chosen entry point on the edge of the field. No sweeps were conducted in the middle of the fields. Each field was surveyed by net sweep seven times during the study period. Net sweeps began at the edge of a field working inwards approximately 10 metres while performing a sweeping motion back and forth with the net (38cm diameter) both above and below the tops of plants to ensure full coverage. An average transect line consisted of 15-20 sweeps back and forth while walking forward. The net is swung at varying heights on the plant to achieve as much coverage as possible.

Figure 20. Typical depth of transect, roughly 10 metres into the field to perform net sweeps.
Source: James Thordarson

Sweeps were conducted at four different locations in the field to reduce potential bias from the differences in edge cover such as a road versus trees. Of the eight total fields, six were in the Slate River valley area close to Hwy 61 (Figure 21), while two others were in the Murillo area located off John St Road (Figure 22).

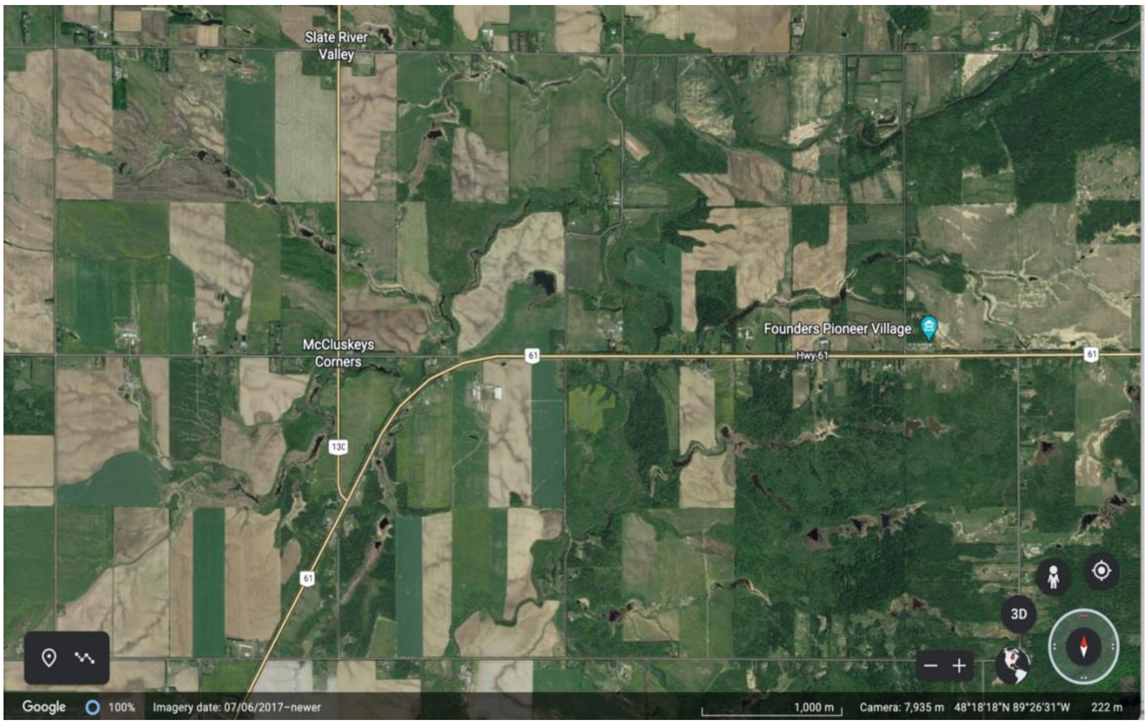

Figure 21. A map showing the general location of the six fields in the Slate River Valley outside Thunder Bay, ON

Source: Google Earth

Figure 22. Map of the John Street Road area (the road running east west across the map) with arterial roads branching off and fields visible.

Source: Google Earth

Sweeps were conducted from beginning of June after seedlings' emergence (Figure 23) until the beginning of September when the canola was deemed ready for the drying period to begin. Field sizes ranged from roughly 30 acres up to almost 100 acres. During net sweeps, plants were also observed for visible signs of decline from insect pests or diseases such as Aster Yellows or Clubroot and recorded for data compilation. The fields studied all had similar surroundings of open fields and very few trees except one field. This single field was away from most others and was surrounded on all sides by trees and did not have any openness between it and other fields.

Figure 23. Two-week-old canola crop growing in straight rows. This early stage with no plant overlap makes it easy to monitor for damage and perform net sweeps.

Source: James Thordarson

The survey also included the collection of soil samples at varying times through the growing season and observation of dead or dying plants for signs of possible fungal infection and will be mentioned throughout the narrative, while maintaining a primary focus of the net sweep surveys. Soil samples were taken from the entrance and middle of each field to determine whether Clubroot was present. These samples were only taken once at the beginning of the year. Samples were sent to, processed by and received back from the Ontario Ministry of Agriculture, Food and Rural affairs after they had been tested at the Agriculture and Food Lab at the University of Guelph. Several random plots were chosen in each of the fields following harvest to survey canola stems for signs of Blackleg of canola.

In the lab, specimens were unpacked from frozen Ziploc bags and emptied onto white paper to create contrast. From each bag insect pests were sorted into groups, counted, and compared to photos and descriptions to determine species. Detailed analysis of all specimens was conducted to ensure proper identification. The DinoXcope computer camera was used occasionally to help identify specimens with zoom capabilities.

Figure 24. Crucifer Flea beetle picture taken with a DinoXcope computer camera
Source: James Thordarson

Statistical analyses were performed using R studio to attain regressions, the regression plot graphs, and an Analysis of Variance (ANOVA's). Microsoft Excel was used to determine the results of the t-tests and graph the insect pest numbers.

Regressions indicate the percentage of the variance in the dependent variable that the independent variables explain collectively. This means that on a scale of 0-100% the r-squared value determines how much of the variance can be explained by the model. A high or low number does not always mean the model is good or bad as certain models can explain all the variance but are still poor descriptors and vice versa. This analysis was used to determine whether significant differences existed within the data sets

An ANOVA is a statistical analysis of how similar the means of two or more populations are. The significance is determined by the F and P values. F or P value of less than 0.05 is generally considered to be statistically significant as this value means there is less than a 5% chance that the null hypothesis is accepted. An ANOVA will also include regression values and several other additional values such as the mean square value, sum of squares and the standard error found within the data.

A t-test is used to directly compare the means of up to two data sets and has multiple variations such as a paired test, equal variance, and unequal variance. It will also allow a comparison between different sample sizes. t-tests use the t value for determining significance. These t values are one- or two-tailed and will be compared to a critical t value that has been previously determined and is based on the degrees of freedom found within and between data sets. If the calculated t value from the data is larger than the critical t value, then the data is determined to be significantly different.

RESULTS

The results of this study used three insect pests, Flea beetles, Lygus bugs and Diamondback moth that were determined to be the most potentially harmful to the canola crops. These insect pests are compared against three factors, rotation age of fields, the capture date of insect pests and the field size. These results will also compare the survey incidence of different diseases within the fields.

Rotation Age

The rotation age of a field is determined by the number of crop species cropped between a particular crop for which you are attempting to preserve against pests, diseases, and other potential detriments. Field rotation ages ranged from zero (never having had a canola crop planted previously; used as a control) up to six years between two canola crops. The specific ages were zero, one, two, four and six (Table 3). The rotation age that appeared the most in the study was the control age of zero with three fields (the number of insect pests sampled were averaged across all three), the four-year-old rotation age appeared twice (these numbers were also averaged) and each other age group appeared once (Table 3). Flea beetles were most abundant in the four-year rotation, while Lygus bug numbers were highest in the zero-year group and DBM were most captured in the six-year rotation. Lygus bugs and DBM were generally found with similar frequencies in all rotations except for Lygus bugs being found less only in the six-year rotation.

Table 3. Total number of insect pests collected within each rotation age

	Number of Insect pests		
Rotation age	Flea beetle	Lygus bug	Diamondback moth
0 (never had canola)*	42	22	11
1	73	17	12
2	46	18	12
4**	89	20	13
6	38	6	14

*Numbers of insects were averaged across three fields that had previously never had canola
** Numbers of insects were averaged across two fields that had a four-year rotation.

The number of insect pests captured within each rotation age were totaled and for rotation ages that appeared in more than one field these numbers were averaged across the number of fields. Figures 25, 26 and 27 show each different insect pest when compared to the rotation age. Each insect pest has a different Y axis scale, and the format allows for better interpretation of the results. Figure 28 shows all the insect pests together against the rotation age to show how the trends show together and Figure 29 shows the entire totaled number of insect pests regardless of species and the average number of insect pests.

