Effects of Late Season Flea Beetle Feeding on Canola Seed Yields

Canola Council of Canada Project AG#2004-13

Final Report
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Executive Summary

Field trials were established during the 2004-2006 summer seasons to determine the effects of late-season flea beetle feeding on seed yields of canola at the Saskatoon Research Centre farm at Saskatoon. The natural flea beetle population over most of the prairies crashed in the spring of 2004, recovering only slowly in the two years that followed. As a result, few effects of flea beetle feeding on canola yields were found. With financial assistance from the Pest Management Centre of AAFC, this project was extended to include the 2007-2008 summer seasons, during which time flea beetle numbers approached damaging levels. Two cultivars of canola were seeded in early (mid-May) and late spring (early June) in three activities. In the first activity, plots of canola were allowed to be infested by natural populations of flea beetles in late summer, and half of the plots were sprayed with insecticide to eliminate flea beetles. In the second activity, metre^3 screen cages were placed over early and late seeded canola, and each cage was infested with 16,00 to 26,000 flea beetles that were collected from areas of infestation. In the third activity, 60 cm long sleeve cages were placed over individual canola plants and each was infested with 100 flea beetles. Harvest parameters, including seed yields and 1000 seed weights, were measured from sprayed and unsprayed plots and from infested and uninfested cages.

When harvest results were combined over years, seeding dates, and cultivars, the application of insecticide to naturally infested plots or infestation of metre^3 and 60 cm long sleeve cages with flea beetles did not have any impact on canola seed yields or weights, indicating that significant flea beetle damage to canola prior to harvest is not a common occurrence. In all studies in all years, seeding date had the greatest influence on harvest parameters of the three factors investigated. In most experiments earlier seedings outyielded later ones. In this investigation, the best defense against fall flea beetle damage to canola seed yields was to seed at mid-May or earlier.

Within seeding dates, fall feeding by flea beetles had no detrimental effects on early-seeded canola in any experiment in any year. Flea beetles did affect seed yields of late-seeded plots of individual cultivars in some years. Two applications of insecticide in August, 2008, the first at growth stages 5.1-5.2 and the second at growth stages 5.2-5.4, controlled natural infestations of both flea beetles and diamondback moths, and significantly increased seed yields in late-seeded plots of one cultivar but not another. Over both cultivars in 2008, when late-seeded cage plots were in the 5.1-5.2 growth stages, having seeds in lower pods turning from translucent to green in colour, there was a 3.6 bushel/acre reduction with infestation levels of about 350 flea beetles per plant. Likewise in 2008, seed weights from plants in late-seeded plots were decreased from 2.68 g per 1000 seeds in uninfested cages to 2.44 g per 1000 seeds in infested cages. Populations of 100 flea beetles per plant in sleeve cages had no effect on harvest parameters of any cultivar in any seeding date or year.

In terms of late season economic thresholds, this project found that flea beetle feeding that occurs when seeds in lower pods of canola are beyond the green stage is unlikely to affect seed yields. And even when seeds are still green, numbers higher than 100 flea beetles per plant, and for some cultivars higher than 350 per plant, may be necessary to cause significant yield reductions. An adjustment to these numbers may be necessary for conditions in which multiple pests such as flea beetles and diamondback moths are present concurrently in the field late in the season.

In a second activity, series of yellow sticky traps were used to monitor the presence of flea beetles near and in canola fields from the beginning of April until the beginning of July, 2004-2006, and again after harvest. Traps were placed at the edges of field headlands, grass verges, or shelterbelts, and at three or four distances into canola fields in an attempt to determine the timing and direction of flea beetle invasion into the fields. Spring flea beetle numbers were very low, and few conclusions could be drawn from their analyses. Results were site-specific, applicable only to those fields from which they came. The study found that the use of yellow sticky traps as a monitoring and predictive tool for flea beetle invasion into canola fields is not reliable, and many questions must be answered before it may or may not become a useful tool in flea beetle management.

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I. Introduction

On occasion, numbers of flea beetles in the summer generation are high in many areas across the prairies. Extensive flea beetle feeding on maturing canola foliage, stems, and pods can occur in years with long, warm autumns. Producers anxious to maintain seed yields wish to know how much feeding maturing canola can tolerate before economic damage occurs. At present there are no economic thresholds for flea beetle damage to canola late in the season.

The objectives of this project were to determine the impact of fall feeding by crucifer-feeding flea beetles on canola growth and seed yield, with the aim of developing an economic threshold for fall flea beetle feeding, and to monitor flea beetle populations to determine the patterns of movement to and from crops, with the aim of developing methods of forecasting flea beetle populations in the spring.

II. Materials and methods

A. Field trials

Field trials were established at the Saskatoon Research Centre Farm in May of 2004-2008 to investigate fall flea beetle feeding effects on canola. These included monitoring of naturally infested field plots prior to harvest, and applying two types of cages to canola with the intent of introducing known numbers of flea beetles to the cages and determining the impact of late feeding on canola development and seed yields.

Field trials included

1. Large cage trial conducted in 2004 and 2005: three canola cultivars, 45H21, 5020, and 46A65 treated with thiamethoxam (Helix®) were seeded early and late in abutting plots of 12 rows at 100 seeds/3.0 m row (5.6 kg/ha). In the third week of July at growth stage 4.2, when both early and late-seeded canola were in full bloom and the early canola was starting to elongate pods, a 1.3x1.3x6.1m screen cage was placed in the center of each plot to cover equal numbers of early and late seeded plants. Cages were maintained as pest-free as possible until the time that the early maturing canola reached pod ripening, whereupon known numbers of flea beetles were to be introduced into each cage and their feeding injury and subsequent canola seed yields measured.

2. In a large cage second trial in 2004, cultivar 45H21 treated with Helix® was seeded in an arrangement of three plots in each of four replicates on May 14, each plot in 24 rows, 30 cm apart and 3.0 m long. Screen cages of 1.3x1.3x6.1 m dimensions were placed in the center of each plot at full bloom. At pod fill, a high density and a very high density of field-caught flea beetles were to be added to two of the cages of each replicate, and the third cage kept as a flea beetle free control. Because of a general scarcity of flea beetles, only 80,000 flea beetles were collected; these were from a plot of *Brassica juncea* cv Cutlass at the AAFC Farm at Scott, SK in mid-August. These were divided into four lots of 20,000 beetles, and on September 1 each lot was placed in one of the three cages in each replicate, with the other two cages in each replicate remaining uninfested. Thirty plants per cage were removed Sept. 22-23, and the following parameters recorded: number of stems with pods, number of pods on main raceme, number of pods on lateral racemes, number of flea beetle feeding pits per pod measured on 10 pods, presence or absence of flea beetle feeding on stems, and seed yield per plant.

3. Natural infestation trial conducted 2004-2008: two or three canola cultivars were seeded early and late in 24 rows at 30 cm row spacings and 200 seeds/6.1 m row, for a seeding rate of approximately 5.6 kg/ha, and monitored for natural infestations of flea beetles in the fall. All seed planted was purchased pre-coated with Helix® (thiamethoxam low rate) to minimize flea beetle damage to plots in spring. The cultivars 45H21 (Roundup Ready® hybrid) and 5020 (Liberty Link® hybrid) were seeded in all five years; as well, 46A65 (conventional open pollinated cv) was seeded in 2004 to 2006. The trial was laid out in a split plot design with four replicates, with seeding (=maturity) dates comprising the main plots and cultivars comprising the subplots. Early seedings were planted on May 13, 13, 16, 11, and 16, and late seedings were planted on May 26, 30, June 2, 2, and 5 in 2004-2008 respectively. Estimates of fall flea beetle numbers and/or damage as measured by feeding pits per pod were to be monitored, and comparisons in feeding damage and seed yields between early and late plots were to be determined. In 2007 and 2008 the experiment was modified into a split split plot design, with 45H21 and 5020 seeded in 12 replicates of 8-row plots, rows 30 cm apart and 6.1 m long, at a rate of 200 seeds/m row. Treatments were duplicated so that half of the plots could be sprayed late in the season to control natural infestations of flea beetles. On August 16, 2007, one day after the summer generation of flea beetles was detected in appreciable numbers, the spray plots were sprayed with Decis® insecticide for their control. Because of the advancing season, both early and late seeded plots were sprayed on August 20, 2008, although natural populations of flea beetles were low. Late seeded plots were sprayed again on August 29 (early seeded plots having been swathed in the interim), as flea beetle numbers rose and became noticeable. Comparisons in seed yields between early and late seeded plots (main treatment comparison), cultivars (sub treatment comparison), and spray and no-spray treatments (sub sub treatment comparison) were determined.

4. Cube cage trial: In 2006 - 2008, 200 seeds in each of eight rows, 6.1 m long, of the same three (2006) or two (2007, 2008) canola cultivars as in the natural infestation trial were planted in four (2006), 10 (2007) or 12 (2008) replicates at the same two early- and late-seeded dates as listed for the natural infestation trial. At growth stage 4.2 or full bloom in late July/early August, three 1.0x1.0x1.5 m “cube” field cages were placed on one half of each plot so as to cover three rows of canola in each cage. Cages were maintained as pest free as possible until the time that the summer generation of flea beetles emerged, whereupon known numbers of flea beetles were placed in one set of cages (Infested), and a second set of cages was maintained flea beetle-free (Control). Because local flea beetle populations were not large enough and early enough to allow cage infestation, collection surveys were undertaken in each year. A volume of insects equal to 16,500 flea beetles collected from Lethbridge, AB, on August 10, 2006 was introduced into each of the Infestation cube cages of both early- and late-seeded plots on August 14. In 2007, insects were swept from canola fields north of Saskatoon, south of Vegreville, AB, around Kindersley, Maple Creek, and Pike Lake, SK, and in research plots near Saskatoon on August 7-17, the insects returned to Saskatoon and sorted. A volume of insects equal to 26,850 flea beetles was introduced into each of the late-seeded Infestation cube cages on August 18. By this time the early-seeded plots of both cultivars had matured and were ready to combine, well beyond the flea beetle-susceptibility stage, and the cages on the early-seeded canola were not infested with flea beetles. In 2008 flea beetles were collected from canola fields near Lethbridge on August 13 and a volume equal to about 24,300 flea beetles was introduced into each cage of early and late seeded canola on August 15. In all three years plants were hand threshed at maturity and seed yields were determined from each cube cage; in 2007 and 2008 three lots of 100 seeds were weighed per treatment, and 1000 seed weights were calculated from the average of the 100 seed weights.

