ANNUAL REPORT

To:
AHDB Horticultural Development Council
Stoneleigh Park
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Warwickshire
CV8 2TL

Brassica: companion planting for pest control

HortLINK project HL0174
HDC Project FV 251

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The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

Project title:	Brassica: companion planting for pest control
Project number:	HL0174; FV 251
Project Leader:	Rosemary Collier Warwick HRI**,** Wellesbourne, Warwick CV35 9EF
Annual report:	2008
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Location of project:	Warwick HRI**,** Wellesbourne, Warwick CV35 9EF
Project co-ordinators:	Phillip Effingham
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Signed on behalf of: Warwick HRI

Signature:…………………………………………… ***Date***: ……………………………

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The following are members of the Consortium for LINK project no HL0174:

Elsoms Seeds Ltd
R Fountain & Son
Horticultural Development Council
Marshall Brothers (Butterwick) Limited
The University of Warwick

GROWER SUMMARY

SCIENCE SECTION

GROWER SUMMARY

Headline

- Carrots and birds foot trefoil show promise as Brassica companion plants for the control of cabbage root fly. Lettuce produces the greatest amount of foliage, a trait desirable in companion plants, but it can have adverse effects on crop yield. These companion plants are undergoing further investigation.

Background and expected deliverables

UK Brassica crops currently occupy about 32 000 hectares, with an annual market value of about £160M. Cabbage root fly (CRF) and aphids are the major brassica pests. Two insecticides are approved currently for control of CRF on leafy brassica crops. They are chlorpyrifos (organophosphorus insecticide (OP)) and spinosad (Tracer).

The use of pesticides, particularly OP insecticides, is a major concern for the horticultural industry and for the public. This is for environmental reasons, for operator safety and because of the possibility of residues in food. At present, most leafy brassica crops are treated prophylactically for CRF control using chlorpyrifos.

Many researchers have shown that the numbers of pest insects found on cruciferous and other crop plants are reduced considerably when they are grown with other plant species. Earlier attempts to develop commercially viable systems of polyculture in northern Europe have often failed. This is because the companion plants chosen were too competitive with the main crop, and there was a lack of detailed understanding of how insects not only use chemical cues, but also visual cues, to find their host plants.

A new theory of host plant selection indicates that it is visual cues from companion plants, particularly the amount of green surfaces, rather than the volatile chemicals such plants release, that disrupt insects from finding their host plants. In particular, the protracted time spent on the non-host plants appears to be the underlying mechanism that disrupts insects from finding host plants in diverse plantings. Stimulated by this theory, some growers have investigated the use of companion planting to control CRF and have obtained encouraging results. They now require scientific input is to develop a system that consistently produces a commercially acceptable crop under all pest pressures. Whilst most of the recent experimental work has been done on brassicas and their pest insects, the approach is likely to be applicable to other non-cruciferous crops and their pests.

The aim of this project is to use companion plants instead of insecticides for controlling CRF in conventional (ICM) production of leafy brassica crops. The technique will form a basis for development of an Integrated Pest Management (IPM) strategy that will be applicable to other pests, crops and production systems, including organics, and may also impact on weed and disease control, through increased plant species diversity within the crop.

Summary of the project and main conclusions

The experimental work done during 2008 (Year 3) addressed Objectives 5 and 6 of the project.

Objective 5 *Develop and refine robust systems for growing brassicas and companion plants together, so that the negative effects of competition are offset by the positive effects of reduced pest numbers*

Six field trials were done to evaluate the companion plant species/combinations identified in 2007. The trials were done at three times during the summer, targeted at periods of peak egg-laying by the three generations of CRF, and using three appropriate cauliflower varieties. Each trial was done at two locations (6 trials in total). The companion plant treatments (Table A) were selected on the basis of the results from the field trials undertaken in 2007 to determine the effect of companion plant species and number on the yield and quality of cauliflower plants. Some of the more competitive companion plants were sown at a rate of 2 or 4 per module, whilst others were sown at a rate of 4 or 8 per module. There were two control treatments: 1) cauliflower sown alone and drenched with Dursban prior to planting (positive control) and 2) cauliflower sown alone and left untreated (negative control). The plants were machine-planted at one location (Elsoms, Spalding, Lincolnshire) and hand-planted at the other sites (belonging to Marshalls, near Boston, Lincolnshire) (Table B).

Table A. Companion plant treatments including control treatments for Trials 1 and 2

Treatment	No. companion plants per cell	Treatment
1. Cauliflower alone	None	Drenched with Dursban
2. Cauliflower alone	None	No insecticide
3. Carrot	4	No insecticide
4. Carrot– Elsoms only	8	No insecticide
5. Lettuce	2	No insecticide
6. Lettuce – Elsoms only	4	No insecticide

7. Birds foot trefoil	4	No insecticide
8. Sorrel	4	No insecticide
9. Tarragon	4	No insecticide

Table B. Locations of trials, planting dates and cauliflower varieties grown in 2008

Planting	Location	Planting date	Cauliflower variety
1	Elsoms	6 May	Boris
1	Marshalls	6 May	Boris
2	Elsoms	30 June	Skywalker
2	Marshalls	14-15 July	Skywalker
3	Elsoms	21 July	Bodilis
3	Marshalls	30 July	Bodilis

It was difficult to achieve the correct number of companion plants in every module. To a certain extent this depended on the companion plant seed – both its size and viability. Even if the modules contained the correct number of companion plants prior to transplanting (every effort was made to ensure this) then some of them 'disappeared' either as a result of planting or for other reasons during the first few weeks of growth.

As a result of early assessment of Trial 1, a decision was made to evaluate some 'carrot' and 'lettuce' treatments in Trial 3 (Table C) which might maximize the 'impact' of the companion plants at planting. These treatments involved sowing more seeds per cell (8 carrots versus 4 carrots), sowing the companion plants slightly earlier than the cauliflowers, or growing the plants in slightly larger modules (216 trays). On the whole, the 'early-sowing' treatments were unsuccessful as the companion plants became too competitive (Figure A).

Table C. Companion plant treatments including control treatments for Trial 3

Treatments	No. companion plants per cell	Tray size	Sow companions early
1. Cauliflower alone	None	308	
2. Cauliflower alone + Dursban	None	308	
3. Carrot	4	308	No
4. Carrot	4	308	Yes
5. Carrot	4	216	Yes
6. Lettuce	4	308	No
7. Lettuce	4	308	Yes
8. Lettuce	4	216	Yes
9. Carrot	8	308	Yes

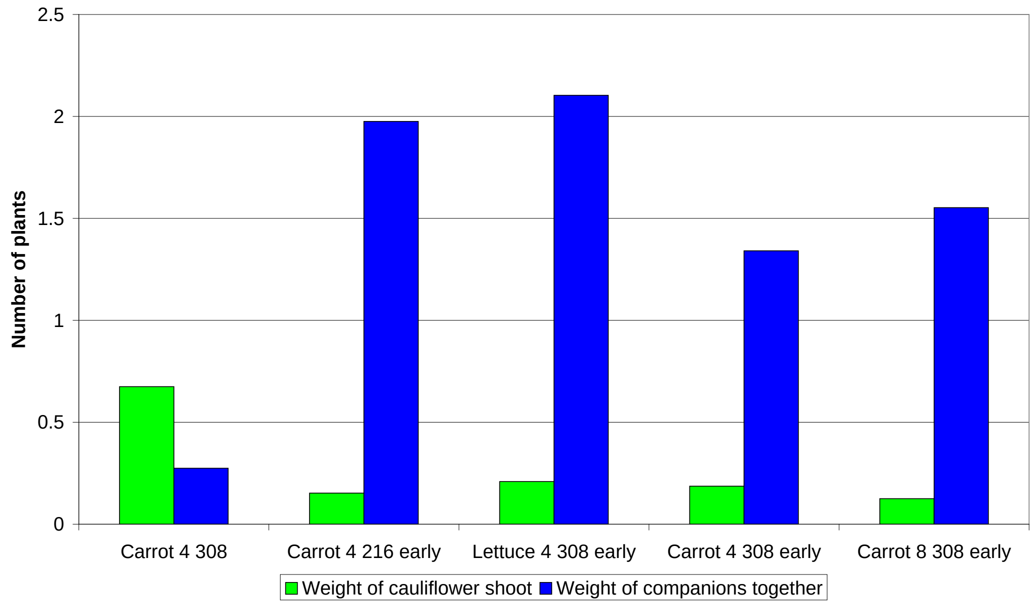

Figure A. Trial 3 - the average weights of cauliflower plants and companion plants in a 40-plant sample from each tray

In all trials, assessments were made of cauliflower and companion plant survival after one CRF generation (generally about 6 weeks after planting). Larval feeding damage to the cauliflower roots and lower stem was also assessed at this stage. Damage due to other pests was also assessed. The cauliflowers were then left to grow to maturity when further assessments were made of maturity date, yield and curd quality. In general, the cauliflower plants treated with Dursban suffered the least larval feeding damage to the roots but none of the treatments were damaged severely by CRF. However, as in 2007, the relative performance of the different companion plant treatments varied between trials. The performance of the various companion plants is summarised in Table D.

Table D. Summary of the performance of the different companion plant species

Carrot	Survived well and did not appear to be very competitive.
Lettuce	Produced the greatest amount of foliage but the 4-plant treatments did not survive as well as 2 plants per module. Probably the most 'consistent' treatment. On some occasions appeared to reduce CRF damage to roots and stems. On some occasions had adverse effects on crop 'yield'.
Birds foot trefoil	Quite thin and wispy. Very uncompetitive with cauliflower so did not affect 'yield'.
Sorrel	Many of them disappeared in some plantings.
Tarragon	Did not produce a large amount of green material by transplanting.

The preliminary conclusions drawn from the field trials are:

- It is sometimes difficult to achieve the correct density of companion plants in every module in an experimental trial on this scale. To a certain extent this depends on the companion plant seed – both its size and viability. This needs consideration when commercially-viable systems of growing brassicas with companion plants are being developed.
- Even if the modules contain the correct number of companion plants prior to transplanting then some of them may 'disappear' either as a result of planting or for other reasons during the first few weeks of growth.
- If cauliflowers are not 'presented' with a sufficient amount of alternative green surfaces (companion plants) then they are likely to be more susceptible to egg-laying by female CRFs. Thus when considering the effects of the 'treatments' it is also important to take into account how close companion plant numbers were to those intended.
- Generally the cauliflower plants treated with Dursban suffered lower levels of CRF feeding damage to the roots, but this was not true for damage to the lower stem area.
- Despite the different pressures that the different types of companion plant placed on the growing cauliflowers, many of the companion plant treatments in the trials yielded good quality curds. There were considerable differences between trials in the proportion of good quality curds produced and some of these are likely to be attributable to the very variable conditions under which the trials were grown in 2008.
- Future work should concentrate on producing cauliflower plants surrounded by a relatively large and consistent area of alternative green surfaces (companion plants) to disrupt egg-laying by the CRF.

Objective 6 Determine how the companion plant system developed for CRF control affects levels of pest predation and parasitism compared with 'bare soil' crops

The aim of field experiments done at Wellesbourne in 2008 was to determine the effect of the presence of companion plants on survival of brassica pests compared with 'bare soil' crops. These experiments used lettuce as a companion plant – four per cell and grown in 216 module trays. The pest species investigated were CRF, cabbage aphid, diamond-back moth and large white butterfly. In some experiments potted plants were infested in the laboratory and then planted into a 'background' plot of either cauliflowers or cauliflowers with lettuce companions (Figure B). In others, the plants in field plots were infested directly. Pest survival was assessed over appropriate periods of time. All insects were obtained from the cultures maintained at Warwick HRI, Wellesbourne. Most of this work was done in August and September. Very heavy rainfall had a negative effect on the experimental trial as experiments on cabbage aphid (*Brevicoryne brassicae*) were washed out.

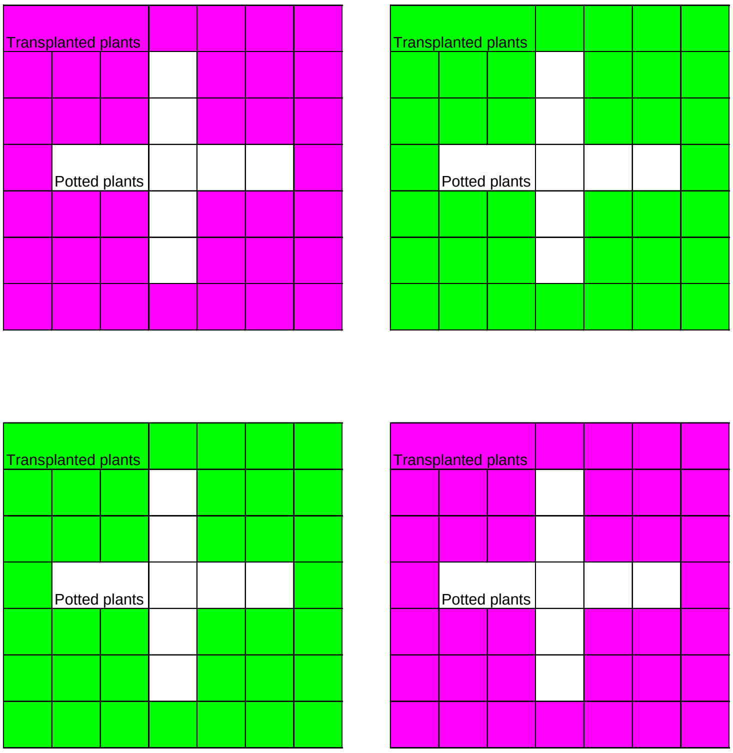

Figure B. Plan of field plots to study pest insect survival. Potted test plants were planted into the 'cross' in the centre of each plot

The results of experiments to measure the survival of newly-hatched diamond-back moth or large white butterfly larvae over periods of 4-6 days are shown in Figure C. Overall, although the numbers of insects recovered varied between experiments, there was little difference between the two treatments for any pest insect species/development stages tested.

