ANNUAL REPORT

To:
Horticultural Development Council
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Brassica: companion planting for pest control

HortLINK project HL0174
HDC Project FV 251

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December 2006

Commercial - In Confidence

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.

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Project Leader:	Rosemary Collier Warwick HRI, Wellesbourne, Warwick CV35 9EF
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Project co-ordinators:	Mel Miles (Project co-ordinator)
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Signed on behalf of: Warwick HRI

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The University of Warwick

Grower Summary

Brassica: companion planting for pest control

HortLINK project HL0174
HDC Project FV 251

Annual Report 2006

GROWER SUMMARY

Headline

An ‘ideal’ companion plant should be ‘green’, situated close to the plant it is protecting and it should have a certain leaf area and vertical distribution of leaves relative to the crop plant.

A number of companion plants show promise and are undergoing further investigation.

Background and expected deliverables

UK brassica crops currently occupy about 32,000 ha, with an annual marketed value of about £160M. Cabbage root fly and aphids are some of their most important pests. Three insecticides are approved currently for control of cabbage root fly on leafy brassica crops. They are chlorpyrifos (organophosphorus insecticide (OP)) and carbosulfan (carbamate) 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 cabbage root fly 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, 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 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 the cabbage root fly 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.

The aim of this project is to use companion plants instead of insecticides for controlling the cabbage root fly 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

Laboratory tests confirmed that companion plants made from green card reduce the numbers of eggs laid by female cabbage root flies on cauliflower plants. Although the companion plant leaf area, the vertical distribution of companion plant leaves and the proximity of the companion plants were critical, leaf size and shape were not. The size of the reduction in egg laying varied from one experiment to another and is likely to be determined by the ‘effectiveness’ of each treatment and also by the effectiveness of the other treatments with which it was presented – as these were essentially 'choice' tests. The information from this study, backed up by data from other studies, indicates that an 'ideal' companion plant should be green, situated close to the plant it is protecting and that it should have a certain leaf area and leaf distribution relative to the crop plant. It appears from the tests reported here that neither the size nor the shape of individual leaves is critical.

Sixteen potential companion plants were selected on this basis. These were mainly edible plants and all are readily available as seed at a reasonable price. Cauliflower plants were grown in modules with either 1, 2 or 4 companion plants of the 16 different types (species and varieties). The modules were transplanted into unreplicated plots in three locations, two of which were irrigated. Assessments of plant growth were made at transplanting, approximately 6 weeks after transplanting and at maturity. Many of the plants at the non-irrigated site died and data collection was limited. Survival was good at the two other sites. Some of the companion plants were extremely competitive and would not be suitable for a commercial situation. However, other species were less competitive and appeared to have little effect on maturity date and yield.

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 the cabbage root fly
- 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.
- The other 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.
- If shown to be effective, then 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 first year of a four-year project to use companion plants for controlling the cabbage root fly in conventional (ICM) production of leafy brassica crops. They have shown that:
    - ‘green’ companion plants reduce egg-laying on cauliflower by female cabbage root flies.
    - 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.

- Further work is required to refine the technique under field conditions and verify that companion plants are effective in this situation.

SCIENCE SECTION

Introduction

UK brassica crops currently occupy about 32,000 ha, with an annual marketed value of about £160M (Defra Basic Horticultural Statistics). Cabbage root fly and aphids are some of their most important pests. Three insecticides are approved currently for control of cabbage root fly on leafy brassica crops. They are chlorpyrifos (organophosphorus insecticide (OP)) and carbosulfan (carbamate) 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 cabbage root fly 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 cabbage root fly 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 cabbage root fly 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 four objectives addressed during this reporting period are:

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 cabbage root fly 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.

Experimental

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.

The information obtained in Objectives 1 and 2 will provide a more detailed understanding of the behaviour of insects on plants, so that informed decisions can be made concerning the selection of effective species as the test companion plants for use in Objective 3 and beyond. The experiments were done using artificial companion plants, so that the effects of companion plant size and shape could be determined.

