2010 Research **FINAL REPORT** *to the*
Agricultural Research Foundation (ARF)
and the
Oregon Processed Vegetable Commission (OPVC)

Title: A future without organophosphorus insecticides – yet plenty of cabbage maggots in *Brassica* crops!

Project Leaders:

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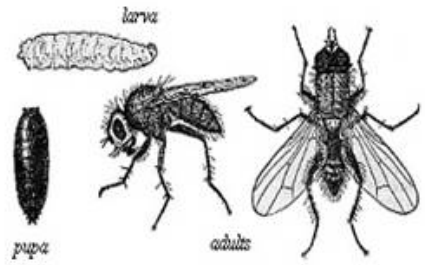
Introduction:

The cabbage root fly (*Delia radicum* (L.); Diptera: Anthomyiidae; CRF)) is a universal pest problem. The impact of CRF is widespread throughout the Pacific Northwest and many other Brassica growing regions around the US and world (midwest, south, and northeast mainland US; Canada and European countries). *Brassica* production in western Oregon is reliant on the use of chlorpyrifos (organophosphate; Lorsban®) as the singular method of control for cabbage root fly (*Delia radicum* (L.); Diptera: Anthomyiidae; CRF)). The potential for losing this product is immediate. The threat of crop failure, resistance, lack of treatment efficacy, and loss of livelihood has increased grower willingness to test and adopt new management strategies for an old pest.



Degree-day (DD) modeling (http://uspest.org/cgi-bin/ddmodel.pl?spp=cm1) and scouting for CRF egg presence at a plant's base were examined to help predict when CRF may become a problem and when to better schedule and time a treatment to high risk CRF-periods.

Also, an effort to find available and efficacious products and precise timing for managing CRF was explored.

The aim of this study was to reduce dependence on chlorpyrifos by comparing efficacy and insecticidal duration of novel insecticides as seed treatments, at planting (infurrow), and foliar-banded during critical windows of CRF egg-laying; and exploring the feasibility of degree-day modeling and on-farm monitoring for detecting egg-laying.

Research Objectives:

1) Evaluate efficacy and persistence of non-OP seed, infurrow, and foliar treatments for control of CRF (See attached report for efficacy results)

2) Test the CRF degree-day model describing high risk periods to avoid high risk planting dates and optimal harvest dates; and synchronize insecticides to high populations of CRF

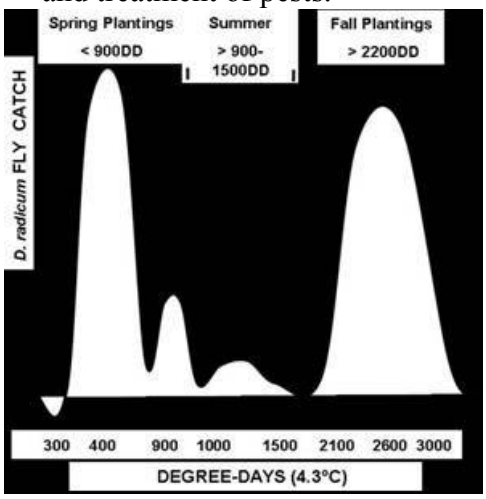
3) Determine the relationship between egg counts and CRF injury in transplanted cauliflower in order to adjust the timing of insecticide applications to optimize insecticide efficacy

Methods

Obj. 1) Evaluate efficacy and persistence of non-OP's as seed treatments and foliars to reduce CRF injury to Brassica crops---Please see additional attached report for results.

Obj. 2) Test CRF degree-day (DD) model describing high risk periods (high damage) to avoid high risk planting dates and determine optimal harvest dates: and synchronize insecticides to high populations of CRF

Twenty-one plantings were monitored for plants with CRF eggs, seasonal damage and damage at harvest in 2010. The intent was to test the DD model found at: http://uspest.org/cgi-bin/ddmodel.pl?spp=cm1 that estimates the timing of CRF activity in the field, without the use of yellow water traps (tedious and laborious), and how the model relates to the timing of planting and treatment of pests.