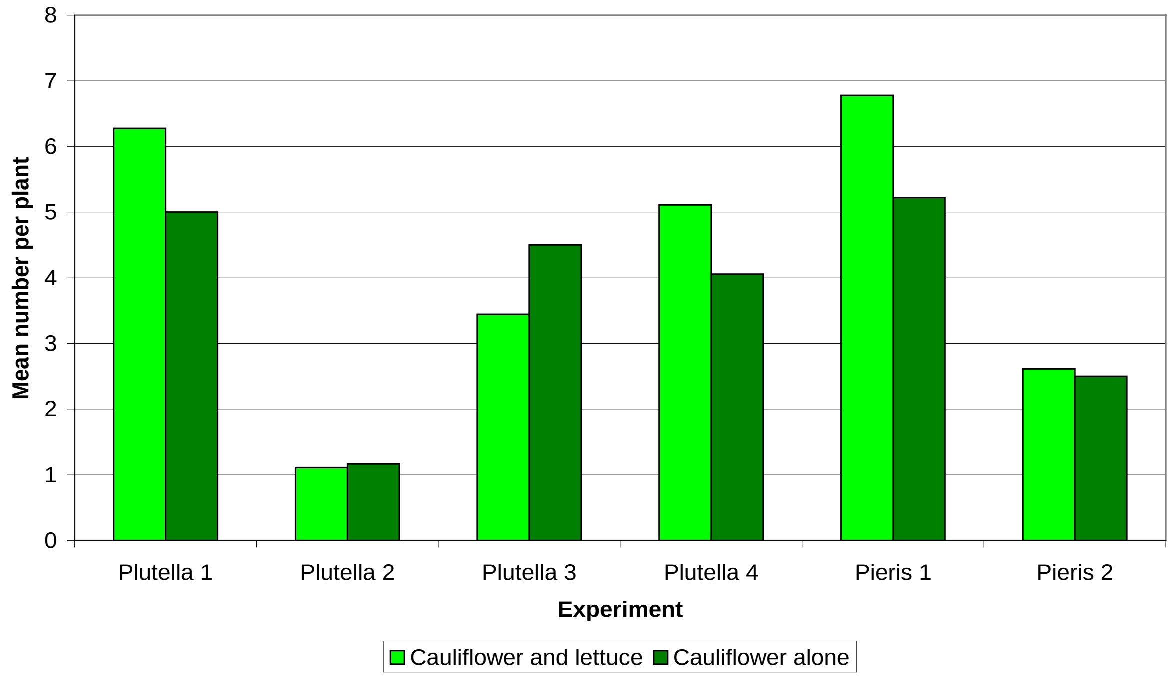

Figure C. The mean number of newly-hatched diamond-back moth (*Plutella*) or large white butterfly (*Pieris*) larvae remaining per plant (inoculated with 20 per plant)

Financial benefits

- UK brassica crops currently occupy about 32 000 ha, with an annual marketed value of about £160M. Without adequate insecticidal control, it is estimated that about 24% of the plants in field brassica crops would be rendered unmarketable by CRF.
- Companion planting costs depend on the cost of companion plant seed and the method used. In Marshalls' 2002 trials, companion planting with cauliflower cost £25-60/ha (4 companion plants/module), so costs could be less than Gigant seed treatment.
- There is likely to be little additional financial return compared with current prices. However, it is essential for growers to continue to seek methods of reducing pesticide usage, simply to remain competitive in the market. Benefits of non-chemical insect control will far exceed any savings in production costs by maintaining and improving consumer confidence in the integrity of UK vegetable production and ensuring safe working conditions for operatives under Health and Safety legislation, particularly those working in glasshouses.
- If shown to be effective, the market potential of this technique is excellent, since it reduces the risk of insecticide residues in produce and has environmental benefits. Grower uptake of this technique could be very high and in theory it could be applied to all leafy brassica crops (32,000 ha). A reduction in the risk to propagators of using insecticides would be viewed very favourably. Customer acceptance of reduced pesticide use would also be

high and such a technique should improve the market potential of crops grown in this way and could be used as a basis for promoting the purchase of brassica vegetables. This would have a beneficial effect on growers, propagators and seed producers.

Action points for growers

These are the results from the third year of a four-year project to use companion plants for controlling the CRF in conventional (ICM) production of leafy brassica crops. They have confirmed that:

  - There are a number of plant species that could potentially be used as companion plants without affecting the yield, quality and maturity time of cauliflower adversely.
  - If cauliflowers are not 'presented' with a sufficient amount of alternative green surfaces (companion plants) then they are likely to be more susceptible to egg-laying by female CRF's. Thus when considering the effects of the 'treatments' it is also important to take into account how complete the companion plant treatments were.

- Further work is required to refine the technique under field conditions and to verify that companion plants are effective in the control of CRF and other brassica pests.

SCIENCE SECTION

Introduction

UK brassica crops currently occupy about 32,000 ha, with an annual marketed value of about £160M (Defra Basic Horticultural Statistics). CRF and aphids are some of their most important pests. Two insecticides are approved currently for control of CRF on leafy brassica crops. They are chlorpyrifos (organophosphorus insecticide (OP)) and spinosad (Tracer), which is a relatively new insecticide.

The use of pesticides, particularly OP insecticides, is a major concern for the horticultural industry and for the public. This is for environmental reasons, for operator safety and because of the possibility of residues in food. At present, most leafy brassica crops are treated prophylactically for CRF control using chlorpyrifos.

Many researchers have shown that the numbers of pest insects found on cruciferous and other crop plants are reduced considerably when they are grown with other plant species (Andow, 1991). Earlier attempts to develop commercially viable systems of polyculture in northern Europe have often failed. This is because the companion plants chosen were too competitive with the main crop, or to a lack of detailed understanding of how insects use not only chemical cues, but also visual cues, to find their host plants. A new theory of host plant selection (Finch & Collier, 2000), indicates that it is visual cues from companion plants, particularly the amount of green surfaces, rather than the volatile chemicals such plants release, that disrupt insects from finding their host plants. In particular, the protracted time spent on the non-host plants appears to be the underlying mechanism that disrupts insects from finding host plants in diverse plantings (Finch et al., 2003; Morley et al., 2005). Stimulated by this theory, growers have investigated the use of companion planting to control the CRF and have obtained encouraging results, but consider that scientific input is now required to develop a system that consistently produces a commercially acceptable crop under all pest pressures. Whilst most of the recent experimental work has been done on brassicas and their pest insects, the approach is likely to be applicable to other non-cruciferous crops and their pests.

Many studies have shown that the numbers of pest insects found on crop plants are reduced considerably when plant diversity is increased within the crop (Andow, 1991). Several different hypotheses have been proposed and in 2000, following detailed studies of the behaviour of pest insects of cruciferous plants, Stan Finch and Rosemary Collier put forward their theory (Finch & Collier, 2000) to explain this phenomenon. This theory proposes that the colour, size and shape of companion plants, rather than the volatile chemicals they release, determine their effectiveness in reducing insect colonisation.

Much of the evidence to support this theory was provided from insect behaviour studies done at Warwick HRI during collaborations between Stan Finch and three visiting workers/students. Although this work has been based on cruciferous plants and their pests, the results are relevant to crops from other plant families. Key findings to support this theory are that:

- Searching insects land on green surfaces, but avoid brown surfaces such as the soil.
- Artificial green plants or green paper (releasing no volatile chemicals) are as effective as companion plants as living green plants. The insects do not appear to discriminate between green surfaces on the basis of differences in colour or odour.
- Aromatic companion plants are no more effective than less pungent species and pest insects do not avoid the foliage of aromatic plants.

The theory proposes that the host plant selection process occurs as follows:

a) Plant odours stimulate searching insects to land.
b) The insects land on any green object (but avoid brown objects such as bare soil). Whilst landing, they do not differentiate between the greens, or the odours, of host and non-host plants. Therefore the insects may land on a host plant (appropriate landing) or on a non-host plant (inappropriate landing).
c) The insects that make inappropriate landings remain on the plant for some time and then fly off. They may repeat the process, or they simply leave the area.
d) Once an insect lands on a host plant it then assesses the suitability of the plant using chemical receptors on its feet and mouthparts. This may involve the insects making short flights from leaf to leaf. On plants surrounded by bare soil, most of the insects land back on the same plant (appropriate landing). On plants surrounded by non-host plants, some insects land on the non-host plants (inappropriate landing) and then leave.

Although the colour, size and shape of companion plants, rather than the volatile chemicals they release, appear to determine their effectiveness in reducing insect colonisation, it is likely that volatile chemicals provide the initial stimulus to land in the vicinity of a host plant. In addition, the final decision to accept a host plant for egg laying or as a feeding site is based on contact chemical stimuli. Thus, although this study will focus on the visual aspects of host plant selection, it will take into account the possible contributory role of volatile and contact chemicals.

Increased plant diversity within the crop will also impact on the diversity and activity of the natural enemies of pest species. Some studies indicate that the effects of plant diversity on pests and their natural enemies are complementary, whilst others indicate that they are antagonistic (Andow, 1991). The proposed project should provide new information to determine whether diversity *per se* helps natural enemies to control pest insect species, as despite what many organic growers believe, this is still debatable. This can be achieved by fairly simple manipulative experiments, in which pest infested plants are placed in bare soil and diverse crop situations to monitor levels of parasitism (Richards, 1940). Similarly, by placing plants infested with pest insects into bare soil and diverse backgrounds it should be possible to determine whether predation is higher on infested plants surrounded by non-host plants than on plants surrounded by bare soil.

The aim of this project is to use companion plants instead of insecticides for controlling the CRF in conventional (ICM) production of leafy brassica crops. The technique will form a basis for development of an Integrated Pest Management (IPM) strategy that will be applicable to other pests, crops and production systems, including organics, and may also impact on weed and disease control, through increased plant species diversity within the crop. The two objectives addressed during this reporting period are:

5. Develop and refine robust systems for growing brassicas and companion plants together, so that the negative effects of competition are offset by the positive effects of reduced pest numbers.

6. Determine how the companion plant system developed for CRF control affects 2) levels of pest predation and parasitism compared with 'bare soil' crops.

EXPERIMENTAL

Objective 5

5. *Develop and refine robust systems for growing brassicas and companion plants together, so that the negative effects of competition are offset by the positive effects of reduced pest numbers*

The aim of the trials in 2008 was to evaluate the companion plant species/combinations identified in 2006 and evaluated in 2007. The plan was to undertake trials at three times during the summer, using three appropriate cauliflower varieties and to locate each trial at two sites (Table 1).

Table 1. Proposed sowing and planting dates for the 2008 field trials

Planting/fly generation	Sowing date	Planting date	Cauliflower variety	Potential sites
1	Early Feb	Late April	Boris	Elsoms, Marshalls
2	15-May	Late June	Skywalker	Elsoms, Marshalls
3	Early June	Mid July	Bodilis	Elsoms, Marshalls

The treatments for Trials 1 and 2 are shown in Table 2. As a result of early assessment of Trial 1, a decision was made to evaluate some 'carrot' and 'lettuce' treatments in Trial 3 (Table 3) which might maximize the 'impact' of the companion plants at planting. These treatments involved sowing more seeds per cell (8 carrots versus 4 carrots), sowing the companion plants slightly earlier than the cauliflowers or growing the plants in slightly larger modules (216 trays). The trays for all three trials were sown according to schedule.

Table 2. Companion plant treatments including control treatments for Trials 1 and 2

Treatment	No. companion plants per cell	Treatment
1. Cauliflower alone	None	Drenched with Dursban
2. Cauliflower alone	None	No insecticide
3. Carrot	4	No insecticide
4. Carrot– Elsoms only	8	No insecticide
5. Lettuce	2	No insecticide
6. Lettuce – Elsoms only	4	No insecticide
7. Birds foot trefoil	4	No insecticide
8. Sorrel	4	No insecticide
9. Tarragon	4	No insecticide

Table 3. Companion plant treatments including control treatments for Trial 3

Treatments	No. companion plants per cell	Tray size	Sow companions early
1. Cauliflower alone	None	308	
2. Cauliflower alone + Dursban	None	308	
3. Carrot	4	308	No
4. Carrot	4	308	Yes
5. Carrot	4	216	Yes
6. Lettuce	4	308	No
7. Lettuce	4	308	Yes
8. Lettuce	4	216	Yes
9. Carrot	8	308	Yes

Trial design

The trials were laid out as randomised blocks with 3 replicates of each treatment per site and each replicate consisted of 10 x 12 plants. Planting dates and locations are shown in Table 4.

Table 4. Planting dates 2008

Planting	Location	Planting date
1	Elsoms	6 May
1	Marshalls	6 May
2	Elsoms	30 June
2	Marshalls	14-15 July
3	Elsoms	21 July
3	Marshalls	30 July

All three plantings went according to schedule, with small delays.

Assessments

The assessments are shown below.

After one CRF generation (4-6 weeks from planting)

- Number of dead/wilting cauliflower plants
- Number of surviving cauliflower and companion plants
- Destructive sample to assess root damage and stem damage (30 plants per plot)
- Roots weighed
- Assessment for damage by pests other than CRF

At maturity

- Maturity date, size, condition of each curd and number of surviving companion plants (30 plants per plot)
- Assessment for other pests

The assessments went according to plan, but the cauliflowers in Plantings 2 and 3 took a long time to mature and most of the cauliflowers from Planting 3 at Marshalls did not reach maturity.

Analysis

The data were entered into EXCEL spreadsheets and subjected to Analysis of Variance. For each response variable analysed, there were two sets of analyses. The first analysis was for all data collected. The second analysis was carried out using only the data where the correct numbers of companion plants were observed. Only the results of the second analysis are presented in this report.

Interpretations of the analyses were made using treatment means with associated SED and 5% LSD values for pair-wise comparisons. A P-Value, given with each analysis, determines the overall significance of the treatment factor using an F test. Some caution should be taken when making pair-wise comparisons where this test is not significant at a 5% level.

Results

Trials 1 and 2

Module 'quality' at planting

The first trial was assessed at both sites (Elsoms and Marshalls) on 20 May 2008. A summary of the observations made is shown in Table 5.

Table 5. Visual assessment of Planting 1 at Elsoms and Marshalls on 20 May 2008

	No. companions	Companion plants - comments
1. Cauliflower alone	None	
2. Cauliflower alone	None	
3. Carrot	4	Survived well
4. Carrot	8	Survived pretty well
5. Lettuce	2	Sufficient modules produced and these seemed to have the greatest amount of foliage
6. Lettuce	4	There were relatively few modules with 4 companions in the trays
7. Birds foot trefoil	4	Quite thin and wispy
8. Sorrel	4	Many of them had disappeared at Elsoms in particular
9. Tarragon	4	Not a huge amount of green material

Trials at Elsoms

The analyses were carried out assuming a balanced incomplete block design with 3 columns, 9 rows and 3 replicates of each treatment (1 replicate per column). Table 6 shows how many cauliflowers per treatment had the correct number of companion plants. Where only a small number of correct companions were observed, subsequent means presented should be treated with caution. Of particular concern were the sorrel and tarragon companions for the first planting.

Table 6. Number of cauliflower plants per treatment with the correct number of companion plants (0, 2, 4 or 8) – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	**Planting Date 1**				**Planting Date 2**			
	No of Companion plants planted	**Rep 1**	**Rep 2**	**Rep 3**	**No of Companion plants planted**	**Rep 1**	**Rep 2**	**Rep 3**
Cauliflower Alone - Dursban	0	**30**	**30**	**30**	0	**30**	**30**	**30**
Cauliflower Alone	0	**30**	**30**	**30**	0	**30**	**30**	**30**
4 Carrot	4	6	6	6	4	**14**	**9**	**10**
8 Carrot	8	0	3	3	8	8	2	6
2 Lettuce	2	**17**	**15**	**16**	2	**22**	**14**	**13**
4 Lettuce	4	6	1	3	4	12	8	8
4 Birds Foot Trefoil	4	3	2	6	4	2	2	9
4 Sorrel	4	0	4	0	4	3	3	6
4 Tarragon	4	0	0	1	4	1	1	4

Weight of cauliflower plants

A natural log transformation was applied to ensure the homogeneity of variances between treatments. The results of the analysis are summarised in Table 7 and Figure 1.

There were statistically significant differences between treatments in the first planting, although these differences should be treated with caution due to the low counts of cauliflowers with the correct number of companion plants in certain circumstances. For the first planting, the cauliflower plants with birds foot trefoil and tarragon had lower mean weights than the cauliflower plants that were drenched with Dursban and the cauliflower plants with 4 sorrel plants had a mean weight that was greater than the insecticide-free control (cauliflower alone). For the second planting, the cauliflower plants with 4 lettuce plants or 4 sorrel plants had lower mean weights than the cauliflower plants that were drenched with Dursban.