5. Sleeve cage trial: In the same plots as the larger "cube" cages, organdie sleeve cages 14 cm in diameter and 60 cm long were placed over single, randomly selected canola plants, tied at the bottom and top with string, and supported with bamboo stakes (Figure 2). On August 6, 2006, 100 flea beetles that had been collected from a canola field near LaRiviere, MB, on August 3 were added to each of three Early Infestation sleeve cages per plot. A similar number collected from a field near Lethbridge on August 10 was added to three more sleeve cages per plot on August 14 for the Late Infestation, and three cages per plot were kept as a flea beetle-free control. The three infestations of flea beetles were replicated four times for each of the three cultivars and two seeding dates. On August 10, 2007, 100 flea beetles that had been collected from canola fields near Saskatoon on August 8 and near Castor, AB, on August 9 were added to each of two sleeve cages per plot, 150 more flea beetles were added to each of two more sleeve cages, and two sleeve cages per plot were left uninfested as flea beetle-free controls. The two repetitions of the three densities of flea beetles were randomly arranged per row of canola, and replicated 10 times for each of the two cultivars and two seeding dates. On August 15, 2008, 100 flea beetles collected from south of Lethbridge, AB, were added to each of three sleeves per treatment, with three sleeves left uninfested, in 10 replications for each of two cultivars and seeding dates. At maturity, for each plant enclosed in a sleeve, the number of stems per plant, pods per stem, seeds per pod, seed yield per plant, and 100 seed weight were measured. Further, the number of shattered pods per cage, flea beetle feeding damage per pod, and the number of beetles remaining in the cage were recorded. The level of flea beetle feeding on maturing plants and pods was measured according to a 0-4 point rating scale, in which 0 indicated no flea beetle feeding, 1 indicated minor damage, with fewer than five circular feeding pits per pod, 2 indicated 6 -10 circular feeding pits per pod, with some coalescing of pits, and 5-30% of pod exterior damaged, 3 indicated extensive feeding, with more than 10 feeding pits per pod, considerable coalescing of pits, or 30-75% of the pod epidermis damaged, and 4 indicated pods that were almost totally debarked from flea beetle feeding.

B. Monitoring of flea beetle movement with sticky card traps

In order to forecast the presence of flea beetle populations before they entered canola fields, yellow sticky traps (125x75 mm, Phero Tec, Delta, BC, Fig. 3) were placed in locations near Saskatoon to trap flea beetles from the beginning of April until late June and again after harvest in 2004-2006. Efforts were made to find fields that were to be seeded to canola and that were near canola stubble fields. Traps were placed at the edges of field headlands, grass verges, or shelterbelts, and then at distances into canola fields to determine the timing and direction of flea beetle invasion into the fields (Fig. 1). The traps were anchored with wires and placed with the bottom edge 2 to 5 cm above the soil surface. At AAFC sites data loggers (StowAway TidbiT XT® temperature logger, Onset Computer Corporation), recording air temperatures 30 cm above ground level and soil temperatures 2.5 cm below the surface, were placed near the center of each row of sticky traps along the hedges, and downloaded once or twice during the season for computer storage and later analysis. In 2004 two sites on the AAFC research farm near Saskatoon and four commercial canola fields around Saskatoon were monitored; in 2005 and 2006 one AAFC site and three commercial fields were monitored.

On several weekly occasions in the spring, the amount of flea beetle damage to 10 randomly selected canola seedlings near each trap within the fields was recorded and the growth stage monitored. Ratings were taken on the four youngest tissues, cotyledon, 1st leaf and 2nd leaf stage when the seedlings were young, and then on the youngest true leaves as the plants aged. Ratings were on a 0 to 10 scale, with a rating of 0 indicating no damage and 10 indicating the leaf was entirely removed. Plant counts per 1 m row near each sticky trap were taken at each rating date, as was growth stage (Harper and Berkenkamp 1975) of the plants evaluated for beetle feeding. Damage ratings continued until all threat of crop loss was past, usually to bud or flower stage. The headland traps were maintained from early spring to late autumn. In 2006 traps in the fields were placed on bamboo rods just above the crop canopy as the summer progressed, removed from the fields just before swathing, and returned to just above stubble height after combining until October, at which time all traps were removed from the fields. Flea beetle numbers, species, and sex were recorded from both sides of the sticky cards. If flea beetle numbers were greater than 200 per side, a subsample, one randomly selected quarter of each trap face, was used as the sample unit and data was determined for that subsample.

III. Results

A. Weather Conditions

1. 2004

In 2004 the canola in all three field experiments established and grew well. The cool, cloudy spring and cool summer resulted in little difference in the maturity rates between the early and late seeded entries at the end of the season. Feeding pressure from all insects was extremely light, and control measures were unnecessary throughout the season. Numbers of flea beetles counted on the yellow sticky traps were disappointingly low.

2. 2005

Although all trials established well, the weather conditions were extremely unfavourable for flea beetle population development over the summer of 2005, and insufficient flea beetles were collected to complete the cage trial. Natural infestations of flea beetles were also below levels for detecting detrimental effects on canola maturation and yield, and no data were obtained from the field investigation in 2005. Flea beetle numbers on sticky traps were also very low.

3. 2006

Flea beetle feeding levels in the spring of 2006 were very low, not exceeding 10% of leaf area eaten, well below the economic threshold of 25%. The development of the summer flea beetle generation was delayed and the magnitude of the natural population low. Significant numbers of flea beetles were not seen until late August, when most of the canola in the area had reached maturity.

4. 2007

Weather in the 2007 growing season was mixed - early spring was normal, June was wet, July was very hot and dry, and August was cooler than normal. Both early and late seedings established well. Feeding pressure from all insects was so light in the spring that control measures were unnecessary. Maturity differences between the two seedings were evident in June, with early seeded plants in the 4.2-4.3 stages of growth and late seeded plants in the 3.2-4.1 stages of growth in mid-June. The heat and lack of significant rainfall in July rapidly advanced the maturity of both seedings, resulting in early plant maturity in August. There was an outbreak of diamondback moth *Plutella xylostella* L. larvae in the plots in late July, and all plots were sprayed with Decis® 5.0 EC deltamethrin at a rate of 60 ml/acre on July 31. At that time no flea beetle adults were present in the plots or in the area. Natural infestations of flea beetles were found on August 16, following several warm, calm, sunny days. The 10 days following infestation of tall cages with flea beetles on August 18 were rainy and windy, or overcast and cool.

5. 2008

The spring of 2008 was dry, and germination of the early seeding of the natural infestation field trial was very uneven, causing uneven development throughout the season and variability in maturity of early seeded plots. Because of timely rains the late seeding established well, growing and maturing evenly. Better moisture conditions also prevailed for the cube cage and sleeve cage trials, and germination of both the early and late seedings of these trials was excellent. The summer was generally cool, and the maturity differential between seedings lasted until harvest. Diamondback moth larvae were found in noticeable numbers on canola pods in some of the cube cages, and although 12 replicates of cages were placed on the plots, only nine were harvested.

B. Field Trial Data

1. 2004

The summer flea beetle population development was so depressed in 2004 that the Natural Infestation trial was discontinued because there was insufficient feeding by flea beetles to result in differences in damage to early or late seedings.

Despite extensive sweep net sampling in several areas of the province, the number of flea beetle collected was insufficient to conduct the cage trials as originally designed, and the early-late cultivar cage trial was abandoned. When approximately 20,000 flea beetles were placed in each of four randomly selected large cages seeded to 45H21, with two cages near each infested cage remaining uninfested, subsequent flea beetle feeding levels in the caged plots were very light. Some feeding was found in uninfested cages, attesting to the tenacity of the few beetles in the area to gain access to the uninfested tents. Little difference was found between infested and uninfested cages in any of the canola yield components analysed (Table 1). Low flea beetle numbers in cages and weather conditions favourable to canola growth and unfavourable to flea beetle feeding were the main reasons that no differences were found in canola yield parameters between infested and uninfested cages.