==========EVENTS TABLE==========

1. 200 DD after Jan 1: initial spring emergence (10%)
2. 334 DD after Jan 1: spring peak emergence (50%)
3. 417 DD after Jan 1: egg-laying notes a) prefers plants at least 30 days after seeding
4. 500 DD after Jan 1: notes b) prefer maturing plants with developing roots, > 7 leaves;
5. 900 DD after Jan 1: approx. end of spring flight (95%)
6. 2200 DD after Jan 1: fall flight begins

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Typically, CRF begins development in the spring by emerging as flies from pupae (in soil under previous Brassica crops) above a threshold temperature averaging ~40°F. CRF becomes less active averaging 85°F. Fields planted *before* an accumulation of 900 DD°C (Spring; 1st April

2010) usually have higher yield losses than fields planted *after* 900 DD°C (Summer; mid-June 2010) and harvested before 2200 DD°C (Fall; mid Sept 2010). Fall planted fields (after 2200 DD°C) can be at higher risk of CRF during CRF's fall flight period. Spring emergence begins around 330 DD°C (>10% of population; ≈ 1st week in April 2010) and CRF are typically less active (95%) after 900 DD°C (≈ mid-June 2010) and before Fall flight is initiated 2200 DD°C (≈ mid-Sept 2010 extending into November, 2600 DD°C). When CRF Fall flight begins (along with cooler temperatures & light rains), growers can experience damage in western Oregon. However, spring flight of CRF can lag and be delayed up to 3 weeks, if rain and cold temperatures (<45F) persist as weather conditions did in 2010. The weather was unusual in 2010 and many insects did not move, mate, or lay eggs until late in the season. The model did not closely follow the degree-day model. Spring and fall CRF populations generally are higher, hence higher damage levels in fields compared to summer populations. In 2010, early plantings did not get the level of damage as expected, most likely due to unusual cold and rainy environmental conditions. Monitoring is key to supplementing the DD model that predicts CRF presence.

Comparison of EGG-Scouting Techniques

Our goal of the following studies was to compare cabbage maggot egg-scouting methods in order to identify a technique for determining risk of maggot infestation that might be adopted by farmers or agricultural professionals; a method that would not be excessively labor intensive but would give a reasonably accurate assessment of CRF risk.

Methods: We compared three egg-scouting methods: 1) "soil scraping" where the scout positions themselves on their knees close enough to gently scrape soil away from the base of individual plants while searching for maggot eggs with a hand lens, 2) radish "plugs pull" where the scout pulls plug transplants and examines them for eggs with a hand lens while in the standing position, and 3) digging up seedlings with a "hand trowel" then searching for eggs with a hand lens while in the standing position. At each scouting event, forty plants were examined with each method for radish and broccoli spring plantings.

Results: No CRF damage was reported upon examination of any of the fields. The Soil Scrape method detected some CRF maggot egg-laying in most cases, while the less rigorous Hand Trowel method found none (Table 1). The same was true when we compared the soil scrape method against pulling radish plugs. In some cases, not always, the Soil Scrape method was more sensitive and detected more maggot eggs that the less rigorous plug pulling method (Table 2). The more rigorous scouting method involving soil scraping around individual plants is a superior method for detecting cabbage maggot eggs. It is hard to imagine, however, farmers or agricultural professionals putting in this level of effort to determine risk of maggot infestation. The hand trowel method may under estimate cabbage maggot egg laying pressure. It was still a valuable "relative" sampling method that could be calibrated to crop damage in future trials.

Table 1. Comparison of egg-scouting methods, Broccoli Plantings, Dever-Conner Oregon

2010 Date	Event/ Stage	Insecticide	Method	Eggs/plt[1)]	Strike/10plts[2)]	Larvae %Infested[3)]
April 17	Planting One	Chlorpyrifos[4)]	Banded			
June 16	8-10 lf		Hand Trowel	0.18	0.50	0%
			Soil Scrape	0.13	1.00	0%
April 24	Planting Two	Chlorpyrifos[4)]	Banded			
June 16	6-8 lf		Hand Trowel	0	0	0%
			Soil Scrape	0.03	0.25	0%
May 12	Planting Three	Chlorpyrifos[4)]	Banded			
June 16	2-4 lf		Hand Trowel	0.03	0.25	0%
			Soil Scrape	0.03	0.25	0%

1) Average number of CRF eggs per plant.
2) Average number of strikes (plants where eggs were observed) per ten plants.
3) Percent infested with actively feeding maggots on their roots.
   At harvest, no root damage by CRF was observed in these plantings.
4) Chlorpyrifos (Lorsban 15G) banded over the row at 9.2 oz product per 1000 ft of row.

