Flea beetle herbivory in canola impacted by seed size, seeding date and seeding rate.

Abstract

The Canola Council of Canada advises that canola should be sown with high seeding densities and preferably using larger seed size (up to 2.2mm). Moreover, seeding later in the season should be considered rather than seeding on earlier dates. Briefly, greater plant densities produced by high seeding rates compensate for flea beetle leaf damage. Canola sown Mid-May to early June were greater yielding if seedlings sprouted from bigger seeds. Moreover, late seeding canola was less affected by fleabeetle damage compared to canola seeded at earlier dates. Currently, there is limited research showing how all these recommendations, acting in conjunction, affect canola production. Therefore, this study aimed to evaluate the impact of seeding rate, seed size, and seeding date by three flea beetle populations and its damage on canola foliage: crucifer (*Phyllotetra cruciferae Goeze* Goetze), striped (*Phyllotetra striolata Fabricius Fabricius* Fabricius) and hop (*Psylliodes punctulate* Melscheimer). A split-plot factor analysis was set for three seeding rates (5.2, 10.4 and 15.6 plants foot^{-2}; low, control and high rates respectively), three seed sizes (small; less than 2.2mm, large; greater than 2.2mm and unsorted) and two seeding dates. At later seeding dates emergent and mature stand counts, yield, number, and total number of flea beetles, in particular, striped and hop flea beetles were greater. Control seeding rates produced more yield and more emergent and mature stands. Seeds greater than 2.2mm and unsorted seed were greater yielding and with greater number of striped flea beetles than seeds smaller than 2.2mm. Flea beetle number may have increased in late seeding dates because there are more canola plant available for feeding and yield is greater at later dates likely due to warmer temperatures that facilitate faster growth and development plant development and thus more tolerance towards flea beetle herbivory.

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Introduction

Adult flea beetles (*Phyllotetra* spp.) feed on the cotyledons of canola seedlings and carry on feeding throughout the developmental stages of the plant (Gavloski et al. 2000). Seed-coated insecticides and subsequent applications of foliar sprays are used to reduce flea beetle populations. However, the time frame at which the insecticide is effective is narrow, meaning that the insecticide is unable to protect canola stands throughout all its developmental stages (Dosdall and Stevenson 2005; Lamb 1984). In addition, the application of insecticides such as neonicotinoid are systemic in the plant. They can translocate to the plant pollen and potentially cause toxicity to pollinators such as honeybees and birds (Thompson 2003). Chemical applications therefore need to be accompanied by cultural methods to reduce flea beetle populations and hence reduce the extent of damage.

Increased seeding rate (Dosdall et al. 1999), late seeding date (mid-May to early-June) (Cárcamo et al. 2008), and larger seed size (Elliot et al. 2008; Bodnaryk and Lamb 1991) have been some of the agronomic methods used to reduce flea beetle populations. Dosdall et al. (1999) showed that increased seeding rates significantly reduced leaf damage in canola stands owing to greater foliar density. Moreover, seeding dates have been shown to influence presence of flea beetles in the first stages of canola plant development. Cárcamo et al. (2008) observed opposite results in northern and southern regions in Alberta. In northern regions flea beetle incidence tended to be greater if planting date was later in the season (mid to late May) compared to earlier dates between late April to early May. A shift has occurred since where southern regions show the same trend as that found in Northern regions (Knodel et al. 2008). Overall, the interaction between higher seeding rates along with later seeding dates may help to reduce population and damage of flea beetles.

Bodnaryk and Lamb (1991) noticed that seed sizes can influence flea beetle damage in canola stands. Basically, seedlings from larger seed sizes may be more tolerant to flea beetle damage than those coming from small seeds. Similarly, Elliot et al (2008), showed that canola stands from larger seed sizes provided better establishments and had heavier shoots. However, larger seeds are more costly than smaller, causing growers to reduce seeding rates and hence lower yields (Harker et al. 2015) Indeed, seed size should be considered for canola establishment against flea beetle control.

