Carrot Rust Fly Study

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Carrot rust fly (CRF) is a major pest of carrots in western Washington and can cause significant economic losses especially in early-planted carrots. Currently, non-chemical options to effectively control CRF include carrot rotation at least every other year, covering the carrot crop with row covers, and delayed planting combined with early harvest to avoid CRF infestation. All these options are effective but they each have major drawbacks and result in a limited carrot growing season for the grower. In our study at Washington State University Vancouver Research and Extension Unit (WSU VREU) we monitored adult CRF activity in a carrot field, we tested the efficacy of interseeded cover crops to reduce CRF larval damage in carrots, and we integrated cover crops with two biological control organisms, *Beauveria bassiana* and *Steinernema feltiae. Beauveria bassiana* is a fungal pathogen that occurs naturally in the soil and attacks soft-bodied insects. *Steinernema feltiae* is an entomopathogenic nematode that attacks and feeds on insects. The nematode kills its host insect by transferring a pathogenic bacterium to the host, causing the host to stop feeding and quickly die. Interseeded cover crops may prevent CRF adults from finding carrots when they lay their eggs. Also the cover crops may result in increased numbers of predatory beetles that feed on CRF eggs. The CRF lays eggs in the soil in the crown region of the carrot plant. After hatching, the larvae migrate down the carrot and feed in the side roots for the first two instar stages. In the third instar stage, the CRF larvae penetrate the taproot and feed in the taproot creating large holes or tunnels and rust colored frass on the root's surface. Early in the infestation process, the holes are quite small and carrots may still be considered marketable. The larvae grow quickly within the taproot and within a few weeks of infestation the feeding damage is noticeable and the carrots are not acceptable for market.

Materials and Methods

This study was conducted at WSU VREU in 2002 and 2003, and on a commercial carrot farm in Woodland in 2003. Treatments varied between years and locations.

WSU Vancouver REU. The carrot variety Mokum was planted on May 23 2002, and on May 15 2003. In 2003 we replanted carrots on June 3 in spots where there was poor germination. Total field size in 2002 was 48 feet by 80 feet (0.09 A), and plots measured 4 rows (8 feet) wide by 20 feet long. In 2003 the total field size was 120 feet by 120 feet (0.33 A), and plots measured 10 rows (20 feet) wide by 20 feet long. Both years carrots were planted in single rows spaced 2 feet apart. In 2002, 5 cover crops were broadcast seeded over the tops of the carrots on August 19 in a randomized complete block design with 4 replications. Treatments in this study were harbinger medic (*Medicago littoralis)* at 26 lbs. per acre, crimson clover *(Trifolium incarnatum)* at 30 lbs. per acre, subterranean clover *(Trifolium subtranean)* at 30 lbs. per acre, white clover *(Trifolium repens)* at 14 lbs. per acre, common vetch *(Vicia sativa)* at 20 lbs. per acre, and no cover crop. After cover crop seed was broadcast in the plots, plots were cultivated to incorporate the seed. In 2003, treatments in this study were *Beauveria bassiana*, *Steinernema feltiae,* crimson clover *(Trifolium incarnam)*, crimson clover plus *Beauveria bassiana*, crimson clover plus *Steinernema feltiae,* and a control. Treatments were in randomized block design with four replications. *Beauvaria* was applied on August 8 at a rate of 19 grams per 1000 ft^2, and *Steinernema* was applied at a rate of 12 mil. per 1000 ft^2. Both *Beauvaria* and *Steinernema* were applied with a backpack CO_2 sprayer. Crimson clover was drilled in on August 8 at the rate of 16 pounds per acre in a single row between the carrot rows. After the cover crop was planted, plots were hand cultivated.

To determine the impact of the cover crop on predatory beetle and beneficial insect populations, we used pitfall traps (2002 and 2003) and a D-vac (2003 only) to collect and monitor insect populations on a weekly basis. Pit fall traps were placed in the field and monitored on a weekly basis from six weeks prior to planting the cover crops to six weeks after planting the cover crops. Adult CRF populations were monitored both years using yellow sticky traps. Carrots were harvested, inspected and graded for CRF damage on October 8 and again on December 5 2002, and on September 10 2003.