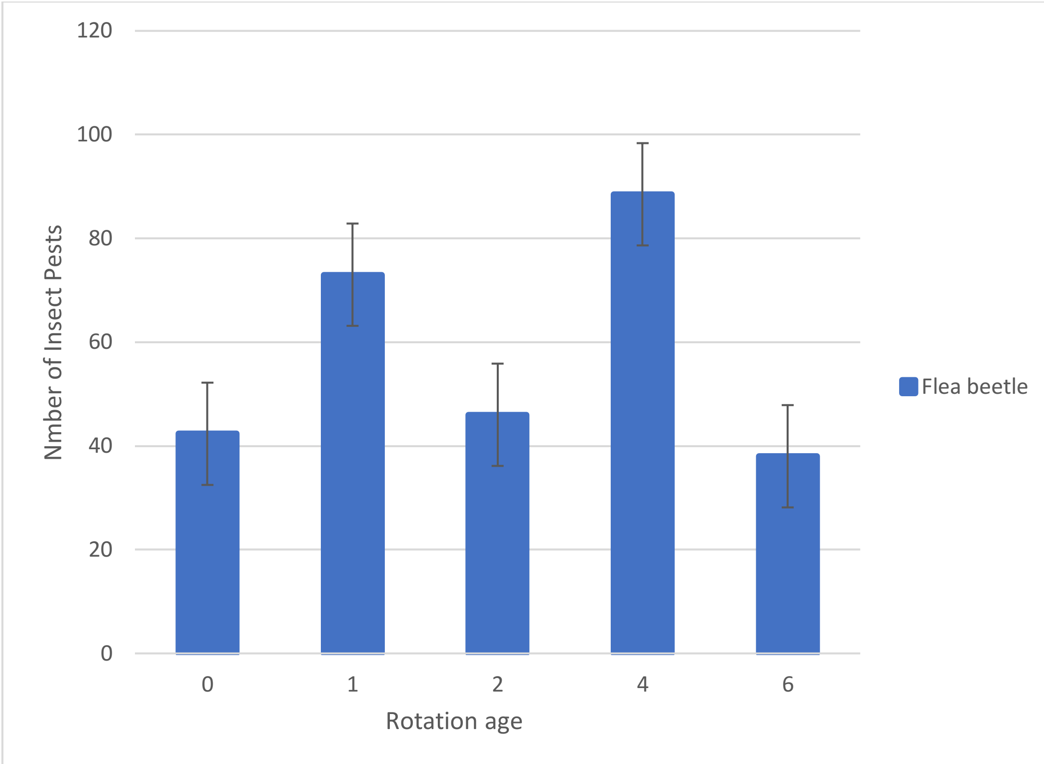

Figure 25. Mean number of Flea beetles in each rotation age with standard error

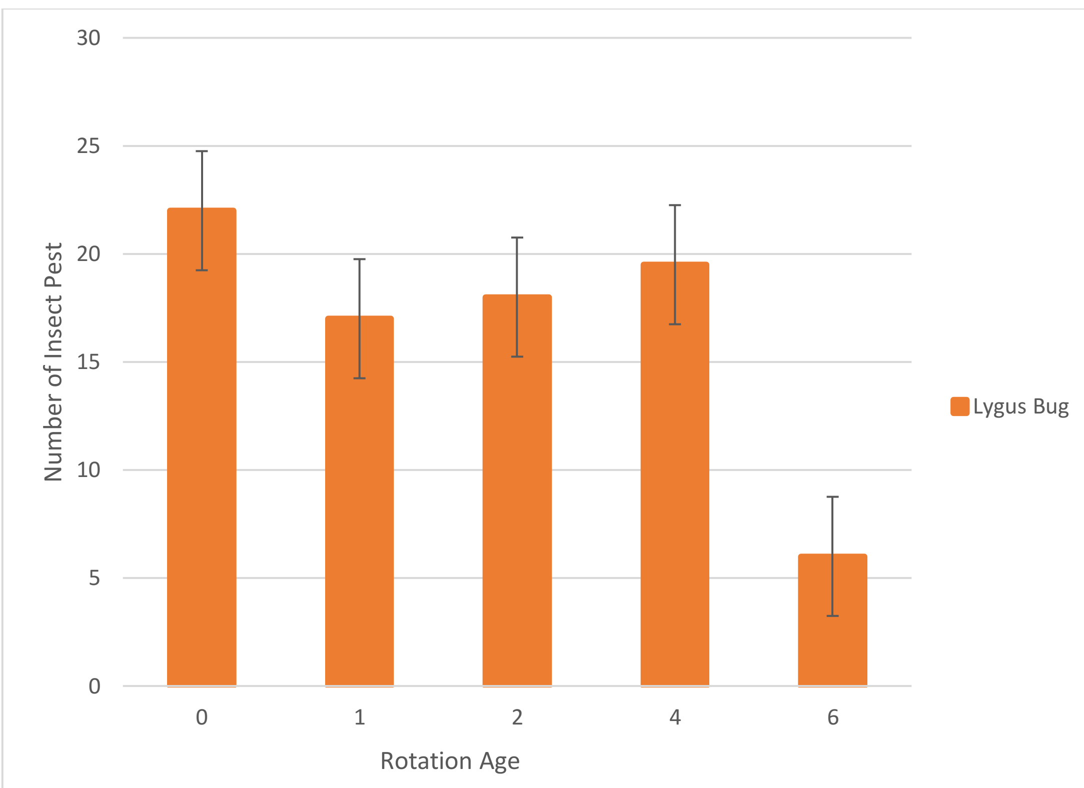

Figure 26. Mena number of Lygus bugs found in each rotation age with standard error

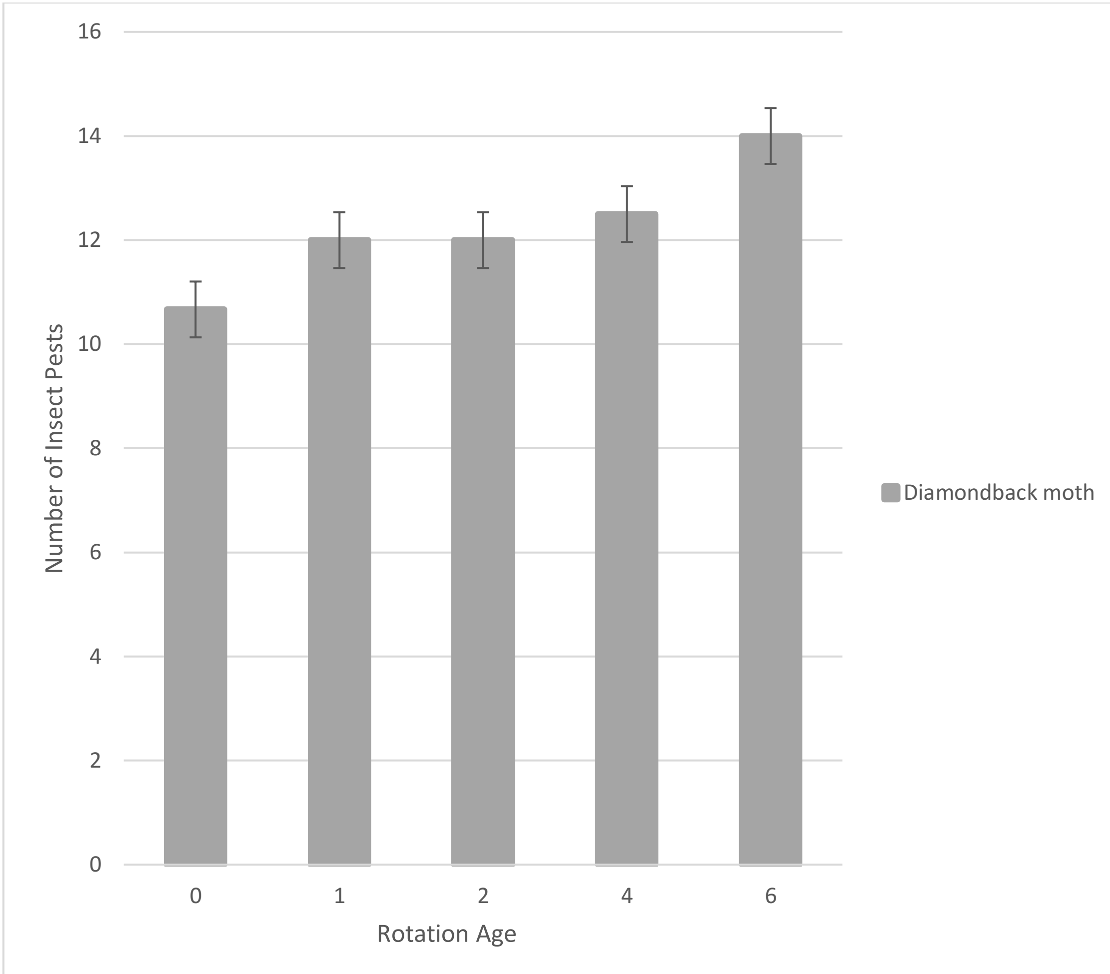

Figure 27. Mean number of Diamondback moths in each rotation age with standard error

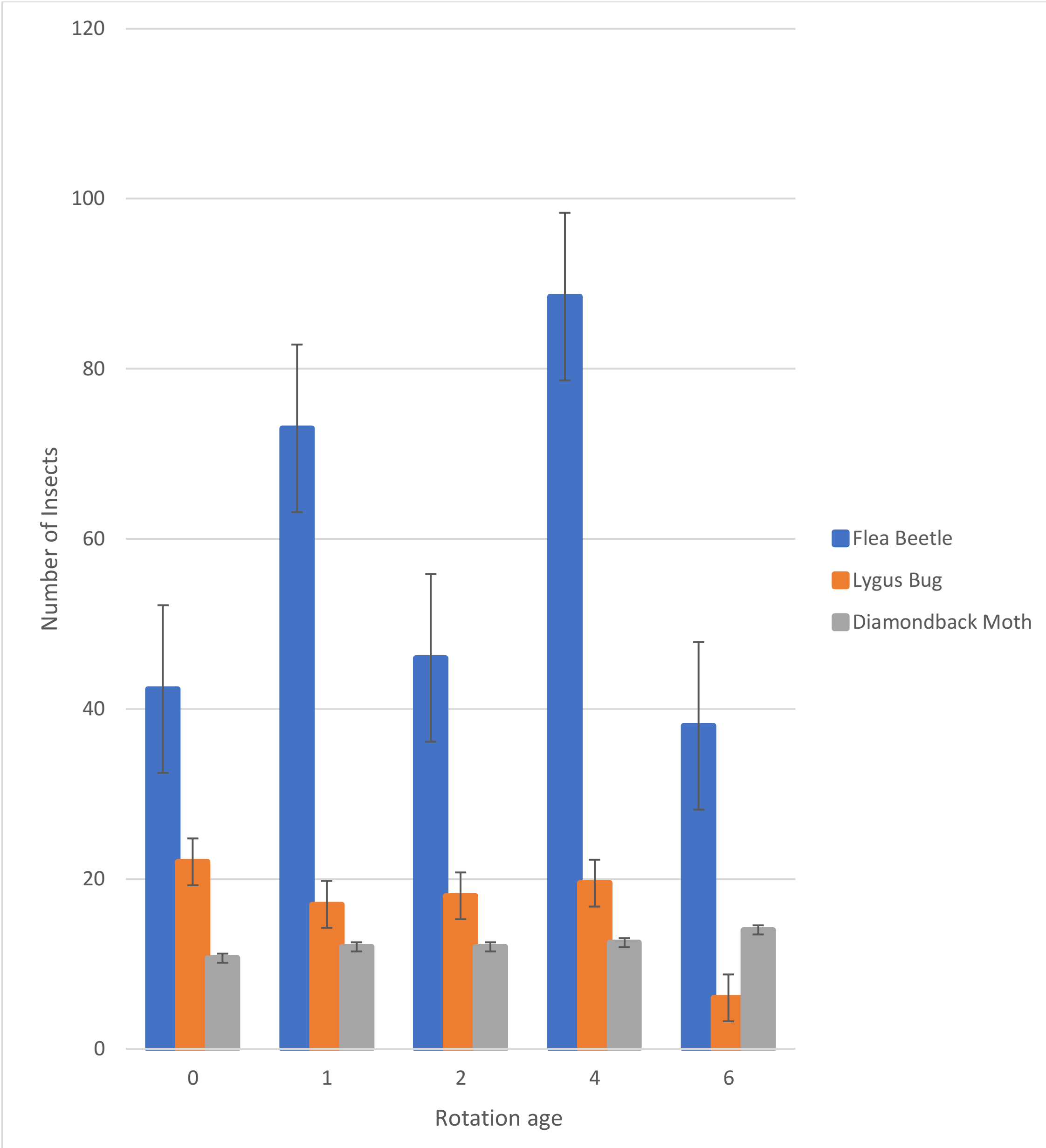

Figure 28. Comparison of mean number of insect pests across all rotation ages

Statistical analyses were performed in three ways, a two-tailed t-test, a regression, and an ANOVA. The t-test uses degrees of freedom and compares two sets of data directly against each other and was separated into different rotational comparisons for each individual insect pest species. The test is used to determine if there is significance in the differences found in the data sets. Tables 4, 6 and 8 show a compilation of raw data for each insect pests that are used for the t-tests. Tables 5, 7, and 9 show the t-test results and how they compare to the determined critical-t values. These values are compared to determine the significance of the data at a confidence level of 95%.