Companion plant leaves were constructed from green card. For the initial experiments on leaf area and leaf size, a 'standard' leaf was a disk of green card of a pre-determined diameter. A short strip of green twist tie was glued to each leaf and used to attach the leaf to a 'stem', which consisted of a carnation cane painted black. Each leaf was fixed to the stem using clear sticky tape. The companion plants were 'constructed' by inserting the appropriate number of canes into a pot containing a young cauliflower plant, which provided an oviposition site for female cabbage root flies.

Experiments were done to determine the effect of the following companion plant characteristics on egg laying by female cabbage root flies:

- Leaf size
- Leaf height
- Leaf area
- Leaf shape
- Proximity of companion plant to cauliflower plant

Each experiment was done in a 'rotating' cage at Warwick HRI, Wellesbourne (Figure 1), using adult cabbage root flies from the Warwick HRI culture and potted cauliflower plants (cv Jerez) that had been grown in a greenhouse.

The rotating cage was a wooden-framed test chamber with two equal sized compartments (160 x 160 x 63 cm high) arranged one above the other. Each compartment contained a 145 cm diameter turntable, which rotated once every 4 minutes. As the adult cabbage root fly is positively phototactic, the rotation ensured that everything placed on the turntables was exposed equally to the insects, which tended to aggregate near the fluorescent lights used to illuminate the test chamber.

Figure 1 Rotating cage showing the two compartments into which cabbage root flies are released.

Each turntable had space for four custom-made trays. Each of these was segment –shaped and covered one quarter of the turntable. For these experiments the trays were filled to the top with sieved soil and a single empty plant pot (9 x 9 cm) was inserted into the centre of each tray to hold a pot containing a cauliflower plant and its associated companion plants. The soil was then spread over the surface of the pots so that the plants were presented in a bare soil background, as they would be in the field.

Most of the experiments consisted of more than four treatments and so it was not possible to present all the treatments together in a single cage. Consequently, a randomised balanced incomplete block design was used for some of the experiments, so that each treatment was replicated the same number of times and was also presented with all of the other treatments in turn. Each experiment was done over of a number of runs, using both compartments of the rotating cage. A control treatment was used in each compartment in each run and this consisted of a cauliflower plant without companion plant leaves, but with a similar number of black sticks (stems) (to account for the physical impedance to oviposition that they might cause).

For each experimental run, eight fresh cauliflower plants of the same age were selected from the greenhouse. The total number of leaves and the height of each plant were recorded. The pots were topped up with a layer of silver sand followed by sieved soil. The companion plant treatments were then added to the pots before they were placed in the two compartments of the rotating cage. Once the plants were in place, twenty 5-6 day old female cabbage root flies were released into each compartment of the cage, where they remained for 24 hours. The cage was maintained in a constant temperature room at 19 $\pm$ 2^{o}C with a 16 h photoperiod.

After 24 h, the plants were removed from the cages, labelled by treatment and then taken to a laboratory. The eggs were removed from the soil and silver sand by flotation and counted.

The number of eggs laid within each segment of the cage was analysed using ANOVA.