Woodland. Carrot variety Mokum was planted in this study on June 25 2003. Total trial size was 150 feet by 60 feet (0.21 A), and plots measured 6 rows (15 feet) wide by 15 feet long. The 10 treatments included in this study were *Beauveria bassiana* at 19 g per 1000 ft^2 applied at planting, *Beauveria bassiana* at 19 g per 1000 ft^2 applied late, S*teinernema feltiae* at 3.3 mil. nematodes per 1000 ft^2 applied at planting, S*teinernema feltiae* at 8.3 mil. nematodes per 1000 ft^2 applied at planting, S*teinernema feltiae* at 27.5 mil. nematodes per 1000 ft^2 applied at planting, *Steinernema feltiae* at 27.5 mil. nematodes per 1000 ft^2 applied late, crimson clover *(Trifolium incarnatum)*, crimson clover plus *Beauveria bassiana* at 19 g per 1000 ft^2, crimson clover plus *Steinernema feltiae* at 27.5 mil. nematodes per 1000 ft^2, and a control. The early treatments of *Beauveria bassiana* and *Steinernema feltiae* were applied on June 26, and the late treatments were applied when the first CRF were captured with yellow sticky traps in the plots, on August 8. Crimson clover was drilled in a single row between the carrot rows at the rate of 16 pounds per acre. Insect populations were monitored in the study area the same as at WSU Vancouver REU. Carrots were harvested, inspected and graded on October 10.

Pit Fall Traps. Pit fall traps were used both years at WSU Vancouver REU to monitor populations of predatory beetles *Carabidae* and *Staphelynidae* to determine if the cover crop treatments affected the populations of either of these two beneficial beetles. These two types of beetles are the main predators of CRF and they feed on CRF eggs. By monitoring beetle populations in the study area we are able to determine if the numbers increased or decreased in response to the different treatments. In 2002, pit fall traps were placed in all plots six weeks prior to sowing cover crop treatments (July 8) and were collected once a week until six weeks after sowing the cover crops (September 30). In 2003, the some procedure was followed and traps where collected weekly from August 18 until September 22. In 2003 traps were only placed in plots with crimson clover, crimson clover plus *Beauvaria,* and crimson clover plus *Steinernema*. Traps were placed in the center of a carrot row, approximately a ½-inch from the carrots on each side (Figure 1). By placing the pit fall traps in the center of the carrot row and protecting the traps with covers prior to cultivation, it was possible to continue normal field cultivation without removing the traps. It was important to keep the pit fall traps free of soil so that beetles could be more easily identified. Pit fall traps were made by placing 16 oz. beverage cups in the field and filling them with approximately ¾-cup of animal-safe antifreeze. Insects fell into the cups and drowned. Antifreeze was used because it did not evaporate, and the antifreeze was filtered and reused throughout the course of this study. To make the pit fall traps we dug a hole and inserted two 16 oz. beverage cups, one inside the other, ensuring that the cup lips were level with the ground (Figure 2). The first cup maintained the hole and the second cup was labeled and removed weekly for sampling. It was necessary to check pit fall traps regularly to make sure they remained level with the ground. Water or dirt that fell into the first cup caused the second cup to be raised above the soil level and prevented beetles from falling into the traps. Before a heavy rainfall, covers were placed on all traps. We scheduled our weekly pit fall trap sampling according to our weekly irrigation schedule. Before irrigation, we collected all pit fall traps, brought them into the laboratory, and emptied their contents into funnels lined with labeled filter paper (Figure 3). It took approximately 3-5 hours to filter the contents from each trap depending on the amount of soil. Filter papers were placed flat on paper towels to dry (Figure 4). We identified and counted the two types of beetles of interest (*Carabidae* and *Staphelynidae*) and discarded all other insects that were collected in the pit fall traps such as grasshoppers, moths, bees, wasps, ladybugs, spiders, cucumber beetles, flies, mosquitoes, and springtails. Trap cups were placed back in the ground and filtered antifreeze was placed back into the clean cups.

Figure 1. White flags mark the pit fall trap cups that were placed in the middle of the carrot row.

Figure 2. (A) The first cup is in the ground, ready for placement of the second, labeled cup that contains antifreeze. **(B)** Correct placement of the two cups so that lips are level with the soil surface. **(C)** Incorrect placement of the trap cups.

Figure 3. **(A)** Pit fall trap cups were emptied into labeled filter paper funnels that were placed into glass beakers. **(B)** Antifreeze drains through the filter paper funnels into the glass beakers; filtered antifreeze was then placed back in pit fall traps in the field.

Figure 4. Drained filter papers drying flat on a paper towel.

D-vac. Beneficial beetle populations in the cover crop and check plots were also monitored using a D-vac. A D-vac is a large vacuum mounted on a back pack and equipped with a lawn mower engine and a large hose that creates suction to collect plant material, insects, dirt, and other material in its path (Figure 5). A sheer collection bag was attached to the end of the hose, and samples from each plot were carefully transferred to a labeled zip lock bag and placed in a freezer for later separation and identification. D-vac samples where collected separately from the cover crop stand and the carrot stand in all cover crop plots, and from the carrot stand in check plots. Samples where collected once a week throughout the study, from August 25 through September 29. Insects that were collected with the D-vac included minute pirate bug, damsel bug, green lacewing adult and larva, big eyed bug, leaf hoppers, aphids and many others.

