UNIVERSITY OF SASKATCHEWAN

VEGETABLE CULTIVAR AND CULTURAL TRIALS

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PREPARED BY:
D. WATERER
P. SZAROZ
R. SZAROZ
B. NEWTON
S. BERTELSEN

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Department of Plant Sciences
University of Saskatchewan, 51 Campus Drive
Saskatoon, Saskatchewan, Canada, S7N 5A8
Telephone: (306) 966-5855 Fax: (306) 966-5015
E-mail: doug.waterer@usask.ca steffen.bertelsen@usask.ca
Website: www.usask.ca/agriculture/plantsci/vegetable

Saskatchwan Agriculture and Food

Root Maggot Control Trial

Root maggots (*Delia radicum*) represent a major problem for growers of vegetable cole crops in Saskatchewan. Maggot damage to the roots renders them less capable of delivering the water and nutrients required for optimal growth. In crops grown for their roots (rutabaga and radish), the scars left by the feeding maggots will render the roots unmarketable. Presently the standard approach to controlling maggots is to apply the insecticide chlorpyrifos (Lorsban) as a root drench on several occasions through the growing season. The timing of chlorpyrifos application(s) is targeted to correspond to the development of the maggot population. Application of chlorpyrifos must cease 30 days prior to harvest for rutabaga. Organophosphates like chlorpyrifos have been targeted for phase out as soon as effective reduced-risk alternatives are identified.

The objectives of this project were to;

a) test new reduced-risk insecticides for potential use in root maggot management
b) look for alternatives to insecticides as means to control root maggots

Insecticide Testing

The insecticide testing project was conducted in 2009, 2010 and 2011 at the U of S Vegetable Crops Research Station in Saskatoon. Because of heavy root maggot pressure, production of vegetable cole crops is difficult at this site – even with repeated applications of pesticides.

Each treatment consisted of two adjacent rows of rutabaga (cv. Laurentian) spaced 60 cm apart, with each treatment replicated four times in a randomized complete block design. The plants were hand thinned to a 10 cm spacing soon after emergence. The plot was kept weed free using herbicides and hand weeding. Overhead irrigation was used to maintain optimum soil moisture levels throughout the growing season. No problems with crop development or health were observed, beyond the expected problems with root maggots. Growing conditions in all three years were favorable for rutabagas.

The root maggot control treatments tested are outlined in Table 1. Except for Trmt 1, the control products were applied three times over the season, starting at the first true leaf stage and then repeated at two week intervals (late June, mid-July and late July). In all cases except Trmt 9 the control products were applied using 80-08 flood nozzles to deliver the product in the equivalent of 1000 L/ha of water over a 15cm wide spray band. Trmt 9 was applied to the foliage in 100 L/ha of water. Trmt 10 involved application of just water and served as the control. **Only Trmt 6 (chlorpyrifos) is presently registered for root maggot control on rutabaga in Canada.**

The efficacy of each round of spraying was evaluated 2 weeks after treatment. For the first 3 rating dates, 10 plants from each treatment replicate were evaluated for root damage using a semi-quantitative 0-5 rating scale (0=no damage : 5=severe damage). A 0-4 damage scale was used for evaluations made at the final harvest. This method of evaluation is based on the number of knife cuts required to remove the maggot damaged tissues from mature roots (maximum of 4). Roots requiring 2 or fewer cuts to remove the maggot damaged tissues were considered marketable.

Results

Root maggot damage was less severe in 2010 than in 2009 or 2011. In all three years maggot damage to the roots increased as the season progressed. In 2009 and 2011 none of the roots in the untreated controls were marketable by the end of the growing season (Table 1 and 3), but in 2010 about 1/3 of the roots in the untreated control treatments were marketable (Table 2). The chlorpyrifos treatment provided a significant degree of maggot control in all three years, resulting in a relatively high proportion of the crop meeting grade standards at the final harvest. The presently unregistered product CCCCC also provided a fairly consistent degree of root maggot control and was especially effective in 2011. Access to effective alternatives to Lorsban is highly desirable – especially as repeated applications of Lorsban is exerting significant selection pressure for pesticide resistance.