Individual experiments

Leaf Size

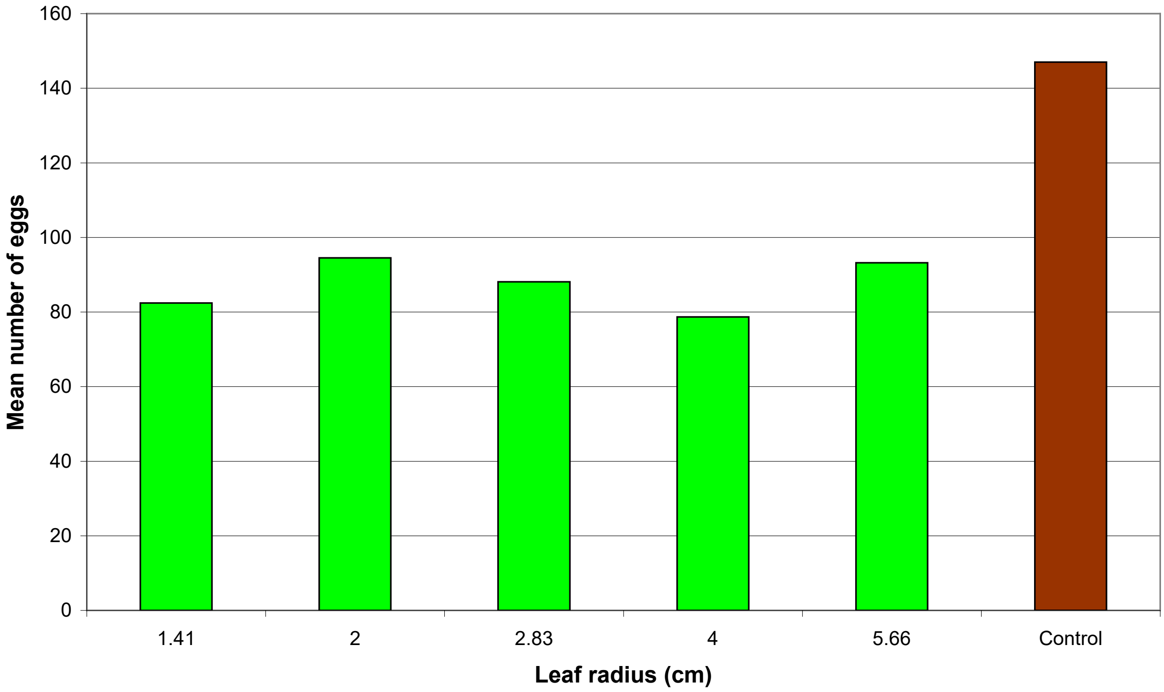
In this experiment, the companion plant treatments consisted of circular leaves and the treatments were as follows:

Leaf radius (cm)	Number of leaves presented	Number of leaves per stick	Number of sticks per pot
1.41	32	4	8
2	16	4	8
2.83	8	2	8
4	4	1	8
5.66	2	1	8
Control	0	0	8

The same total leaf area was presented in each treatment and to achieve this, the treatments consisted of 32, 16, 8, 4 and 2 leaves respectively. These were distributed on 8, 4, 4, 4, and 2 black sticks respectively and additional black sticks were added to certain treatments to make the total number of sticks per pot up to 8. Eight bare black sticks were added to the pots containing the control treatments. The cauliflower plants had a mean of 4.9 leaves and were 22.1 cm tall, the companion plant leaves were at a height of 16 cm above the soil. The total area of companion plant foliage presented with each cauliflower plant in this experiment was 200 cm^2.

There were 10 experimental runs (5 treatments x 2 compartments) and each companion plant treatment was replicated 6 times.

Figure 2. Effect of the size of companion plant leaves on the mean number of eggs laid around cauliflower plants by female cabbage root flies.



The ANOVA results suggested that more eggs were laid on the control treatment (mean of 147 eggs) than on any of the companion plant treatments (F pr. = 0.023; 25 df), but no statistically significant differences were evident between the five companion plant treatments (range 78.7 – 94.5 eggs) (Figure 2).

Plant Height

Two experiments were done to determine the effect of companion plant height on oviposition by female cabbage root flies on cauliflower.