2. Natural infestation trial

a. 2006

No significant natural infestation of flea beetles occurred in the late summer, so that spraying of the open field trial was not undertaken, and feeding of maturing canola by naturally occurring populations of flea beetles was too light to cause damage to early or late seedings. Early-seeded plots matured several days earlier than later seeded plots. When growth stage was assessed on August 14, early-seeded 46A65 and 5020 were at pod ripening stage 5.4, seeds in lower pods yellow or brown, while 45H21 was at stage 5.2, seeds at lower pods green. On this date all three cultivars of the late seeding had pods that were at growth stage 5.3, seeds mottled green-yellow. Early seeded plots had substantially greater yields than did later sown plots (Table 2). Yield variation occurred in cultivars, also, with 5020 having the highest seed yields (Table 2).

b. 2007

The excellent establishment conditions in the spring resulted in treatments with even stands and uniform plant densities. Flea beetle feeding levels in the spring were low. An inspection of the plots on August 13 found no flea beetles present. By this time the early seeded material was ripe and beyond the effects of flea beetle damage. Therefore, the early plots were swathed August 14. On August 16, 1338 flea beetles were found in 60 sweeps of the plots, averaging 22.3 flea beetles per sweep, and Decis® 5.0 EC deltamethrin was applied at a rate of 60 ml/acre to both the early seeded plots already swathed and the late seeded plots that were still standing. At the time of pesticide application late-seeded 45H21 plots were in the 5.3 growth stage, with oldest seeds mottled green-yellow or green-brown, while 5020 seeds were in the 5.4 growth stage, yellow or brown in colour. As in 2006, feeding by these naturally occurring populations of flea beetles was too late to cause differences in seed yields between sprayed and unsprayed plots over the entire trial, or within either early or late seeded treatments (Table 2). Spraying for natural flea beetle infestation on August 16 did not influence seed yields of either cultivar. Early-seeded plots had substantially greater yields than did later sown plots ($P \leq 0.0001$), but over both seeding dates, seed yields did not differ between cultivars (Table 2). This may have been because of opposing trends in cultivar yields between the two seeding dates; in the earlier seeding, seed yields from 45H21 plots were larger than from 5020 ones, but in the late seeding the reverse occurred.

c. 2008

On August 19, 60 sweeps were taken from each plot. Flea beetle counts from the sweep samples were low:

45H21 Early	2.47 flea beetles/sweep
5020 Early	1.48 flea beetles/sweep
45H21 Late	0.85 flea beetles/sweep
5020 Late	2.23 flea beetles/sweep

Growth stages at this time were 5.3-5.5 in early seeded plots, with seeds in lower pods mottled green-brown to brown in colour and mostly ready to swath, while late seeded plots were in growth stages 5.1-5.2, seeds in lower pods translucent to green. Despite the low numbers of flea beetles, Decis® 5.0 EC or deltamethrin was applied at a rate of 60 ml/acre to all plots as per the standard protocol. Early seeded plots were swathed on August 22.

On August 29, an influx of flea beetles was noted and the late seeded plots were sprayed with Decis® 5.0 EC at the usual rate. At this time flea beetle counts from 60 sweep samples were:

45H21 Late	26.4 flea beetles/sweep
5020 Late	12.6 flea beetles/sweep

Canola growth stages were 5.2-5.3 for 45H21 Late seeded plots, with seed in lower pods green to green yellow and mottled, while those in 5020 Late seeded plots were 5.3-5.4, green-brown to brown.

The uneven germination of the early seeding and the long season favourable to canola development was expressed in the increased seed yields of the late seeded plots over the seed yields of the early seeded plots (Table 2). Over both seedings and cultivars, there were no differences in seed yields between sprayed and unsprayed plots. In the late seedings, sprayed plots of 45H21 had seed yields similar to those of unsprayed plots; on the other hand, sprayed plots of 5020 had greater seed yields than did unsprayed plots of this cultivar ($df=1,11$, $F=2.82$, $P \leq 0.05$).

In 2008 seed lots from plots of the natural infestation trial were examined and 1000 seed weights, % green seed, and % germination were determined. No differences were found between spray and no spray plots in 1000 seed weights or % germination (Table 3). There were slightly greater percentages of green seeds in unsprayed plots than in sprayed plots, but the overall rate of green seed was very low in this year (Table 3).

d. Data combined over years

Because insecticide application was not carried out in 2006, only seeding date, the cultivars 45H21 and 5020, and year could be compared when examining seed yield values in the three years of this trial. Over unsprayed plots in all three years, year and seeding date significantly affected yields, as did year* seeding date interaction terms (Tables 2, 4). Thus, there were greater seed yields in 2008 than in 2007, which in turn had greater seed yields than in 2006. Early-seeded plots outyielded late-seeded ones in 2006 and 2007, while in 2008 the reverse was true (Table 2), likely because of the better moisture conditions at seeding of the late seeded plots and the long, relatively cool summer in that year. Over all three years seed yield differences between cultivars were not significant.

When data were compared over the spray and control plots in the open field trials of 2007 and 2008, insecticide application for control of natural infestations of flea beetles late in the summer did not increase seed yields over seed yields in unsprayed plots (Tables 2, 4).

3. Cube cage trial

a. 2006

In the late summer of 2006 a heavy infestation of imported cabbageworm *Artogeia rapae* (L.) inflicted random damage to maturing canola pods before plants could be caged. In the cube cage trial, although there was flea beetle damage to plants and pods in the infested cages, this damage occurred when pods were almost ready to harvest. As a consequence, none of the canola harvest parameters measured was affected by the late infestation of flea beetles (Table 5). There was slight flea beetle feeding found on pods in uninfested cages, which may have occurred prior to caging of the plants. There were greater feeding levels on pods in the infested cages than in the uninfested ones (Table 5), but damage in infested cages was light, averaging fewer than five feeding pits per pod. None of the infestation by seeding date or treatment by cultivar interactions was significant, indicating that main effects were the only factors contributing to the results obtained. When only late seeded plots of 45A21 and 5020 were considered, there were no significant differences in yield parameters among infested and uninfested treatments in 2006 (Table 5).

Early seeded plants had greater numbers of pods per stem, yield per cage, and 1000 seed weights than did later seeded plants (Table 5). On the other hand, later seeded plants had more pod feeding by flea beetles than did earlier sown plants, although damage levels were very low. The cultivar 5020 had fewer pods per stem, greater numbers of seeds per pod, fewer shattered pods, and greater seed yields per cage than plants of 46A65 and sometimes 45H21, 46A65 had more flea beetle feeding than did 45H21, with feeding levels on 5020 falling in between (Table 5). Again, however, feeding levels were very low. There was a significant seeding date by cultivar interaction for yield ($P \leq 0.01$): 46A65 plots had the lowest yields in both seedings (147 and 86.6 g per cage in early and late seeded plots, respectively). 5020 yielded slightly more than 45H21 in early seeded plots (219 vs 185 g per cage), while values were similar in late seeded plots (124 and 121 g per cage for 45H21 and 5020, respectively).

b. 2007

At the time of infestation of Late seeded cube cages on August 18 plants were in the 5.3 to 5.4 growth stages, mottled green to solid yellow or brown in colour. Because of this late infestation, seed yields did not differ between cages infested and not infested with flea beetles (Table 6). Yields were affected by cultivar, with 5020 having higher seed yields and decreased 1000 seed weight compared to 45H21 ($P \leq 0.05$). Thousand seed weights were significantly decreased by the presence of flea beetles in the cultivar 45H21 ($P \leq 0.001$) (Table 6).

c. 2008

In the late summer a heavy infestation of diamondback moth inflicted random damage to maturing canola pods in some replicates before plants could be caged. Because of this, data from three replicates were not included, leaving nine in the trial.

At the time of infestation of cube cages with flea beetles on August 15, plots of both cultivars that were seeded early were in growth stage 5.3, with seeds in lower pods mottled and green-yellow or green-brown in colour; late seeded 45H21 plots had seeds that were in growth stages 5.1-5.2, with seeds from lower pods translucent or green, and lower-podded seeds of late seeded 5020 were in growth stage 5.2, green or dark green in colour.

For the first time in this three year study considerable flea beetle feeding damage was observed in the infested cages. More feeding was apparent on plants in the greener, late seeded cages than on plants in the early seeded cube cages. Feeding transformed leaves into a skeleton of holes, while feeding on the pods stripped away the green epidermis. These observations were supported by harvest data.

Early seeded plots had greater seed yields, greater seed weights, fewer green seeds, and greater germination levels than late seeded ones ($P<0.0001$ for all parameters, Table 7). Except for 1000 seed weights, which were heavier for 45H21 ($P<0.002$), recorded harvest parameters were similar between the two cultivars (Table 7).

Over both seeding dates, seed yields were significantly greater in uninfested control cages than in infested ones by 163 kg/ha or about 2.4 bu/acre ($P<0.0002$, Table 7). The infestation by seeding date interaction term was significant ($P=0.05$); flea beetle feeding did not influence yields in the early seeded plots, but did so in late seeded plots ($P \leq 0.05$). Both cultivars had decreased seed yield in late seeded infested plots ($P \leq 0.024$ for 45A21, 0.0009 for 5020). Thousand seed weights were lower in infested cages, specifically in cages of late seeded plots infested with flea beetles ($P<0.0001$, Table 7), where seeds were 8 to 10% lighter in 45H21 and 5020 plots, respectively. Seed weights in early seeded caged plots were not affected by the presence of flea beetles.

Although the proportion of green seed in this trial was low, more green seed was found in infested than in uninfested cages. Again, this effect was seen primarily in late seeded plots ($P<0.0005$), where uninfested cage plots of 45H21 had significantly fewer green seeds ($P<0.005$)

than did their infested counterparts. Within a seeding date, flea beetle infestation of cube cages did not influence germination levels of subsequent seeds from either cultivar (Table 7).

d. Data combined over years

When data were combined from both early and late-seeded plots over 2006 and 2008 (early-seeded cages were not infested in 2007), the addition of flea beetles to cube cages did not affect seed yields (P=0.06) or 1000 seed weights (P=0.38) of the canola in those cages (data not presented). Likewise, when data were combined from early-seeded plots over all three years, the addition of 16,000-26,000 flea beetles to 1m cube cages had no effect on canola seed yields (P=0.39) or weights (P=0.10)(data not presented). Only seeding date had a consistent effect on harvest parameters in the cube cage trial. Early seeded, caged canola had seed yields averaging 2477 kg/ha and 1000 seed weights of 3.23 g, while late-seeded canola had seed yields averaging 1585 kg/ha and 1000 seed weights of 2.74 g over years (P<0.0001 for both variables).