Table 4. A compilation of raw data for Flea beetle numbers with statistical analysis

Rotation Age (Years)	6	4	2	1	0
	1	10	2	12	0
	5	9	4	11	4
	2	0	0	0	4
	6	4	8	10	5
	7	3	12	15	9
	6	5	11	10	9
	11	6	9	15	10
		30			1
		26			7
		0			0
		22			7
		18			6
		19			8
		25			12
					10
					11
					6
					3
					8
					3
					4
Count	7	14	7	7	21
Average	5.43	12.64	6.57	10.43	6.05
Variance	10.95	107.63	21.29	25.62	12.45
SD	3.309	10.375	4.614	5.062	3.528
Standard Error of Mean	1.25	2.77	1.74	1.91	0.77

Table 5. Comparison of rotation ages to determine significance on Flea beetle populations

Rotation age comparison	6 vs 4	4 vs 2	2 vs 1	1 vs 0
Degrees of freedom	17	18	12	8
T-TEST Value	0.03	0.08	0.04	0.07
CRITICAL T*	2.11	2.101	2.179	2.306

*As determined by the Critical T value table at a 95% confidence for a two tailed t test

Table 6. A compilation of raw data for Lygus bug numbers with statistical analysis calculations.

Rotation Age (years)	6	4	2	1	0
	0	0	0	0	0
	0	6	4	7	1
	1	3	5	0	3
	3	7	5	4	5
	0	3	2	1	2
	1	3	1	2	3
	1	2	1	3	3
		4			2
		3			4
		1			5
		1			2
		0			5
		2			2
		4			2
					0
					6
					6
					4
					3
					4
					4
Count	7	14	7	7	21
Average	0.86	2.79	2.57	2.43	3.14
Variance	1.14	4.18	4.29	6.29	3.03
SD	1.069	2.045	2.070	2.507	1.740
Standard Error of Mean	0.40	0.55	0.78	0.95	0.38

Table 7. Comparison of rotation ages to determine the significance on Lygus bug populations.

Rotation age comparison	6 vs 4	4 vs 2	2 vs 1	1 vs 0
Degrees of freedom	18	11	12	8
T-TEST Value	0.01	0.83	0.91	0.50
CRITICAL T*	2.101	2.201	2.179	2.306

*As determined by the Critical T value table at a 95% confidence for a two tailed t test

Table 8. A compilation of raw data for Diamondback moth numbers with statistical analysis calculations.

Rotation Age (years)	6	4	2	1	0
	1	0	0	0	0
	3	2	4	3	0
	3	2	0	0	4
	1	4	2	2	2
	2	0	2	1	1
	2	4	2	3	3
	2	4	2	3	1
		0			0
		2			0
		1			0
		1			3
		1			3
		2			1
		2			3
					0
					0
					0
					5
					2
					2
					2
Count	7	14	7	7	21
Average	2.00	1.79	1.71	1.71	1.52
Variance	0.67	2.03	1.90	1.90	2.36
SD	0.816	1.424	1.380	1.380	1.537
Standard Error of Mean	0.31	0.38	0.52	0.52	0.34

Table 9. Comparison of rotation ages to determine the significance on Diamondback moth populations

Rotation age comparison	6 vs 4	4 vs 2	2 vs 1	1 vs 0
Degrees of freedom	18	12	12	11
T-TEST Value	0.67	0.91	1.00	0.76
CRITICAL T*	2.101	2.179	2.179	2.201

*As determined by the Critical T value table at a 95% confidence for a two tailed t test

Tables 10, 13 and, 16 shows results from regression analysis (R-squared. R-squared; the goodness-of-fit measure for linear regression models). ANOVA results (Tables 11, 12, 14, 15, 17 and, 18) are also used to determine significance of data but uses the *F* value and *P* value instead of a *t* value.

Table 10. Regression statistics for Flea beetle versus rotation age

Multiple R	0.8049
R Squared	0.6479
Adjusted R Squared	0.5892
Standard Error	1.4711
Observations	8

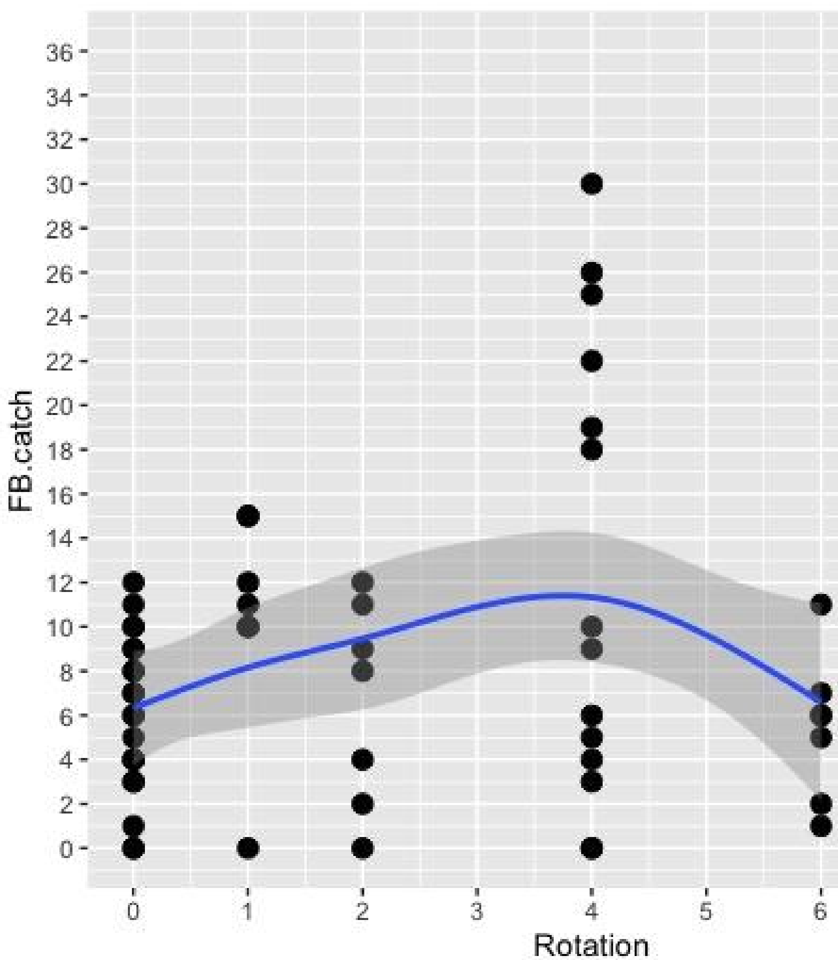

Figure 29. Regression plot graph of Flea beetle catches (FB catch) versus rotation age (0-6)

Table 11. ANOVA results for Flea beetle versus rotation age

	df	SS	MS	F	Significance F
Regression	1	23.8905	23.8905	11.0395	0.0160
Residual	6	12.9845	2.1641		
Total	7	36.8750			

Table 12. Additional ANOVA results for Flea beetle versus rotation age

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-0.8982	1.0481	-0.8570	0.4243	-3.4627	1.6663
Flea beetle	0.0525	0.0158	3.3226	0.0160	0.0138	0.0911

Table 13. Regression statistics for Lygus bug versus rotation age

Multiple R	0.0510
R Squared	0.0026
Adjusted R Squared	-0.1636
Standard Error	2.4759
Observations	8

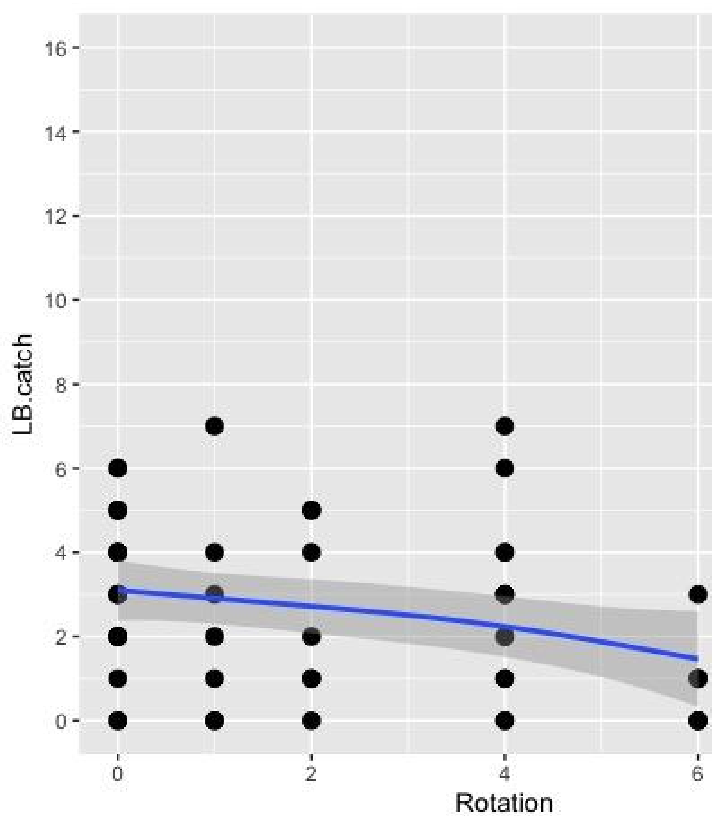

Figure 30.Regression plot graph of Lygus bug catches (LB catch) versus rotation age (0-6)

Table 14. ANOVA results for Lygus bug versus rotation age

	df	SS	MS	F	Significance F
Regression	1	0.0959	0.0959	0.0156	0.9046
Residual	6	36.7791	6.1299		
Total	7	36.8750			