Table 7. The mean weight of cauliflower plants after one generation of CRF – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	Planting 1		Planting 2	
	Back transformed	Transformed	Back transformed	Transformed
Cauliflower Alone - Dursban	**209.600**	**5.350**	**92.900**	**4.542**
Cauliflower Alone	**167.300**	**5.126**	**58.050**	**4.078**
4 Carrot	225.400	5.422	**70.890**	**4.275**
8 Carrot	139.400	4.944	72.820	4.302
2 Lettuce	**209.300**	**5.348**	**49.330**	**3.919**
4 Lettuce	165.000	5.112	41.130	3.741 D
4 Birds foot trefoil	96.600	4.581 D	74.450	4.323
4 Sorrel	386.800	5.960 U	49.150	3.915 D
4 Tarragon	13.500	2.675 D	72.620	4.299
F - Value		25.610		1.430
P - Value		<.001		0.277
SED		0.260		0.303
5% LSD		0.589		0.660
df		9		12

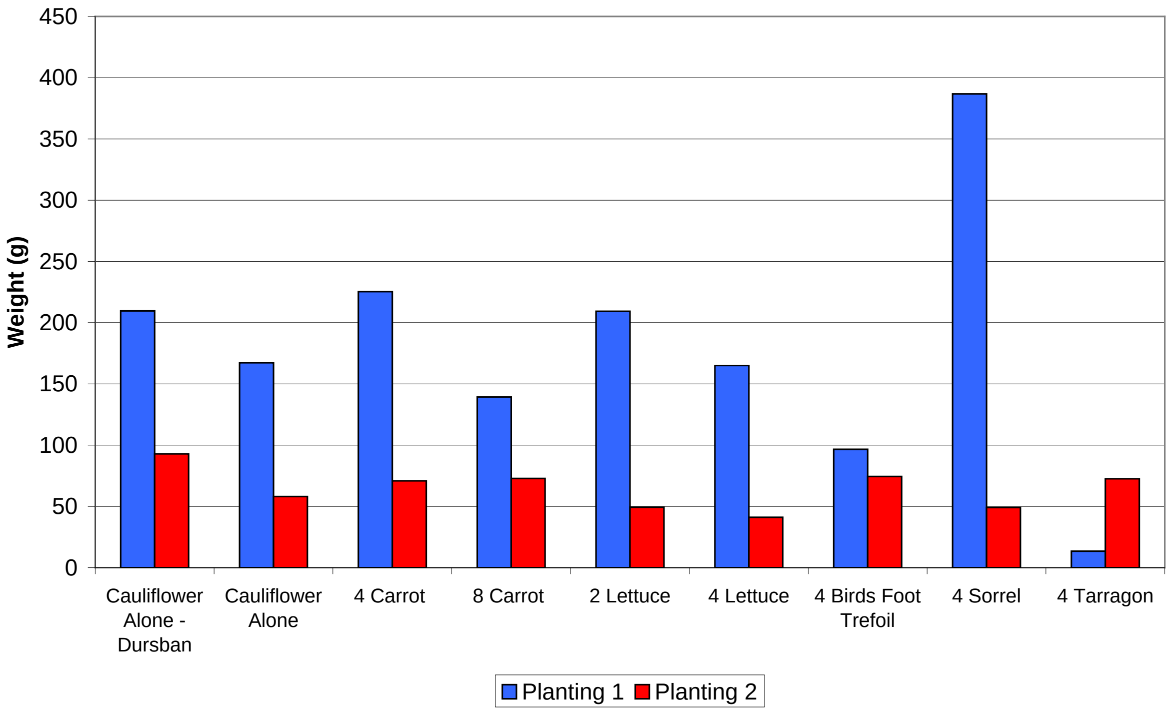

Figure 1. The mean weight of cauliflower plants after one generation of CRF – Elsoms (back-transformed data)

Weight of companion plants

Natural log transformations were used to ensure homogeneity of variance between treatments. For both plantings, the treatment factor was significant at the 5% level. The lettuce companion plants had the largest mean weights (Table 8; Figure 2).

Table 8. The mean weight of companion plants after one generation of CRF – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1		Planting 2	
	Back transformed	Transformed	Back transformed	Transformed
Cauliflower Alone - Dursban	*	*	*	*
Cauliflower Alone	*	*	*	*
4 Carrot	1.223	0.799	**6.500**	**2.015**
8 Carrot	1.557	0.939	3.630	1.533
2 Lettuce	**24.800**	**3.250**	**95.850**	**4.573**
4 Lettuce	15.818	2.822	47.850	3.889
4 Birds foot trefoil	0.867	0.624	2.250	1.179
4 Sorrel	0.182	0.167	8.780	2.281
4 Tarragon	3.064	1.402	9.770	2.377
F - Value		58.390		21.400
P - Value		<.001		<.001
SED		0.216		0.378
5% LSD		0.510		0.843
df		7		10

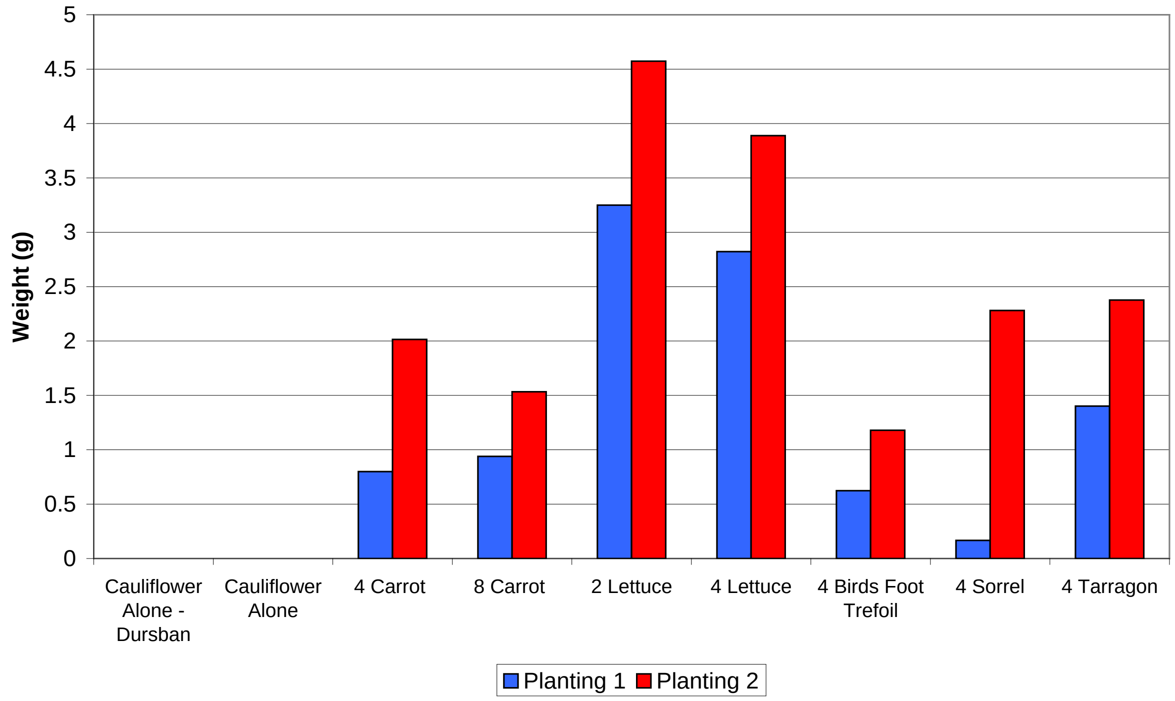

Figure 2. The mean weight of companion plants after one generation of CRF – Elsoms (back-transformed data)

Weight of cauliflower roots

A natural log transformation was used to ensure homogeneity of variance between treatments.

In Planting 1, the roots of cauliflower plants grown alone (no insecticide), with 8 carrots, 4 birds foot trefoil or 4 tarragon weighed less than those of the cauliflowers treated with Dursban (Table 9, Figure 3). The roots of cauliflowers treated with Dursban or grown with 4 sorrel were heavier than those from the insecticide-free control (cauliflower alone). In Planting 2, the roots of cauliflower plants grown with 2 or 4 lettuce, 4 sorrel or 4 tarragon weighed less than those of the cauliflowers treated with Dursban.

At the second planting, both lettuce treatments had smaller roots than the cauliflower plants drenched with Dursban.

Table 9. The mean weight of cauliflower plant roots after one generation of CRF – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	Planting 1		Planting 2	
	Back transformed	Transformed	Back transformed	Transformed
Cauliflower Alone - Dursban	**17.210**	**2.845 U**	**5.527**	**1.710**
Cauliflower Alone	**8.800**	**2.175 D**	**4.394**	**1.480**
4 Carrot	9.850	2.288	3.347	1.208
8 Carrot	4.650	1.537 D	**3.656**	**1.296**
2 Lettuce	**14.320**	**2.662**	**2.772**	**1.020 D**
4 Lettuce	13.310	2.588	2.534	0.930 D
4 Birds foot trefoil	5.180	1.645 D	3.634	1.290
4 Sorrel	27.110	3.300 U	2.750	1.011D
4 Tarragon	0.910	0.099 D	2.280	0.824D
F - Value		22.930		2.590
P - Value		<.001		0.067
SED		0.294		0.248
5% LSD		0.666		0.541
df		9		12

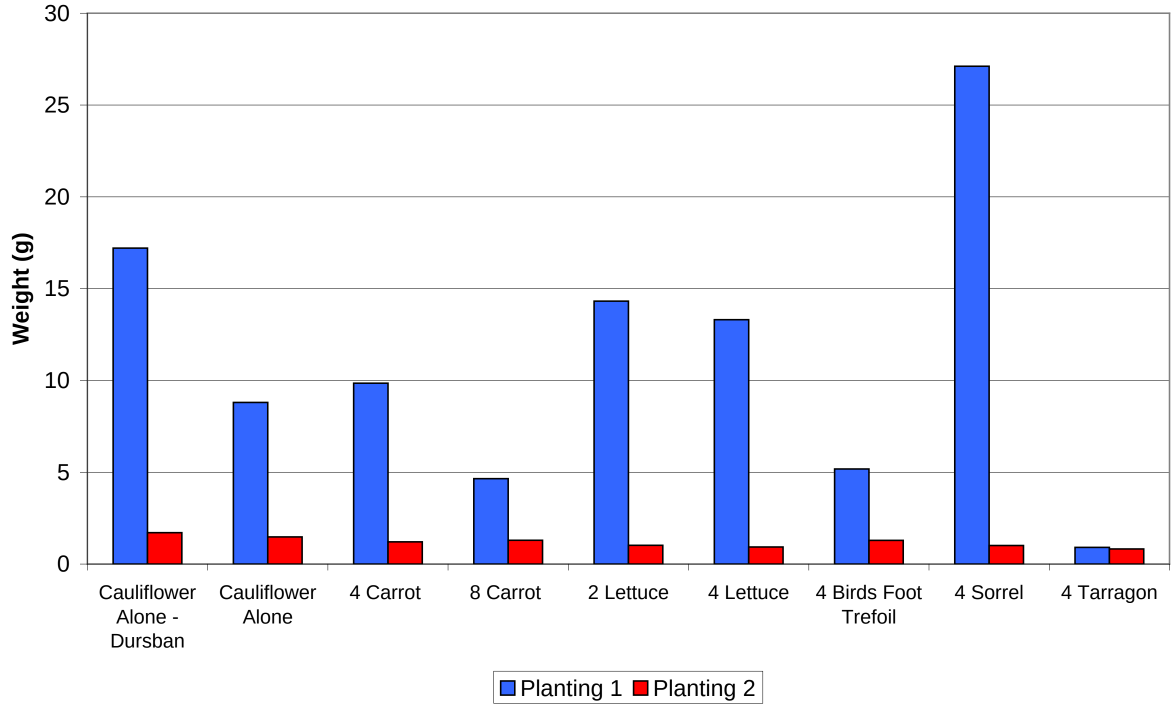

Figure 3. The mean weight of cauliflower plant roots after one generation of CRF – Elsoms (back-transformed data)

Root damage score

Square root transformations were used to ensure homogeneity between treatments.

In Planting 1, roots from all of the other treatments were more damaged than those from the cauliflower plants treated with Dursban (Table 10; Figure 4). Dursban was also one of the most effective treatments in Planting 2.

Table 10. The mean root damage score after one generation of CRF – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	Planting 1		Planting 2	
	Back transformed	Transformed	Back transformed	Transformed
Cauliflower Alone - Dursban	**0.059**	**0.243 U**	**1.768**	**1.330**
Cauliflower Alone	**3.589**	**1.895 D**	**2.538**	**1.593**
4 Carrot	3.830	1.957 D	**2.523**	**1.588**
8 Carrot	4.193	2.048 D	3.432	1.853 D
2 Lettuce	**2.183**	**1.477 D**	**2.702**	**1.644 D**
4 Lettuce	2.849	1.688 D	2.822	1.680 D
4 Birds foot trefoil	4.654	2.157 D	2.631	1.622 D
4 Sorrel	1.423	1.193 D	2.271	1.507
4 Tarragon	4.897	2.213 D	0.773	0.879 U
F - Value		11.900		9.950
P - Value		<.001		<.001
SED		0.255		0.125
5% LSD		0.578		0.272
df		9		12

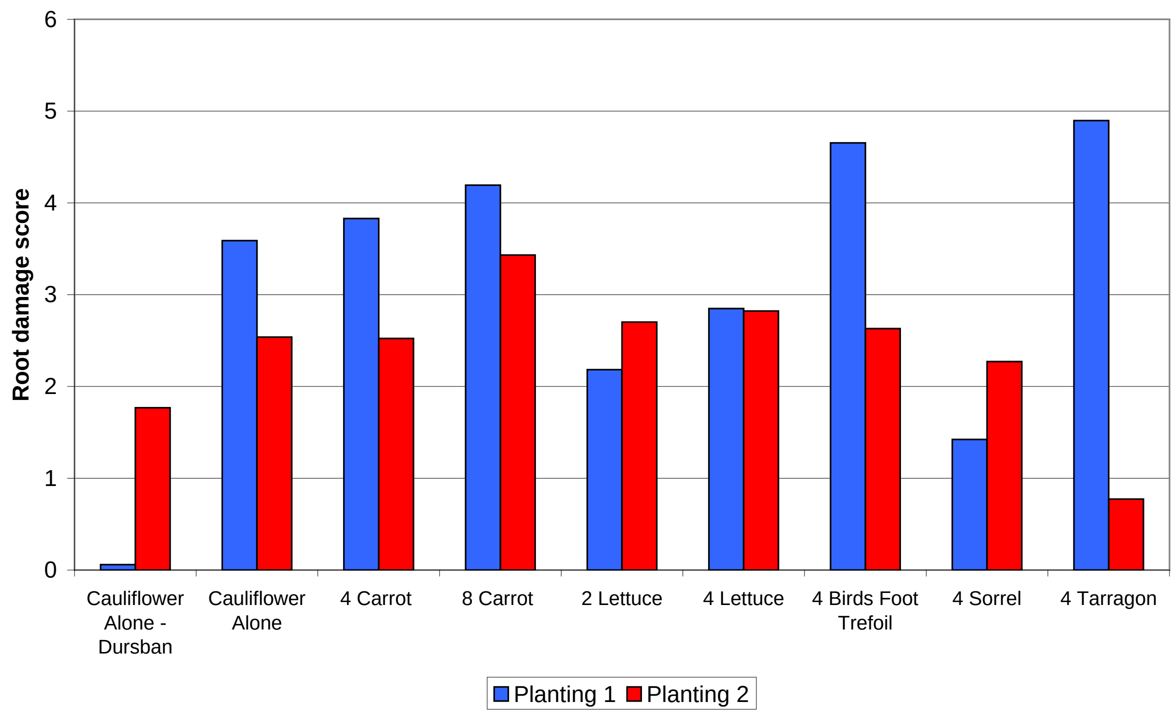

Figure 4. The mean root damage score after one generation of CRF – Elsoms (Back-transformed data)

Stem damage score

A square root transformation was used to ensure homogeneity between treatments.