Managing flea beetles by increasing seeding rates may ameliorate leaf damage, however, there is no evidence that flea beetle populations per se were affected (Dosdall et al. 1999). Thus, seeding date may impact these populations if seeded late rather than early in the season in this region (Cárcamo et al. 2008; Knodel et al. 2008), Bigger seeds may promote healthier stands, but there is no research showing how these stands are impacted with seeding rates, and seeding dates. Thus, this study aims to investigate the simultaneous effects of seeding rate, seed size and seeding date, from undisturbed soil on flea beetle management. Potential interactions among these effects may uncover further answers and even help to reduce the applications of insecticides in fields.

The objective is to evaluate the impact of seeding date (second to third week of May and fourth week of May to first week of June), seed size (small; less than 2.2mm, large; greater than 2.2mm and unsorted), and seeding rate (5.2, 10.4 and 15.6 plants foot^{-2}) on flea beetle leaf damage and flea beetle population and how this manifests in oilseed yield.

Materials and methods

All sites were located in Alberta in 2020, 2021 and 2022 at the North Peace Applied Research Association (NPARA) facility in North Star (56°51'17.9"N 117°38'11.9"W), the Mackenzie Applied Research Association (MARA) in Fort Vermillion (58°23’5.53”N, 116°2’35.09”W) and the Smoky Applied Research and Demonstration Association (SARDA) in Fahler (55°43’28.8”N, 117°12’6.822”W). The experiment was set up as a four replicate, split plot analysis with three treatments. Plots were set at 1.6 m x 8 m. Treatments consisted of canola seeding rate. As such, canola was sown at recommended (control at 10.4 plant foot^{-2}, 7.4 lb ac^{-1}), half (5.2 plant foot^{-2}, 3.7 lb ac^{-1}) and one and a half (15.6 plant foot^{-2}, 11.1 lb ac^{-1}) of the recommended seeding rates, since planting at greater seeding rates can be cost prohibitive for growers. Each seeding rate was divided into three canola seed sizes. Sizes were classified as small (<2.2mm), large (>2.2mm) as well as an unsorted control of both sizes. The split plot factor was seeding date, divided into early, which consisted of a period between late April and early May, and normal which was between the second to third week of May. However, these dates did not agree with weather conditions, such as frequent precipitation events. Hence early seeding dates were considered as those within the second to third week of May and late dates were those within the fourth week of May and the first week of June. Seeding dates can be seen in Table 1. Temperature and precipitation at each month during the growing season is compiled in Table 2.

Table 1 Research locations and seeding dates over three years at three sites where canola was sown at 5.2, 10.4 and 15.6 plants foot^{-2} by separating it as 1.4-1.7mm, 1.8-2.2mm and unsorted seed diameter sizes

				Early			Late		
Site	Location	Coordinates		2020	2021	2022	2020	2021	2022
Mackenzie Applied Research Association	Fort Vermillion	56°51'17.9" N 117°38'11.9" W	*Seeding*	May 12	May 21	May 26	May 18	June 2	June 2
			Harvest	October 2	September 7	September 26	October 15	September 29	September 26
North Peace Applied Research Association	North Star	56°51'17.9" N 117°38'11.9" W	*Seeding*	May 21	May 18	May 24	May 28	June 3	June 3
			Harvest	September 8	October 1	October 21	October 2	October 15	October 21
Smoky Applied Research and Demonstration Association	Falher	55°43’28.8” N, 117°12’6.822” W	*Seeding*	May 28	May 15	May 28	June 3	May 26	June 7
			Harvest	September 30	September 29	-[a]	October 15	October 1	-

[a]Canola was not harvested. Believed to be RoundUp ready canola, Glyphosate was applied on Clearfield canola. The canola was killed, and no harvest was possible.