Table 2. Comparison of egg scouting methods, Radish Plantings, Dever-Conner Oregon

2010 Date	Event/ Stage	Insecticide	Method	Eggs/plt[1)]	Strike/10plts[2)]	CRF Larvae % Infested[3)]
April 16	**Planting One**	Chlorpyrifos[4)]	Banded	1.50	7.50	
June 16	flowering		Plug Pull	2.03	6.75	0%
			Soil Scrape	3.33	7.50	0%
April 18	**Planting Two**	Chlorpyrifos[4)]	Banded			
June 16	flowering		Plug Pull	0.65	4.00	0%
			Soil Scrape	3.33	8.50	0%
April 24	**Planting Three**	Chlorpyrifos[4)]	Banded			
June 16	flowering		Plug Pull	0.15	1.00	0%
			Soil Scrape	0.48	2.25	0%

1) Average number of CRF eggs per plant.
2) Average number of strikes (plants where eggs were observed) per ten plants, replicated 4 times.
3) Percent roots infested, the percent of plants that had actively feeding maggots on their roots. At harvest, no root damage by CRF was observed in these plantings.
4) Chlorpyrifos (Lorsban 15G) banded over the row at 9.2 oz product per 1000 ft of row.

Additional comments and conclusions, 2010:
Brassica fields with high damage levels (a baseline level of greater than 20% damage appears to be a baseline level in which growers notice loss) from CRF are known to be associated with the occurrence of other heavily infested fields close by, within a 1/4mile (400 m) radius. The odds that a field would be heavily infested were 5 to 12.0 times greater for fields with high damage neighbors than in fields without high damage neighbors.

Soil texture, distance from river, proximity to cull piles and *Brassica* weed hosts, field manager/grower, field area and perimeter are not significant factors affecting CRF damage levels.

The average damage in spring-planted *Brassicas* (prior to accumulation of 900 DD) was consistently higher than in either the preceding or subsequent Fall-planted Brassicas. However, in some cases as we saw in 2010, no damage was detected. Perhaps the persistent rains and cool springs deterred CRF and flight was delayed. Some egg-laying was reported but no larvae materialized.

Fields planted in the spring and within 1/4mile of a source of overwintering CRF flies (i.e., field damage exceeding 15%; harvested after 2000 DD the previous fall) can exceed 50% damage. In contrast, fields that were not planted near an overwintering source can average <30% damage. Unfortunately this level of damage is still too high!

Rutabaga crops have higher CRF damage than turnip crops. Cauliflower plants were more affected by CRF egg-laying than Brocolli plants

Damage levels from CRF were significantly higher in fields planted near nurseries ($p < 0.014$) and marginally higher in fields bordering houses ($p = 0.055$).

Damage rates in nearby fields within approx. 125 m were more similar than would be expected from the effects of the environmental factors alone. Correlations between neighboring fields was 0.38, while fields separated by over 600 m were virtually uncorrelated.
After accounting for the effects of environmental covariates, some groups of fields still tended to have higher damage levels than others. Unknown effects might include: topographical effects, local environmental conditions, and wind currents.

Spring fields with high damage (>20%) appear to have served as maggot sources for fall fields planted nearby. Typically a CRF damage level of less than 10% was not recognized by growers as significant. The average damage among fall *Brassica* fields that were not planted in the vicinity (within 400 m; ¼ mile) of spring maggot sources was ~10% damage, compared with ~30% among fall fields that were planted near spring maggot sources.

Damage levels in a field were associated not only with damage levels among neighbors but also with the relative timing of planting in the neighboring fields.

Neighboring fields (small lag distance) that were planted more or less in succession , overlapping little in time (small temporal overlap), tended to have correlated damage rates. When fields were harvested, neighboring fields tended to have significant increases in fly populations, spikes in fly trap counts, and increased damage levels compared to more distant fields.