When data from late-seeded cube cage plots of 45H21 and 5020 were combined over all three years, flea beetle presence tended to decrease seed yields (P=0.06) and 1000 seed weights (P=0.07) (Table 6). However, only the 1000 seed weights of 45H21 from infested cages was significantly different than that from uninfested cages, being lower by 0.13g (Table 6). Year was the only factor significantly affecting seed yields and weights (P≤0.0002 for both yield components), with the highest yields but lowest seed weights occurring in 2008 and the lowest yields but highest seed weights in 2006. Over all years the year by flea beetle presence interaction term was significant for both seed yields and seed weights, indicating that results were not consistent when factors were considered in combination with each other over time. In 2006 seed yields weights were lower in cages without flea beetles than in those with flea beetles, while in the next two years the opposite was the case (Table 6).

Data over all years were analyzed substituting actual growth stage of canola at the time of infestation of cages instead of Early or Late seeding terms. Canola plants at growth stages more mature than 5.2, seeds in lower pods green, were unaffected by the presence of large numbers of flea beetles. Only canola in the 5.1-5.2 growth stage, the earliest stage measured with seeds translucent to just turning green, was affected by flea beetle infestation. This growth stage was seen in the 2008 Late seeded infested plots of both cultivars, when control cages averaged seed yields of 2052 kg/ha and 1000 seed weights of 2.68 g, while infested cages averaged 1811 kg/ha and 1000 seed weights 2.44 g (P<0.0001 for both parameters, Table 6).

4. Sleeve Cage Trial

a. 2006

By the time enough flea beetles were collected for the early infestation on August 6, seed of all three varieties of early seeded canola was turning colour. Growth stages on this date were: early seeded - 45H21 - 5.2, 46A65 - 5.2-5.3, 5020 - 5.2-5.3; late seeded - 45H21 - 5.2-5.3, 46A65 - 5.1-5.2, 5020 - 5.3. At the late infestation on August 14, early seeded 46A65 and 5020 were at pod ripening stage 5.4, seeds in lower pods yellow or brown, while 45H21 was at stage

5.2, seeds at lower pods green; all three cultivars of the late seeding had pods that were at growth stage 5.3, seeds mottled green-yellow.

Of the factors analyzed, seeding date had the greatest effect on canola harvest parameters, mirroring results from the cube cage trial (Table 8). Early-seeded plots had more stems per plant and pods per stem, greater seed yields per plant, heavier thousand seed weights, and fewer shattered and damaged pods than late-seeded plots. For unknown reasons, there were fewer flea beetles found in cages in late-seeded plots than in early seeded ones. Considering the effects of flea beetle infestation, the presence of flea beetles did not influence seed yield or weight; most of the canola harvest parameters were similar in value among early, late, and uninfested sleeve cages (Table 8). As expected, pods in both early and late infested cages had greater feeding levels than pods in the uninfested cages, with damage being similar between early and late infested cages (Table 8). Likewise, numbers of flea beetles found in both early and late infested cages were similar and greater than in the uninfested cages, which were not entirely free of flea beetles. Cultivar had variable effects on harvest components. 5020 had more seeds per pod but fewer stems per plant than the other two cultivars, and lower seed yield; 1000 seed weights were comparable among cultivars. None of the seeding date by cultivar interaction terms was significant.

Seeding date by infestation date interactions were significant for seed yield, pod damage, and number of beetles per cage ($P \leq 0.05$, 0.05, and 0.005, respectively). In early seeded plots, seed yields were greater in early infested than in uninfested plots, with yields in late infested cages in between. Seed yields from early seeded cages were 5.66, 4.93, and 4.31 grams per cage in early, late, and uninfested cages, respectively, while yield figures among infestation dates in late seeded plots were similar to each other at 2.53, 2.53, and 2.74 g per cage, respectively. In early seeded plots damage per pod in early infested cages was considerably higher than in late infested ones (0.84 *vs* 0.58, with damage ratings in uninfested plots at 0.22). In late seeded plots, damage ratings in early and late infested cages were similar (1.53 *vs* 1.50, respectively), while uninfested plots had low pod damage ratings of 0.50. Pod damage also had a significant cultivar by infestation date interaction term ($P \leq 0.02$). Damage to pods of 45H21 plants in both early and late infested cages was less than in 46A65 or 5020 cages (0.92 and 0.88 in early and late infested 45H21 cages, while comparable figures for 46A65 were 1.12 and 1.17, and those for 5020 were 1.36 and 1.07, respectively.

b. 2007

When the sleeve cages were infested on August 10, both cultivars of early seeded canola were nearing maturity, having pods that were almost dry and seeds that were nearly mature, with the oldest pods close to shattering - growth stage 5.4. In the late seeded plots the pods of both cultivars were still green or greenish yellow in colour at the time of infestation; the seeds of 45H21 were greenish yellow (growth stage 5.3), the seeds of 5020 were green (growth stage 5.2). At harvest several of the control cages had a small number of flea beetles in them, suggesting that they had been on the plants previous to caging or had managed to enter the cages after cage placement. It was noted that more of the flea beetles in the late seeded cages were alive and active than in the early seeded cages.

As in previous trials, seeding date had a strong impact on harvest parameters, with late-seeded plots having fewer stems per plant, fewer seeds per pod, lower seed yields, and lighter 100 seed weights than their earlier seeded counterparts (Table 9). Further, there was considerably more flea beetle feeding damage per pod on later compared to earlier seeded plants. The numbers of beetles found per cage were statistically similar in early and late seeded plots. On the other hand, number of shattered pods per sleeve cage was much lower on later-seeded than earlier-seeded plants.

Cultivar had little effect on any of the measurements taken. As was found in sleeve cages in 2006, the cultivar 5020 had slightly fewer stems per plant, but more seeds per pod than did 45H21 plants. These effects countered each other, and seed yields per plant, seed weight, number of shattered pods, damage per pod, and number of beetles per cage was similar between cultivars (Table 9).

Over both seeding dates and cultivars, there was a trend towards decreasing seed yields and weight with increasing numbers of flea beetles placed in the cages (Table 9). However, the differences were not statistically significant. Indeed, all of the canola harvest parameters measured were similar in value among uninfested sleeve cages and those infested with 100 or 150 flea beetles except for number of stems per plant, where sleeves that had been infested with 150 beetles contained fewer stems than those infested with 100 beetles. Over both seeding dates and cultivars, number of beetles per cage and damage levels varied directly with flea beetle infestation level. When parameters were examined within a seeding date, the variation in stems per plant was significant in later plantings, but not so in earlier ones (Table 9). Thousand seed weights decreased and number of shattered pods increased with increased number of flea beetles per cages of early-seeded plants, but not in later-seeded ones. Damage to pods in the early seeded trial was very low compared to that on pods in the later planting. Nevertheless, pods in cages infested with 150 beetles had greater feeding levels than pods in the uninfested cages in both early and late seedings, and damage in cages infested with 150 beetles in the late seeded trial was greater than damage to pods in cages infested with 100 beetles (Table 9). Numbers of flea beetles found in infested cages on late-seeded plots were greater than in the uninfested cages. A small number of flea beetles managed to find their way into the uninfested sleeve cages, contributing to the small level of pod damage found there.

c. 2008

The trial established well in 2008, and at the time of infestations on August 15 plants in the early seeded cages were in the 5.2-5.4, primarily 5.3 or seed turning from green to tan, growth stage; late seeded plants of both cultivars were in the 5.1-5.2, primarily 5.2 or seeds green growth stage. Stems of early-seeded plants were cut on August 21, and the plants brought into the lab August 28th. Stems of 5020Late were cut on Sept. 2 and harvested Sept. 15, with 45H21L stems were cut on Sept. 8, and harvested two weeks later.

Seeding date was the only parameter that affected seed yields in sleeve cages, with early seedings having greater seed yields and larger seeds than later seedings (Table 10). Although cultivar differences did occur in plant architecture, with number of stems per plant, seeds per pod, and 1000 seed weights varying between 45H21 and 5020, overall seed yields did not differ between the two cultivars. Infestation of sleeve cages with 100 flea beetles for a week or more had no impact on any harvest parameters, including seed yield or size (Table 10). Pod damage and number of flea beetles were significantly greater in infested than in uninfested sleeve cages (Table 10).

d. Data combined over years

To facilitate analyses of data combined over years, only figures from 45H21 and 5020 plots were used. Further, figures from sleeve cages with 100 beetles in 2006 were averaged over the two infestation dates. And, finally, data from the cages infested with 150 beetles in 2007 were not included in the combined analyses.

Given the results from the three years individually, it is not surprising that, when data was combined over years, seeding date had the greatest effect on canola harvest parameters of any of the factors investigated. Significantly more stems per plant, pods per plant, and seeds per pod, as well as greater seed yields and heavier seeds were harvested from early-seeded compared to late-seeded canola plots (Tables 11 and 12). Earlier-seeded plants had significantly less feeding damage per pod than did later-seeded plants. The number of shattered pods was greater in early-seeded plots than in late-seeded ones, in large part because most early-seeded plants were very mature when harvested in 2007. Over the three years, the cultivar 5020 had fewer stems and pods but more seeds per pod than did 45H21, resulting in similar seed yields and weights for the two cultivars. The inclusion of 100 flea beetles per caged plant did not result in any appreciable damage to canola yield components, nor did flea beetles affect the propensity of pods to shatter. Inclusion of flea beetles did increase damage to pods and number of beetles per cage (Table 12). Seed yields varied among years: seed yields per plant were higher but 1000 seed weights were lower in 2008 than in both 2006 and 2007 (Table 12). Pod damage was similar over three years.

Few second, third or fourth order interaction terms were significant in the analyses of harvest components (Table 11), indicating that main effects accounted for most of the variability in the parameters measured. The only interaction influencing seed yields was year by date, which affected most harvest variables measured. Seed yields and seed weights were both lower in late seeded *vs* early seeded plots in all three years, but the differences were not uniform, the greatest difference in seed yield per plant and the smallest difference in 1000 seed weight between early and late seeded plants occurred in 2007 (Table 12).