Table 15. Additional ANOVA results for Lygus bug versus rotation age

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	2.4583	2.8049	0.8764	0.4145	-4.4051	9.3216
Lygus bug	-0.0183	0.1460	-0.1251	0.9046	-0.3756	0.3390

Table 16. Regression statistics for Diamondback moth versus rotation age

Multiple R	0.2475
R Square	0.0612
Adjusted R Square	-0.0952
Standard Error	2.4020
Observations	8

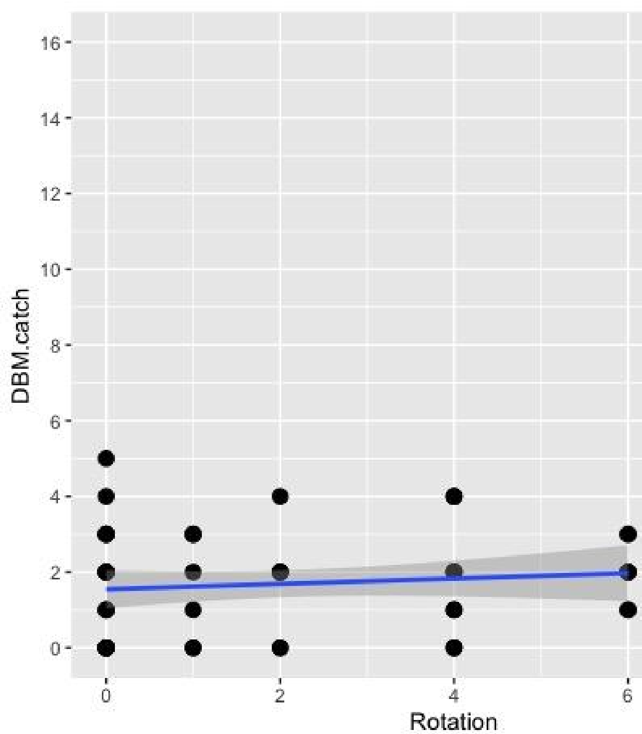

Figure 31. Regression plot graph of Diamondback moth catches (DBM catch) versus rotation age (0-6)

Table 17. ANOVA results for Diamondback moth versus rotation age

	df	SS	MS	F	Significance F
Regression	1	2.2585	2.2585	0.3915	0.5546
Residual	6	34.6165	5.7694		
Total	7	36.8750			

Table 18. Additional ANOVA results for Diamondback moth versus rotation age

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	5.1470	4.9040	1.0495	0.3344	-6.8528	17.1467
DBM	-0.2545	0.4067	0.6257	0.5546	-1.2497	0.7408

Date of Capture

When determining possible variables that may affect the number of insect pests in a field it is important to be thorough in your assumptions. Date of capture or the seasonality of insect pests and diseases is important. Insect pests and diseases will sometime follow cycles in weather ad climate and have different reactions to different moisture conditions. As such, date of capture will have the potential to have a significant impact on the total number of insect pests that are captured. Table 19 shows the date of each field visit, and the total number of each insect pest species captured that day from all fields. Figure 33 shows the progression through the summer with each date of capture marked with the trendlines showing the general direction which the insect pest populations followed.

Table 19. Total number of each insect pest collected on each day of field study

Date	Flea beetle	Lygus bug	Diamondback moth
2021-06-10	66	6	1
2021-06-25	77	31	14
2021-07-07	12	24	10
2021-07-16	59	28	19
2021-08-04	78	16	12
2021-08-18	71	18	19
2021-09-01	92	20	19

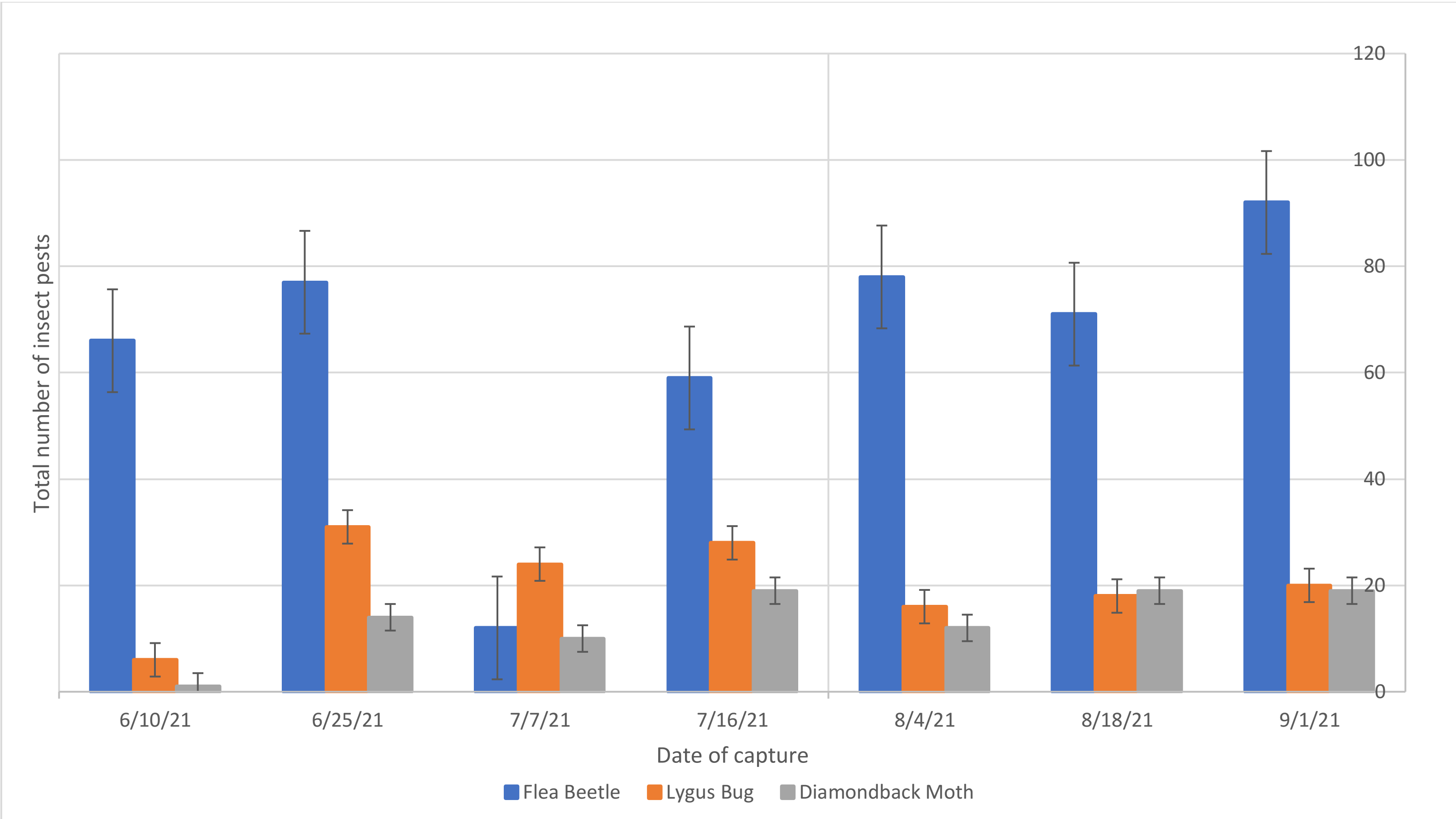

Figure 32. Total number of each insect pest found throughout the study period with error bars for each insect pest species.

Table 20. A compilation of raw data for number of all insect pests captured on each day of field study with statistical analysis.

Date	2021-06-10	2021-06-25	2021-07-07	2021-07-16	2021-08-04	2021-08-18	2021-09-01
Flea beetle catches	1	5	2	6	7	6	11
	0	4	4	5	9	9	10
	1	7	0	7	6	8	12
	10	11	6	3	8	3	4
	10	9	0	4	3	5	6
	2	4	0	8	12	11	9
	12	11	0	10	15	10	15
	30	26	0	22	18	19	25
Total	66	77	12	65	78	71	92
Lygus bugs catches	0	0	1	3	0	1	1
	0	1	3	5	2	3	3
	2	4	5	2	5	2	2
	0	6	6	4	3	4	4
	0	6	3	7	3	3	2
	0	4	5	5	2	1	1
	0	7	0	4	1	2	3
	4	3	1	1	0	2	4
Total	6	31	24	31	16	18	20
DBM catches	1	3	3	1	2	2	2
	0	0	4	2	1	3	1
	0	0	0	3	3	1	3
	0	0	0	5	2	2	2
	0	2	2	8	0	4	4
	0	4	0	2	2	2	2
	0	3	0	2	1	3	3
	0	2	1	1	1	2	2
Total	1	14	10	24	12	19	19
Overall total	73	122	46	120	106	108	131

For date of capture the t-tests are a comparison of the first half of the study period versus the second half for each insect pest. Table 20 shows a compilation of collected data for all insect pests captured from all fields on that date. Tables 21-23 show the t-tests for date of capture presented as the first half of the study period versus the second. Table 24 is an excel regression for all insects versus date of capture and tables 25 and 26 are ANOVA results.