As with the root damage score, the lowest means in Planting 1 were obtained for the cauliflowers planted without companions and drenched with Dursban (Table 11). Lettuce companions also resulted in stem damage scores which were lower than for other treatments, though these differences were not always significant. For the first planting, treatments with both 2 and 4 lettuce companions had low mean scores, whilst for the second planting, only the treatment with 4 lettuce companions had a small mean score relative to all other treatments.

Table 11. The mean stem damage score after one generation of CRF – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	**Planting 1**		**Planting 2**	
	Back transformed	**Transformed**	**Back transformed**	**Transformed**
Cauliflower Alone - Dursban	1.109	1.053 U	2.990	1.729
Cauliflower Alone	3.435	1.853 D	3.098	1.760
4 Carrot	4.324	2.079 D	3.010	1.735
8 Carrot	5.257	2.293 D	3.539	1.881
2 Lettuce	2.182	1.477 D	3.256	1.804
4 Lettuce	2.319	1.523 D	2.703	1.644
4 Birds foot trefoil	3.512	1.874 D	2.483	1.576
4 Sorrel	2.535	1.592 D	3.074	1.753
4 Tarragon	4.900	2.214 D	2.021	1.421
F - Value		11.000		1.440
P - Value		<.001		0.276
SED		0.170		0.161
5% LSD		0.385		0.350
df		9		12

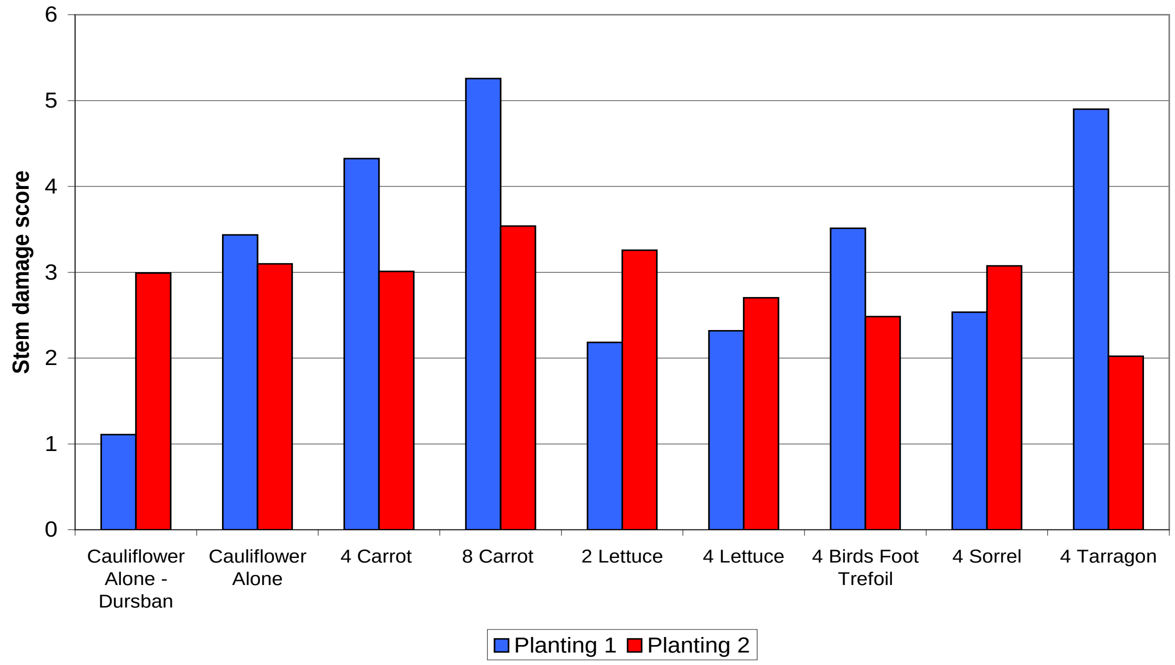

Figure 5. The mean stem damage score after one generation of CRF – Elsoms (back-transformed data)

Trials at Marshalls

Table 12 shows how many cauliflowers from each treatment had the correct number of companion plants. Means presented where only a small number of correct companions were observed should be treated with caution. Of particular concern were the tarragon companions for the first planting and the birds foot trefoil companions for the second planting.

Table 12. Number of cauliflower plants per treatment with the correct number of companion plants (0, 2 or 4) – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1				Planting 2			
	No of Companion plants planted	**Rep 1**	**Rep 2**	**Rep 3**	**No of Companion plants planted**	**Rep 1**	**Rep 2**	**Rep 3**
Cauliflower Alone - Dursban	0	**30**	**30**	**30**	0	**30**	**30**	**30**
Cauliflower Alone	0	**30**	**30**	**30**	0	**30**	**30**	**30**
4 Carrot	4	**16**	**17**	**12**	4	**18**	**19**	**21**
2 Lettuce	2	**21**	**23**	**17**	2	**23**	**27**	**22**
4 Birds foot trefoil	4	5	2	6	4	0	0	2
4 Sorrel	4	**8**	**17**	**8**	4	11	13	4
4 Tarragon	4	0	1	2	4	**15**	**13**	**10**

Weight of cauliflower plants

A natural log transformation was used to ensure the homogeneity of variance between treatments. There was no overall statistically-significant treatment effect on plant weight for Planting 1 (Table 13; Figure 6). For Planting 2, cauliflower plants grown with any of the companion plant species were smaller than the cauliflower plants treated with Dursban.

Table 13. The mean weight of cauliflower plants after one generation of CRF – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	Planting 1		Planting 2	
	Back transformed	Transformed	Back transformed	Transformed
Cauliflower Alone - Dursban	**166.200**	**5.119**	**272.400**	**5.611**
Cauliflower Alone	**125.600**	**4.841**	**185.100**	**5.226**
4 Carrot	**86.500**	**4.472 D**	**121.100**	**4.805 D**
2 Lettuce	**115.500**	**4.758**	**120.300**	**4.798 D**
4 Birds foot trefoil	156.600	5.060	85.100	4.456 D
4 Sorrel	**114.300**	**4.748**	76.400	4.349 D
4 Tarragon	115.400	4.757	**101.300**	**4.628 D**
F - Value		2.070		11.120
P - Value		0.140		<.001
SED		0.213		0.188
5% LSD		0.469		0.419
df		9		10

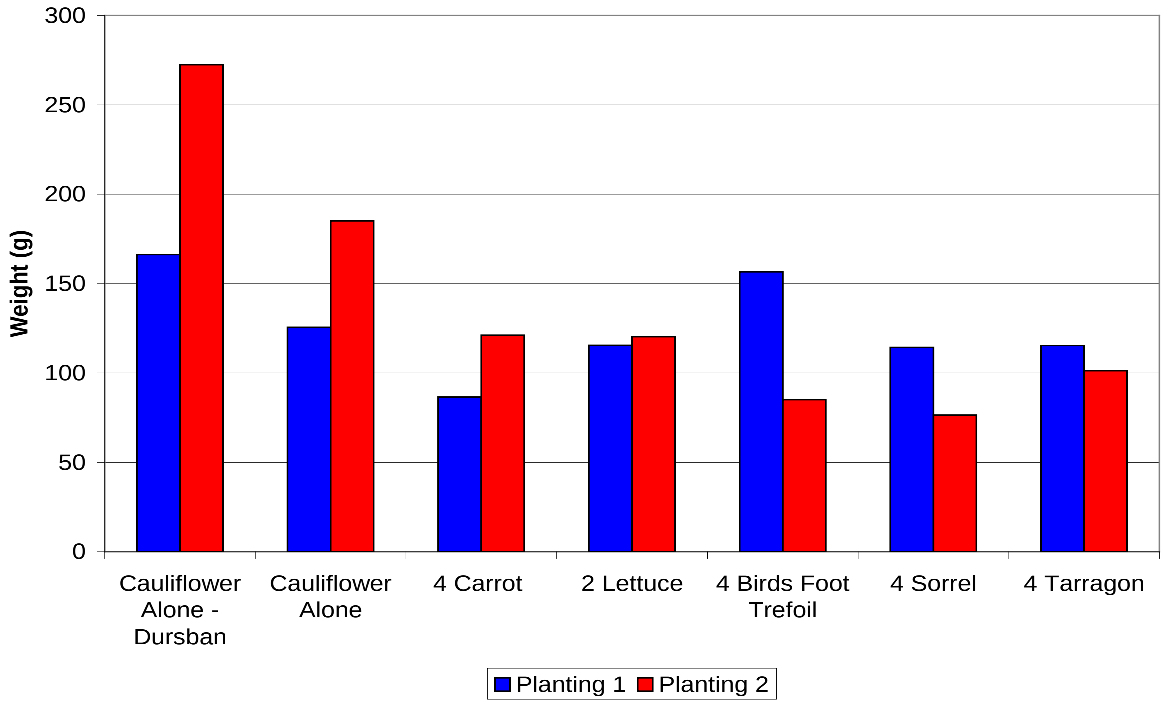

Figure 6. The mean weight of cauliflower plants after one generation of CRF – Marshalls (back-transformed data)

Weight of companion plants

A natural log transformation was used to ensure homogeneity between treatments.

The lettuce treatments had mean weights significantly larger than all other treatments (Table 14; Figure 7). For the second planting, the sorrel plants were significantly larger than all other treatments (bar the lettuce companions).

Table 14. The mean weight of companion plants after one generation of CRF - Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1		Planting 2	
	Back transformed	Transformed	Back transformed	Transformed
Cauliflower Alone - Dursban	*	*	*	*
Cauliflower Alone	*	*	*	*
4 Carrot	**1.762**	**1.016**	**1.860**	**1.051**
2 Lettuce	**46.883**	**3.869**	**49.720**	**3.926**
4 Birds foot trefoil	0.307	0.268	2.190	1.160
4 Sorrel	**1.646**	**0.973**	19.510	3.021
4 Tarragon	3.324	1.464	**6.560**	**2.023**
F - Value		134.910		45.480
P - Value		<.001		<.001
SED		0.175		0.259
5% LSD		0.415		0.596
df		7		8

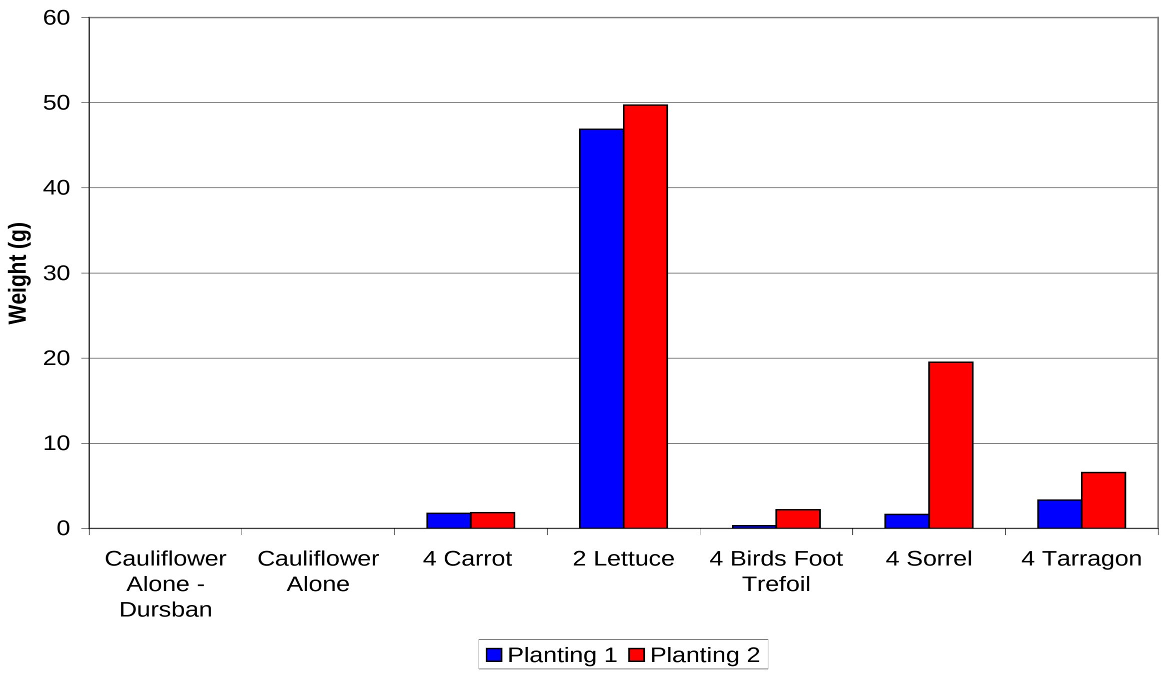

Figure 7. The mean weight of companion plants after one generation of CRF – Marshalls (back-transformed data)

Weight of cauliflower roots

Data were available only for the first planting. A natural log transformation was used to ensure homogeneity of variance between treatments.

The cauliflower drenched with Dursban had the heaviest roots (Table 15; Figure 8). This was only significantly greater than the 4-carrot and 4-sorrel treatments.

Table 15. The mean weight of cauliflower plant roots after one generation of CRF – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	Planting 1	
	Back transformed	Transformed
Cauliflower Alone - Dursban	**10.659**	**2.366**
Cauliflower Alone	**6.357**	**1.850**
4 Carrot	**4.584**	**1.523 D**
2 Lettuce	**6.804**	**1.918**
4 Birds foot trefoil	7.959	2.074
4 Sorrel	**5.530**	**1.710 D**
4 Tarragon	6.092	1.807
F - Value		2.030
P - Value		0.147
SED		0.268
5% LSD		0.591
df		11

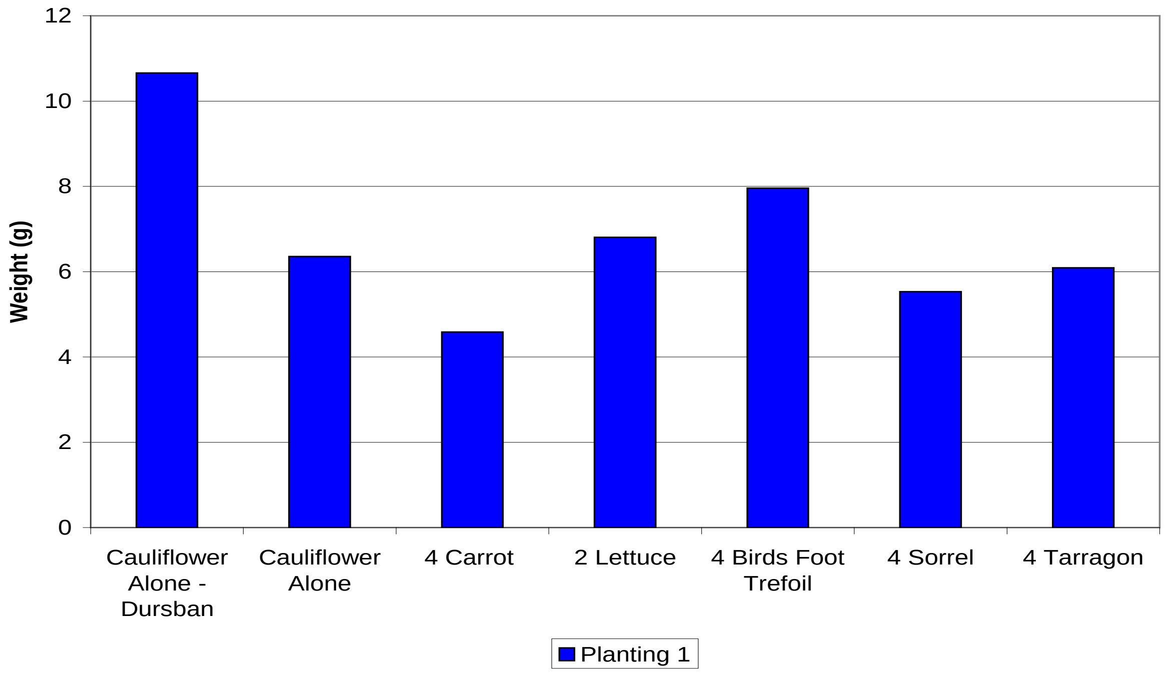

Figure 8. The mean weight of cauliflower plant roots after one generation of CRF – Marshalls (back-transformed data)

Root damage score

A square root transformation was used to ensure homogeneity between treatments.