Table 1. Influence of pesticides on root maggot damage rates in rutabaga (Saskatchewan 2009).

Treatment	Rate[1]	Maggot Damage Ratings				
		Jul-08[1)]	Jul-23	Aug-07	Aug-25[2)]	% marketable[3)]
1. AAAAA	1 X Root drench	0.80	2.65	3.30	3.60	0
2. AAAAA	3 X Root drench	0.80	2.10	2.80	3.25	0
3. BBBBB	3 X Root drench	0.70	2.30	3.30	3.75	0
4. CCCCC (rate 1)	3 X Root drench	0.50	2.10	3.30	3.15	10
5. CCCCC (rate 2)	3 X Root drench	0.55	1.5	2.85	2.50	20
6. Chlorpyrifos	3 X Root drench	**0.05**	**0.25**	**0.75**	**0.85**	**75**
7. EEEEE	3 X Root drench	0.20	3.25	3.35	3.40	0
8. FFFFF	3 X Root drench	1.05	2.60	3.25	3.25	0
9. GGGGG	3 X Foliar	1.20	2.75	3.05	3.95	0
10. Water (control)	3 X Root drench	**1.10**	**3.25**	**3.45**	**3.85**	**0**

1. For Jul 8, Jul 23 and Aug 7 … a damage rating of 0=no damage : 5 = severe damage.
2. For Aug 25 … a damage rating of 0 = no damage : 1 = damage removed with one cut, 2 = two cuts, 4 = maximum.
3. Roots with a damage rating of 2 or less were considered to be marketable.

Table 2. Influence of pesticides on root maggot damage rates in rutabaga (Saskatchewan 2010).

Treatment	Rate[1]	Root maggot damage rating					
		Jul-07[1)]	Jul-23	Aug-06	Aug-26	Oct 6[2)]	% marketable[3)]
1. AAAAA	1 X Root drench	0.45	1.25	2.40	1.85	1.85	75
2. AAAAA	3 X Root drench	0.55	1.50	1.35	1.30	1.10	95
3. BBBBB	3 X Root drench	2.05	1.95	2.50	1.90	1.80	75
4. CCCCC (rate 1)	3 X Root drench	1.15	1.45	1.55	2.0	1.30	78
5. CCCCC (rate 2)	**3 X Root drench**	**1.15**	**0.85**	**1.25**	**0.65**	**0.50**	**98**
6. Chlorpyrifos	**3 X Root drench**	**0.15**	**0.25**	**1.30**	**1.15**	**0.93**	**93**
7. EEEEE	3 X Root drench	2.0	2.50	3.1	2.85	2.60	50
8. FFFFF	3 X Root drench	1.05	2.05	2.3	3.0	2.28	63
9. GGGGG	3 X Foliar	1.70	2.70	3.1	3.25	2.38	55
10. Water (control)	3 X Root drench	**1.20**	**2.70**	**2.65**	**3.60**	**2.88**	**38**

1 For Jul 7, Jul 23, Aug 6 and Aug 26 … a damage rating of 0=no damage : 5 = severe damage.
2 For Oct 6 … a damage rating of 0 = no damage : 1 = damage removed with one cut, 2 = two cuts, 4 = maximum.
3 Roots with a damage rating of 2 or less were considered to be marketable.

Table 3. Influence of pesticides on root maggot damage rates in rutabaga (Saskatchewan 2011).

Treatment	Rate[1]	Root Maggot Damage Rating				
		June-28	Jul-12	Aug-03	Oct-05	% marketable
1. AAAAA	1 X Root drench	0.6	3.5	2.6	3.9	4
2. AAAAA	3 X Root drench	0.3	2.4	1.7	2.9	50
3. BBBBB	3 X Root drench	0.4	3.8	2.0	3.0	26
4. CCCCC (rate 1)	3 X Root drench	0.5	2.9	1.6	2.8	52
5. CCCCC (rate 2)	**3 X Root drench**	**0.3**	**2.6**	**1.4**	**1.4**	**86**
6. Lorsban	**3 X Root drench**	**0.1**	**0.6**	**0.7**	**2.9**	**48**
7. EEEEE	3 X Root drench	1.1	4.0	2.9	3.7	4
8. FFFFF	3 X Root drench	1.6	3.2	2.5	4.0	0
9. GGGGG	3 X Foliar	1.3	3.1	2.8	3.4	0
10. Water (control)	3 X Root drench	**2.2**	**4.0**	**3.3**	**3.9**	4