Table 21. Two tailed t test for Flea beetle catches in the first half of the study versus the last half

	First Half	Last Half
Mean	5.859375	7.74375
Variance	23.171596	17.8738839
Observations	8	8
df	14	
t Stat	-0.8319163	
P(T<=t) one-tail	0.20971026	
t Critical one-tail	1.76131014	
P(T<=t) two-tail	0.41942051	
t Critical two-tail	2.14478669	

Table 22. Two tailed t test for Lygus bug catches in the first half of the study versus the last half

	First Half	Last Half
Mean	2.390625	2.109375
Variance	0.88141741	0.5671317
Observations	8	8
df	13	
t Stat	0.66095351	
P(T<=t) one-tail	0.26009204	
t Critical one-tail	1.7709334	
P(T<=t) two-tail	0.52018409	
t Critical two-tail	2.16036866	

Table 23. Two tailed t test for Diamondback moth catches in the first half of the study versus the last half

	First Half	Last Half
Mean	1.19642857	1.975
Variance	0.35863095	0.36270833
Observations	7	7
df	12	
t Stat	-2.4253683	
P(T<=t) one-tail	0.01600108	
t Critical one-tail	1.78228756	
P(T<=t) two-tail	0.03200216	
t Critical two-tail	2.17881283	

Table 24. Regression statistics for all insect pest catches versus the date of capture

Multiple R	0.9193
R Square	0.8451
Adjusted R Square	0.6901
Standard Error	16.5780
Observations	7

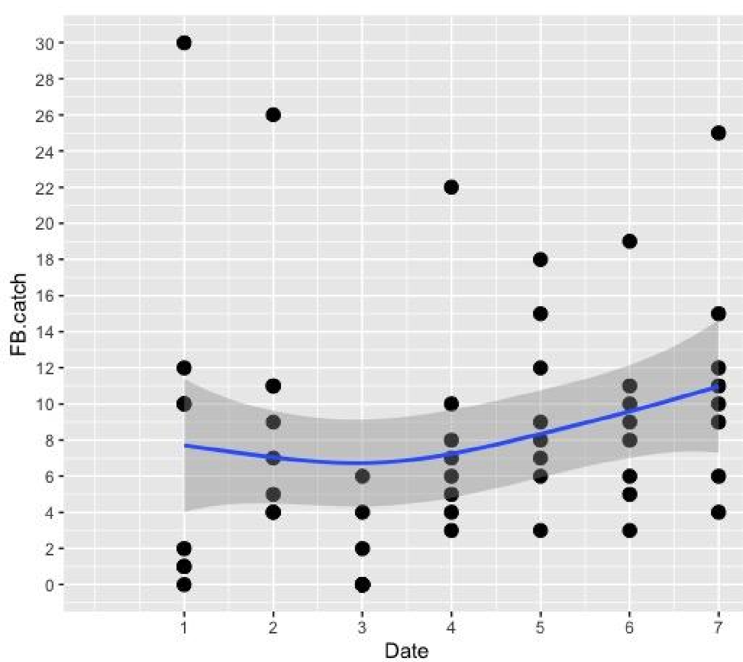

Figure 33. Regression plot graph of Flea beetle catches (FB catch) versus date of capture (days 1-7 of field research)

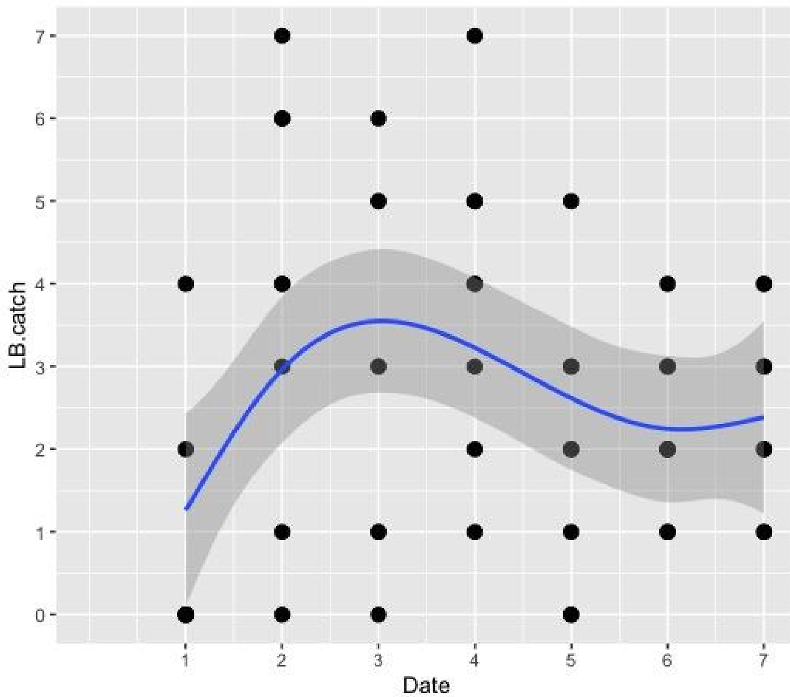

Figure 34. Regression plot graph of Lygus bug catches (LB catch) versus date of capture (days 1-7 of field research)

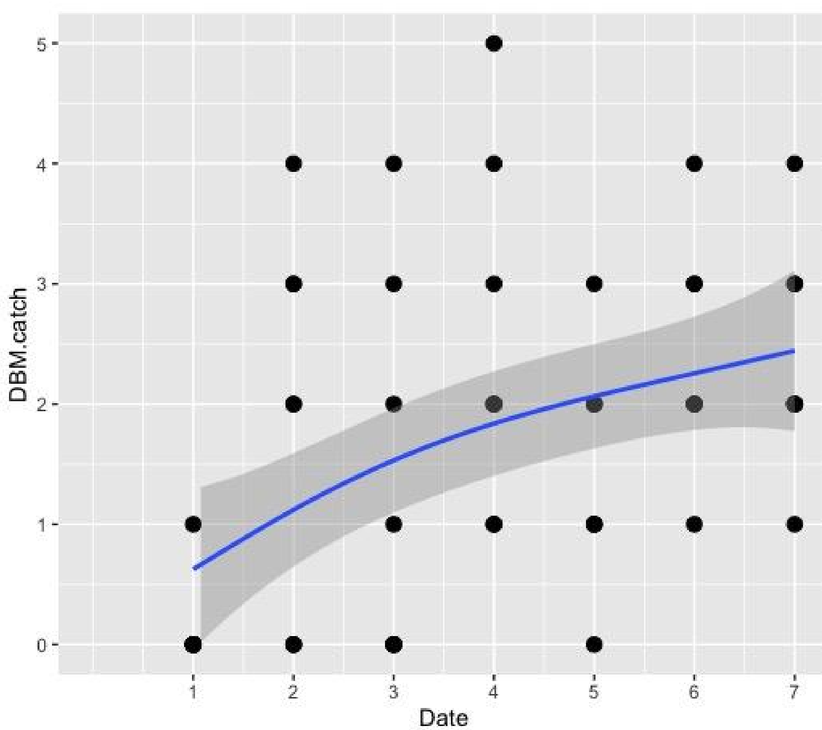

Figure 35. Regression plot graph of Diamondback moth catches (DBM catch) versus date of capture (days 1-7 of field research)

Table 25. ANOVA results for all insect pest catches versus the date of capture

	df	SS	MS	F	Significance F
Regression	3	4496.938	1498.979	5.454	0.099
Residual	3	824.490	274.830		
Total	6	5321.429			

Table 26. Additional ANOVA results showing t-values and P-values for each different insect pest

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	44381.555	27.824	1595.071	0.000	44293.007	44470.104
Flea beetle	-0.080	0.315	-0.255	0.815	-1.083	0.922
Lygus bug	-2.561	1.179	-2.172	0.118	-6.314	1.191
Diamondback moth	5.489	1.540	3.565	0.038	0.589	10.389

Field Size

The size of the fields in the study were quite variable, ranging from 28 to 95 acres. Field size can influence the drift of a species to, from, and within each field. A larger field is less likely to incur bias. Table 27 shows the total number of insect pests of each species captured in each field of each size.

Table 27. Total number of each insect pest collected from each field compared to the size of that field in acres.

	Total Number of Insect pests		
Field size (acres)	Flea beetle	Lygus bug	Diamondback moth
28	45	27	11
30	41	17	11
35	38	6	14
42	41	22	10
46	37	24	16
90	46	18	12
95	73	17	12
95	140	15	9
TOTAL	461	146	95

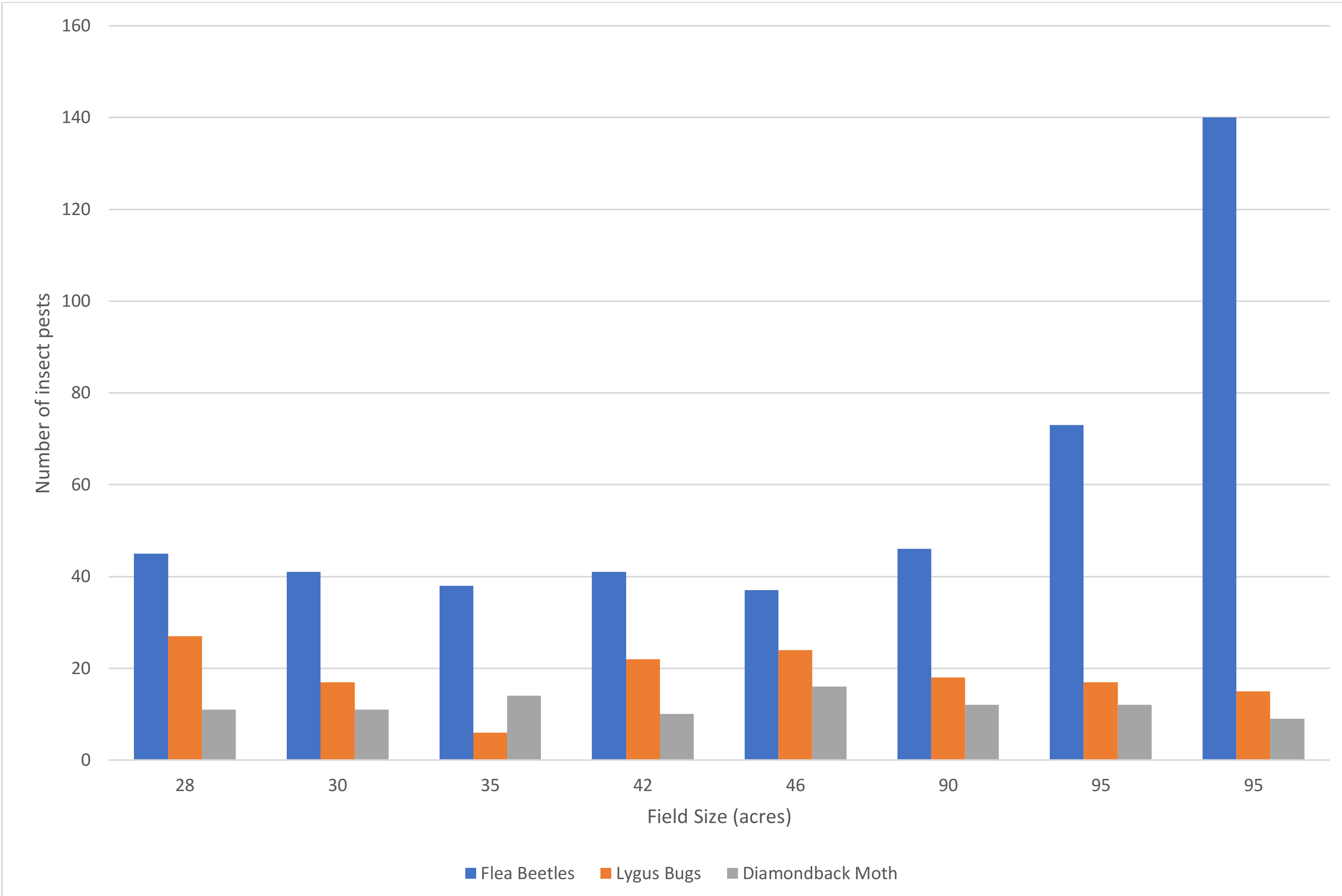

Figure 36. Bar graph of field size vs. number of insect pests captured with error bars

Table 28. Number of collected insect pests of all species on each collection day for fields greater than and less than 50 acres with statistical analysis.