The borders of fields (15 feet), especially on the prevailing wind side, showed increased numbers of plants with eggs (2X) than plants inside of the field. These pieces of information are useful in planning a monitoring program for fly activity and egg presence and improving the quality of information based upon which a grower can make decisions.

Obj. 3) Determine the relationship between egg counts and CRF injury in transplanted cauliflower in order to adjust the timing of insecticide applications to optimize insecticide efficacy

A simple and precise method for detecting CRF egg levels was explored that can be used by field reps or growers. Unless otherwise noted, the pull plug and in some cases the trowel method was selected for use for studies reported below. These methods were most useful during the first 4 weeks of plant growth; and appear to be a good relative method for estimating number of plants with eggs. However, in most fields examined few to no eggs were seen in direct-seeded fields before plants had at least 4-6 leaves and ~ ¼ inch root. Eggs were found in transplanted plugs within 1 week of transplanting. We would guess that foliar-applied Lorsban at planting did not persist when CRF finally arrived. Fields that transplanted young seedlings had higher proportion of plants with eggs within 1 week of transplanting up to 7 weeks of CRF pressure.

Field Scouting for Cabbage Maggot in Radish, Broccoli, and Cauliflower

Our goal for the field scouting effort in this pilot project was to determine if we could detect the beginning of cabbage maggot egg laying in a given planting and subsequent CRF-intensity over time.

Methods: Vegetable and specialty seed-crop plantings on cooperating farms in three areas of the Willamette Valley were scouted for CRF eggs on a weekly basis throughout the growing season. Scouting began with radish plantings, progressed to broccoli plantings, and finished with cauliflower plantings. Both the broccoli and cauliflower results reported below were from direct seeded plantings. Insecticide was applied at planting by grower cooperators. In cauliflower (Tables 5, 6 and 7) plantings, two foliar insecticide sprays in addition to granular insecticide applied at planting.

All together, twenty one plantings were scouted on a weekly basis for cabbage maggot. Radish plantings were evaluated using the "plug pull" method. Broccoli and cauliflower plantings were evaluated using the "hand trowel" method. In every case, forty plants were evaluated per scouting event. Field scouting for cabbage maggot eggs ceased when the plants grew too large to evaluate with these scouting methods (5 to 10 weeks after planting).

Results: We were able to detect low levels of cabbage maggot egg-laying in broccoli plantings in Gervais, when it occurred (Table 3). In Dever Conner broccoli plantings, few to no maggot eggs were observed throughout the evaluation period with no reported CRF damage(Table 4). There are times, fortunately, when CRF does not attack a field. Scouting for plants with eggs and determining if CRF is present, could help eliminate unnecessary treatments. We were able to detect increased CRF egg laying in cauliflower when it occurred (Table 5). Fifteen percent of the cauliflower seedlings in planting number one were damaged by CRF. Approximately five percent of the cauliflower seedlings in plantings two and three were damaged. The damage occurred at the soil level where seedlings were "girdled" by numerous larvae surrounding the

stem. Later during the growing season, mature plants collapse, apparently due to the death of the root system in the girded plants.

Even though the “hand trowel” method was less precise than the more rigorous method used in research, it was significantly easier on the person doing the field scouting and may be more readily adopted by our target audience, farmers and agricultural professionals trying to detect cabbage maggot egg laying events. The egg field scouting method detected egg laying prior to the discovery of infested plants.

The presence of cabbage maggot eggs generally was not detected until several weeks following planting. This may be due to the presence and the eventual decomposition of the insecticide applied at planting. This may also be due to the egg laying behavior of the adult cabbage maggot fly. It has been observed that egg laying females prefer to deposit their eggs on host plants that are at the 4-6 leaf-stage or larger (Dreves 2006 thesis dissertation). It is surprising that maggot damage occurred despite three insecticide applications. One must question whether the insecticide is reaching the base of the plant where the eggs reside or chemical resistance is occurring.