Figure 5. Collecting insect samples in carrot plots with a D-vac.

Yellow Sticky Traps. In 2002 and 2003, yellow sticky traps were placed in the field after carrots were planted, and monitored weekly until carrots were harvested. In 2002, 12 yellow sticky traps were placed approximately 40 feet apart throughout the CRF plots. Eight sticky traps were placed around the perimeter of the carrot plots with two on each side, and four traps were placed in the center of the study area. Wooden dowels were inserted into the ground and labeled sticky traps were attached with binder clips 1-inch above the carrot foliage and at a 135^{o} angle to the ground (Figure 6). In 2003, six yellow sticky traps were placed approximately 40 feet apart around the perimeter of the CRF study plots. Two sticky traps where placed on each of the north and south sides, and one trap was placed on each of the east and west sides of the study. Textured garden stakes were inserted into the ground and labeled sticky traps were attached with binder clips 1-inch above the carrot foliage and at a 90^{0} angle to the ground. Both years traps were moved up the stake as the carrot crop grew.

Sticky traps were checked every three days for CRF, and were collected and replaced once a week. In the laboratory, sticky traps were dried for two days, examined on both sides, and then stored in labeled zip lock bags. CRF were identified by their red eyes, yellow legs that are ¼-inch long, and head and thorax that are approximately equal in size (Figure 7). As soon as one adult CRF was found on a yellow sticky trap, the larvae could be expected to appear in the carrots approximately 25 days later.

Figure 6. Yellow sticky traps attached to dowels approximately 1-inch above the carrot canopy at a 135° angle to the ground.

Figure 7. CRF has red eyes, yellow legs, and a head and thorax that are approximately equal in size (Source http://www.surecrop.com/Insects/vegetable/carrotfly.htm).

CRF Larvae Assessment. In 2002, we sampled 10-feet of carrot row in the center of each plot on October 8 and December 10. Carrots were topped in the field, washed and examined for potential CRF damage. At the first sampling date carrots were examined with magnifying visors, and at the second sampling date carrots were examined with the naked eye (Figure 8). In 2003, carrots were sampled from 60-feet of carrot row in the center of each plot on September 10. We also measured the amount of time to harvest each plot. Carrots were topped, washed, and sorted into five categories: 1) marketable 2) marketable but crooked, 3) small but marketable 4) unmarketable, and 5) damaged. Carrots in each category were weighed and counted.

Figure 8. CRF damage on carrots at WSU Vancouver REU.

Results and Discussion

WSU Vancouver REU. In 2002, there were no significant difference due to the treatments in weight and number of carrots nor in the number of carrots with CRF damage (Table 1). CRF damage was found in approximately 5% of the carrots in all plots. In 2003, the greatest number and weight of carrots effected by CRF occurred in the control plots, while the lowest numbers and weights of carrots affected by CRF occurred in plots with crimson clover + *Beauvaria* and crimson clover + *Steinernema* (Tables 2 and 3). However these differences were not significant. The number and weight of good carrots was highest in plots with crimson clover + *Beauvaria* and lowest in plots with crimson clover alone and *Beauvaria* alone, however these differences were also not significant. In Woodland in 2003, the greatest number and weight of carrots effected by CRF occurred in the plots where *Beauvaria* was applied at planting, while the lowest numbers and weights of carrots affected by CRF occurred in plots with crimson clover alone (Tables 4 and 5). The number and weight of good carrots was highest in plots with crimson clover + *S. feltiae* applied at planting at the rate of 8.3 mil. nematodes per 1000 ft^2, and lowest in plots with *B. bassiana* applied later in the season, however these differences were also not significant.

Due to the low population pressure of the CRF, we were unable to verify if cover crops reduced CRF damage. We have grown carrots in this field location for three consecutive years, and for the past two years we have left the carrots in the ground throughout the winter to increase the over wintering CRF population. Although CRF populations have been increasing each year, they were still so low that our field site was not heavily infested.

Table 1. Total number and weight (g) of carrots, and number of carrots with CRF damage at WSU VREU in 2002.

Treatment	No. of Marketable Carrots	Total Wt. of Carrots	No. Carrots w/ CRF
Medic	14	823.1	7
Vetch	11	503.5	7
White Clover	10	756.9	6
Sub. Clover	13	1027.4	8
Crimson Clover	14	528.1	5
Control	14	970.5	7
P Value	0.816	0.1402	0.9697

Table 2. Number of carrots in categories at WSU Vancouver REU in 2003.