Group	1	2
Field size (acres)	<50	>50
	1	30
	5	26
	2	0
	6	22
	7	18
	6	19
	11	25
	10	2
	9	4
	0	0
	4	8
	3	12
	5	11
	6	9
	0	12
	4	11
	4	0
	5	10
	9	15
	9	10
	10	15
	1	
	7	
	0	
	7	
	6	
	8	
	12	
	10	
	11	
	6	
	3	
	8	
	3	
	4	
Count	35.00	21.00
Average	5.77	12.33
Variance	11.48	76.03
SD	3.39	8.72
Standard Error of Mean	0.57	1.90

Table 29. Comparison of field sizes to determine their significance on insect pest numbers using a t-test

Field size comparison	<50 vs >50
Degrees of freedom	23
T-TEST Value	-3.302
CRITICAL T*	2.069

*As determined by the Critical t value table at a 95% confidence for a two tailed t test

Table 30. Regression statistics for field size versus the number of catches for all insect pests

Multiple R	0.6984
R Squared	0.4878
Adjusted R Squared	0.1036
Standard Error	28.5691
Observations	8

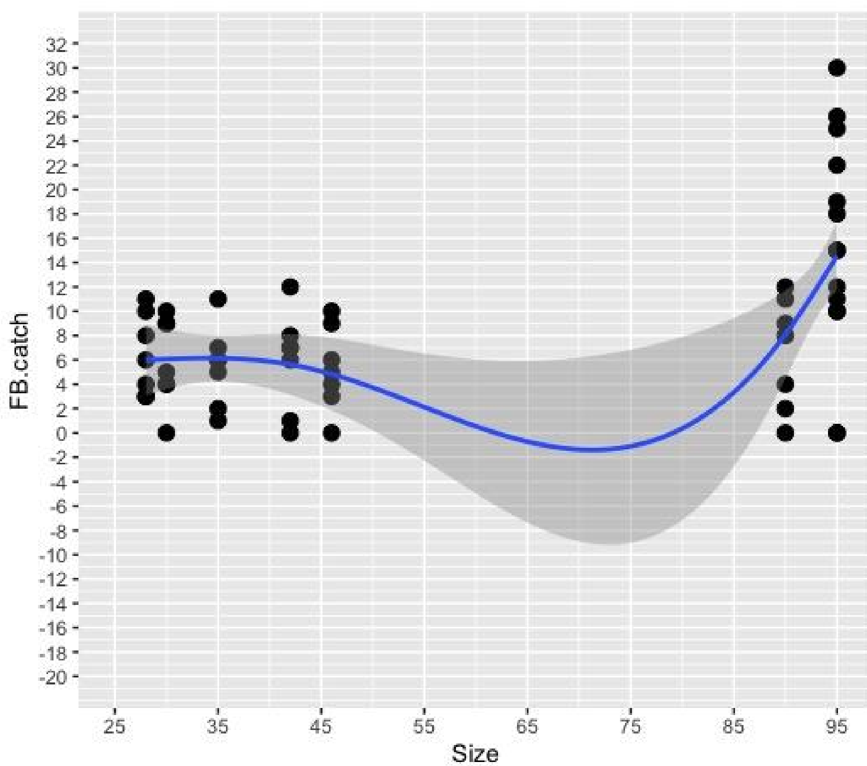

Figure 37. Regression plot graph for Flea beetle catches (FB catch) versus field size in acres

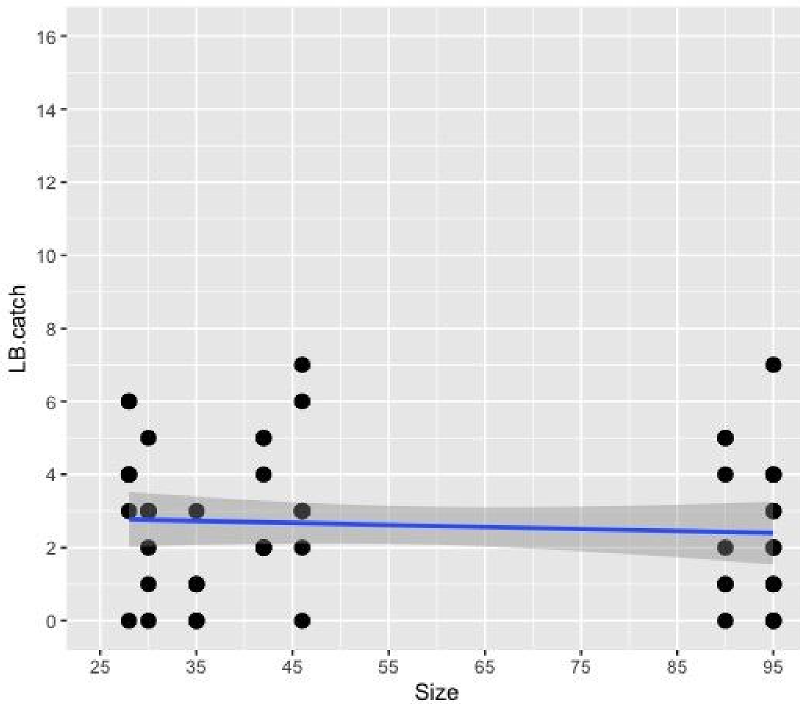

Figure 38. Regression plot graph for Lygus bug catches (LB catch) versus field size in acres.

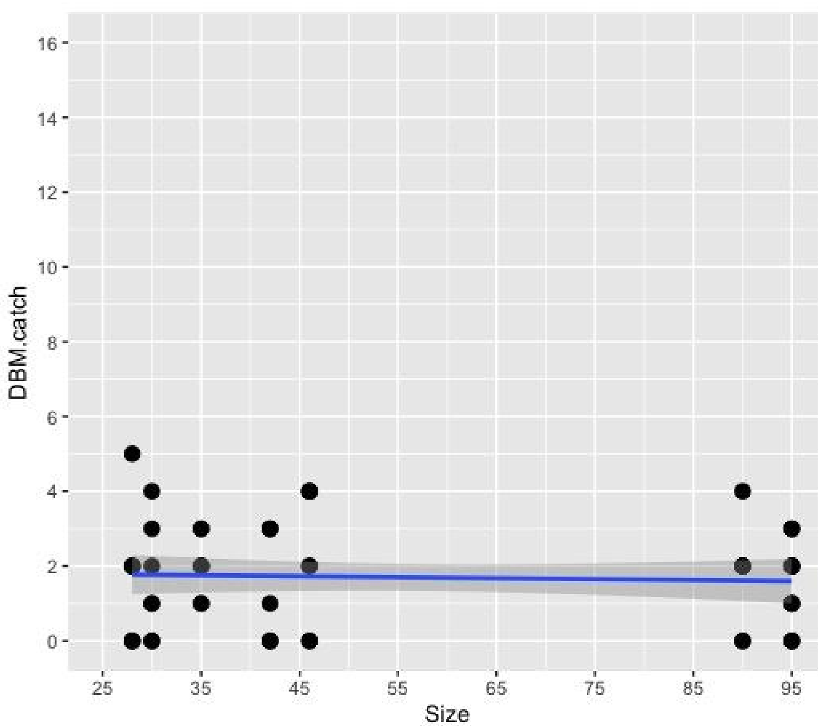

Figure 39. Regression plot graph for the number Diamondback moth catches (DBM catch) versus field size in acres.

The regression graphs in Figures 38, 39 and 40 have a large gap in the goodness of fit line as no fields had areas between 50 and 90 acres. The data should not be split into two sets to ensure that all data is encapsulated by the model. The gap in data does not seem to negatively affect the regression line in either of the other two figures (39 and 40). Nonetheless, the result from the regression analysis suggested that Flea beetle catches were significantly higher in large sized fields, compared to those in small fields (significance of smooth terms $p<0.01$) (Figure 38). However, catches of Lygus bug and Diamondback moth did not differ among different field sizes (Figures 39 and 40).

Table 31. ANOVA results for field size versus the number of total insect pest catches for all species

	df	SS	MS	F	Significance F
Regression	3	3109.1053	1036.3684	1.2698	0.3976
Residual	4	3264.7697	816.1924		
Total	7	6373.8750			

Table 32. Additional ANOVA results for each species of insect pest

	Coefficients	Standard Error	P-value	Lower 95%	Upper 95%
Intercept	-10.0739	99.4661	0.9242	-286.2361	266.0884
Flea beetle	0.6701	0.3852	0.1569	-0.3994	1.7395
Lygus bug	-0.0744	1.7620	0.9684	-4.9665	4.8177
Diamondback moth	2.5637	5.9690	0.6897	-14.0089	19.1364

Diseases

There are several common diseases of canola that can be found throughout the Prairie regions of Canada, as have been outlined and discussed earlier. The number of diseases that are currently present in Northwestern Ontario canola is unknown. The purpose of these observations was to deem whether certain diseases that are common in other parts of Canada, specifically Alberta and Saskatchewan, were identifiable in this year's canola crops in Northwestern Ontario. These diseases had been previously observed but not in a capacity that has been detrimental to yield.

Table 33. Determination of which diseases were present in fields based on knowledge of what diseases were known to be in the region.

	Disease Type		
Field Number	Clubroot	Aster Yellows	Blackleg of canola
1	No evidence found	No evidence found	No evidence found
2	No evidence found	No evidence found	No evidence found
3	No evidence found	No evidence found	No evidence found
4	No evidence found	Signs of presence	No evidence found
5	No evidence found	No evidence found	No evidence found
6	No evidence found	Signs of presence	No evidence found
7	No evidence found	Signs of presence	No evidence found
8	No evidence found	No evidence found	No evidence found

Only Aster Yellows was found to be present in fields and the average number of plants affected by Aster Yellows was calculated in Table 34. This number was calculated by counting the number of plants with Aster Yellows in a circular plot with a radius of 11.28m or an area of $400m^2$.

Table 34. Distribution of Aster Yellows in fields where it was found.

Field	Amount of Aster Yellows found
4	4 affected plants per $400m^2$
6	2 affected plants per $400m^2$
7	2 affected plants per $400m^2$

DISCUSSION

The results of the net sweeps showed promisingly low numbers of insect pests in the fields. The insect pest numbers or their damage potential were below typical economics thresholds as set by the canola Council of Canada. Flea beetles were the most prevalent insect pests, but the damage was well below the threshold of 20% leaf area eaten. Very few incidences of disease were surveyed within the fields and damage caused was minimal during the survey period. However, the significance of the data is in question for both insect pests and the diseases that will be discussed in each individual section.