C. Monitoring flea beetle movement with sticky cards

In the flea beetle movement monitoring project, numbers of spring flea beetles caught in the yellow sticky traps, although highest in 2004, were very low in all three years. Few conclusions regarding flea beetle movement could be drawn because of this low level of flea beetle infestation. Numbers of beetles caught in headlands or shelterbelts were almost always lower than numbers caught in the field (e.g. Fig. 2), although there did not appear to be any correlation between patterns in numbers found on traps in shelterbelts and number of beetles found within fields. Even though the sites surveyed were within 50 km of each other in all three years, there was no consistency in date of occurrence of maximum numbers of flea beetles for most locations in 2004 and 2005. In 2006, however, there appeared to be a temporal pattern of beetle movement correlated with the date of maximum numbers trapped.At all four sites monitored near Saskatoon in 2006 the peak flea beetle numbers in the spring occurred when air temperatures reached 20 to 22°C and soil temperatures reached 14-16°C for the first time (Fig. 3). This corresponded to a value of about 210 degree days at a base temperature of 6°C.

Although flea beetles are thought to invade fields in waves from field edges and the first and worst evidence of flea beetle feeding usually is seen near these edges, in the current investigation this was not the case. There did not appear to be a spatial pattern in flea beetle movement such as gradual dispersal from the field edge inwards within any of the fields sampled in spring in any year or location. For example, in the first period sampled in the field near the Bridge City Speedway in 2004, numbers of flea beetles were greatest on sticky cards set 100m into the field (Fig. 7).Likewise, on occasion feeding levels at distances as far as 100 m into a field were just as great as or greater than feeding levels at the field perimeter (e.g. Fig. 4). Further, monitoring the aspect of the sticky trap on which flea beetles were caught, whether facing the field or facing the hedge or headland, did not aid in discovering the direction of flea beetle movement in to or out of the field. Numbers of flea beetles collected on traps at the edges of the hedgerows early in the spring were approximately evenly divided between facing the hedgerow, pasture, or headland, and facing away from it (data not presented), suggesting that either monitoring the aspect of the trap did not indicate the direction of origin of the flea beetle on the trap, or that the same numbers of flea beetles were coming to the trap from the field as from the hedgerow.

In the fall, there did not appear to be a pattern of movement out of canola fields back to possible overwintering sites. At two sites the greatest numbers of flea beetles were found on traps near newly germinated volunteer canola seedlings in an area where combine spillage had occurred.

III. Discussion and Conclusions:

During the period of this investigation, spring flea beetle populations in the study area were not high, as evidenced by the fact that feeding levels never exceeded 25% of cotyledon area eaten. Noticeable levels of natural infestations of flea beetles were present in the late summer in 2006-08. Despite this, no differences in seed yields were found when naturally-occurring fall flea beetle populations were controlled by spraying plots of two canola cultivars and seeding dates over the course of the study. By the time of the rise in fall flea beetle populations, most of the canola was mature and beyond susceptibility to feeding damage. Likewise, by the time enough flea beetles were collected to infest either cube or sleeve cages, the growth stage of the canola in the cages generally was well beyond susceptibility to pod damage. In the cube cage trial, the infestation of 16,00-26,000 beetles per cage was either of insufficient quantity or too late in the season to cause measurable differences in seed yield between infested and uninfested plots. Over all years one cultivar had significantly decreased seed weights in infested compared to uninfested cages. In the sleeve cage trial, likewise, there were few differences in harvest parameters among plants infested with no, 100, or, in one year, 150 flea beetles per plant. Thus, in three different investigations over five years fall flea beetle feeding had no consistent effects on seed yield of canola, suggesting that canola seed yield reductions from fall flea beetle feeding is not a common event. However, in several specific instances seed yields were affected by the presence of flea beetles.

In 2008 there was an 87 kg/ha increase in seed yield of the late seeded cultivar 5020 that had been sprayed with insecticide at the 5.1-5.2 growth stage, with seeds translucent to green, and sprayed again at the 5.3-5.4 growth stage, seeds green-brown to brown. This increase in seed yield translates to about 1.3 bushels per acre, and may not have been economic given the cost of the two pesticide applications.

Also in 2008, the cube cage infestation level of over 24,000 flea beetles per cage resulted in about 350 flea beetles per canola plant. This level of infestation of two cultivars of canola at the 5.1-5.2 growth stage, having seeds in lower pods translucent to green in colour, resulted in reduction of seed yields and seed weights while % green seed increased over levels in unifested cages. Over two canola cultivars, flea beetle feeding decreased seed yields by 241 kg/ha or 3.6 bu/acre and 1000 seed weights by 9%, while increasing levels of green seed by 40%.

Thus, two elements appear to be necessary for the occurrence of significant damage to canola from late season flea beetle feeding – very high numbers of flea beetles, and very immature canola pods at the time of infestation. Hot, sunny weather at the time these two conditions occur could exacerbate feeding damage.

In all studies in all years, seeding date had the greatest influence on harvest parameters of the three factors investigated, with earlier seedings generally outyielding later ones. In this investigation, the best defense against fall damage to canola seed yields was to seed early**.**

Under the conditions encountered during the period of this investigation, the conclusion drawn from the use of sticky cards for monitoring flea beetles in the early spring is that no conclusions could be drawn from the study. The use of yellow sticky traps as a monitoring and predictive tool for flea beetle invasion into canola fields was not reliable. Results were field specific, with no consistent pattern of movement related to temperature, field aspect, or distance into a field. These findings are similar to those of Lamb (1983), who found the pattern of spring flea beetle invasion into canola fields in the Red River Valley of Manitoba to be unpredictable, with high day to day variation and trap to trap variation in flea beetle numbers. These parallel results occurred under opposite flea beetle population densities – in the current study flea beetle populations were extremely low, while in the earlier study populations of flea beetles were high.

No conclusions about potential spring flea beetle populations could be drawn from monitoring numbers of flea beetle populations in the fall. Elucidation of this project awaits further research.

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Table 1. Mean (± standard error) of harvest parameters per canola plant from a field cage trial to determine the effects of flea beetle feeding late in the season on canola seed yields, Saskatoon, 2004.

	Cage Treatment	
Harvest parameter	Flea beetles absent	Flea beetles present
No. Stems with Pods	4.72±0.05	4.35±0.14
No. Pods on Main Stem	41.1±0.70	40.1±1.30
No. Pods on Remaining Stems	22.3±0.50	20.2±0.90
No. Feeding Pits per Pod	0.19±0.08	0.18±0.06
% Plants with Stem Feeding	35.0±12.9	51.6±16.4
Stem Damage 0-5	1.01±0.04	0.89±0.03
Canola Growth Stage	5.47±0.01	5.48±0.01
Plant Seed Yield(g)	6.48±0.75	6.64±0.75

Table 2. Seed yield of three (2006) or two (2007, 2008) cultivars of canola planted in open field plots near Saskatoon in mid-May (Early) and early June (Late).

Seeding date	Cultivar	Seed yield (kg ha^{-1}) 2006		2007	2008	2007-2008
Early		1582 a[1]		2527 a	2645 b	2586 a
Late		1081 b		1765 b	2906 a	2335 b
	45H21	1309 B		2110 A	2772 A	2441 A
	46A65	1070 B		---	---	---
	5020	1614 A		2182 A	2779 A	2480 A
			Nospray	2139 a	2754 a	2446 a
			Spray[2]	2153 a	2797 a	2475 a
Early	45H21	1524	No spray	2645 A	2615 A	2630 A
			Spray	2600 A	2577 A	2589 A
	46A65	1357	No spray	---	---	---
			Spray	---	---	---
	5020	1865	No spray	2409 a	2662 a	2536 a
			Spray	2451 a	2727 a	2589 a
Late	45H21	1095	No spray	1607 A	2920 A	2264 A
			Spray	1586 A	2978 A	2282 A
	46A65	783	No spray	---	---	---
			Spray	---	---	---
	5020	1364	No spray	1893 a	2819 b	2356 a
			Spray	1973 a	2906 a	2440 a
Year		1482 C		2146 B	2775 A	

[1] Values within columns and categories followed by the same letter not significantly different, PROC MIXED and ANOVA at P≤0.05 (means separation by Least Significant Difference, Tukey-Kramer adjustment).

[2] Plots sprayed with Decis® insecticide on 16 Aug. 2007 (early seeded plots swathed August 14) when natural infestations of flea beetles were high and when late seeded plants were in the 5.3-5.4 growth stages. Plots sprayed with Decis® on 20 Aug. 2008, when canola was in the 5.3-5.5 (Early) and 5.1-5.2 (Late) growth stages; Late plots were sprayed again on 29 Aug. when flea beetle populations were high and plants were in the 5.2 to 5.4 growth stage.

Table 3. Seed weights, green seed content, and germination levels of two cultivars of canola seeded on 5 June (Late) in open field plots in 2008.

Cultivar		1000 seed weight (g)	Green seed (%)	Germination (%)
45H21		3.11 a	0.86 a	96.7 a
5020		2.95 b	1.04 a	97.7 a
	Nospray	3.01 A	1.12 A	97.0 A
	Spray	3.04 A	0.78 B	97.3 A
45H21	Nospray	3.11 a	1.03 a	96.7 a
	Spray	3.11 a	0.70 a	96.7 a
5020	Nospray	2.92 A	1.22 A	97.3 a
	Spray	2.98 A	0.86 A	98.0 a

[1] Values within columns and categories followed by the same letter not significantly different, PROC MIXED and ANOVA at P≤0.05 (means separation by Least Significant Difference, Tukey-Kramer adjustment).

Table 4. Analysis of variance table for seed yields of two cultivars of canola planted in mid-May (Early) and June 2 (Late) in open field plots in 2006 -2008, half of which were sprayed with insecticide in 2007 -2008, and combined over 2007-2008 and 2006-2008 unsprayed.