1 For June 28, July 12 and Aug 3 … a damage rating of 0 = no damage : 5 = severe damage.
2 For Oct.5 … a damage rating of 0 = no damage : 1 = damage removed with one cut, 2 = two cuts, 4 = maximum.
3 Roots with a damage rating of 2 or less were considered to be marketable.

Root Maggot Interference Trials

While there are chemical control products that provide at least some degree of protection against root maggots, alternative methods of management are clearly desirable – especially as the only chemical control product that provides effective root maggot control (Lorsban) is under regulatory review.

One possible alternative approach to maggot control is to physically restrict the pest's access to the crop. Potential options for interfering with access to the crop include;

a) covering the crop with a transparent field cover. Field covers are already extensively used in production of high value vegetable crops, primarily because the covers produce a warm, sheltered growing environment conducive to faster growth and enhanced yields. However, field covers may also be used to protect crops against insect pests.

b) fencing. The adult root maggot fly tends to stay less than a meter above the ground when seeking its preferred egg laying sites at the base of the host plants. It is therefore possible to use relatively short fences to protect the crop – assuming that the fence is designed from material that is too finely woven to allow the fly access to the crop.

In 2010 and 2011 we assessed field covers and fencing as means of protecting rutabaga crops from root maggot damage.

The trials were conducted at the University of Saskatchewan Vegetable Research plots in Saskatoon. All production practices were as previously outlined. Each treatment consisted of 15 rows (8 m long) of rutabaga (cv. Laurentian) spaced 0.5 m apart, with a single plot for each treatment. As soon as the crop was seeded the "interference" treatments were put into place.

In 2010 Agryl P-17 (1.7 oz/m2) was used as a field cover. This material is thin and light weight, allowing about 80% of sunlight to pass. The mesh for the woven polyester is far too small to allow passage by root maggot flies, but is hopefully sufficiently airy to prevent overheating of the crop. The entire plot was covered with a single sheet of the cover, with the edges sealed with soil. The covers were only removed briefly to allow for thinning, weeding, and crop evaluation. In the 2011 trial, P-17 was tested again, along with a specifically designed insect cover. This insect material has a more open mesh – (20/inch) although the holes are still too small to allow passage of the root maggot fly.

In the 2010 trial a "maggot fence" was constructed by tacking a sheet of finely woven row cover (Agryl P-17) to a standard plastic snow fence. The fence stood about 1.3 m high. In 2011 we tested a custom manufactured "maggot fencing" system designed by scientists at AAFC Agassiz, B.C. The unique aspect of this custom fence is that the mesh material forms a crook at the top of the fence – this feature is designed to deflect downward any fly encountering the fence.

While the field covers and fences may be effective at preventing access to the crop by passing maggot flies, they cannot protect the crop against any flies that may emerge from pupae that have overwintered within the protected crop area. For that reason half of each plot was treated at regular intervals with the insecticide Lorsban, as this product has provided effective root maggot control in other trials.

In both years a late planted crop was also tested to determine if it might be possible to reduce maggot damage to the crop by avoiding at least some of the peak egg laying period. In previous trials we had found that egg laying commenced in late May and peaked in mid-late June. The late planted crop was therefore planted in mid-June.

Standard crop maintenance procedures were employed in both years. The crops were kept relatively weed free using herbicides supplemented by hand weeding. Overhead irrigation was applied as required.