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Table 2 Monthly air temperature and precipitation recorded for each growing season Fort Vermillion, Ballater and Manning for the research stations located in Fort Vermillion, Falher and North Star respectively

Year	Month	Fort Vermillion Air Temperature (°C) Minimum	Fort Vermillion Air Temperature (°C) Maximum	Fort Vermillion Air Temperature (°C) Average	Fort Vermillion Precipitation (mm)	Falher (Ballater) Air Temperature (°C) Minimum	Falher (Ballater) Air Temperature (°C) Maximum	Falher (Ballater) Air Temperature (°C) Average	Falher (Ballater) Precipitation (mm)	North Star (Manning) Air Temperature (°C) Minimum	North Star (Manning) Air Temperature (°C) Maximum	North Star (Manning) Air Temperature (°C) Average	North Star (Manning) Precipitation (mm)
2020	April	-25.6	18.3	-0.6	9.4	-32	18.1	-0.3	9.3	-30.3	19	0.2	12.9
	May	-5.8	25.3	9.7	24.2	-3.6	25.4	10.1	50.9	-4.1	25.5	9.9	20.6
	June	3.6	28.6	15.2	30.4	1.3	27	14.4	84.4	3.4	27.8	14.6	79.5
	July	8.2	29.9	17	89.9	6.8	30.9	16.5	55.2	7.8	30.3	16.5	124.7
	August	0.6	30.4	15.2	94	4.1	31.6	15.4	37.4	-0.6	30.4	15	52.4
	September	-1	21.2	9.7	17.9	-5.2	26	11.1	9.8	-3.4	25.1	9.9	19.4
	October	-15.2	17.3	-0.7	16.9	-16.9	24.8	0.8	31.3	-16.9	23.4	0	23.6
2021	April	-16.1	16.1	0.0	9.0	-10.7	19.6	2.6	16.3	-12.7	20.2	1.7	5.3
	May	-2.7	26.1	10.7	15.7	-2.4	25.7	11.2	49.4	-3.6	26.8	10.7	21
	June	3.9	34.2	18.1	59.3	-0.4	39.8	17.8	28.6	-1.1	36.8	17.8	45.5
	July	5.3	31.9	18.1	27	4.3	32.1	18	13.5	4.5	33	17.3	84.5
	August	2.6	33.3	15.5	55.3	1.8	33.9	15.8	53.6	0.6	32.5	15.4	32.8
	September	-0.5	23.9	10.4	48.1	-0.6	25.1	11.8	34.2	-1.6	24.6	10.5	37.3
	October	-8.3	16.9	3.2	20.1	-10.4	17.9	3.9	14.6	-11	16.2	2.6	13.6
2022	April	-18.6	13	-0.9	21.7	-12.6	19.6	1.6	42.3	-14.8	18.2	-0.3	44
	May	-4.1	22.5	9.1	52.6	-5.6	21.7	8.9	39.2	-4.5	21.9	8.3	88.5
	June	6.1	27.6	17.0	42.1	2.2	26.7	15.6	41.6	3.5	27	15.7	54.9
	July	8.3	29.4	18.2	51.6	3.0	34.2	17.4	29.2	3.1	33.1	17.2	40.9
	August	5.2	32.6	18.3	15.8	4.1	32.3	18.2	32.4	3.7	29.9	16.7	63.8
	September	-0.3	29.1	12.3	18.4	-3.2	30.8	12.9	15.6	-2.7	29.9	11.3	15.1
	October	-4.6	23.7	4.8	9.9	-8.7	24.7	7.6	8.0	-7.9	24.7	6.0	16.6

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Emergence, insect traps, and leaf damage

Emerged plants at each plot were counted from the two middle sown rows and averaged. After canola individuals emerged, three quadrats of 25 cm x 25 cm were set at each plot. Quadrats were marked using flags. At each quadrat, an insect sticky trap was placed in the center to count numbers of flea beetles. **Every three days flea beetle counts and leaf damage percentage were conducted until canola stands reached the four-leaf cotyledon stage. The events from which fleabeetle counts and leaf damage rates were assessed were considered repeated measurements** Flea beetles were counted from each sticky trap and then placed under a dissecting microscope to count flea beetle populations per species. Visual estimates of leaf damage were performed from ten plants randomly selected from each quadrat. **Assessments were performed based on the parameters established by the Canola Council of Canada (2023).** Stand counts were performed at florescence and at maturity. A combine was used to harvest yield from each plot.