	2006		2007		2008		2007-2008		2006-2008 unsprayed	
Variable	F=	P<F	F=	P<F	F=	P<F	F=	P<F	F=	P<F
Seeding date	31.8	0.0004	218	<0.0001	18.8	0.0003	37.1	<0.0001	28.4	<0.0001
Cultivar	10.1	0.011	1.96	0.167	0.01	0.930	0.87	0.362	3.15	0.082
Date*cult	0.22	0.804	26.3	<0.0001	2.38	0.137	4.37	0.043	1.32	0.257
Spray			0.11	0.739	1.93	0.172	1.27	0.264	---	---
Spray*cult			1.27	0.266	1.14	0.291	2.51	0.117	---	---
Spray*date			0.14	0.714	0.90	0.348	0.78	0.379	---	---
Spray*date*cv			0.01	0.934	0.34	0.562	0.08	0.773	---	---
Year							102	<0.0001	112	<0.0001
Year*cult							0.62	0.441	2.44	0.098
Year*date							154	<0.0001	37.9	<0.0001
Year*spray							0.33	0.568	---	---
Year*date*cult							188	<0.0001	6.17	0.004
Yr*date*spray							0.08	0.782	---	---
Yr*cult*spray							0.08	0.784	---	---
Yr*date*cv*spray							0.18	0.671	---	---

Table 5. Canola harvest parameters and flea beetle damage to three cultivars of canola planted on May 16 (Early) and June 2 (Late), 2006 near Saskatoon and caged with m^3 cages that were infested with 15,600 flea beetles on August 14.

Seeding date	Cultivar	Infestation date	stems $plant^{-1}$	pods $stem^{-1}$	seeds pod^{-1}	yield (kg ha^{-1})	1000 seed weight (g)	shattered pods $cage^{-1}$	damage[1] pod^{-1}
Early			5.44 a[2]	12.9 a	22.4 a	1845 a	3.12 a	10.7 a	0.15 b
Late			4.75 a	9.29 b	20.9 a	1106 b	2.81 b	7.06 a	0.76 a
	45H21		5.79 A	12.0 A	21.8 AB	1544 A	3.11 A	7.62 B	0.27 B
	46A65		5.42 AB	11.1 AB	19.8 B	1168 B	2.80 A	6.17 B	0.64 A
	5020		4.08 B	9.77 B	23.3 A	1732 A	2.99 A	12.8 A	0.46 AB
		None	4.92 a	11.2 a	21.6 a	1468 a	2.92 a	7.62 a	0.38 b
		Late	5.46 a	10.5 a	21.7 a	1479 a	3.07 a	11.4 a	0.60 a

[1] Damage expressed on a scale of 0, no damage, to 4, extensive feeding on the pod pericarp, with 75-100% of the pod epidermis damaged.

[2] Values within columns and categories followed by the same letter not significantly different, ANOVA at $P \leq 0.05$ (means separation by Least Significant Difference, Tukey-Kramer adjustment).

Table 6. Seed yields and 1000 seed weights of two cultivars of canola planted in early June (Late seeded) in field plots near Saskatoon and caged with 1x1x1.5 m screen cages that were infested with 16,500 (2006), 27,000 (2007), or 24,000 (2008) flea beetles per cage in mid-August.

		2006		2007		2008		All years	
Cultivar	flea beetles	seed yield (kg ha^{-1})	1000 seed weight (g)	seed yield (kg ha^{-1})	1000 seed weight (g)	seed yield (kg ha^{-1})	1000 seed weight (g)	seed yield (kg ha^{-1})	1000 seed weight (g)
45H21		1250 a	2.85 a	1379 b	2.72 a	1979 a	2.66 a	1536 a	2.74 a
5020		1228 a	2.95 a	1632 a	2.52 b	1884 a	2.46 b	1582 a	2.66 a
	absent[2]	1202 A	2.88 A	1523 A	2.64 A	2052 A	2.68 A	1592 A	2.74 A
	present	1277 A	2.94 A	1487 A	2.60 A	1811 B	2.44 B	1525 A	2.66 A
45H21	absent	1228 a	2.88 a	1421 a	2.75 a	2089 a	2.77 a	1659 a	2.78 a
	present	1272 a	2.79 a	1337 a	2.68 b	1869 b	2.56 b	1543 a	2.65 b
5020	absent	1176 A	2.87 A	1626 A	2.54 A	2014 A	2.60 A	1703 A	2.67 A
	present	1283 A	3.09 A	1637 A	2.51 A	1753 B	2.33 B	1620 A	2.64 A
2006								1240 a	2.91 a
2007								1505 a	2.62 b
2008								1931 b	2.56 b

[1] Values within columns and categories followed by the same letter not significantly different, PROC MIXED and ANOVA at P≤0.05 (means separation by Least Significant Difference, Tukey-Kramer adjustment).

Table 7. Plant densities, seed yields, 1000 seed weights, and percent green seed and germination of two cultivars of canola planted in mid-May (Early seeding) and early June (Late seeding) in field plots near Saskatoon and caged with 1x1x1.5 m screen cages that were infested with 24,000 flea beetles per cage on August 15, 2008.

Seeding date	Cultivar	Cage Infestation	Plant density	Seed yield (kg/ha)	1000 Seed weight (g)	Green seed (%)	Germination (%)
Early			60.9 a	2942 a[1]	3.19 a	0.77 b	97.9 a
Late			67.5 a	1931 b	2.56 b	3.16 a	93.9 b
	45H21		64.6 A	2421 A	2.96 A	1.87 A	96.1 A
	5020		63.8 A	2452 A	2.77 B	2.06 A	95.7 A
		Control	64.2 a	2518 a	2.94 a	1.59 b	96.3 a
		Infested	64.2 a	2355 b	2.82 b	2.33 a	95.5 a
Early	45H21		60.6 A	2864 A	3.26 A	0.89 A	97.3 B
	5020		61.1 A	3020 A	3.12 B	0.65 A	98.5 A
Late	45H21		68.5 a	1979 a	2.66 a	2.85 a	94.9 a
	5020		66.5 a	1884 a	2.46 b	3.46 a	92.9 a
Early		Control	62.2 A	2984 A	3.19 A	0.80 A	98.0 A
		Infested	59.6 A	2899 A	3.19 A	0.74 A	97.8 A
Late		Control	66.2 a	2052 a	2.68 a	2.39 b	94.6 a
		Infested	68.8 a	1811 b	2.44 b	3.93 a	93.2 a
Early	45H21	Control	61.7 A	2935 A	3.27 A	0.74 A	97.8 A
		Infested	59.6 A	2793 A	3.26 A	1.04 A	96.8 A
	5020	Control	62.7 a	3034 a	3.13 a	0.85 a	98.2 a
		Infested	59.6 a	3006 a	3.11 a	0.44 a	98.8 a
Late	45H21	Control	66.2 A	2089 A	2.77 A	1.81 B	95.8 A
		Infested	70.8 A	1869 B	2.56 B	3.89 A	94.0 A
	5020	Control	66.1 a	2014 a	2.60 a	2.96 a	93.4 a
		Infested	66.9 a	1753 b	2.33 b	3.96 a	92.4 a

[1] Values within columns and categories followed by the same letter not significantly different,

PROC MIXED and ANOVA at $P \leq 0.05$ (means separation by Least Significant Difference, Tukey-Kramer adjustment).

Table 8. Canola harvest parameters and flea beetle damage to three cultivars of canola planted on May 16 (Early) and June 2 (Late), 2006, in open field plots near Saskatoon and caged with organdie sleeve cages that were infested with 100 flea beetles on August 6 (early) or August 14 (late).

Seeding date	Cultivar	Infestation date	stems $plant^{-1}$	pods $plant^{-1}$	seeds pod^{-1}	yield (g $plant^{-1}$)	1000 seed weight (g)	shattered pods $cage^{-1}$	damage pod^{-1} [1]	beetles $cage^{-1}$
Early			6.01 a[2]	77.0 a	22.0 a	4.97 a	3.26 a	7.06 a	0.54 b	53.9 a
Late			4.76 b	41.7 b	22.1 a	2.60 b	2.88 b	9.59 a	1.17 a	39.4 b
	45H21		6.15 A	65.2 A	21.5 B	4.19 A	3.14 A	10.6 A	0.77 A	42.8 AB
	46A65		5.71 A	62.8 AB	20.5 C	3.77 AB	2.99 A	7.36 A	0.90 A	41.6 B
	5020		4.29 B	50.0 B	24.1 A	3.39 B	3.07 A	7.03 A	0.90 A	55.6 A
		early	5.85 a	64.7 a	21.7 a	4.09 a	2.98 a	9.25 a	1.18 a	62.2 a
		late	5.32 ab	58.6 a	22.1 a	3.73 a	3.00 a	8.61 a	1.04 a	74.2 a
		none	4.99 b	54.6 a	22.2 a	3.53 a	3.23 a	7.12 a	0.34 b	3.71 b

[1] Damage expressed on a scale of 0, no damage, to 4, extensive feeding on the pod pericarp, with 75-100% of the pod epidermis damaged

[2] Values within columns and categories followed by the same letter not significantly different, ANOVA at $P \leq 0.05$ (means separation by Least Significant Difference).

Table 9. Canola harvest parameters and flea beetle damage to two cultivars of canola planted on May 11 (Early) and June 2 (Late), 2007 in field plots near Saskatoon and caged with organdie sleeve cages that were infested with no, 100 or 150 flea beetles on August 10.