Maggot damage was assessed at intervals over the course of the 2010 and 2011 growing seasons. For the in-season evaluations (July 4, July 23, Aug 6 and Aug 23 in 2011 and June 28, July 12 and Aug 3 in 2011) the previously described 0-5 damage rating system was used. Ten randomly selected roots were assessed at each sampling date. A standard non-protected plot was included in all comparisons. The plot was harvested once the crop matured, at which time the weight and degree of root maggot damage was

evaluated for 20 randomly selected roots from each treatment. At the final harvest the degree of root maggot damage was evaluated using the rating system based on the number of cuts required to remove the maggot damaged tissues.

Results

Crop growth – in both years, favorable conditions after seeding resulted in an excellent stand in all treatments. Within 3 weeks of crop emergence it became clear that both the field cover and fencing treatments were enhancing crop growth relative to the non-covered treatments. This beneficial effect persisted through the 2010 growing season for the fenced trial but became less obvious as time passed in the other treatments. While it was not possible to determine the exact cause of this beneficial effect, it seems likely that the crop covers and fences were protecting the crop from wind damage. The crop covers may also have been increasing air temperatures in the crop canopy which may have been beneficial early in the season.

By mid-summer in both years the crop covered with the P-17 material began to take on an abnormally "leggy" appearance – the tops were taller and thinner than normal. At the same time development (swelling) of the tap root appeared to stall. This growth effect was not observed when the crop was covered with the better ventilated insect cover.

Treatment management – the field covers were relatively easy to install and maintain. They stayed in place through several severe storm events and were easily repositioned if they did blow loose. Late in the growing season the growing crop began to push upwards against the covers and this tended to dislodge the covers more frequently. This problem was largely addressed in the 2011 trial by leaving more slack in the covers in anticipation of crop growth. By comparison to the field covers, the maggot fence systems required much more work to install and maintain. The fences interfered with all forms of machinery used in crop maintenance – by contrast the field covers were easily removed and replaced once tillage or spraying was completed.

Maggot control – damage to the roots increased as the season passed in all treatments (Tables 4 and 5), although the progression of this increase was not smooth**.** Late in the season the rate of expansion of the tap root appeared to exceed the rate at which the maggot damage was increasing – and during these intervals the damage ratings actually declined. In both years the field cover treatments provided a significant degree of root maggot protection relative to the non-covered controls. In the 2011 trial, the insect cover was preferable to the P-17 field cover as it provided a higher degree of crop protection and was also easier to work with as it was stronger and more resistant to tearing during handling. In both years the fencing treatments also provided a significant degree of protection from root maggot relative to the non-protected control. However, for both the fences and covers, the degree of maggot control achieved was still insufficient to allow the crop to be grown successfully without the use of insecticides.

The extensive root maggot damage observed in both the covered and fenced treatments suggests that; a) either these treatments were relatively ineffective at prohibiting the adult maggot flies' access to the crop or b) the indigenous populations trapped under the covers or inside the fence were large enough to cause extensive crop damage. In all treatments, the plants treated with Lorsban had far less maggot damage than in the corresponding untreated areas (Tables 4 and 5) – these results along with the results from the chemical testing trial attest to the efficacy of the Lorsban treatments. Combining the field cover and fencing treatments with Lorsban treatment provided a high level of crop protection – but it is questionable whether the additional degree of protection achieved using the covers or fence would have offset the cost of the materials and labor required to construct and maintain these crop protection systems.

Delaying planting by 3 weeks did not appear to mitigate the maggot pressure. Perhaps an even later planting date is required in order to avoid the first egg laying generation but this will necessarily delay crop development, leading to a loss in yields and also increasing the risk of damage to the crop by the 2nd larger generation of maggot flies that emerges in late summer.

Table 4. Root maggot damage to rutabaga over the course of the 2010 growing season as influenced by various protection systems, with or without supplemental application of the insecticide Lorsban.