Table 3. Results of CRF field scouting for Broccoli Plantings, Gervais Oregon[1)]

2010 Date	Event/ Stage	Insecticide	Method	Eggs/plt[2)]	Strike/10plts[3)]	CRFLarvae %Infested[4)]
May 14	planted	chlorpyrifos[5)]	Banded			
June 30	5-6 lf			0.45	2.50	12.5%
July 7	8-10 lf			0.15	1.00	17.5%
July 12	10-12 lf			0.23	1.00	8.0%
July 21	15-16 lf			0.03	0.25	<10%

1) At broccoli harvest, no significant root damage by CRF was observed. Roots compensated for damage and outgrew initial infestation and evident tunnels were not noticeable.
2) Average number of CRF eggs per plant. Forty plants were dug and examined at each field scouting.
3) Average number of "strikes" (plants where eggs were observed) per ten plants.
4) Percent infested plants that had actively feeding maggots on their roots.
5) Chlorpyrifos (Lorsban 15G) banded over the row at 9.2 oz product per 1000 ft of row.

Table 4. Results of CRF field scouting for Broccoli Plantings, Dever Conner Oregon[1)]

2010 Date	Event/ Stage	Insecticide	Method	Eggs/plt[2)]	Strike/10plts[3)]	Larvae %Infested[4)]
April 17	Planting One	chlorpyrifos[5)]	banded			
June 3	6-7 lf			0	0	0
June 10	8-10 lf			0	0	0
June 16	9-11 lf			0	0	0
April 24	Planting Two	chlorpyrifos[5)]	banded			
June 3	4-5 lf			0	0	0%
June 10	6-8 lf			0	0	0%
June 16	7-9 lf			0	0	0%
June 28	8-10 lf			0	0	0%
May 12	Planting Three	chlorpyrifos[5)]	banded			
June 3	1-2 lf			0	0	0%
June 10	4-6 lf			0	0	0%
June 16	5-7 lf			0	0	0%
June 28	7-9 lf			0	0	0%
July 9	9-10 lf			0	0	2.5%
July 14	10-12 lf			0	0	0%

1) At broccoli harvest, no significant root damage by CRF was observed.
2) Average number of CRF eggs per plant. Forty plants were dug and examined at each field scouting.
3) Average number of "strikes" (plants where eggs were observed) per ten plants.
4) Percent infested plants that had actively feeding maggots on their roots.
5) Chlorpyrifos (Lorsban 15G) banded over the row at 9.2 oz product per 1000 ft of row.

Table 5. Results of CRF field scouting for Cauliflower Planting 1, Woodburn Oregon[1)]

Date	Event/ Stage	Insecticide	Method	Eggs/plt[2)]	Strike/10plts[3)]	%Infested[4)]
June 18	**Planting One**	chlorpyrifos[5)]	banded			
July 9		bifenthrin[6)]	broadcast			
July 14	2-3 lf			0	0	0
July 21	5-6 lf			0.03	0.25	0
July 26	6-7 lf			0	0	0
Aug 2	7-8 lf			0.35	0.75	5%
Aug 4		chlorpyrifos[7)]	broadcast			
Aug 9	8-9 lf			0.33	2.00	3%

1) At harvest, 15% of the plants in cauliflower planting one (grower estimate) were damaged by CRF and actually collapsed from the presence of CRF larvae and suffered a loss from larvae; the rest of the CRF-infested plants outgrew and tolerated CRF damage. Only a few roots with CRF damage was detectable on Aug 9.
2) Average number of CRF eggs per plant. Forty plants were examined for eggs at each scouting.
3) Average number of "strikes" (plants where eggs were observed) per ten plants.
4) The percent of plants that had actively feeding maggots on their roots and stems.
5) Chlorpyrifos (Lorsban 15G) was applied in a band over the seed row at planting at a rate of 9.2 ounces product per 1000 ft of row.
6) Bifenthrin (Tundra) was applied as a foliar application at 6.4 fluid ounces product per acre.
7) Chlorpyrifos (Lorsban 75W) was applied as a foliar application at 1.3 pounds product per acre.