Seeding date	Cultivar	flea beetles/cage	stems $plant^{-1}$	pods $plant^{-1}$	seeds pod^{-1}	yield (g $plant^{-1}$)	1000 seed weight (g)	shattered pods $cage^{-1}$	damage pod^{-1} [1]	beetles $cage^{-1}$
Early			5.94 a[2]	85.7 a	25.1 a	5.19 a	2.54 a	19.9 a	0.12 b	21.9 a
Late			4.50 b	64.0 b	22.8 b	2.58 b	2.32 b	3.18 b	1.02 a	29.3 a
	45H21		5.64 A	84.6 A	22.8 B	3.81 A	2.39 A	8.25 B	0.55 A	22.4 A
	5020		4.58 B	61.5 B	24.9 A	3.66 A	2.44 A	13.2 A	0.59 A	30.1 A
		0	5.31 ab	76.7 a	23.9 a	4.00 a	2.45 a	9.07 a	0.39 a	2.15 a
		100	5.46 a	76.6 a	24.1 a	3.85 a	2.41 a	11.0 a	0.60 b	21.8 b
		150	4.65 b	67.7 a	23.3 a	3.37 a	2.38 a	11.8 a	0.72 c	54.1 c
Early		0	6.25 A	91.0 A	25.1 A	5.52 A	2.63 A	17.5 A	0.038 A	1.44 A
		100	6.00 A	86.4 A	24.9 A	5.16 A	2.56 AB	20.7 A	0.153 AB	22.3 A
		150	5.56 A	79.8 A	25.2 A	4.88 A	2.44 B	21.4 B	0.181 B	42.1 A
Late		0	4.55 ab	65.3 a	23.0 a	2.77 a	2.32 a	2.30 a	0.745a	2.72 a
		100	5.02 a	68.8 a	23.5 a	2.80 a	2.29 a	3.28 a	1.045 b	21.4 b
		150	3.92 b	58.0 a	21.8 a	2.17 a	2.34 a	3.98 a	1.271 c	63.8 c

[1] Damage expressed on a scale of 0, no damage, to 3, extensive feeding on the pod pericarp, with 75-100% of the pod epidermis damaged.

[2] Values within columns and categories followed by the same letter not significantly different, ANOVA at $P\leq0.05$ (means separation by Tukey's test).

Table 10. Canola harvest parameters and flea beetle damage to two cultivars of canola planted on May 16 (Early) and June 5 (Late), 2008 in field plots near Saskatoon and caged with organdie sleeve cages that were infested with no or 100 flea beetles on August 15.

Seeding date	Cultivar	flea beetles/cage	stems $plant^{-1}$	pods $plant^{-1}$	seeds pod^{-1}	yield (g $plant^{-1}$)	1000 seed weight (g)	shattered pods $cage^{-1}$	damage pod^{-1} [1]	beetles $cage^{-1}$
Early			3.32 b[2]	79.2 a	25.1 a	5.18 b	3.35 a	2.92 a	0.35 b	10.2 b
Late			3.88 a	60.2 b	25.4 a	3.88 a	2.69 b	2.01 a	0.56 a	15.4 a
	45H21		3.85 A	75.8 A	23.8 B	4.44 A	3.15 A	0.88 B	0.43 A	12.2 A
	5020		3.34 B	63.7 B	26.6 A	4.62 A	2.90 B	4.05 A	0.47 A	13.5 A
		0	3.55 a	70.1 a	25.3 a	4.62 a	3.03 a	2.32 a	0.23 b	3.41 b
		100	3.64 a	69.4 a	25.2 a	4.44 a	3.02 a	2.60 a	0.67 a	22.3 a
Early		0	3.37 A	80.4 A	25.6 A	5.22 A	3.33 A	2.55 A	0.06 B	0.32 B
		100	3.27 A	78.2 A	24.6 A	5.13 A	3.38 A	3.28 A	0.64 A	20.1 A
Late		0	3.73 a	59.7 a	25.0 a	4.01 a	2.70 a	2.10 a	0.41 b	6.50 b
		100	4.02 a	60.7 a	25.8 a	3.76 a	2.68 a	1.92 a	0.71 a	24.4 a

[1] Damage expressed on a scale of 0, no damage, to 3, extensive feeding on the pod pericarp, with 75-100% of the pod epidermis damaged.
[2] Values within columns and categories followed by the same letter not significantly different, ANOVA at $P \leq 0.05$ (means separation by Tukey's test).

Table 11. Analysis of variance results for canola harvest parameters and flea beetle damage to canola cultivars 45H21 and 5020 planted Early and Late in open field plots near Saskatoon in 2006 to 2008, and caged with organdie sleeve cages into which 100 flea beetles were or were not introduced in mid-August.

Parameter	No. stems/ plant	No. pods/ plant	No. seeds/ pod	Seed yield (g plant^{-1})	1000 seed weight (g)	Flea beetles/ cage	Shattered pods/ plant	Damage per pod [1]
Year	<0.0001	0.0009	<0.0001	0.014	<0.0001	<0.0001	<0.0001	0.002
Cultivar	<0.0001	0.0004	<0.0001	n.s.	n.s.	0.026	0.011	n.s.
Seeding date	0.033	<0.0001	0.016	<0.0001	<0.0001	n.s.	<0.0001	<0.0001
Date*cult	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Treatment (infestation)	n.s.	n.s.	n.s.	n.s.	n.s.	<0.0001	0.072	<0.0001
Trt*cult	n.s.	n.s.	n.s.	n.s.	n.s.	0.020	n.s.	0.051
Date*trt	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Date*cult*trt	n.s.	0.016	n.s.	n.s.	n.s.	n.s.	n.s.	0.040
Year*cult	n.s.	0.028	n.s.	n.s.	0.024	n.s.	0.0009	n.s.
Year*date	<0.0001	0.044	0.031	0.002	0.0003	0.026	<0.0001	<0.0001
Year*cult*date	n.s.	n.s.	0.0004	n.s.	n.s.	n.s.	n.s.	n.s.
Year*trt	n.s.	n.s.	n.s.	n.s.	n.s.	<0.0001	n.s.	0.0005
Year*trt*cult	n.s.	n.s.	n.s.	n.s.	n.s.	0.019	n.s.	0.018
Year*trt*date	0.038	n.s.	n.s.	n.s.	n.s.	0.004	n.s.	<0.0001
Year*trt*date*cult	n.s.	n.s.	0.033	n.s.	n.s.	n.s.	n.s.	0.0005

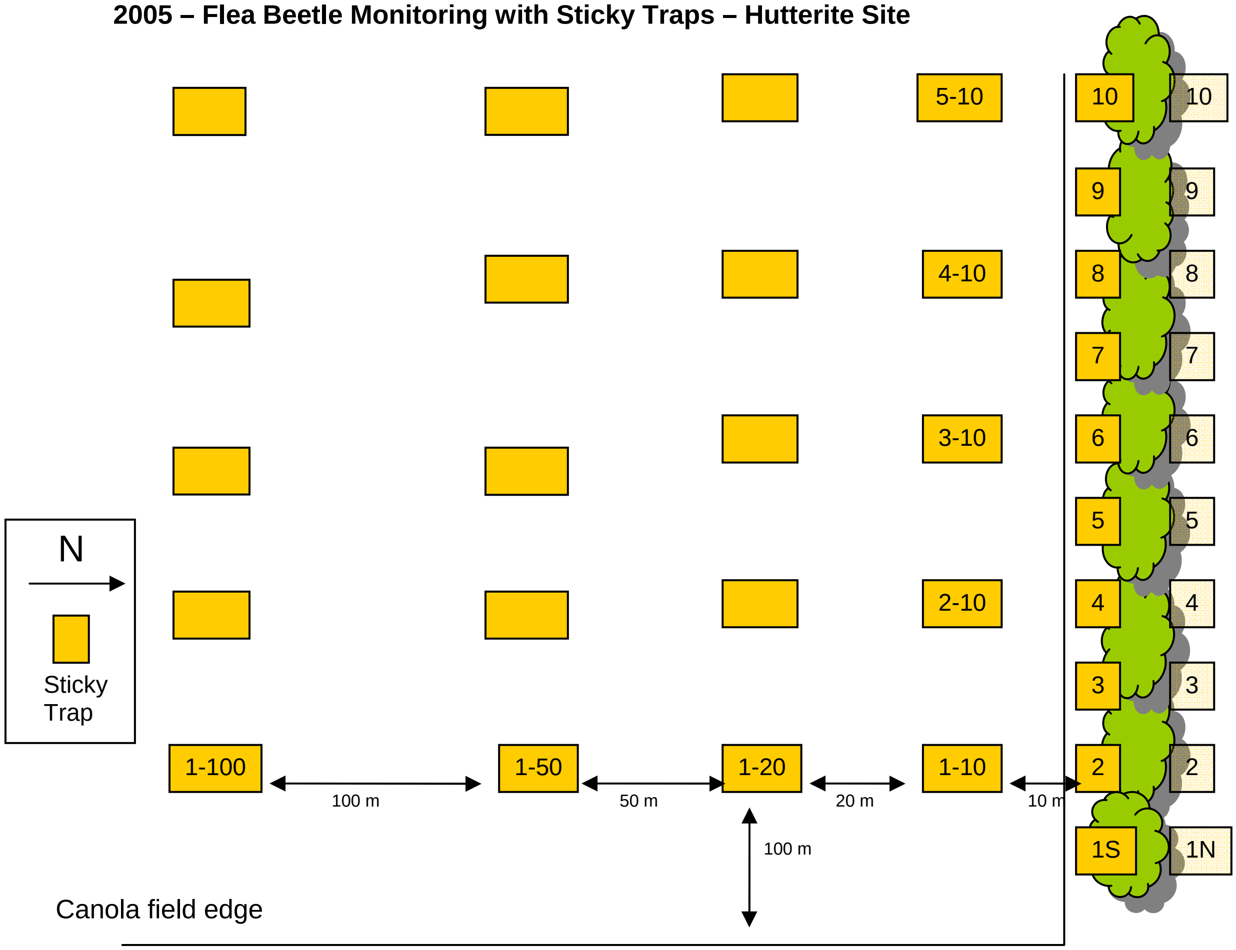
Table 12. Harvest traits of and flea beetle damage to canola cultivars 45H21 and 5020 planted Early and Late in open field plots near Saskatoon in 2006 to 2008, and caged with organdie sleeve cages into which 100 flea beetles were or were not introduced in mid-August.