The plants treated with Dursban were the least damaged but the difference was significant only for the cauliflower alone with no insecticide, 4 carrot and 4 tarragon treatments (Table 16; Figure 9).

Table 16. The mean root damage score after one generation of CRF – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	Back transformed	Transformed
Cauliflower Alone - Dursban	**0.968**	**0.984 U**
Cauliflower Alone	**3.169**	**1.780 D**
4 Carrot	**3.324**	**1.823 D**
2 Lettuce	**1.909**	**1.382**
4 Birds foot trefoil	2.060	1.435
4 Sorrel	**2.460**	**1.568**
4 Tarragon	3.654	1.912 D
F - Value		2.360
P - Value		0.103
SED		0.296
5% LSD		0.652
df		11

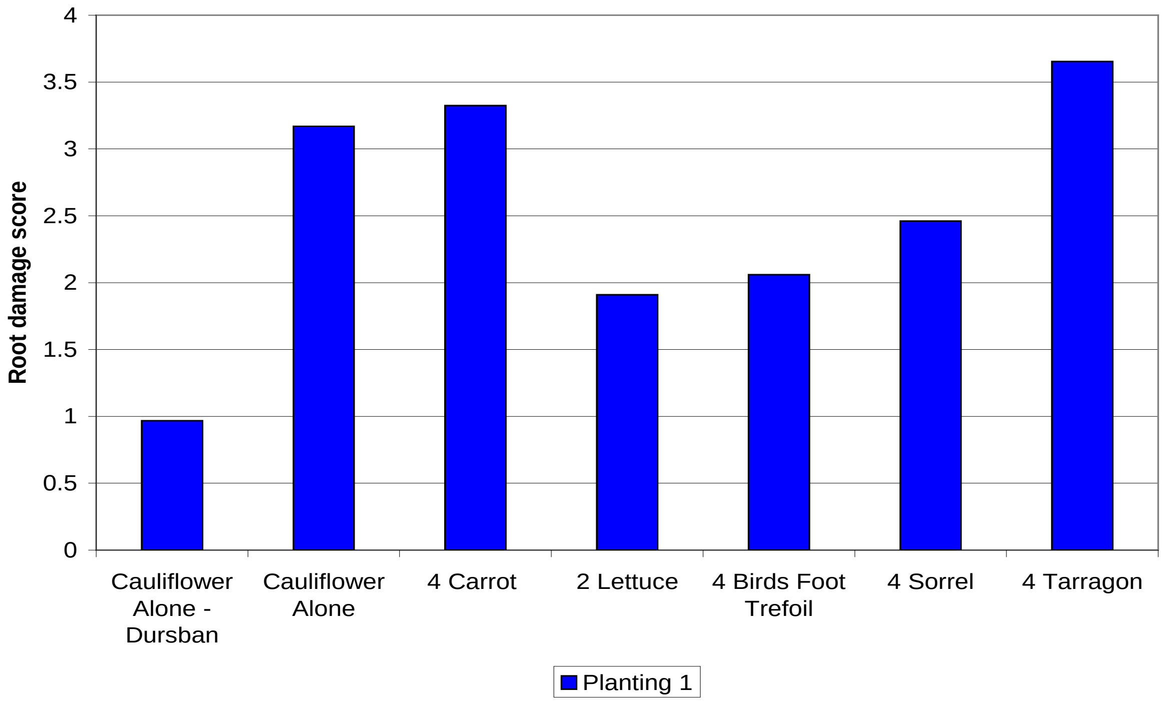

Figure 9. The mean root damage score after one generation of CRF – Marshalls (Back-transformed data)

Stem damage score

A square root transformation was used to ensure homogeneity between treatments.

There were no statistically significant differences between any of the treatments although the lettuce treatments had the smallest means (Table 17; Figure 10).

Table 17. The mean stem damage score after one generation of CRF – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Back transformed	Transformed
Cauliflower Alone - Dursban	**1.752**	**1.324**
Cauliflower Alone	**2.692**	**1.641**
4 Carrot	**2.795**	**1.672**
2 Lettuce	**1.264**	**1.124**
4 Birds foot trefoil	1.471	1.213
4 Sorrel	**1.730**	**1.315**
4 Tarragon	1.915	1.384
F - Value		0.560
P - Value		0.754
SED		0.389
5% LSD		0.856
df		11

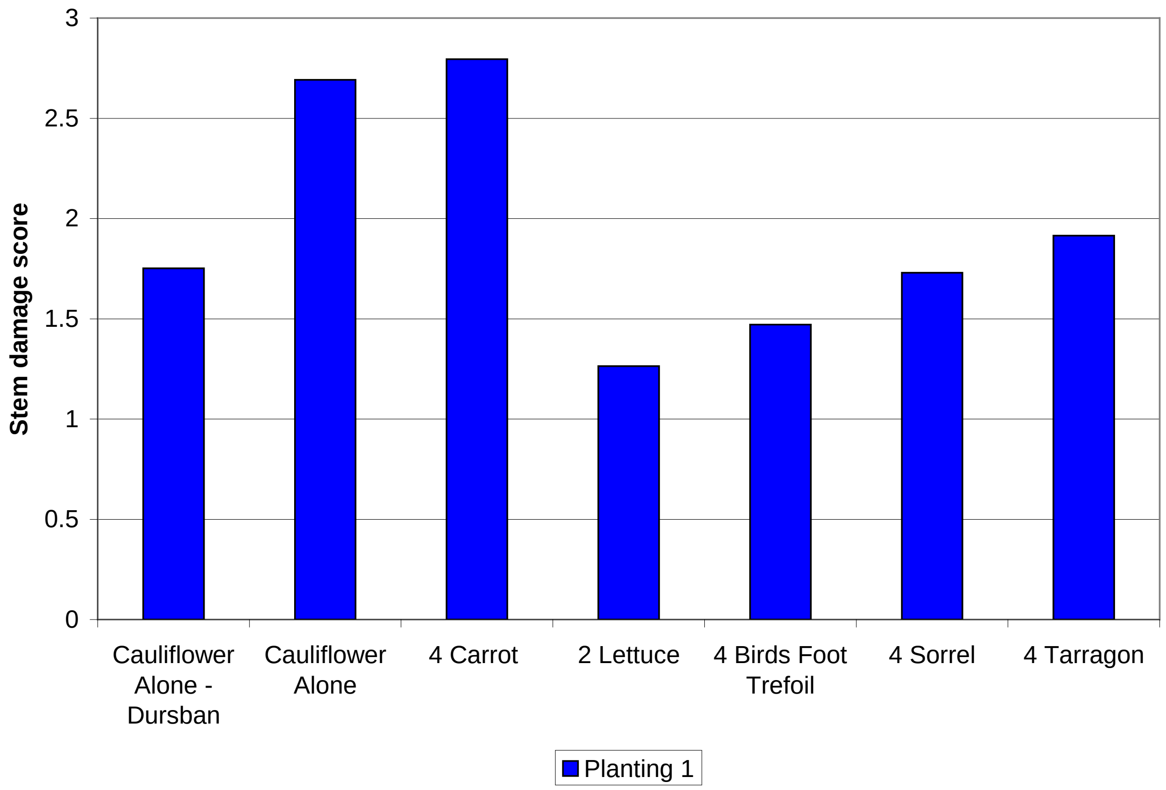

Figure 10. The mean stem damage score after one generation of CRF – Marshalls (Back-transformed data)

<u>After one generation of CRF - assessments in the field</u>

Trials at Elsoms

Table 18 shows how many of the cauliflower plants in each plot had the correct number of companion plants. Each plot contained 30 cauliflower plants. For the first planting in particular, there were a substantial number of cauliflowers that did not have the correct number of companion plants when assessed. This was particularly the case for the sorrel and tarragon treatments. Interpretations of analyses carried out on these treatments should be treated with caution.

Table 18. Number of cauliflowers with the correct number of companion plants – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1				Planting 2			
	No of Companion plants planted	**Rep 1**	**Rep 2**	**Rep 3**	**No of Companion plants planted**	**Rep 1**	**Rep 2**	**Rep 3**
Cauliflower Alone - Dursban	0	**30**	**30**	**30**	0	**30**	**30**	**30**
Cauliflower Alone	0	**30**	**30**	**30**	0	**30**	**30**	**30**
4 Carrot	4	**24**	**22**	**24**	4	**29**	**24**	**29**
8 Carrot	8	**13**	**9**	**19**	8	**29**	**27**	**28**
2 Lettuce	2	**17**	**17**	**17**	2	**28**	**28**	**29**
4 Lettuce	4	11	7	5	4	**25**	**29**	**26**
4 Birds foot trefoil	4	**10**	**10**	**18**	4	**20**	**25**	**23**
4 Sorrel	4	5	4	1	4	**17**	**11**	**9**
4 Tarragon	4	2	3	8	4	**14**	**20**	**13**

Proportion of plants damaged by aphids

An angular transformation was used to ensure homogeneity between treatments.

Overall, there was a general increase between Planting 1 and Planting 2 in the proportion of cauliflower plants showing aphid damage (Table 19). There were no overall statistically-significant treatment effects.

Table 19. Proportion of plants damaged by aphids – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1		Planting 2	
	Back Transformed	Transformed	Back Transformed	Transformed
Cauliflower Alone - Dursban	**1.15**	**6.15**	**15.31**	**23.03**
Cauliflower Alone	**5.18**	**13.16**	**4**	**11.54**
4 Carrot	**1.95**	**8.03**	**14.57**	**22.44**
8 Carrot	**0.88**	**5.37**	**9.1**	**17.55**
2 Lettuce	**11.3**	**19.65**	**13.72**	**21.74**
4 Lettuce	1.04	5.85	**9.42**	**17.87**
4 Birds foot trefoil	**0**	**0**	**21.23**	**27.44**
4 Sorrel	2.37	8.86	**10.36**	**18.77**
4 Tarragon	0	0	**2.71**	**9.47**
F- Value		2.21		1.09
P-Values		0.09		0.42
SED		5.86		7.65
5% LSD		12.56		16.41
df		14		14

Proportion of plants damaged by flea beetle

An angular transformation was used to ensure homogeneity between treatments.

The cauliflower plants grown with 4 lettuce, 4 birds foot trefoil and 4 sorrel in Planting 1 suffered no flea beetle damage (Table 20). For the second planting, there were no statistically significant effects.

Table 20. Proportion of plants damaged by flea beetle – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1		Planting 2	
	Back Transformed	Transformed	Back Transformed	Transformed
Cauliflower Alone - Dursban	**20.39**	**26.84**	**18.7**	**25.62**
Cauliflower Alone	**8.44**	**16.89**	**7.66**	**16.06**
4 Carrot	**3.57**	**10.9**	**14.3**	**22.22**
8 Carrot	**9.62**	**18.07**	**20.37**	**26.83**
2 Lettuce	**29.3**	**32.77**	**17.53**	**24.75**
4 Lettuce	0	0	**14.51**	**22.39**
4 Birds foot trefoil	**0**	**0**	**13.99**	**21.96**
4 Sorrel	0	0	**28.71**	**32.4**
4 Tarragon	1.44	6.9	**30.33**	**33.42**
F- Value		5.78		2
P-Values		<0.001		0.12
SED		7.11		5.39
5% LSD		15.25		11.56
df		14		14

Proportion of plants damaged by birds

An angular transformation was used to ensure homogeneity between treatments.

Overall, a large number of cauliflower plants suffered damage due to birds (Table 21), but there was no overall statistically significant treatment effect. The cauliflower plants with lettuce companions had relatively low proportions of bird-damaged plants.

Table 21. Proportion of plants damaged by birds – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	**Planting 1**		**Planting 2**	
	Back Transformed	**Transformed**	**Back Transformed**	**Transformed**
Cauliflower Alone - Dursban	**98.46**	**82.86**	**50**	**45**
Cauliflower Alone	**95.85**	**78.25**	**46.54**	**43.02**
4 Carrot	**100**	**90**	**19.85**	**26.46**
8 Carrot	**100**	**90**	**38.38**	**38.28**
2 Lettuce	**63.65**	**52.92**	**23.65**	**29.1**
4 Lettuce	70.12	56.86	**27.98**	**31.93**
4 Birds foot trefoil	**93.3**	**75**	**38.21**	**38.18**
4 Sorrel	89.56	71.14	**29.92**	**33.16**
4 Tarragon	100	90	**32.78**	**34.93**
F- Value		2.09		1.01
P-Values		0.11		0.47
SED		13.69		8.65
5% LSD		29.35		18.56
df		14		14

Proportion of healthy plants

An angular transformation was used to ensure homogeneity between treatments.

For the first planting, the cauliflower drenched with Dursban and the 2-lettuce treatments produced the highest proportion of healthy plants, although there was no overall statistically-significant treatment effect. For the second planting, the cauliflower drenched with Dursban again produced a large proportion of healthy cauliflowers but there was a reduction in the number of healthy plants for the 2-lettuce treatment.

Table 22 Proportion of healthy plants – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1		Planting 2	
	Back Transformed	Transformed	Back Transformed	Transformed
Cauliflower Alone - Dursban	**98.51**	**82.99**	**93.61**	**75.36**
Cauliflower Alone	**89.55**	**71.14**	**87.82**	**69.58**
4 Carrot	**83.39**	**65.95**	**94.4**	**76.31**
8 Carrot	**92.14**	**73.72**	**83**	**65.65**
2 Lettuce	**100**	**90**	**74.12**	**59.42**
4 Lettuce	94.75	76.75	**77.42**	**61.63**
4 Birds foot trefoil	**86.31**	**68.28**	**93.85**	**75.64**
4 Sorrel	93.3	75	**80.01**	**63.44**
4 Tarragon	93.3	75	**82.44**	**65.22**
F- Value		0.63		3.55
P-Values		0.74		0.02
SED		13.15		4.84
5% LSD		28.21		10.37
df		14		14

Trials at Marshalls

Table 23 shows the number of cauliflower plants in each plot with the correct number of companion plants.

Table 23. Number of cauliflower plants with the correct number of companion plants – in field assessment – Marshalls

Treatment	Planting 1				Planting 2			
	No of Companion plants planted	Rep 1	Rep 2	Rep 3	No of Companion plants planted	Rep 1	Rep 2	Rep 3
Cauliflower Alone - Dursban	0	30	30	30	0	30	30	30
Cauliflower Alone	0	30	30	30	0	30	30	30
4 Carrot	4	22	21	16	4	29	21	29
2 Lettuce	2	28	26	19	2	30	22	28
4 Birds foot trefoil	4	10	23	29	4	27	29	30
4 Sorrel	4	15	17	27	4	30	30	30
4 Tarragon	4	19	7	20	4	23	20	30

Proportion of plants damaged by aphids

An angular transformation was used to ensure homogeneity between treatments.

For the first planting, there were insufficient non-zero data for analyses to be carried out using ANOVA. Here total counts are presented instead. Considering the second planting, the insecticide-free cauliflowers without any companions had the greatest aphid damage, although there was no overall statistically-significant treatment effect (Table 24).