Table 6. Results of CRF field scouting for Cauliflower Planting 2, Woodburn Oregon[1)]

2010 Date	Event/ Stage	Insecticide	Method	Eggs/plt[2)]	Strike/10plts[3)]	CRF larvae % Infested[4)]
June 22	**Planting Two**	chlorpyrifos[5)]	banded			
July 9		bifenthrin[6)]	foliar broadcast			
July 14	1-2 lf			0	0	0%
July 21	3-4 lf			0	0	0%
July 26	4-5 lf			0	0	0%
Aug 2	5-6 lf			0.15	0.75	0%
Aug 9	7-8 lf			0.10	0.75	35%
Aug 9		chlorpyrifos[7)]	foliar broadcast			
Aug 16	8-9 lf			0.38	2.00	43%

1) At harvest, 5% of the plants in cauliflower planting two (grower estimate) were damaged and actually collapsed from the presence of CRF larvae and suffered a loss from larvae; the rest of the CRF-infested plants outgrew and tolerated the CRF damage.
2) Average number of CRF eggs per plant. Forty plants were examined for eggs at each scouting.
3) Average number of "strikes" (plants where eggs were observed) per ten plants.
4) The percent of plants that had actively feeding maggots on their roots and stems.
5) Chlorpyrifos (Lorsban 15G) was applied in a band over the seed row at planting at a rate of 9.2 ounces product per 1000 ft of row.
6) Bifenthrin (Tundra) was applied as a foliar application at 6.4 fluid ounces product per acre.
7) Chlorpyrifos (Lorsban 75W) was applied as a foliar application at 1.3 pounds product per acre.

Table 7. Results of CRF field scouting for Cauliflower Planting 3, Woodburn Oregon[1)]

2010 Date	Event/ Stage	Insecticide	Method	Eggs/plt[2)]	Strike/10plts[3)]	CRF larvae % Infested[4)]
June 25	**Planting Three**	chlorpyrifos[5)]	banded			
July 9		bifenthrin[6)]	foliar broadcast			
July 14	0-1 lf			0	0	0%
July 21	2-3 lf			0	0	0%
July 26	4-5 lf			0	0	0%
Aug 2	5-6 lf			0.13	0.25	0%
Aug 9	6-7 lf			0.15	1.00	18%
Aug 16	7-8 lf			0.15	0.50	53%
Aug 21	8-9 lf	chlorpyrifos[7)]	foliar broadcast			
Aug 23	10-11lf			0.90	3.50	43%

1) At harvest, 5% of the plants in cauliflower planting three (grower estimate) were damaged by CRF and actually collapsed from the presence of CRF larvae and suffered a loss from larvae; the rest of the CRF-infested plants outgrew and tolerated the CRF damage.
2) Average number of CRM eggs per plant. Forty plants were examined for eggs at each scouting.
3) Average number of "strikes" (plants where eggs were observed) per ten plants.
4) The percent of plants that had actively feeding maggots on their roots and stems.
5) Chlorpyrifos (Lorsban 15G) was applied in a band over the seed row at planting at a rate of 9.2 ounces product per 1000 ft of row.
6) Bifenthrin (Tundra) was applied as a foliar application at 6.4 fluid ounces product per acre.
7) Chlorpyrifos (Lorsban 75W) was applied as a foliar application at 1.3 pounds product per acre.

Other comments and conclusions:
A plant count of less than 2 plants out of 10 revealed less than 20% damage (little to unnoticeable loss and LOW Risk); MEDIUM risk of 3-6 plants per 10 plants (>20-40% loss) and HIGH risk count of 7-10 plants with eggs (>40% loss) is our 'best guess' guideline for evaluating risk of CRF loss. However, when plants were attacked early by CRF (young plant growth) like the Cauliflower plants, loss of plants occurred otherwise the plant was able to tolerate injury. Protecting plants in the first 4 weeks of transplanting is critical.

Improved spatial and temporal management of CM by simply planting more distant from heavily damaged Fall fields or delaying planting in high risk areas may reduce risk of heavy CRF damage.

Delia radicum adults aren't highly mobile nor are they strong fliers. So the probability that a field will suffer high damage increases when other high CRF-damaged fields are within a distance of ¼ mile. Average damage to Brassicas in spring-planted fields (<1/4 mile) was consistently higher than in either the crops produced in that field the preceding or subsequent fall-planted fields. Growers are encouraged to avoid planting new *Brassica* crops near heavily-infested fields.