Effects of Rotation Age

The rotation age of the fields was one of the primary points for this research, yielding mixed results. Flea beetles were most common in the four-year rotation while Lygus bugs were most prevalent in the zero-year rotation, and the Diamondback moth held predominance in the six-year rotation. Both Flea beetles and Lygus bugs were found the least in the six-year rotation and Diamondback moths in the zero-year rotation. Direct comparisons in the form of two tailed t-tests showed no significance when comparing one rotation age against another. All calculated t-values for Flea beetle, Lygus bugs and Diamondback moths were substantially lower than their critical t counterparts.

When performing the regressions and ANOVA's the results were very similar for both the Lygus bug and Diamondback moth catches with F values of 0.9046 and 0.5546, respectively and R^2 values of 0.0026 and 0.0612. The R^2 values are extremely low for these models, with each only encompassing less than 1% of the differences in the data. The regression graphs showed very little data falling within the regression line and the trends were not very explanatory. The trend for Flea beetle catches was highest in the four-year rotation age. Lygus bug had a general downward slope and DBM had a slightly upward slope. These data reveals that the incidence of insect pests may not have been overly affected by the age of rotation. Contrary to this, the results of the regression and ANOVA for Flea beetle catches, when compared to the rotation age, were favourable. With a significant F or P-value (as they are the same for this single data ANOVA) of 0.0160, the P-value is well below the 95% confidence level of 0.05 for significance. While the P-value does not give indication as to what rotation is better, it does indicate significant differences exist between different rotation ages. These results are promising for future studies to build upon with larger data sets and more controlled experimental designs.

Effects of Date of Capture

The date on which an insect pest was captured can correlate to the climate and weather occurrences which could influence the number of insect pests captured. For instance, temperatures are typically hotter and drier in August than June. This can affect the number of insect pests surviving to adulthood and vice versa for those that prefer warmer, drier weather. Specifically, as it pertains to this study and the surveys conducted, on the one hand, the lowest number of insect pests captured was on the third day (early July) and the weather on that day was a continuation of a drought that had begun two weeks prior. The drought continued throughout almost all the survey. While on the other hand, the greatest number of insect pests captured occurred on the final survey day (early September), shortly after the drought had been broken by a period of rainfall that lasted approximately one day and the final survey day was two days after this rainfall event. As evidenced by the statistical analysis, the drought had significant effect on the overall results.

The t-test results for each insect pest in the first half of the study period when compared to the second half showed statistical significance for the Diamondback moth but not for Flea beetles and Lygus bugs. The results were a t stat of -0.831, 0.660, and -2.425 against critical t values for a two tailed test assuming unequal variance of 2.144, 2.160 and 2.178 for Flea beetle, Lygus bug and Diamondback moth respectfully for both values. A value of 2.425 is higher than the critical t value of 2.178 and therefore the differences in the data are deemed to be statistically significant.

The regression that was run for all dates versus all the insect pests captured values created an R^2 value of 0.8451 which determines that roughly 85% of the variation or differences in the data can be described by just the independent variables. A higher number is generally considered to be better as the model can explain the variance in data more accurately.

Regressions were performed for each individual species of insect pest compared to the date of capture (with figures). The graph in Figure 34 shows the best fit for insect pest catches versus the date of capture with the other two graphs not having the regression line encompassing much of the data. The general trends in data for Flea beetle, Lygus bug and DBM were upwards for Flea beetle and DBM but Lygus bugs had a wave like pattern suggesting time of year may not affect their incidence patterns.

The ANOVA results showed the same results as the t-test in that the date of capture had a significant effect on diamond back moths but not the Lygus bugs or Flea beetles. The P-values were 0.815, 0.118 and 0.038 for Flea beetle, Lygus bugs and Diamondback moths. A value of 0.038 is lower than the 95% confidence level of 0.05 making it statistically significant. The F stat also showed that there was nearly significance for the data for all insect pests when compared to date of capture. A value of 0.099 shows that there would be significance at a 90% confidence level but not at a 95% confidence level.

Effects of Field Size

When looking at the raw data there is a clear outcome that the 95-acre fields had a higher average number of Flea beetles captured. For Lygus bugs and Diamondback moth the number of insect pests captured did not seem to be affected by the field size as shown in, and previously discussed, Figure 37. The statistical analysis for the results of field size were promising. When comparing field sizes above and below 50 acres in size with a t-test there was found to be significant differences in the data. The calculated t value was 3.302 against a two tailed t-test critical value of 2.069. However, when the number of catches for each insect pest species was compared with all field sizes no statistical significance was found. The ANOVA for field size gave F and P values for each insect pest. The F value of 0.3976 and P values of 0.1569, 0.9684, and 0.6897 showed no significance at a 95% confidence level for any insect pest. The R^2 value for field size versus all insect pest catches showed only 48% of the data's variance was accounted for by the model which is low and could contribute to the overall insignificance of the differences in the data. The regression graphs for field size showed similar results with less than 50% of the data within the best fit line. The regression lines followed a trend that was fairly level but decreased slightly as field size went up for both

Lygus bugs and DBM. The trend for Flea beetle was very different taking the shape of a hump decreasing in between the smaller sized fields followed by a sharp increase within the larger sized fields. This may indicate that in smaller field sizes the incidence is more constant, but a larger field could provide more room for population growth, possibly due to less predation or decreased competition pressures. These results could also be due to the location of the field or more directly related to the specific fields as they were all close together geographically and two had shorter rotations. One of the 95 acre fields had a four-year rotation and had more than double the number of Flea beetles captured across the study of the next highest field.

Effects of Diseases

The number and prevalence of diseases was too low to perform a meaningful statistical analysis. Three diseases were surveyed for or found during surveys and therefore included. There was no presence of Clubroot found in any fields after soil samples were taken and analyzed and no blackleg was found after the harvest period when stems were cut to see evidence of infection. This does not, however, completely rule out any presence of these two diseases in those fields or in the locale.

Field testing for soil borne or stem borne diseases can be difficult to pinpoint if no damage or distress is visible in the upper sections of the plant. Future surveys of the fields can help to determine the frequency at which these diseases may be present. The only disease that was visible in the fields was Aster Yellows and it was only present in three fields making the data set much too small to be compared using statistical analyses. The highest number of infected plants was in field 4 which was 28 acres in size and had a zero-year rotation age (had never been previously seeded with canola). The other two fields were 6 and 7 which had sizes of 90 and 95 acres and rotations of two years and one year.

Potential Error and Bias

Sample sets were small for this experiment as only eight fields were surveyed and there was no true control field to compare against. Bias may have occurred as fields sweeps were performed at the edges of fields where most insect pests tend to be found. Experimental error also occurs as a field with a longer rotation age may have had canola directly adjacent to the previous year. This crop placement essentially negates the effects of regular population movement obstacles. The chances of a population moving from a prior year's volunteer crop or weeds that are part of the Brassicaceae family increases when the field is less than a few metres away.

A factor that was detrimental to this experiment was the weather for the year. The region experienced a drought that lasted roughly 3 months from the end of June to September. When discussing the drought with the farmers they reported decreased yield and severe lodging of the crop. Lodging is when a crop falls over and becomes entwined and difficult to combine and remove from the field with machinery. The severe drought causing yield losses makes it difficult to determine whether the end results of insect pests' populations had any effect on yields for that year.

Similar Studies

There have been several studies performed regarding the rotation age of canola crops and the impacts that the change in rotation can have. A study by Harker et al. (2015a) was conducted to determine the effect of rotation on crop pests, like Root Maggots, and diseases, such as blackleg disease, as well as seed yield and quality of canola. The study only had results for up to two years between successive crops but showed promising results. Performed in Alberta, the experiment determined that both the incidence of blackleg and the ensuing severity of the disease were influenced by the number of crops in between successive canola plantings (Figure 41).

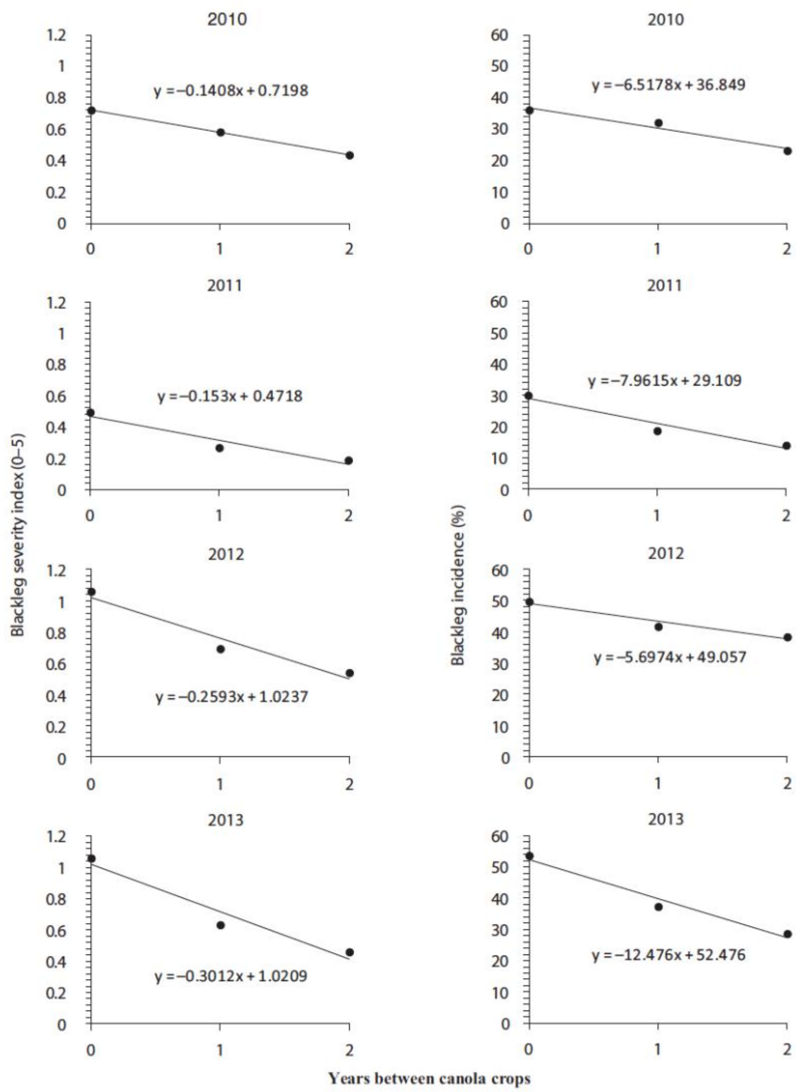

Fig. 3. Blackleg severity (left) and incidence (right) response to canola rotation frequency. Means are averaged over glyphosate- and glufosinate-resistant canola. Wheat was the rotational crop for a 1-yr rotation break; field peas and barley were the rotational crops for a 2-yr rotation break. *P* values for linear and quadratic contrasts of blackleg severity against rotation frequency were 0.013 and 0.974, 0.001 and 0.282, 0.001 and 0.305, and <0.001 and 0.234, for 2010, 2011, 2012 and 2013, respectively. *P* values for linear and quadratic contrasts of blackleg incidence against rotation frequency were 0.007 and 0.518, <0.001 and 0.298, <0.001 and 0.222, and <0.001 and 0.271, for 2010, 2011, 2012 and 2013, respectively.