Statistics

The experiments were treated as a split plot analysis with repeated measures for leaf damage, and total flea beetle populations. Other observations used for statistical analysis were plant stand counts at emergence, florescence, and maturity as well as yield and flea beetle counts per flea beetle species. This is because flea beetle counts per species were too low to be analysed by repeated measurements. Fixed factors consisted of seeding rate, seed size and seeding date. Random effects considered are year, replicate, and the repeated measures conducted at each plot. Interactions between fixed effects included seeding date*seeding rate, seeding date*seed size, seeding date*seeding rate*seed size, and seeding rate*seed size. Interactions between fixed effects and random effects were considered random.

Response variables were flea beetle populations (total and per species), leaf percent damage, emergence, florescence and maturity count, and canola yield. All analyses were performed in SAS 9.4 (SAS Institute, 2008) using PROC MIXED. If the interactions between site-year and treatment were not significant (i.e., Z-test > 0.05), data for all years was combined. Significance was tested at a confidence level of 0.05. Tukey's HSD test was used to compare means for each parameter among the different seeding rates and seed sizes to observe differences between leaf damage, flea beetle populations, stands counts at each developmental stage and yield.

Results and Discussion

Flea beetle traps layout and fleabeetle counts were delayed in 2020 to mid to late May because due to the many precipitation events (Table 2). These events were so numerous, flooding caused many commercial growers close to these areas had their yield significantly reduced. Overall, 2020 was a very wet year and canola struggled so much with it yields recorded were the lowest throughout the length of the experiment. In 2021, seeding conditions were optimal and the year was warmer compared to 2020 and yields were greater than those harvested in 2020. In 2021, planting conditions were also optimal, and it was so warm that plants matured quickly to the four-leaf cotyledon stage and few recording of fleabeetle number and fleabeetle damage were performed.

Emergence and number of plants stands.

For a general reference of this report, all P- values are summarized in Appendix A. Data gathered from all three sites showed that number of emergent and mature stands was influenced by seeding date ($P<0.0001$) and seeding rate ($P<0.0001$) but not interaction between these treatments ($P=0.1636$ and 0.4754 for emergence and maturity respectively). Emergent and mature stands were more numerous in late seeding dates compared to earlier dates (Table 3). Moreover, emergent stand number in seeding rates of 10.4 and 15.6 plants per squared foot (control and high seeding rates respectively) were higher compared to those found in plots seeded as 5.2 plants per squared foot (low seeding rate). Mature stand number was greater in control seeding rate followed by high and low seeding rates.

Table 3. Number of emergent and mature canola stands subjected to fleabeetle herbivory sown at two different dates in 2020, 2021 and 2022, at three seeding rates and separated as <2.2mm, >2.2mm and unsorted in Falher, Fort Vermilion and North Star

Effect		Emergence		Maturity	
Seeding rate plants foot^{-2}					
	5.2	0.50[a]	B[b]	3.28	C
	10.4	0.67	A	6.01	A
	15.6	0.66	A	4.83	B
	SE	*0.05*		*0.52*	
Seeding date					
	Early	0.56	B	3.97	B
	Late	0.66	A	5.45	A
	SE	*0.05*		*0.5*	

[a]N=1296 α=0.05

[b]Different letters mean significant differences between values of the same column

Flea beetle counts.