Table 24. Proportion of plants damaged by aphids – Marshalls

Treatment	Planting 1	Planting 2	
		Back Transformed	Transformed
Cauliflower Alone - Dursban	0	0.76	4.99
Cauliflower Alone	0	4.41	12.13
4 Carrot	0	0	0
2 Lettuce	0	0.76	4.99
4 Birds foot trefoil	0	0.42	3.7
4 Sorrel	0	0.76	4.99
4 Tarragon	0	0.49	4.01
F- Value			0.65
P-Values			0.69
SED			6.33
5% LSD			13.79
df			12

Proportion of plants damaged by flea beetle

An angular transformation was used to ensure homogeneity between treatments.

For the first planting, the Dursban, insecticide-free control and 4-carrot treatments had less damage that the tarragon treatment, which in turn was less damaged than the 2-lettuce, sorrel and birds foot trefoil treatments. Almost all cauliflowers grown with birds foot trefoil had some damage (Table 25).

For the second planting, there were no significant differences of interest.

Table 25 Proportion of plants damaged by flea beetle – Marshalls

Treatment	Planting 1		Planting 2	
	Back Transformed	Transformed	Back Transformed	Transformed
Cauliflower Alone - Dursban	32.91	35.01	91.18	72.72
Cauliflower Alone	35.55	36.6	91.66	73.21
4 Carrot	40.28	39.4	86.63	68.56
2 Lettuce	76.7	61.14	70.73	57.25
4 Birds foot trefoil	95.19	77.33	80.73	63.96
4 Sorrel	94.1	75.95	81.55	64.56
4 Tarragon	58.93	50.15	97.43	80.78
F- Value		5.8		1.1
P-Values		0.01		0.42
SED		10.63		10.33
5% LSD		23.16		22.51
df		12		12

Proportion of plants damaged by birds

An angular transformation was used to ensure homogeneity between treatments.

For the first planting, there were no significant differences between any of the treatments. For the second planting, the cauliflower with 2 lettuce treatment was less damaged than all other treatments although there was no overall statistically-significant treatment effect (Table 26).

Table 26. Proportion of plants damaged by birds – in field assessments – Marshalls

Treatment	Planting 1		Planting 2	
	Back Transformed	Transformed	Back Transformed	Transformed
Cauliflower Alone - Dursban	96.31	78.93	37.52	37.78
Cauliflower Alone	91.93	73.49	53.39	46.94
4 Carrot	92.22	73.8	55.51	48.16
2 Lettuce	99.57	86.23	15.25	22.99
4 Birds foot trefoil	100	90	28.89	32.51
4 Sorrel	100	90	34.65	36.06
4 Tarragon	100	90	50.22	45.12
F- Value		0.8		0.79
P-Values		0.59		0.6
SED		12.05		14.4
5% LSD		26.25		31.37
df		12		12

Proportion of healthy plants

Angular transformations were used to ensure homogeneity between treatments.

There were no overall statistically-significant treatment effects for either planting. For the first planting, there was little difference between the treatments, with a large proportion of healthy plants.

For the second planting, the cauliflowers with no companions had larger means than all other treatments (Table 27).

Table 27. Proportion of healthy plants - Marshalls

Treatment	Planting 1		Planting 2	
	Back Transformed	Transformed	Back Transformed	Transformed
Cauliflower Alone - Dursban	99.63	86.49	98.51	82.99
Cauliflower Alone	99.24	85.01	98.51	82.99
4 Carrot	93.41	75.12	91.45	73
2 Lettuce	97.5	80.9	82.92	65.59
4 Birds foot trefoil	100	90	84.19	66.57
4 Sorrel	100	90	94.72	76.72
4 Tarragon	100	90	94.42	76.34
F- Value		1.94		2.22
P-Values		0.16		0.11
SED		5.72		6.67
5% LSD		12.47		14.53
df		12		12

<u>Harvest Assessments</u>

Trials at Elsoms

Table 28 shows the number of cauliflowers within each plot which had the correct number of companion plants at harvest. Some plots had a very small number of cauliflowers with the correct number of companion plants.

Table 28 Cauliflowers with the correct number of companion plants at harvest – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1				Planting 2			
	No of Companion plants planted	Rep 1	Rep 2	Rep 3	No of Companion plants planted	Rep 1	Rep 2	Rep 3
Cauliflower Alone - Dursban	0	**30**	**30**	**30**	0	**30**	**30**	**30**
Cauliflower Alone	0	**30**	**30**	**30**	0	**30**	**30**	**30**
4 Carrot	4	**9**	**10**	**12**	4	**19**	**24**	**23**
8 Carrot	8	0	3	3	8	6	11	10
2 Lettuce	2	**13**	**13**	**13**	2	**23**	**22**	**24**
4 Lettuce	4	4	5	2	4	5	0	4
4 Birds foot trefoil	4	**18**	**15**	**24**	4	**23**	**26**	**28**
4 Sorrel	4	4	4	9	4	**13**	**16**	**17**
4 Tarragon	4	5	4	7	4	**11**	**23**	**23**

Curd diameter

No transformations were required in the analysis. There were no overall statistically-significant differences for the first planting, although the mean curd diameter of plants grown with 8 carrots was smaller than the Dursban treatment (Table 29). For the second planting, the cauliflowers with 2 lettuce and 4 tarragon had a mean curd diameter that was significantly smaller than the Dursban treatment.

Table 29. Mean curd diameter (cm) – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	Planting 1	Planting 2
Cauliflower Alone - Dursban	**11.23**	**12.81**
Cauliflower Alone	**9.99**	**12.81**
4 Carrot	**11.31**	**12.87**
8 Carrot	7.33 D	11.41
2 Lettuce	**11.43**	**9.64 D**
4 Lettuce	10.22	13.41
4 Birds foot trefoil	**10.79**	**13.03**
4 Sorrel	11.31	**13.29**
4 Tarragon	9.83	**10.31 D**
F- Value	1.68	6.32
P-Values	0.195	<.001
SED	1.417	0.541
5% LSD	3.06	1.168
df	13	13

Proportion Class 1 curds

An angular transformation was used to ensure homogeneity between treatments. The results are summarised in Table 30. There was no overall treatment effect for Planting 1. In Planting 2 there were fewer Class 1 curds in the plots with 4 lettuce companions than in the plots treated with Dursban.

Table 30 Proportion of Class 1 curds – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	**Planting 1**		**Planting 2**	
	Back Transformed	**Transformed**	**Back Transformed**	**Transformed**
Cauliflower Alone - Dursban	**85.47**	**67.6**	**98.46**	**82.87**
Cauliflower Alone	**52.77**	**46.59**	**96.14**	**78.67**
4 Carrot	**90.42**	**71.97**	**97.75**	**81.38**
8 Carrot	59.98	50.76	96.98	80
2 Lettuce	**90.47**	**72.02**	**88.28**	**69.98**
4 Lettuce	72.04	58.08	72.55	58.41 D
4 Birds foot trefoil	**75.04**	**60.03**	**100**	**90**
4 Sorrel	57.94	49.57	**98.96**	**84.15**
4 Tarragon	61.31	51.54	**100**	**90**
F- Value		0.62		3.16
P-Values		0.746		0.032
SED		17.7		7.92
5% LSD		38.23		17.1
df		14		13

Analyses were also carried out on the estimated date of maturity of the cauliflowers. Results are not presented as there were no significant differences of interest.

Trials at Marshalls

Table 31 shows the number of cauliflowers with the correct number of companions when harvested.

Table 31 Cauliflowers with the correct number of companion plants at harvest – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1				Planting 2			
	No of Companion plants planted	Rep 1	Rep 2	Rep 3	No of Companion plants planted	Rep 1	Rep 2	Rep 3
Cauliflower Alone - Dursban	0	**30**	**30**	**30**	0	**30**	**30**	**30**
Cauliflower Alone	0	**30**	**30**	**30**	0	**30**	**30**	**30**
4 Carrot	4	12	12	3	4	**25**	**26**	**29**
2 Lettuce	2	7	12	9	2	0	11	0
4 Birds foot trefoil	4	**3**	**16**	**19**	4	**29**	**22**	**25**
4 Sorrel	4	7	9	9	4	**30**	**29**	**30**
4 Tarragon	4	4	2	6	4	**24**	**27**	**29**

Curd diameter

No transformation of the data was necessary. There were no statistically-significant differences between treatments (Table 32).

Table 32. Mean curd diameter (cm) – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold).

Treatment	Planting 1	Planting 2
Cauliflower Alone - Dursban	**12.85**	**12.76**
Cauliflower Alone	**12.82**	**12.77**
4 Carrot	10.88	**12.74**
2 Lettuce	13.18	12.28
4 Birds foot trefoil	**12.82**	**12.8**
4 Sorrel	12.4	**12.58**
4 Tarragon	11.64	**13.13**
F- Value	2.89	2.05
P-Values	0.06	0.15
SED	0.68	0.26
5% LSD	1.49	0.57
df	12	10

Proportion Class 1 curds

Angular transformations were used to ensure homogeneity between treatments.

There was no overall statistically-significant effect for Planting 2 (Table 33). Cauliflowers grown with tarragon yielded less Class 1 curds than those treated with Dursban.

Table 33. Proportion Class 1 curds – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Planting 1		Planting 2	
	Back Transformed	Transformed	Back Transformed	Transformed
Cauliflower Alone - Dursban	**94.99**	**77.07**	**100.00**	**90.00**
Cauliflower Alone	**94.68**	**76.67**	**95.59**	**77.87**
4 Carrot	68.91	56.11	**100.00**	**90.00**
2 Lettuce	98.95	84.13	95.08	77.19
4 Birds foot trefoil	**99.13**	**84.65**	**98.34**	**82.60**
4 Sorrel	78.30	62.24	99.63	**86.49**
4 Tarragon	63.41	52.78 D	90.61	**72.16 D**
F- Value		3.51		2.63
P-Values		0.03		0.09
SED		10.01		6.01
5% LSD		21.81		13.40
df		10		10

<u>Trial 3</u>

Module 'quality' at planting

For Trial 3, an assessment was made of the number of modules with 0-10 companion plants in a 40-plant sample from each tray with companion plants and the average weight of the cauliflower plants and companion plants (Figure 11).

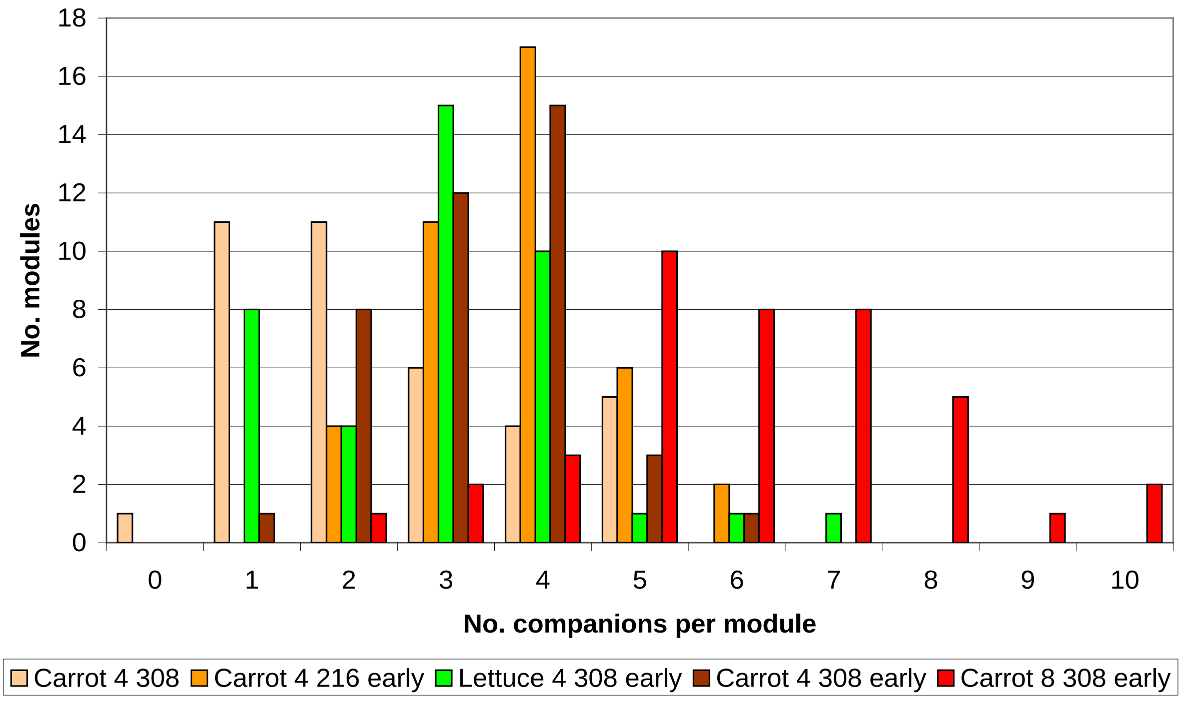

Figure 11. Trial 3 - the number of modules with 0-10 companion plants in a 40-plant sample from each tray

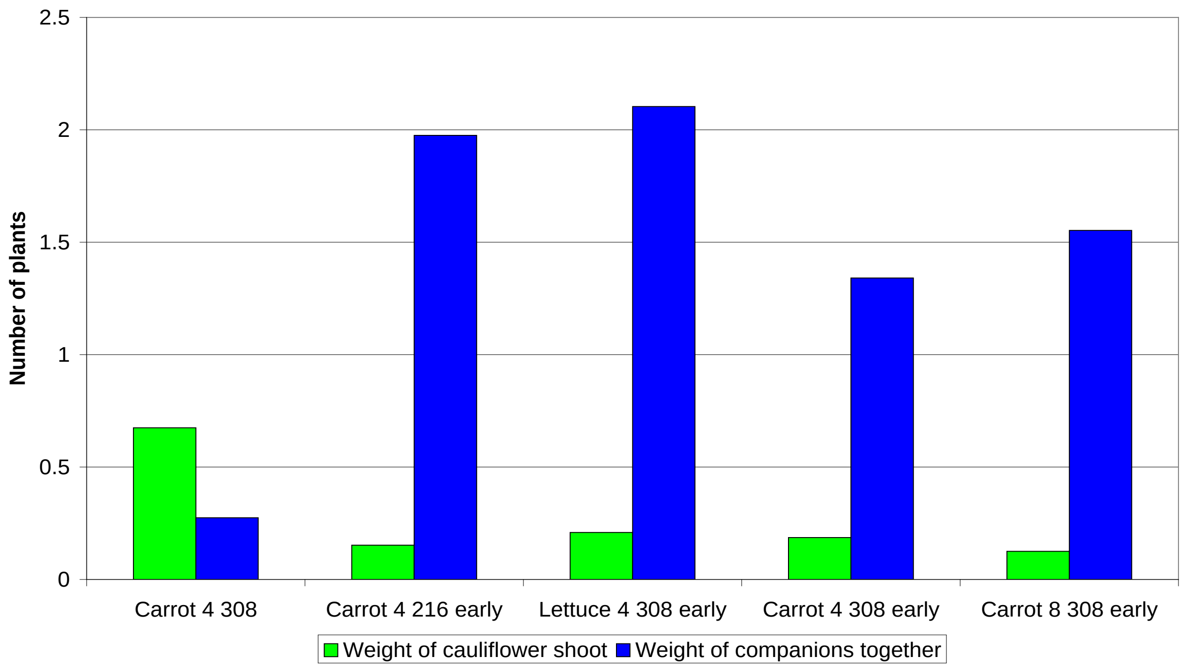

Figure 12. Trial 3 - the average weights of cauliflower plants and companion plants in a 40-plant sample from each tray

Assessments after one CRF generation - Elsoms

Table 34 shows the number of cauliflowers in each replicate of each treatment with the correct numbers of companion plants. Where only a small number of correct companions are observed, means presented should be treated with caution.