	July 7		July 23		Aug 6		Aug 23	
	Lorsban		Lorsban		Lorsban		Lorsban	
	+	-	+	-	+	-	+	-
No cover	0.2±0.16[Z]	2.0±0.53	1.4±0.28	3.2±0.31	0.9±0.28	2.6±0.32	1.6±0.47	3.4±0.38
Covered	0	1.3±0.48	0.2±0.18	1.2±0.52	0.9±0.33	2.3±0.50	0.7±0.38	1.2±0.31
Fenced	0.5±0.34	1.7±0.55	0.5±0.34	2.7±0.12	0.8±0.41	2.8±0.56	0.4±0.22	3.1±0.31
Late planted	-	-	0.1±0.09	1.7±0.15	0.7±0.41	2.8±0.35	2.0±0.38	3.8±0.29
Avg	**0.2**	**1.7**	**0.6**	**2.1**	**0.8**	**2.6**	**1.2**	**2.9**

[Z] Plant roots graded according to method of Dosdall; numbers represent mean±SD of a 10-plant sample.

Table 5. Root maggot damage to rutabaga over the course of the 2011 growing season as influenced by various protection systems, with or without supplemental application of the insecticide Lorsban.

	June28		July 12		Aug 3	
	Lorsban		Lorsban		Lorsban	
	+	-	+	-	+	-
No cover	0[Z]	2.2±0.19	0.9±0.0.27	3.6±0.24	0.5±0.16	2.1±0.37
P17 cover	0	0.3±0.10	0.2±0.21	1.4±0.45	0.1±0.10	0.62±0.22
Insect cover	0	0.6±0.54	0	1.0±0.35	0	0.62±0.15
Fenced	0.1±0.10	0	0.1±0.18	3.0±0.22	0.1±0.1	2.2±0.21
Late planted	-	-	0.6±0.22	1.1±0.39	1.0±0.41	2.1±0.43
Avg	**0**	**0.70**	**0.4**	**2.0**	**0.4**	**1.6**

[Z] Plant roots graded according to method of Dosdall; numbers represent mean±SD of a 10-plant sample.

Yields – in both years root weights were increased by the Lorsban treatments (Tables 6 and 7). This would be expected if the Lorsban treatments had protected the feeder roots from damage by the maggots. The cover treatments appeared to increase total root yields relative to the control treatments. This may reflect the cover enhancing growing conditions, particularly early in the growing season. The fencing treatments did not enhance yields in either year. In the 2010 trial the late planted crop produced only a few exceptionally large roots – this reflects the fact that the stand for this crop was quite thin – so each plant was provided with more growing space than for the earlier planted crops which had a more complete and competitive stand. Total yields from the late planted crop in 2010 would actually have been quite low – as was seen in the 2011 trial. In both years, the Lorsban treatments substantially reduced the amount of root maggot damage seen in all treatments at the final harvest. This resulted in a substantial increase in the proportion of the crop that would have met grade standards for freedom from excessive maggot damage. If no insecticide was used, keeping the crop covered with the P-17 field cover increased the proportion of the 2010 crop that made grade tolerances for maggot damage. In 2011, the fencing treatment and the insect cover increased the marketable % for the crop in the absence of protectant insecticides.

Conclusion/Recommendations – two years of testing suggest that crop covers and fences do have the potential to provide at least some degree of crop protection against maggot damage. However both the crop covers and fences are extremely expensive to install and require considerable maintenance. They also interfere with other aspects of normal crop maintenance. By comparison, application of the standard insecticide Lorsban provided more effective crop protection than either the covers or fences and at a fraction of the cost.

Table 6. Root weights, root damage ratings and % marketable roots as influenced by various protection systems, with or without supplemental application of the insecticide Lorsban – 2010 trial.

	Root weight (kg) [Z]		Damage rating [Y]		% marketable		Marketable Weight (kg)	
	Lorsban		Lorsban		Lorsban		Lorsban	
	+	-	+	-	+	-	+	-
No cover	5.2	3.8	1.7±0.26	2.9±0.26	83	29	4.3	1.1
Covered	5.6	3.8	1.6±0.31	1.9±0.40	83	62	4.6	2.4
Fenced	5.7	6.4	1.0±0.31	2.6±0.40	83	33	4.7	2.1
Late planted	6.4	5.7	1.3±0.29	2.5±0.29	88	37	5.6	2.1
Avg	**5.7**	**4.9**	**1.4**	**2.5**	**84**	**40**	**4.8**	**1.9**

[Z] Weight of 12 randomly selected roots.