Figure 40. Graphs showing the relationship between Blackleg severity and incidence and the number of years between canola (full description in figure).

Source: Harker et al. 2015a

The canola fields also had a general decrease in the damage caused by Root Maggots as rotation age increased from zero to two (Figure 42).

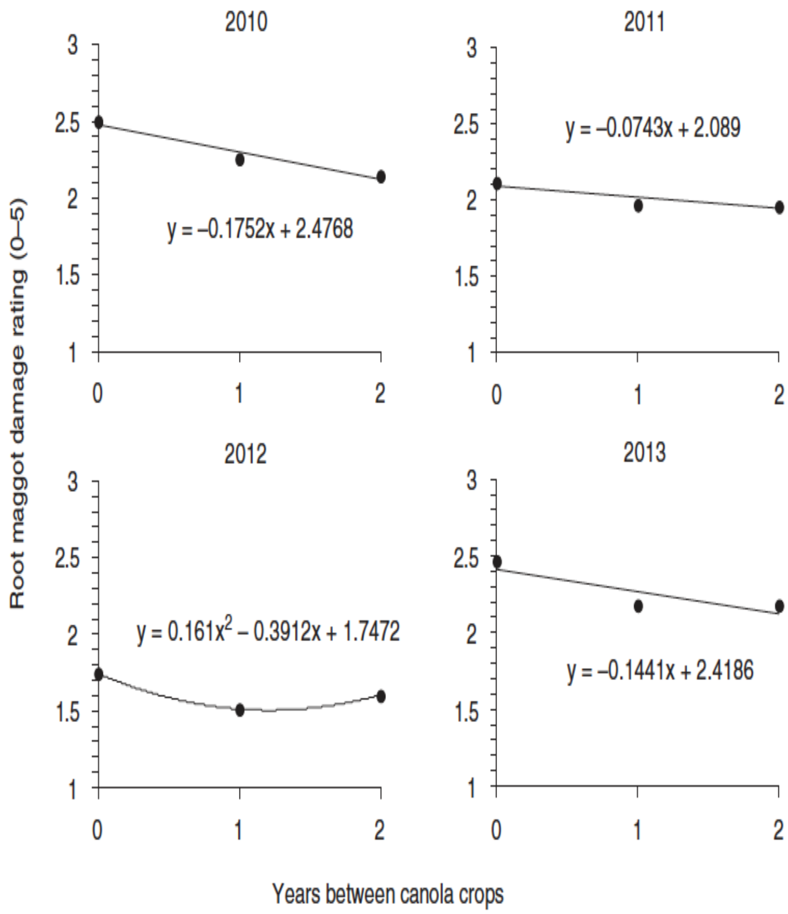

Fig. 4. Root maggot damage rating response to canola rotation frequency. Means are averaged over glyphosate- and glufosinate-resistant canola. Wheat was the rotational crop for a 1-yr rotation break; field peas and barley were the rotational crops for a 2-yr rotation break. *P* values for linear and quadratic contrasts of damage rating against rotation frequency were 0.001 and 0.402, 0.093 and 0.392, 0.056 and 0.013, and 0.036 and 0.213, for 2010, 2011, 2012 and 2013, respectively.

Figure 41. Graphs showing the effects of rotation age on the damage caused by Root maggots (Full explanation in figure).

Source: Harker et al. 2015a

This study was conducted over the course of four years and referred to previous studies by Dosdall et al. 2012 that also conducted similar experiments about rotation age and pests such as root maggot and blackleg as the two can be linked to each other. In another study previously conducted by Harker et al. (started in 2008 as opposed to 2010) the findings were that in a three-year rotation, root maggot damage was reduced overall by 6% and, the incidence and severity of blackleg were both reduced by over 50%. Despite the promising results in both studies, Harker et al. 2015b concluded that root maggot damage may have been more greatly affected by predator species being more prevalent because of weed reduction in the fields than the rotation age.

CONCLUSIONS

Growing of canola as a crop in Northwestern Ontario will continue to gain more popularity as regional farmers realize the value that it can hold for them. When this realization sees more canola crops planted regionally, there is a likelihood of an increase in detrimental insect pest and disease outbreaks will occur. The implementation of an IPM will help to establish a set of best practices for farmers to adhere to or use as guidelines for their farms, resulting in the most favourable outcomes. Part of the IPM should include a section on the use of crop rotation as a method of cultural control of harmful insect pests and diseases to minimize crop yield loss.

This preliminary survey and subsequent statistical analysis show promise and provide insight on which the future research can expand. The results of this study while not significant in all aspects, and as discussed earlier, did show significance when relating the incidence of Flea beetles to the rotational frequency. The results for all insect pests provide credibility to the premise that increased rotation age is a good practice to follow. Based on tabulated results, it follows that in general a higher rotation is better for decreased insect pest and disease frequency. The secondary objectives showed that field size did not seem to directly affect the incidence of insect pests although Flea beetle numbers were greater in the three larger fields that are all located in the Slate River Valley area, with two of them within only several hundred metres of each other. Furthermore, the t-test showed that there were significant differences when comparing fields above and below 50 acres but the regressions for Lygus and Diamondback moth (DBM) remained fairly constant. This indicates that field size had little effect on incidence of insect pests and diseases and as such farmers can plant as large a crop as desired without much consequence. The date of capture data showed that insect pests captures generally tended to increase in the latter half of the season. This was especially true for DBM as there were highly significant differences for DBM in the date of capture data. Knowledge of this later season jump in incidence may allow farmers to plan accordingly. The three hypotheses laid out in the objectives can neither be accepted fully nor rejected fully because of the mixed results.

This survey was unfortunately dogged by the drought and all results may not be as accurate as they could have been in an optimum growth year. This study did not include specific weather observations outside of a general sense of the day-to-day. It would be beneficial to track weather patterns throughout a study period to account for weather bias. The optimum conditions for growth can also create more conducive habitat for both insect pests and diseases and, as all but one of the surveys occurred during a drought this study was not performed in optimum conditions. Surveys and studies will help create more robust data inventories for future use. Studies like this also allow for future research and a growing relationship with the local farmers who may want to have fields surveyed in the future.

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APPENDIX

Raw data collected during study period.

Field	Date	Rotation	Number of Insect pests: Flea beetle	Lygus bug	Diamondback moth	Field size (acres)
Bolt	2021-06-10	6	1	0	1	35
Brekveld 1	2021-06-10	0	0	0	0	30
Brekveld 2	2021-06-10	0	1	2	0	42
Breukelman 1	2021-06-10	0	10	0	0	28
Breukelman 2	2021-06-10	4	10	0	0	46
Jaspers 1	2021-06-10	2	2	0	0	90
Jaspers 2	2021-06-10	1	12	0	0	95
Jaspers 3	2021-06-10	4	30	4	0	95
Bolt	2021-06-25	6	5	0	3	35
Brekveld 1	2021-06-25	0	4	1	0	30
Brekveld 2	2021-06-25	0	7	4	0	42
Breukelman 1	2021-06-25	0	11	6	0	28
Breukelman 2	2021-06-25	4	9	6	2	46
Jaspers 1	2021-06-25	2	4	4	4	90
Jaspers 2	2021-06-25	1	11	7	3	95
Jaspers 3	2021-06-25	4	26	3	2	95
Bolt	2021-07-07	6	2	1	3	35
Brekveld 1	2021-07-07	0	4	3	4	30
Brekveld 2	2021-07-07	0	0	5	0	42

Breukelman 1	2021-07-07	0	6	6	0	28
Breukelman 2	2021-07-07	4	0	3	2	46
Jaspers 1	2021-07-07	2	0	5	0	90
Jaspers 2	2021-07-07	1	0	0	0	95
Jaspers 3	2021-07-07	4	0	1	1	95
Bolt	2021-07-16	6	6	3	1	35
Brekveld 1	2021-07-16	0	5	5	2	30
Brekveld 2	2021-07-16	0	7	2	3	42
Breukelman 1	2021-07-16	0	3	4	5	28
Breukelman 2	2021-07-16	4	4	7	4	46
Jaspers 1	2021-07-16	2	8	5	2	90
Jaspers 2	2021-07-16	1	10	4	2	95
Jaspers 3	2021-07-16	4	22	1	1	95
Bolt	2021-08-04	6	7	0	2	35
Brekveld 1	2021-08-04	0	9	2	1	30
Brekveld 2	2021-08-04	0	6	5	3	42
Breukelman 1	2021-08-04	0	8	3	2	28
Breukelman 2	2021-08-04	4	3	3	0	46
Jaspers 1	2021-08-04	2	12	2	2	90
Jaspers 2	2021-08-04	1	15	1	1	95
Jaspers 3	2021-08-04	4	18	0	1	95
Bolt	2021-08-18	6	6	1	2	35
Brekveld 1	2021-08-18	0	9	3	3	30

Brekveld 2	2021-08-18	0	8	2	1	42
Breukelman 1	2021-08-18	0	3	4	2	28
Breukelman 2	2021-08-18	4	5	3	4	46
Jaspers 1	2021-08-18	2	11	1	2	90
Jaspers 2	2021-08-18	1	10	2	3	95
Jaspers 3	2021-08-18	4	19	2	2	95
Bolt	2021-09-01	6	11	1	2	35
Brekveld 1	2021-09-01	0	10	3	1	30
Brekveld 2	2021-09-01	0	12	2	3	42
Breukelman 1	2021-09-01	0	4	4	2	28
Breukelman 2	2021-09-01	4	6	2	4	46
Jaspers 1	2021-09-01	2	9	1	2	90
Jaspers 2	2021-09-01	1	15	3	3	95
Jaspers 3	2021-09-01	4	25	4	2	95