Statistical analyses from data across all sites showed there was an interaction between seeding dates and repeated measurements (P<0.0001). As such, there were more flea beetles in canola sown at later dates compared to those sown earlier (Table 4). Number of flea beetles seem to decrease as time passes in early sown canola. However, in late seeding canola there is an increase in flea beetle numbers in the penultimate repeated measurement followed by a sharp decrease as low as numbers found in the first to third repeated measurement.

Table 4. *Phyllotetra cruciferae* Goeze, *P. striolata* Fabricius and *Psylliodes punctulata* Melsheimer counts at each repeated measurement in canola sown at two different dates[a] and monitored to a four leaf cotyledon stage in Falher, Fort Vermilion and North Star, Alberta, sown at 5.2, 10.4 and 15.6 plants foot-2 with seed sizes separated as <2.2mm,>2.2mm and unsorted control.

	Individuals foot^{-2}					
Repeated measurement	Early			Late		
a	2.40[a]	(0.4)[b]	BC[c]	1.74	(0.4)	CDE
b	1.77	(0.4)	DE	1.91	(0.4)	CDE
c	2.18	(0.4)	CD	2.14	(0.4)	CDE
d	1.85	(0.4)	CDE	3.34	(0.4)	B
e	1.14	(0.5)	E	11.33	(0.5)	A
f	-	-		0.89	(0.7)	CDE

[a]Early dates were May 12, 2020, May 21, 2021 and May 26, 2020 in Fort Vermillion, May 21, 2019 May 18,2021 and May 24,2022 in North Star and May 18, 2019, May 15,2021 and May 18,2022 in Falher. Late dates were May 18, 2019 and June 2, 2020 and 2021 in Fort Vermillion, May 28, 2019 and June 3, 2020 and 2021 in North Star and June 3,2019 May 16,2020 and June 7, 2021 in Falher.
[b]N=1296 α=0.05
[c]Standard error
[d]Different letters mean significant differences between values of the same column

There were differences among flea beetle species. Since flea beetle individual numbers were too small to analyse independently through repeated measurement a simple analysis of variance was conducted. Crucifer flea beetles, which were the ones with greatest number of individuals showed no difference in either seeding rate (0.8123), seeding date (P=0.7200), seed size (P=0.1585) or any of the interactions between seeding rate and date (P=0.6888), seeding date and seed size (P=0.3770), seeding rate and seed size (P=0.8318) and seeding date, rate and seed size (P=0.6472). In contrast, seeding date influenced striped (P=0.0479) and hop flea beetle (P=0.0040) individual number (Table 5). Numbers indicated that less flea beetles were found at earlier seeding dates compared to the number found in later seeding dates. In addition, striped flea beetle number was also affected by canola seed size. Thus, striped flea beetles had a greater presence in canola plots with greater seed diameter compared to those plots where canola seed was small or unsorted.

Table 5. Crucifer (*Phyllotetra cruciferae* Goeze), Striped (*Phyllotetra striolata* Fabricius) and hop (*Psilliodes punctulata* Melsheimer) fleabettle counts based on different canola seeding dates[a] in Falher, Fort Vermilion and North Star, Alberta sown at 5.2, 10.4 and 15.6 plants foot-2 and separated into <2.2, >2.2 and unsorted seed diameters. (N=1944)

Effect	*Phyllotetra cruciferae* Goeze		*P. striolata* Fabricius		*Psylliodes punctulata* Melsheimer	
	Individuals foot^{-2}					
Seeding date						
Early	1.8[b]	A[c]	1.6	B	4.2	B
Late	1.7	A	1.4	A	2.0	A
	0.2		0.3		1.3	
Seeding rate plants foot^{-2}						
5.2	1.8	A	1.4	A	2.8	A
10.4	1.7	A	1.3	A	2.6	A
15.6	1.7	A	1.7	A	2.3	A
	0.2		0.3		1.3	
Seed size mm						
<2.2	1.9	A	1.4	B	2.7	A
Unsorted	1.6	A	1.3	B	2.7	A
>2.2	1.8	A	1.7	A	2.3	A
	0.2		0.3		1.3	