[Y] Damage rating based on number of cuts required to remove maggot damage (0 to maximum of 4). Mean±SE.
Roots considered marketable if maggot damage can be removed with a maximum of 2 cuts

Table 7. Root weights, root damage ratings and % marketable roots as influenced by various protection systems, with or without supplemental application of the insecticide Lorsban – 2011 trial.

	Root weight (kg/plot)[Z]		Damage rating [Y]		% marketable		Marketable Weight	
	Lorsban		Lorsban		Lorsban		Lorsban	
	+	-	+	-	+	-	+	-
No cover	20.8	17.4	2.4±0.15	3.6±0.31	45	20	9.4	3.5
P17 cover	28.3	22.1	1.0±0.22	3.3±0.27	100	15	28.3	3.3
Insect cover	28.2	15.2	0.8±0.31	1.7±0.45	95	65	26.7	9.9
Fenced	17.4	17.5	2.2±0.22	2.6±0.36	60	50	10.5	8.7
Late planted	9.7	10.7	2.8±0.19	3.8±0.29	40	15	3.9	0.5
Avg	**20.9**	**16.6**	**1.9**	**3.0**	**68**	**31**	**14.2**	**5.1**

[Z] Plots consisted of two 4m long rows.

[Y] Damage rating based on number of cuts required to remove maggot damage (0 to maximum of 4). Mean±SE.
Roots considered marketable if maggot damage can be removed with a maximum of 2 cuts

Companion Cropping Trial

Companion cropping involves mixing two or more crop species within a field in an effort to enhance productivity – with the companion crops "helping" the other crop by repelling insect pests or by providing nutrients. Root maggot flies seeking an appropriate site for egg laying identify suitable hosts by a combination of visual cues and odor. The presence of non-host plants in the immediate vicinity of the potential host tends to "confuse" the flies, reducing egg laying.

This study sought to determine whether root maggot damage to a high value vegetable crop (rutabaga) could be mitigated by inter-planting the rutabagas with either a non-host "companion" crop like wheat that would physically interfere with egg laying or a faster growing and stronger smelling (more attractive) brassica crop like oilseed mustard.

The trial was conducted at the University of Saskatchewan Vegetable Crops Research site in Saskatoon during 2010 and 2011 (see previous for site details). The rutabagas (cv. Laurentian) were planted in rows alternating with rows of;

a) rutabaga (standard) **b) oilseed mustard**
c) wheat **d) no crop (2011 only)**

The wheat and oilseed mustard companion crops were planted 1 week ahead of the rutabaga so that these companion plants would be larger than the emerging rutabaga. It was anticipated that the efficacy of these treatments in either confusing or diverting the maggot flies would be enhanced by increasing plant size. To reduce competition with the rutabaga crop, both companion crops were "topped" to the height of the adjacent rutabaga plants in mid-July and again in mid-August.

Each plot row was 8 m long and each treatment was replicated four times in a randomized complete block design. One half of each treatment row of rutabaga (4m) was treated at regular intervals with Lorsban (see above for description of treatment method). This allowed for comparison of the companion treatments with and without supplemental control via insecticides.

At regular intervals over the growing season, root samples (n=10) were evaluated for root maggot damage using the previously described rating system. The plot was harvested once the crop matured at which time the weight and degree of root maggot damage was evaluated for 20 randomly selected roots from each treatment replicate. At the final harvest the degree of root maggot damage was evaluated based on the number of cuts required to remove visible maggot damage from the roots (0 to a maximum of 4). Roots requiring 2 or less cuts were considered to be marketable.

Results

Crop growth - both the oilseed mustard and wheat established quickly and, as designed, were well advanced prior to the emergence of the rutabaga. Both of the "companion" crops grew more quickly than the rutabaga – this resulted in considerable shading of the rutabaga crop – especially by the sprawling oilseed mustard plants. This competition occurred despite the companion crops being topped twice over the course of the growing season.