Treatments	Good	Crooked	Small	Cull	CRF Affected	Total
S. feltiae	11.4	29.5	3.8	35	26.7	106.3
Crimson Clover	3.5	25.8	7.5	44	31	111.7
B. bassiana	6.3	24.2	6.1	25.1	30.9	92.5
Crimson Clover + *S. feltiae*	9.1	35.2	4	46.7	19.2	114.2
Crimson Clover + *B. bassiana*	14.2	24.2	3.6	45.1	13.5	100.6
Control	5.4	32.7	5.7	47.8	32.4	124.0
Mean	8.3	28.6	5.1	40.6	25.6	108.2
P Value	0.629	0.9698	0.613	0.7401	0.4883	

Table 3. Weight of carrots (g) in categories at WSU Vancouver REU in 2003.

Treatments	Good	Crooked	Small	Cull	CRF Affected	Total
S. feltiae	1312	3171	162	4328	3018	11990
Crimson Clover	442	2577	323	4772	3100	11214
B. bassiana	456	3756	197	2786	3745	10940
Crimson Clover + *S. feltiae*	1002	5095	217	4925	1521	12760
Crimson Clover + *B. bassiana*	1596	2621	174	4903	1558	10851
Control	1474	2363	236	6162	3919	14154
Mean	1047	3264	218	4646	2810	11985
P Value	0.6844	0.4599	0.8766	0.8321	0.5061	

Table 4. Number of carrots in categories at Woodland in 2003.

Treatment	Good	Crooked	Small	Cull	CRF Affected	Total
***B. bassiana* at Planting**	30	31	34	31	14	140
***B. bassiana* Later**	19	46	28	38	2	132
***S. feltiae* at Planting (3.3 mil.)**	33	26	16	24	6	106
***S. feltiae* at Planting (8.3 mil.)**	50	33	24	34	3	145
***S. feltiae* at Planting (27.5 mil.)**	30	41	24	43	3	141
***S. feltiae* Later**	40	37	31	52	4	164
Crimson Clover	34	34	29	39	1	136
Crimson Clover + *B. bassiana*	31	32	36	45	6	150
Crimson Clover + *S. feltiae*	77	41	34	54	10	216
Control	40	44	23	37	9	153
Mean	38	37	28	40	6	148
P Value	0.0603	0.9232	0.9371	0.8746	0.3296	

Table 5. Weight of carrots (g) in categories at Woodland in 2003.

Treatment	Good	Crooked	Small	Cull	CRF Affected	Total
***B. bassiana* at Planting**	2108	1923	575	2057	905	7568
***B. bassiana* Later**	1462	3361	792	2887	170	8672
***S. feltiae* at Planting (S1)**	3390	2190	430	2031	399	8439
***S. feltiae* at Planting (S2)**	4491	3230	746	2785	292	11544
***S. feltiae* at Planting (S3)**	2740	3778	715	3894	283	11410
***S. feltiae* Later**	3231	2628	791	3750	322	10721
Crimson Clover	2646	3399	819	3148	122	10134
Crimson Clover + *B. bassiana*	2251	2662	1129	2708	398	9148
Crimson Clover + *S. feltiae*	3861	2213	647	2415	765	9900
Control	3008	3544	678	2730	670	10629
Mean	2919	2893	732	2840	433	9817
P Value	0.3227	0.764	0.913	0.6829	0.5743	

Although there were no significant differences in the number of predatory beetles collected in the plots at either WSU VREU or Woodland in 2003, plots with crimson clover plus *S. feltiae* tended to have fewer beneficial beetles (Tables 6 and 7). CRF were first captured on yellow sticky traps on June 27 at WSU VREU and on July 11 at Woodland. The number of CRF collected was low throughout the season and averaged less then 1 per trap per week at both locations (Tables 8 and 9). There were no differences in the number of CRF collected by yellow sticky traps due to the location orientation of the traps.

Table 6. Mean number of predatory beetles collected in pitfall traps from August 18 through September 22 at WSU VREU in 2003.

Treatments	Mean No. Predatory Beetles
Crimson Clover	29.0
Crimson Clover + *S. feltiae*	17.3
Crimson Clover + *B. bassiana*	28.5
Mean	24.9
P Value	0.3121

Table 7. Mean number of predatory beetles collected in pitfall traps from August 29 through September 30 at Woodland in 2003.

Treatments	Means No. Predatory Beetles
Crimson Clover	19.5
Crimson Clover + *S. feltiae*	7.5
Crimson Clover + *B. bassiana*	6.8
Mean	11.3
P Value	0.1553

Table 8. .Mean number of CRF collected on yellow sticky traps throughout the growing season at WSU VREU, in 2003.

Trap Location	Mean No. CRF
North	0.6
West	0.8
South	0.7
East	0.5
Mean	0.7
P Value	0.9195

Table 9. Mean number of CRF collected on yellow sticky traps throughout the growing season at Woodland in 2003.

Trap Location	Mean No. CRF
North	0.6
West	0.8
South	0.7
East	0.5
Mean	0.7
P Value	0.9195