[a] Early dates were May 12, 2020, May 21, 2021 and May 26, 2020 in Fort Vermillion, May 21, 2019 May 18,2021 and May 24,2022 in North Star and May 18, 2019, May 15,2021 and May 18,2022 in Falher. Late dates were May 18, 2019 and June 2, 2020 and 2021 in Fort Vermillion, May 28, 2019 and June 3, 2020 and 2021 in North Star and June 3,2019 May 16,2020 and June 7, 2021 in Falher.

[b] α=0.05

[c] Different letters mean significant differences between values of the same column

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Leaf damage

Results of data pooled across all research sites showed that leaf damage percentage overall was greater in the penultimate repeated measurement in comparison to the others in both early and late seeding dates (P=0.0001) (Figure 5). Interaction between repeated measurement and seeding date (P<0.0001) showed that there was more damage in the last two repeated measurements in late seeding dates compared to those measurements in early dates of sowing (Table 6). This shows that damage coincides to an earlier onset of flea beetles in the early seeding rates and herbivory starts at a more developmental plant stage in later seeding rates.

Table 6. Percentage of leaf damage in canola stands sown at either an early or a late date[a] in Falher, Fort Vermilion and North Star, Alberta at 5.2, 10.4 and 15.6 plants foot-2 and separated as <2.2, >2.2 and an unsorted control.

Repeated measurement			%				
Seeding date				Early		Late	
1st	7.51[b]	0.5[c]	B[d]	8.05	C	6.91	D
2nd	7.88	0.5	B	7.92	C	7.84	C
3rd	7.91	0.5	B	8.76	AB	6.87	D
4th	7.32	0.6	B	7.39	CD	7.25	CD
5th	8.85	0.7	A	8.28	BC	9.32	A
6th	8.11	0.9	AB	7.93	BCD	8.28	ABCD
			Standard error	*0.1*		*0.1*	

[a] Early dates were May 12, 2020, May 21, 2021 and May 26, 2020 in Fort Vermillion, May 21, 2019 May 18,2021 and May 24,2022 in North Star and May 18, 2019, May 15,2021 and May 18,2022 in Falher. Late dates were May 18, 2019 and June 2, 2020 and 2021 in Fort Vermillion, May 28, 2019 and June 3, 2020 and 2021 in North Star and June 3,2019 May 16,2020 and June 7, 2021 in Falher.
[b] N=1944 α=0.05
[c] Standard error
[c] Different letters mean significant differences between values of the same column

Yield

Canola yield for all sites except from Falher in 2022 was pooled for statistical analysis. Canola yield from plots sown at control and high rates at early dates as well as canola yield from stands sown at low and control rates were statistically the same (Table 7). Plots sown at the control seeding rate sown late in the

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season produced more yield than canola stands from plots sown at a high rate at the same time in the season as well as canola stands from plots sown at the low rate at earlier dates (P=0.0038). Individually, canola seeded later in the season was more yielding than canola sown earlier in the season (P=0.0056) . Moreover, plots seeded at a control rate yielded more than the high seeding rate followed by the low seeding rate (P<0.0001). Seed size was influential in yield as well. Seeds with a diameter larger than 2.2mm and unsorted seed size produced more yield than seed sorted at a diameter of less than 2.2mm.