Maggot control - the extent of maggot damage to the roots increased as the season progressed, except towards the end of the 2010 season, when the roots grew more rapidly than the damaged area (Tables 8 and 9). As shown in Table 8, neither of the companion crops had any significant impact on the intensity of root maggot damage to the rutabaga crop at any of the sampling dates in the 2010 trial. By contrast, in 2011 the rutabaga crop planted adjacent to a wheat companion crop appeared to experience heavier than normal root maggot pressure, whereas the mustard companion crop appeared to at least marginally reduce root maggot pressure through most of the growing season. As seen in the other experiments, the multiple Lorsban treatments provided a significant degree of maggot protection in both years (Tables 8 and 9).

Table 8. Root maggot damage to rutabaga as a function of various companion crops - with and without Lorsban treatments – 2010 trial.

	July 7 Lorsban		July 23 Lorsban		Aug 6 Lorsban		Aug 23 Lorsban		Average Lorsban	
Companion Crop	+	-	+	-	+	-	+	-	+	-
Mustard	**0.2**	**0.4**	**0.5**	**2.3**	**0.7**	**3.2**	**1.0**	**3.3**	**0.6**	**2.3**
Wheat	**0.2**	**1.6**	**0.7**	**3.3**	**0.6**	**3.0**	**1.2**	**3.6**	**0.7**	**2.9**
Rutabaga	**0.2**	**1.9**	**0.4**	**3.1**	**0.6**	**2.9**	**1.7**	**3.0**	**0.7**	**2.7**
Avg	**0.2**	**1.3**	**0.6**	**2.9**	**0.6**	**3.0**	**1.3**	**3.3**	**0.7**	**2.6**

Plant roots graded according to method of Dosdall; numbers represent mean±SD of four 10-plant samples

Table 9. Root maggot damage to rutabaga as a function of various companion crops with and without Lorsban treatments – 2011 trial.

	June 28 Lorsban		July 12 Lorsban		Aug 3 Lorsban		Sept 2 Lorsban		Average Lorsban	
Companion Crop	+	-	+	-	+	-	+	-	+	-
Mustard	**0**	**0.1**	**0.2**	**1.9**	**0.3**	**2.6**	**1.8**	**2.2**	**0.6**	**1.7**
Wheat	**0**	**0.6**	**0.8**	**2.3**	**1.1**	**3.5**	**2.9**	**3.0**	**1.2**	**2.4**
Rutabaga	**0**	**0.4**	**0.6**	**2.8**	**0.9**	**2.2**	**1.9**	**2.4**	**0.9**	**2.0**
No Crop	**0**	**0.4**	**0.6**	**2.2**	**1.4**	**1.9**	**2.6**	**2.7**	**1.1**	**1.8**
Avg	**0**	**0.45**	**0.6**	**2.2**	**0.9**	**2.6**	**2.2**	**2.6**	**1.0**	**2.0**

Plant roots graded according to method of Dosdall; numbers represent mean±SD of four 10-plant samples

Yields – in the 2010 trial the companion crops reduced yields of the adjacent rutabaga plants relative to when the adjacent plant was a rutabaga (Table 10). By contrast, in the 2011 trial, yields from the plots where the rutabaga crop was interplanted between rows of wheat or mustard were actually higher than when the adjacent row was also planted to rutabaga (Table 11) . However, yields of all three interplanted crops were less than 50% of the yields observed when the rutabaga test rows were flanked by blank, unplanted rows. These results suggest that the rutabaga crop is experiencing intensive competition pressure – irrespective of what the adjacent rows are planted to. This competition occurred despite the fact that the wheat and mustard companion plants were pruned back to the height of the adjacent rutabagas on two occasions over the course of the growing season. Competition is one of the major limitations of using companion planting to limit pests in relatively non-competitive horticultural crops.