Seeding date	Cultivar	flea beetles/cage	stems plant^{-1}	pods plant^{-1}	seeds pod^{-1}	yield (g plant^{-1})	1000 seed weight (g)	shattered pods cage^{-1}	damage pod^{-1} [1]	beetles cage^{-1}
Early			4.85 a[2]	79.3 a	24.4 a	5.08 a	3.11 a	9.96 a	0.31 b	23.4 a
Late			4.48 b	60.2 b	23.6 b	3.08 b	2.64 b	5.05 b	0.82 a	23.8 a
	45H21		5.20 A	75.8 A	22.7 B	4.14 A	2.91 A	6.39 B	0.55 A	21.1 B
	5020		4.13 B	63.7 B	25.3 A	4.01 A	2.84 A	8.62 A	0.59 A	26.2 A
		0	4.64 a	69.5 a	24.0 a	4.13 a	2.94 a	6.81 a	0.33 a	3.55 b
		100	4.69 a	70.1 a	24.0 a	4.03 a	2.82 a	8.20 a	0.80 b	43.7 a
Early		0	4.76 A	78.2 A	24.6 A	5.07 A	3.21 A	8.89 A	0.11 A	1.24 B
		100	4.94 A	80.4 A	24.2 A	5.07 A	3.02 A	11.02 A	0.52 B	45.6 A
Late		0	4.51 a	60.7 a	23.5 a	3.19 a	2.66 a	4.73 a	0.56 a	5.85 b
		100	4.44 a	59.7 a	23.8 a	2.97 a	2.61 a	5.37 a	1.08 b	41.8 a
2006			5.16 A	57.0 B	22.8 C	3.75 A	3.16 A	8.59 B	0.72 A	38.2 A
2007			5.19 A	74.4 A	24.0 B	3.88 A	2.42 B	10.22 A	0.58 A	20.0 B
2007			3.60 B	77.6 A	25.2 A	4.53 B	3.02 A	2.46 C	0.45 A	12.8 C

[1] Damage expressed on a scale of 0, no damage, to 4, extensive feeding on the pod, with 75-100% of the pod epidermis damaged.

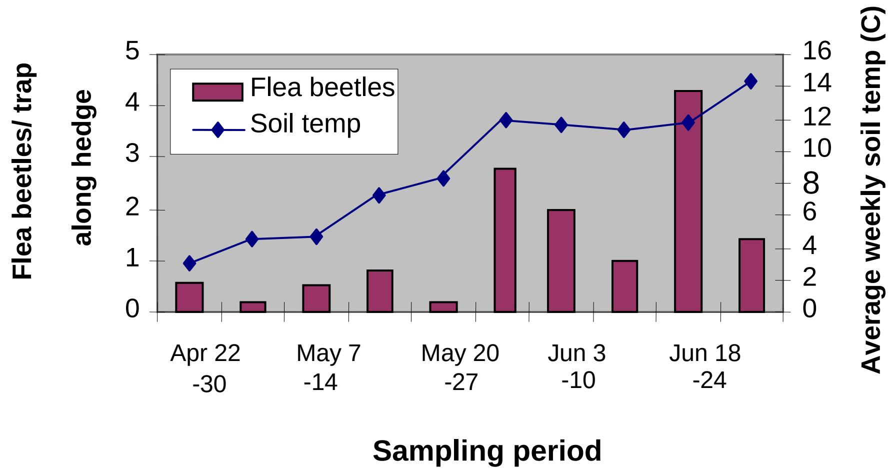
[2] Values within columns and categories followed by the same letter not significantly different, ANOVA at P≤0.05 (means separation by Tukey's test).

Figure 1. Arrangement of yellow sticky traps for monitoring early spring flea beetle populations near Saskatoon, 2005.



graphic adapted from J. Otani, AAFC Beaverlodge, AB

Figure 2. Flea beetle numbers per sticky card trap in a headland and in a canola field near Bridge City Speedway, Saskatoon, SK, 2004, and average weekly soil temperatures at 2.5 cm below soil level in the headland.



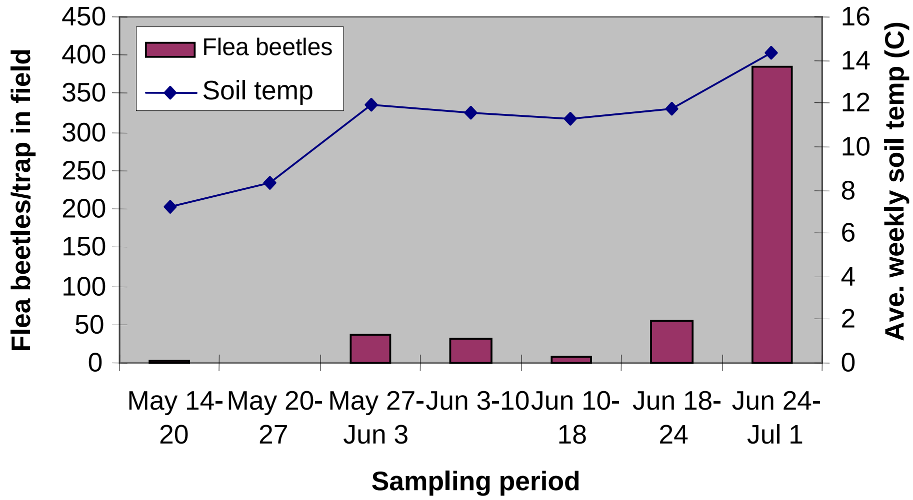


Figure 3. Average number of flea beetles, principally *Phyllotreta* spp., per yellow sticky trap per day at six locations in a canola field and mean soil temperatures at 2 cm depth at the edge of a Manitoba maple hedge on a farm near the Bridge City Speedway in 2006.

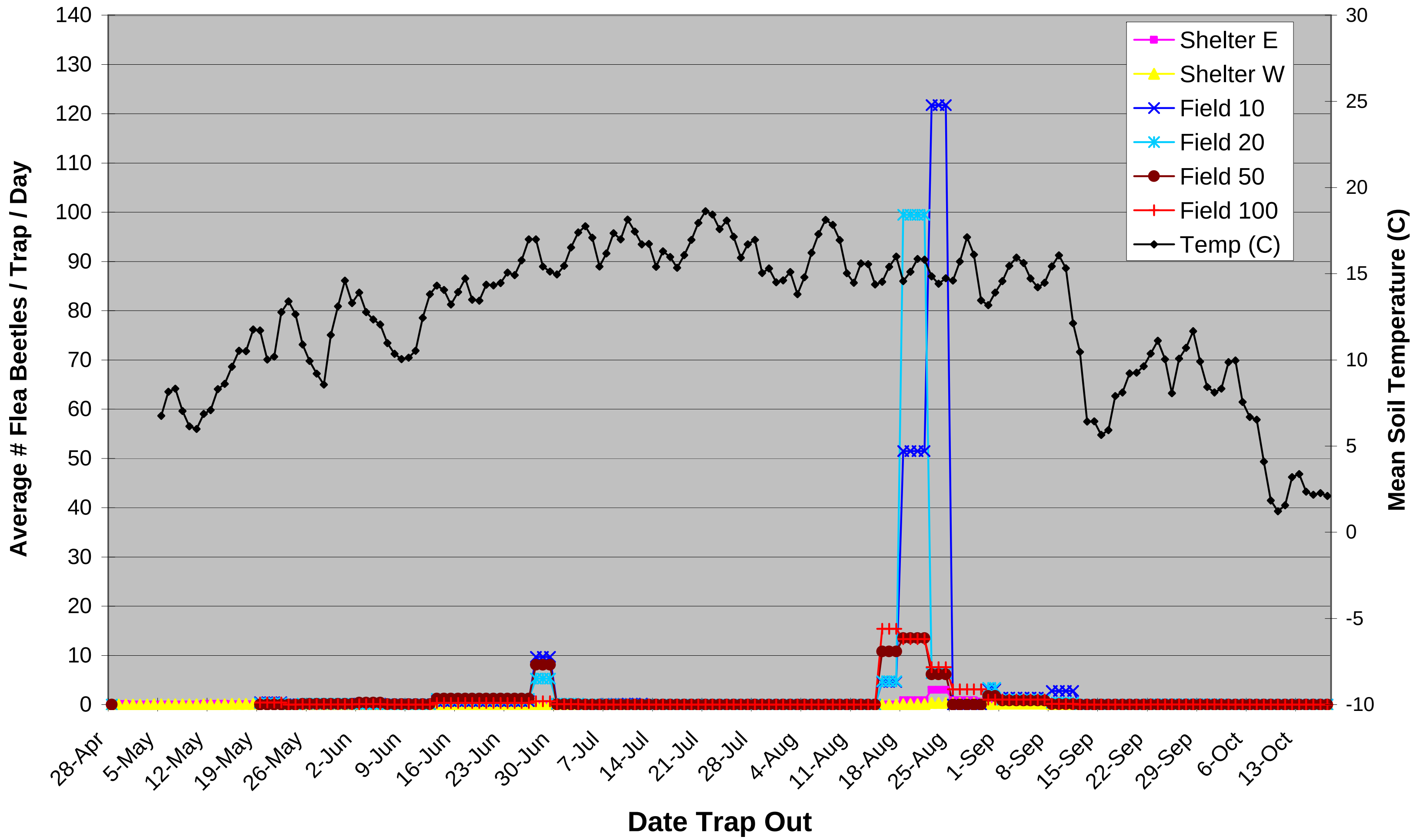


Figure 4. Flea beetles per sticky trap per week on traps at various distances into a canola field near Bridge City Speedway, Saskatoon, SK, in 2004, and the feeding levels seen on canola leaves around the traps.