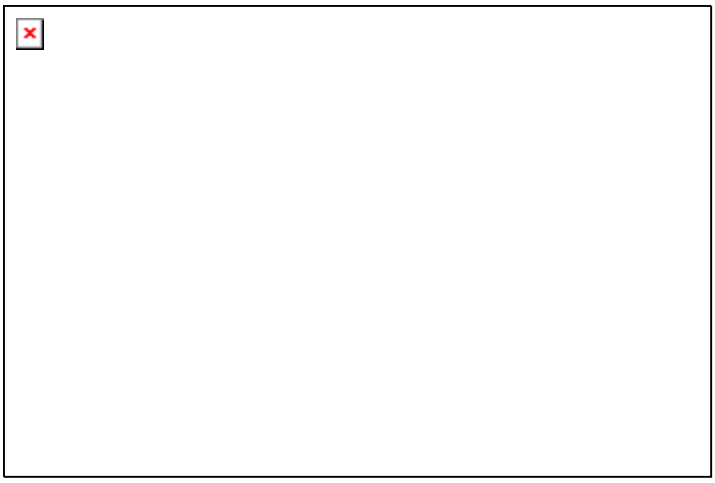
It is important to monitor for CM spring flight by using egg-laying methods (hand trowel method), and inspect plants for seasonal damage (at least 10 roots). Target treatments on high risk fields coupled with monitoring. If possible, treat the periphery of fields, rather that the whole field. If plantings are to be made throughout the season, late plantings should be kept distant from early plantings to minimize risk of heavy damage from flies in the post-harvest spike.

Appendix A: Pictures from Cabbage Root Fly project

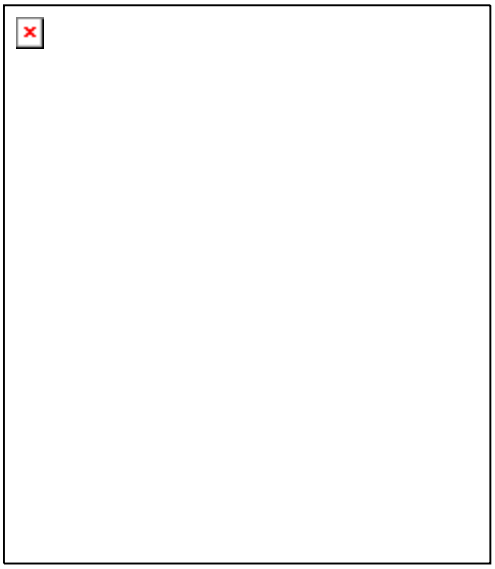

Hands-n-Knees Soil-Scrape technique for eggs at base of *Brassica* plants-tedious and unpractical.

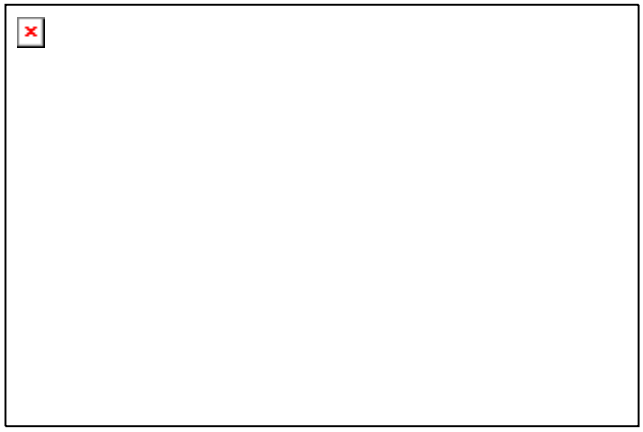
Trowel method was used to assess plants with eggs at early plant growth stage-practical and relatively precise.

Seasonal CRF monitoring (eggs & damage) of Brassica plants in broccoli and cauliflower plantings in the valley. A Hand-Trowel method was used to assess presence of CRF eggs.



Fall insecticide trials for control of CRF using direct-seeded and transplanted Brassicas.





Transplanted cabbage plants were more vulnerable to CRF egg-laying than transplanted or direct-seeded turnips and rutabagas. Lorsban-infurrow caused phytotoxicity, late emergence, and death of some plants.