In the 2010 trial the damage ratings taken early in the growing season had shown little consistent benefit of the companion plantings. However, at the final harvest, having mustard as a companion plant significantly reduced root maggot damage to the adjacent rows of rutabaga (Table 10). The degree of root maggot protection achieved by interplanting with mustard was equivalent to the degree of benefit achieved with multiple applications of Lorsban. When considering the proportion of the crop that would have been considered marketable based on freedom from excess root maggot damage (damage rating <2.0), the combination of Lorsban+mustard as a companion crop was clearly superior (78% marketable), while rutabaga grown without either insecticide or a companion crop had the highest rate of grade-out due to excessive maggot damage (23% marketable). The enhancement in marketable % achieved by interplanting the rutabaga crop with mustard was not sufficient to overcome the negative effect exerted on yields by competition from the mustard crop. As a consequence, the highest marketable yields in the 2010 trial were obtained when a less competitive rutabaga crop was grown in the adjacent rows. Averaged across interplanting treatments, application of the insecticide Lorsban increased the marketable % by 19% and marketable yields by 68%.

Table 10. Root weights, % marketable roots and marketable root weights as influenced by various companion crops with or without supplemental application of Lorsban – 2010 trial.

	Yield (kg/plot)[1]			% Marketable[2]			Marketable (kg/plot)		
	Lorsban			Lorsban			Lorsban		
Companion Crop	+	-	**Avg**	+	-	**Avg**	+	-	**Avg**
Mustard	4.1	5.1	**4.9**	78	50	**64**	3.2	2.6	**2.9**
Wheat	5.5	4.8	**5.1**	45	52	**48**	2.5	2.5	**2.5**
Rutabaga	9.2	6.4	**7.8**	58	23	**40**	5.3	1.5	**3.4**
Avg	**6.2**	**5.4**		**60**	**41**		**3.7**	**2.2**	

[1] Plots consisted of two 4m long rows
[2] Roots considered marketable if maggot damage can be removed with a maximum of 2 cuts

Table 11. Root weights, % marketable roots and marketable root yields as influenced by various companion crops with or without supplemental application of Lorsban – 2011 trial

	Yield (kg/plot)[1]			% Marketable[2]			Marketable (kg/plot)		
	Lorsban			Lorsban			Lorsban		
Companion Crop	+	-	**Avg**	+	-	**Avg**	+	-	**Avg**
Mustard	6.6	4.3	**5.3**	82	65	**74**	5.4	2.8	**4.1**
Wheat	4.3	5.8	**5.0**	40	43	**41**	1.7	2.5	**2.1**
Rutabaga	4.0	3.5	**3.7**	78	50	**64**	3.1	1.8	**2.5**
No Crop	**16.8**	**10.3**	**10.9**	**48**	**45**	**46**	**8.1**	**4.6**	**6.3**
Avg	**8.0**	**6.0**		**62**	**51**		4.6	2.9	

[1] Plots consisted of two 4m long rows
[2] Roots considered marketable if maggot damage can be removed with a maximum of 2 cuts

In the 2011 trial, having mustard as a companion crop had consistently reduced maggot damage in the rutabaga crop through the early root ratings (Table 9). At the final harvest, having mustard as the companion crop increased the proportion of roots that were sufficiently free of maggot damage to be considered "marketable" (damage rating <2.0) by 10% relative to the next best treatment – this was comparable to the average benefit achieved using multiple applications of Lorsban (11% increase in marketable roots)(Table 11). While having no companion crop had resulted in a high % grade out to maggot damage, the lack of competition from adjacent crop rows resulted in the few remaining marketable roots growing to exceptional size. As a consequence, the highest marketable yields in the 2011 trial were obtained when the rutabaga tests rows were flanked by blank rows (Table 11).

Establishing and maintaining the companion crops required some additional effort. The yield data suggests that the companion plants need to be managed in a manner that more effectively limited their ability to compete with the rutabaga crop (ie; wider row spacings, thinner planting density or more frequent/aggressive pruning). This management would need to be achieved without compromising the value of these crops as means of protecting the target crop from insect damage. Another possibility would be to select companion plants with a less aggressive growth habit – for example kale is very attractive to root maggots and has a less aggressive growth habit than mustard. However it is thought that larger plants are more effective as an attractant/distraction – and therefore a less vigorous companion crop may be undesirable.

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