Table 7. Canola yield from stands subjected to flea beetle herbivory, sown at two different dates in 2020, 2021 and 2022, at three seeding rates and two different seed sizes plus an unsorted control in Falher, Fort Vermilion and North Star, Alberta

Seeding date[a]		
Early	34.12[b]	**B**[d]
Late	36.28	**A**
Seeding rate plants foot^{-2}		
5.2	32.90	**C**
10.4	37.33	**A**
15.6	35.67	**B**
Seed size mm		
<2.2	33.23	**B**
Unsorted	35.81	**A**
>2.2	36.56	**A**
Standard error	7.5[c]	

[a] Early dates were May 12, 2020, May 21, 2021 and May 26, 2020 in Fort Vermillion, May 21, 2019 May 18,2021 and May 24,2022 in North Star and May 18, 2019, May 15,2021 and May 18,2022 in Falher. Late dates were May 18, 2019 and June 2, 2020 and 2021 in Fort Vermillion, May 28, 2019 and June 3, 2020 and 2021 in North Star and June 3,2019 May 16,2020 and June 7, 2021 in Falher.
[b] N=1080 α=0.05
[c] Standard error
[c] Different letters mean significant differences between values of the same column

Conclusion

Emergence and maturity were greater at late seeding dates and control seeding rates. Emergent number of stands at high seeding rates plots was as great as those stands emerging in control seeding rate plots. Number of flea beetles and leaf damage were greater in number and percentage respectively during the same repeated measurements. Early seeding canola subjected to flea beetle herbivory showed a decreasing trend over the course of the repeated measurements whereas canola sown in late seeding dates had a peak before reaching the four-leaf cotyledon stage. It is possible that flea beetle number may have increased because there were more canola stands for feeding on both early and late seeding plots. Despite flea beetle number and damage, yield was greater at late seeding dates. Yield was greater in control seeding rate plots compared to high seeding rates. Additionally, unsorted seeds and seeds greater than 2.2mm in diameter produced more yield than canola seeded with seeds of smaller size. The findings of our experiment lead us to demonstrate that while stand count of emergent and mature stands, leaf damage and total flea beetle number of individuals is impacted mostly by seeding date and rate but not seed size. On the other hand, seeding rate, date, and seed size impact canola yield and to some extent some flea beetle species in comparison to others.

Appendix A. P-values computed for all parameters and effects studied whether as part of a repeated measurement or as a general mixed model analysis. Flea beetles species studied were crucifer (*Phyllotetra cruciferae* Goeze), striped (*Phyllotetra striolata* Fabricius) and hop (*Psylliodes punctulata* Melsheimer)

Effect	Yield bu ac^{-1}	Stand counts m^{-2}		% Leaf Damage	Number of fleabeetles m^{-2}			
		Emergence	Maturity		Crucifer	Striped	Hop	Total
Repeated measurement	-	-	-	0.001	-	-	-	≤0.0001
Seeding rate	≤0.0001	0.000	0.000	0.128	0.812	0.280	0.909	0.931
Seeding date	0.215	0.000	0.000	0.318	0.720	0.048	0.004	≤0.0001
Seed size	≤0.0001	0.368	0.675	0.139	0.159	0.011	0.628	0.964
Seeding rate X Repeated measurement	-	-	-	0.748	-	-	-	0.916
Seeding date X Repeated measurement	-	-	-	≤0.0001	-	-	-	≤0.0001
Seed size X Repeated measurement	-	-	-	0.062	-	-	-	0.982
Seeding rate X Seeding date	0.038	0.164	0.475	-	0.689	0.124	0.593	-
Seeding rate X Seeding date X Repeated measurement	-	-	-	0.455	-	-	-	0.908
Seeding date X Seed size	0.381	0.710	0.986	-	0.377	0.176	0.345	-
Seeding date X Seed size X Repeated measurement	-	-	-	0.705	-	-	-	0.960
Seeding rate X Seed size	0.502	0.593	0.723	-	0.832	0.866	0.570	-
Seeding rate X Seed size X Repeated measurement	-	-	-	0.596	-	-	-	1.000
Seeding rate X Seeding date X Seed size	0.956	0.922	0.532	-	0.647	0.629	0.877	-
Seeding rate X Seeding date X Seed size X Repeated measurement	-	-	-	0.978	-	-	-	0.998

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