Table 34. The number of cauliflower plants with the correct number of companion plants (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	**No of Companion plants planted**	**Replicate**		
		1	**2**	**3**
Cauliflower Alone - Dursban	0	**30**	**30**	**30**
Cauliflower Alone	0	**30**	**30**	**30**
4 carrot	4	4	6	8
4 carrot sown early	4	5	5	13
4 lettuce	4	5	4	8
4 lettuce sown early	4	1	0	2

Cauliflower and companion plant weights

Natural log transformations were used to ensure homogeneity of variance between the treatments for all analyses of weights.

The treatment factor was significant in all analyses. For the cauliflower plant weights, the cauliflowers planted alone had the largest means (Table 35).

Considering the companion plant weights; the lettuce companions were heavier than the carrot companions. There was also an indication that the companion plants sown early were heavier than those sown later, although none of these differences were significant.

Table 35. The mean weight of cauliflower and companion plants after one generation of CRF – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	**Cauliflower plant weight**		**Companion plant weight**	
	Back transformed	**Transformed**	**Back transformed**	**Transformed**
Cauliflower Alone - Dursban	**304.800**	**5.720**	*	*
Cauliflower Alone	**332.800**	**5.808**	*	*
4 carrot	187.500	5.234	5.580	1.719
4 carrot sown early	126.500	4.840	6.680	1.900
4 lettuce	223.500	5.410	36.150	3.588
4 lettuce sown early	63.800	4.156 D	60.110	4.096
F - Value		4.250		43.200
P - Value		**0.029**		**<.001**
SED		0.423		0.257
5% LSD		0.958		0.608
df		9		7

Root and stem damage scores

A natural log transformation was used to ensure homogeneity of variance between the treatments for the root weight analyses. The results are summarised in Table 36.

Table 36. The root and stem damage scores and root weights after one generation of CRF – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	**Root damage score**	**Stem damage score**	**Root weight (g)**	
			Back transformed	**Transformed**
Cauliflower Alone - Dursban	**2.790**	**3.030**	**17.290**	**2.850**
Cauliflower Alone	**1.740**	**2.460**	**26.010**	**3.259**
4 carrot	1.550	2.450	12.830	2.552
4 carrot sown early	2.600	2.190	7.000	1.946
4 lettuce	2.620	2.670	12.460	2.522
4 lettuce sown early	4.250	2.190	3.930	1.369
F - Value	5.880	1.320		5.640
P - Value	**0.011**	0.338		**0.013**
SED	0.559	0.393		0.399
5% LSD	1.264	0.889		0.903
df	9	9		9

Trial at Marshalls

Four treatments were included within the analyses. Table 37 shows how many cauliflower plants had the correct numbers of companion plants. None of the cauliflowers sown with 8 companion plants had the correct numbers of companions.

Table 37. The number of cauliflower plants with the correct number of companion plants – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	No of Companion plants planted	Replicate		
		1	2	3
Cauliflower Alone - Dursban	0	**30**	**30**	**29**
Cauliflower Alone	0	**30**	**30**	**30**
4 carrot	4	**15**	**7**	**12**
4 carrot sown early	4	0	0	0

Weight of cauliflower plants

A natural log transformation was used for the cauliflower plant weights to ensure homogeneity of variance between treatments.

The largest means were for the cauliflowers without any companion plants. No formal analyses were carried out on the companion plant weights due to a lack of data.

Table 37. Mean weight of cauliflower plants after one generation of CRF – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	Back transformed	Transformed
Cauliflower Alone - Dursban	**58.07**	**4.062**
Cauliflower Alone	**51.17**	**3.935**
4 carrot	**25.77**	**3.249 D**
4 carrot sown early	*	*
F - Value		11.66
P - Value		0.009
SED		0.1811
5% LSD		0.443
df		6

Root and stem damage scores and root weight

A natural log transformation was used to ensure homogeneity of variance between the treatments for the root weight analyses.

There were no overall treatment effects for damage. The roots from the plants treated with Dursban were heavier than those grown with 4 carrots (Table 38).

Table 38. The root and stem damage scores and root weights after one generation of CRF – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold). N.B. D = treatment 'worse' than Dursban treatment; U = treatment 'better' than insecticide-free control (cauliflower alone)

Treatment	Root damage score	Stem damage score	Root weight (g)	
			Back transformed	Transformed
Cauliflower Alone - Dursban	**1.890**	**2.750**	**3.773**	**1.328**
Cauliflower Alone	**1.060**	**2.856**	**3.255**	**1.180**
4 carrot	**0.840**	**2.856**	**2.100**	**0.742 D**
4 carrot sown early	*	*	*	*
F - Value	1.040	0.240		6.830
P - Value	0.410	0.795		0.028
SED	0.766	0.263		0.165
5% LSD	1.875	0.645		0.404
df	6	7		6

<u>After one generation of CRF - assessments in the field</u>

Trials at Elsoms

Table 39 shows how many of the cauliflower plants in each plot had the correct number of companion plants. Each plot contained 30 cauliflower plants.

Table 39. Number of cauliflowers with the correct number of companion plants – Elsoms

Treatment	No of Companion plants planted	Rep 1	Rep 2	Rep 3
Cauliflower Alone	0	30	30	30
Cauliflower Alone - Dursban	0	30	30	30
4 carrot	4	30	30	30
4 carrot sown early	4	30	-	28
4 lettuce	4	23	30	29
4 lettuce sown early	4	29	29	30

Proportion of plants with aphid damage

An angular transformation was used to ensure homogeneity between treatments.

There were too few data for formal assessment using ANOVA. Treatment means are presented instead (Table 40).

Table 40. Proportion of plants damaged by aphids – Elsoms

Cauliflower Alone - Dursban	1.11
4 Carrot	4.44
4 Carrot sown early	1.67
4 lettuce	10.06
4 lettuce sown early	1.11

Proportion of plants damaged by flea beetle

An angular transformation was used to ensure homogeneity between treatments. There were insufficient data for formal analysis; the treatment means are presented instead (Table 41).

Table 41. Proportion of plants damaged by flea beetle - Elsoms

Cauliflower Alone	2.22
Cauliflower Alone - Dursban	0.00
4 Carrot	12.22
4 Carrot sown early	11.67
4 lettuce	0.00
4 lettuce sown early	0.00

Proportion of plants damaged by birds

An angular transformation was used to ensure homogeneity between treatments. For the third planting, the plots without companion plants had the least damage due to birds (Table 42).

Table 42. Proportion of plants damaged by birds (Elsoms)

Treatment	Back Transformed	Transformed
Cauliflower Alone	5.18	13.16
Cauliflower Alone - Dursban	0.37	3.51
4 Carrot	13.21	21.32
4 Carrot sown early	37.78	37.93
4 lettuce	20.74	27.09
4 lettuce sown early	31.21	33.96
F- Value		14.85
P-Values		<.001
SED		4.75
5% LSD		11.24
df		7.00

Proportion of healthy plants

An angular transformation was used to ensure homogeneity between treatments.

The cauliflower plants with no companions produced the highest proportion of healthy plants (Table 43).

Table 43. Proportion of healthy plants - Elsoms

Treatment	Back Transformed	Transformed
Cauliflower Alone	94.02	75.85
Cauliflower Alone - Dursban	100.00	90.00
4 Carrot	82.75	65.46
4 Carrot sown early	74.92	59.95
4 lettuce	82.72	65.44
4 lettuce sown early	44.07	41.59
F- Value		72.89
P-Values		<.001
SED		2.68
5% LSD		6.33
df		7.00

Trials at Marshalls

Table 44 shows the number of cauliflower plants in each plot with the correct number of companion plants.

Table 44. Number of cauliflower plants with the correct number of companion plants – in field assessment – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	No of Companion plants planted	Planting 3		
		Rep 1	Rep 2	Rep 3
Cauliflower Alone - Dursban	0	**30**	**30**	**30**
Cauliflower Alone	0	**30**	**30**	**30**
4 carrot	4	**28**	**16**	**25**
4 carrot sown early	8	**24**	**0**	**10**
4 lettuce	4	0	12	0
4 lettuce sown early	4	29	0	0

Proportion of plants damaged by aphids

There was little aphid damage.

Proportion of plants damaged by flea beetle

An angular transformation was used to ensure homogeneity between treatments. There were no significant differences (Table 45).

Table 45. Proportion of plants damaged by flea beetle – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Back Transformed	Transformed
Cauliflower Alone - Dursban	**87.82**	**69.57**
Cauliflower Alone	**92.74**	**74.36**
4 carrot	**100.00**	**90.00**
8 carrot sown early	**97.56**	**81.01**
4 lettuce sown early	100.00	89.97
4 carrot sown early	100.00	89.97
F- Value		0.81
P-Values		0.58
SED		14.14
5% LSD		33.44
df		7

Proportion of plants damaged by birds

An angular transformation was used to ensure homogeneity between treatments. There were no significant differences between treatments and very few cauliflowers suffered damage due to birds (Table 46).

Table 46. Proportion of plants damaged by birds – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Back Transformed	Transformed
Cauliflower Alone - Dursban	**1.15**	**6.15**
Cauliflower Alone	**2.46**	**9.02**
4 carrot	**0.49**	**4.01**
8 carrot sown early	**2.44**	**8.99**
4 lettuce sown early	0.00	0.03
4 carrot sown early	0.00	0.03
F- Value		0.36
P-Values		0.86
SED		9.62
5% LSD		22.76
df		7

Proportion healthy plants

Angular transformations were used to ensure homogeneity between treatments.

The cauliflower plants with no companions and drenched with Dursban had a larger proportion of healthy plants than all other treatments (Table 47). The 'Cauliflower Alone' and 4 carrot treatments also had large proportions relative to the other treatments within the trial.

Table 47. Proportion of healthy plants – Marshalls (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Transformed	Back Transformed
Cauliflower Alone - Dursban	**98.46**	**82.86**
Cauliflower Alone	**88.83**	**70.48**
4 carrot	**85.30**	**67.45**
8 carrot sown early	**69.48**	**56.47**
4 lettuce sown early	16.70	24.12
4 carrot sown early	47.85	43.77
F- Value		12.84
P-Values		<.001
SED		8.30
5% LSD		19.64
df		7

Harvest Assessments

Trials at Elsoms

Table 47 shows the number of cauliflowers within each plot which had the correct number of companion plants at harvest. Some plots had a very small number of cauliflowers with the correct number of companion plants.

Table 47 Cauliflowers with the correct number of companion plants at harvest – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	No of Companion plants planted	Planting 3		
		Rep 1	Rep 2	Rep 3
Cauliflower Alone - Dursban	0	**30**	**30**	**30**
Cauliflower Alone	0	**30**	**30**	**30**
4 Carrot	4	10	10	0
4 Carrot sown early	4	**22**	**10**	**8**
4 lettuce	4	3	4	20
4 lettuce sown early	4	6	5	7

Curd diameter

No transformations were required in the analysis. There were no statistically significant differences between treatments (Table 48).

Table 48. Mean curd diameter (cm) – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Cauliflower Alone - Dursban	**13.11**
Cauliflower Alone	**12.73**
4 Carrot	10.91
4 Carrot sown early	**12.52**
4 lettuce	11.48
4 lettuce sown early	11.16
F- Value	2.33
P-Values	0.166
SED	0.848
5% LSD	2.075
df	6

Proportion Class 1 curds

An angular transformation is used to ensure homogeneity between treatments. There were smaller proportions of class 1 cauliflowers for the lettuce companion plants (Table 49).

Table 49 Proportion of Class 1 curds – Elsoms (the treatments with a mean of 10 or more plants with the correct number of companion plants are shown in bold)

Treatment	Back Transformed	Transformed
Cauliflower Alone - Dursban	99.24	**85.01**
Cauliflower Alone	91.8	**73.36**
4 Carrot	65.97	54.31
4 Carrot sown early	99.29	**85.17**
4 lettuce	89.29	70.9
4 lettuce sown early	85.02	67.23
F- Value		1.81
P-Values		0.245
SED		12.24
5% LSD		29.95
df		6

Analyses were also carried out on the estimated date of maturity of the cauliflowers. Results are not presented as there were no significant differences of interest.

Trials at Marshalls

No analyses were carried out for the third planting because the curds did not mature.

Objective 6

Objective 6 *Determine how the companion plant system developed for CRF control affects 1) other pest insects and 2) levels of pest predation and parasitism compared with 'bare soil' crops.*

The aim of field experiments done at Wellesbourne in 2008 was to determine the effect of the presence of companion plants on survival of brassica pests compared with 'bare soil' crops. These experiments used lettuce as a companion plant – four per cell and grown in 216 module trays.

The pest species investigated were CRF, cabbage aphid, diamond-back moth and large white butterfly. In some experiments potted plants were infested in the laboratory and then planted into a 'background' plot of either cauliflowers or cauliflowers with lettuce companions (Figures 13 and 14). In others, the plants in field plots were infested directly. Pest survival was assessed over appropriate periods of time. All insects were obtained from the cultures maintained at Warwick HRI, Wellesbourne.

Most of this work was done in August and September and the very heavy rainfall did not have a positive effect on the experimental material. Experiments on cabbage aphid (*Brevicoryne brassicae*) were washed out.

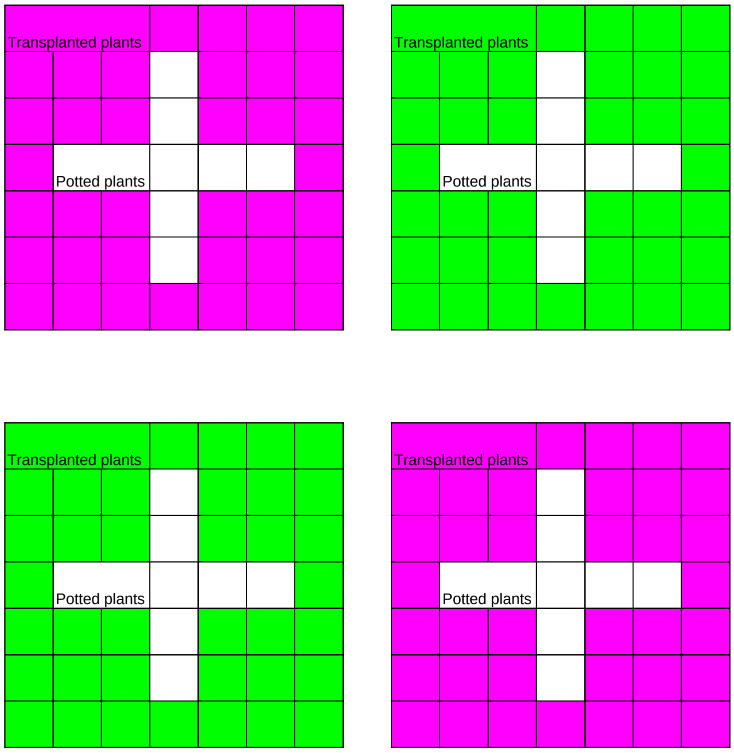

Figure 13. Plan of field plots to study pest insect survival. Potted test plants were planted into the 'cross' in the centre of each plot

Figure 14. One of the field plots at Wellesbourne – with potted plants added

*Survival of diamond-back moth (*Plutella xylostella*) larvae*

Newly-hatched diamond-back moth larvae were placed onto potted plants (with or without lettuce companion plants) at a rate of 20 larvae per plant. The plants were planted into the 'background' plots and left for 4-6 days. They were then taken back to the laboratory where the numbers of larvae remaining were recorded. On each occasion there were two replicate plots and 9 inoculated potted plants per plot.

The results are summarized in Figure 15. Although the numbers of larvae recovered varied between experiments, there was little difference between the two treatments.

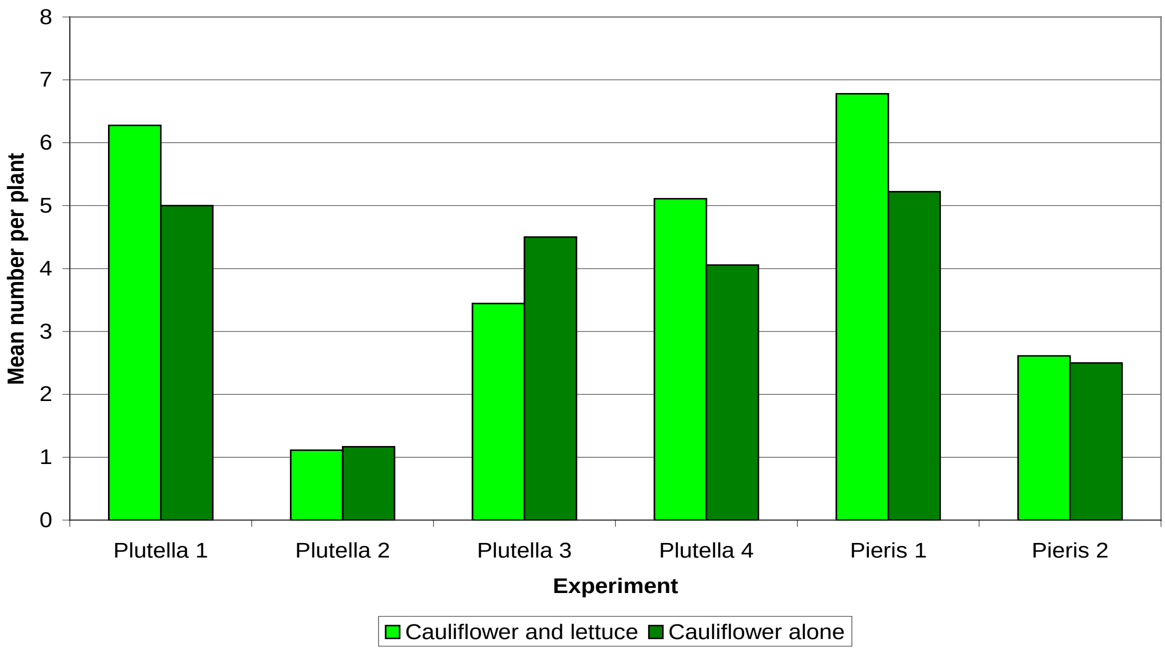

Figure 15. The mean number of newly-hatched diamond-back moth or large white butterfly larvae remaining per plant (inoculated with 20 per plant)

*Survival of large white butterfly (*Pieris brassicae*) larvae*

Newly-hatched larvae were placed onto potted plants (with or without lettuce companion plants) at a rate of 20 larvae per plant. The plants were planted into the field plots and left for 4-6 days. They were then taken back to the laboratory where the numbers of larvae remaining were recorded. On each occasion there were two replicate plots and 9 inoculated potted plants per plot. The results are summarized in Figure 15. Although the numbers of larvae recovered varied between experiments, there was little difference between the two treatments.

In addition, marked plants within the experimental plots were infested with larger larvae from the culture, equal numbers per plot and in similar locations in each plot, and their numbers were recorded at intervals. The results are summarized in Figure 16.

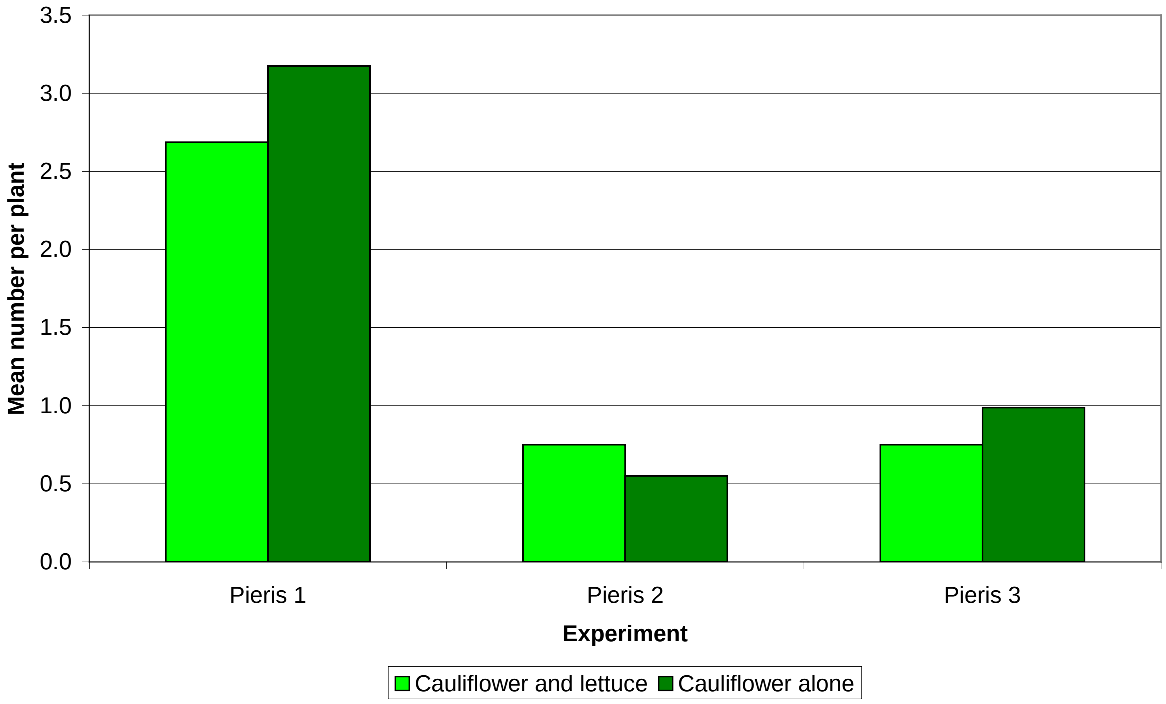

Figure 16. The mean number of large white butterfly larvae and pupae remaining per plant

*Survival of CRF (*Delia radicum*) eggs and larvae*

Eggs

Twenty newly-laid CRF eggs from the culture maintained at Wellesbourne were placed just beneath the soil surface and close to the base of the stem of a potted brassica plant that had wither been grown in a module on its own or with four lettuce companions.

The plants were potted in compost in square plastic pots and then a layer of sand followed by a layer of sieved soil was added to the surface of the pot There were also a number of un-inoculated control plants of each type to take account of background levels of egg laying by 'wild' CRF. The plants were planted in the plots for 2 days and then taken back to the laboratory where the numbers of eggs remaining were recorded. This was done by rinsing the upper layer of soil into a container and counting the eggs that floated subsequently. On each occasion there were two replicate plots and five inoculated potted plants and four control plants per plot. The results are summarised in Figure 17. Although the numbers of eggs recovered varied between experiments, there was little difference between the two treatments.

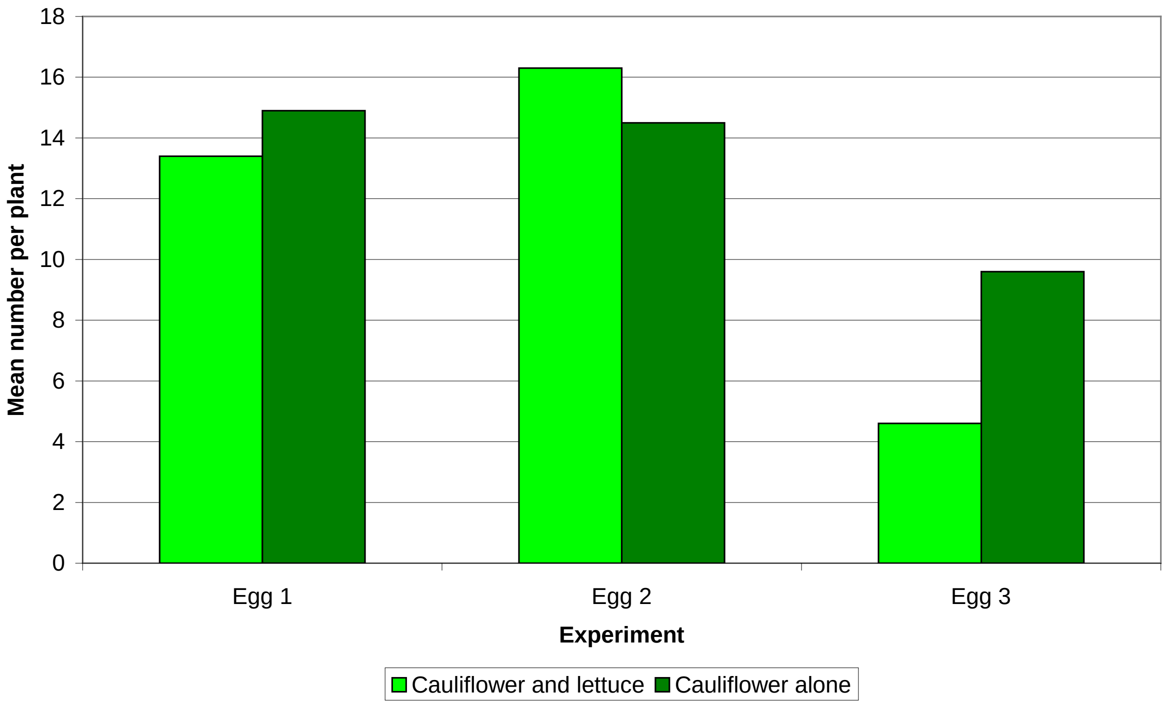

Figure 17. The mean number of CRF eggs remaining per plant (inoculated with 20 per plant)

Larvae

In this experiment, potted plants of cauliflower, with or without lettuce companion plants, were inoculated with 20 newly-laid CRF eggs and placed in trays in an illuminated controlled environment room at 20°C for one week, after which they were planted in the field plots as described above. On each occasion there were two replicate plots and 9 inoculated pots per plot. Some un-inoculated plants (3 per plot) were also planted in the plots at the same time to record infestation by the 'wild' population of CRF. The duration of development to the pupal stage was estimated (250 day-degrees above 6°C) and then the pots were removed from the plots and taken back to the laboratory where the larvae and pupae were extracted by washing, sieving and flotation. The results are summarized in Figure 18. Although the numbers of larvae and pupae recovered varied between experiments, there was little difference between the two treatments.

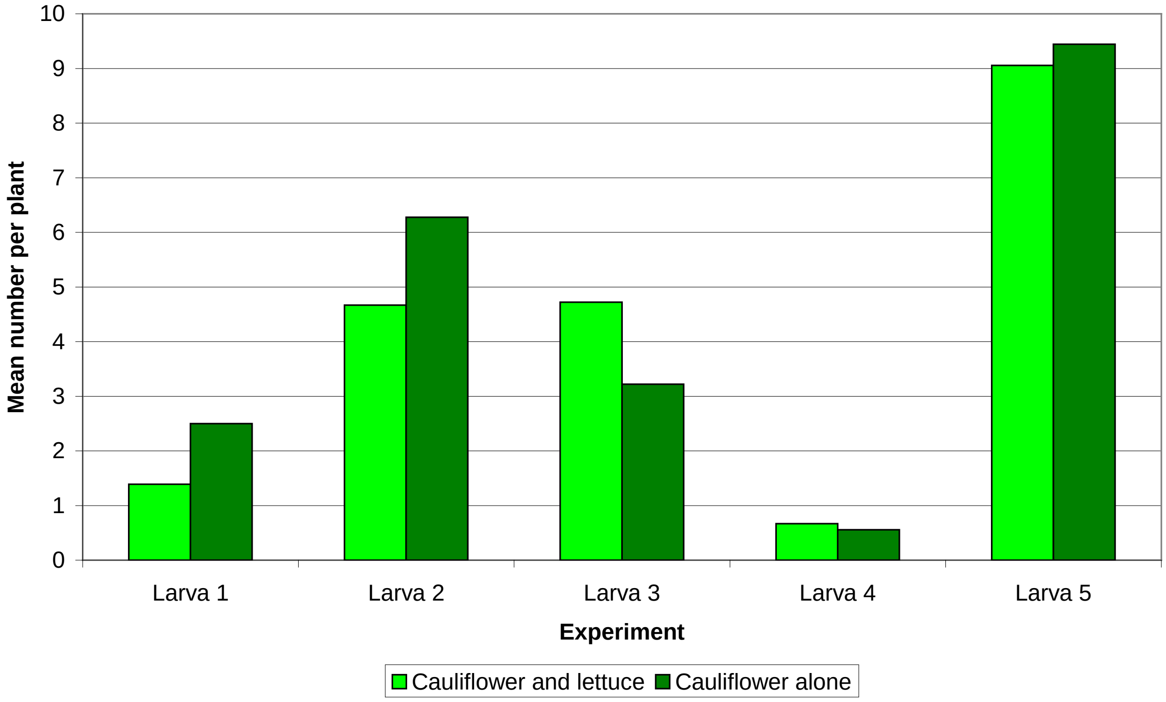

Figure 18. The mean number of CRF larvae and pupae remaining per plant (inoculated with 20 per plant)

TECHNOLOGY TRANSFER

The project was described in article for HDC News in spring 2009.

ACKNOWLEDGEMENTS

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Project objectives

1. Determine how the height, leaf area, proximity and spatial arrangement of the companion plants affects host plant selection and egg laying by female cabbage root flies on brassicas.

2. Determine how the leaf shape of the companion plants affects host plant selection and egg laying by female cabbage root flies on brassicas.

3. Identify companion plant species that would reduce CRF egg laying to the desired level.

4. Determine the parameter values of these species and the associated brassica plants for a growth and competition model to allow the companion species to be identified that would compete least with the brassicas.

5. Develop and refine robust systems for growing brassicas and companion plants together, so that the negative effects of competition are offset by the positive effects of reduced pest numbers.

6. Determine how the companion plant system developed for CRF control affects 1) other pest insects and 2) levels of pest predation and parasitism compared with 'bare soil' crops.

Project milestones

Milestone	**Date**	**Description**
Year 1		
1.1	**17 Feb 06**	**Effects of companion plant size and position on CRF determined**
2.1	**1 Mar 06**	**Effects of leaf structure on CRF determined**
3.1	**31 May 06**	**Up to 10 possible companion species identified for growth trials**
Year 2		
4.1	**25 Oct 06**	**Plant growth characteristics determined in trials**
4.2	**6 Dec 06**	**Competition model re-parameterised**
4.3	**14 Feb 07**	**Scenarios tested using competition model**
5.1	**28 Feb 07**	**Up to 15 companion plant treatments identified for trials in 2007**
Year 3		
6.1	**18 Dec 07**	**Effects of 'optimum' companion plants on other pests determined**
5.2	**31 Jan 08**	**Up to 5 companion plant treatments identified for trials in 2008**
Year 4		
6.2	**18 Dec 08**	**Effects of companion plants on predation/parasitism determined**
5.3	**31 Jan 09**	**Up to 2 companion plant treatments identified for trials in 2009**
Year 5		
5.4	**18 Dec 09**	**Performance of final companion plant system(s) vs CRF evaluated**
6.3	**18 Dec 09**	**Effects of final system(s) on other insects determined**
5.5	**31 Dec 09**	**Final report submitted**