In the first experiment, all companion plant treatments consisted of 8 circular leaves, with a radius of 2.83 cm, presented on 4 black sticks (2 per stick). Four bare black sticks were placed in the pots containing the control treatments. The treatments were as follows:

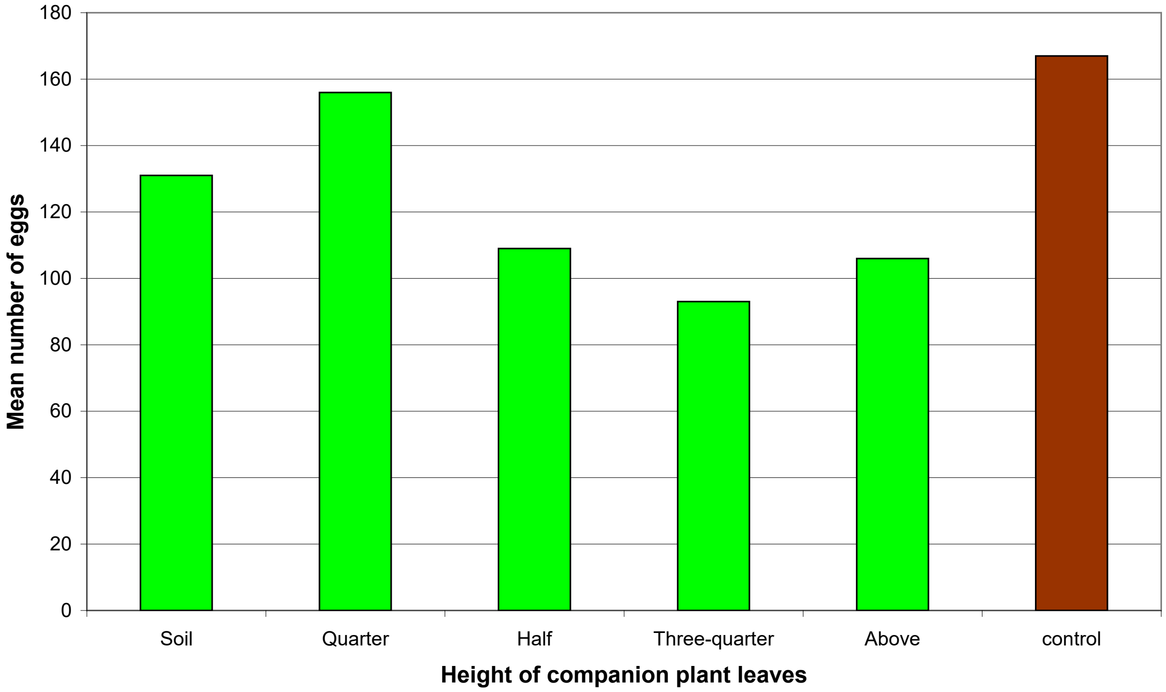
Treatment description	Height of companion plant leaves above soil (cm)
Above plant	28
Three quarter (0.75)	21
Half (0.5)	14
Quarter (0.25)	7
On soil	0
Control	No leaves

The cauliflower plants had a mean of 7.2 leaves and were 31.8 cm tall.

There were 10 experimental runs in each experiment (5 occasions x 2 compartments) and each companion plant treatment was replicated 6 times.

Based on the results from the ANOVA no significant differences were evident between any of the treatments, including the control (F Pr. 0.422; 25 d.f.) (Figure 3).

Figure 3. Effect of companion plant height on the mean number of eggs laid around cauliflower plants by female cabbage root flies.



In the second experiment, all companion plant treatments consisted of 8 circular leaves, with a radius of 2.83 cm, presented on 4 black sticks (2 per stick). Four bare black sticks were placed in the pots containing the control treatments. The treatments were as follows:

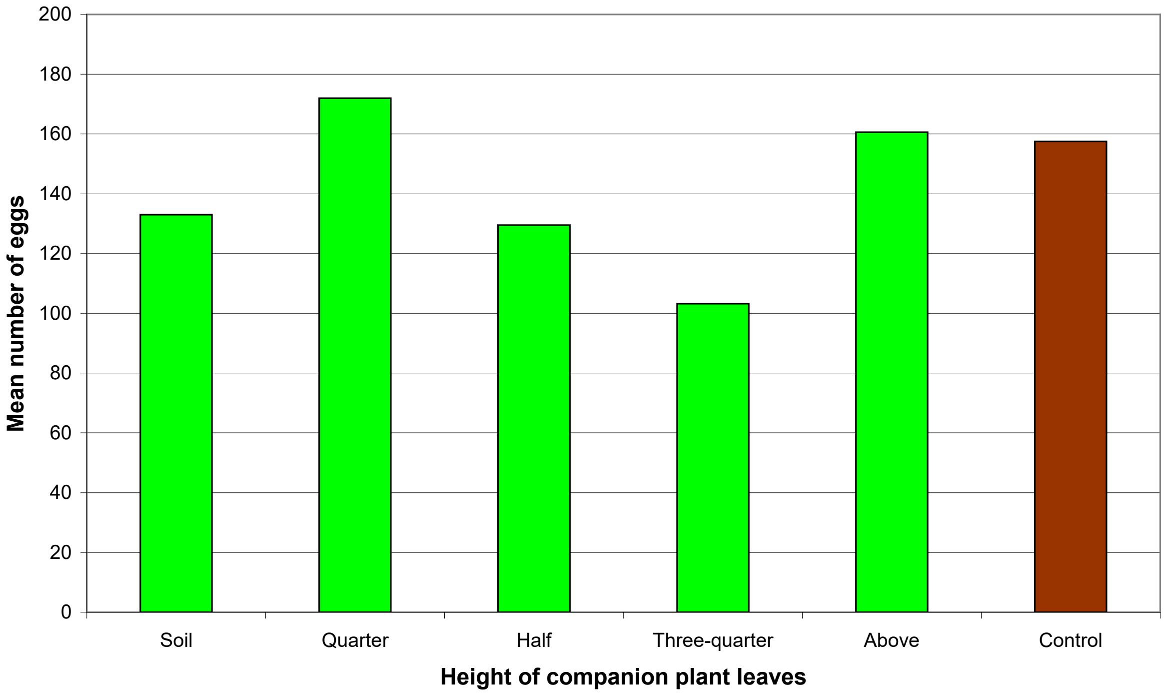
Treatment description	Height of companion plant leaves above soil (cm)
Above plant	22
Three quarter (0.75)	16
Half (0.5)	10
Quarter (0.25)	4
On soil	0
Control	No leaves

The cauliflower plants had a mean of 4.9 leaves and were 20.6 cm tall.

There were 10 experimental runs in each experiment (5 occasions x 2 compartments) and each companion plant treatment was replicated 6 times.

Based on the results from the ANOVA no statistically significant differences were evident between any of the treatments including the control (F Pr. 0.409; 25 d.f.) (Figure 4).

Figure 4. Effect of companion plant height on the mean number of eggs laid around cauliflower plants by female cabbage root flies.



Amount of companion plant foliage and its vertical distribution

Although there were no statistically significant differences between treatments, the previous experiments on leaf height indicated that the half (0.5) and three-quarter (0.75) treatments were the most effective for reducing egg-laying by female cabbage root flies.

In this experiment, different amounts of companion plant foliage were presented at the two most 'effective' heights to determine whether the effectiveness of the companion plants could be increased   All companion plant leaves had a radius of 2.83 cm and were presented as 2 per black stick. All pots contained 8 black sticks. The leaves at three-quarter height (0.75) were 18 cm above the soil surface and the leaves at half height (0.5) were 12 cm above the soil surface.

The treatments were:

Treatment name	Number of leaves at three-quarter (0.75) height	Number of leaves at half (0.5) height	Total number of leaves
0x0.75_8x0.5	0	8	8
4x0.75_4x0.5	4	4	8
4x0.75_8x0.5	4	8	12
8x0.75_0x0.5	8	0	8
8x0.75_4x0.5	8	4	12
8x0.75_8x0.5	8	8	16
Control	Control		

The cauliflower plants had a mean of 5.9 leaves and were 25.3 cm tall. There were a total of 20 runs and each treatment was replicated 10 times.

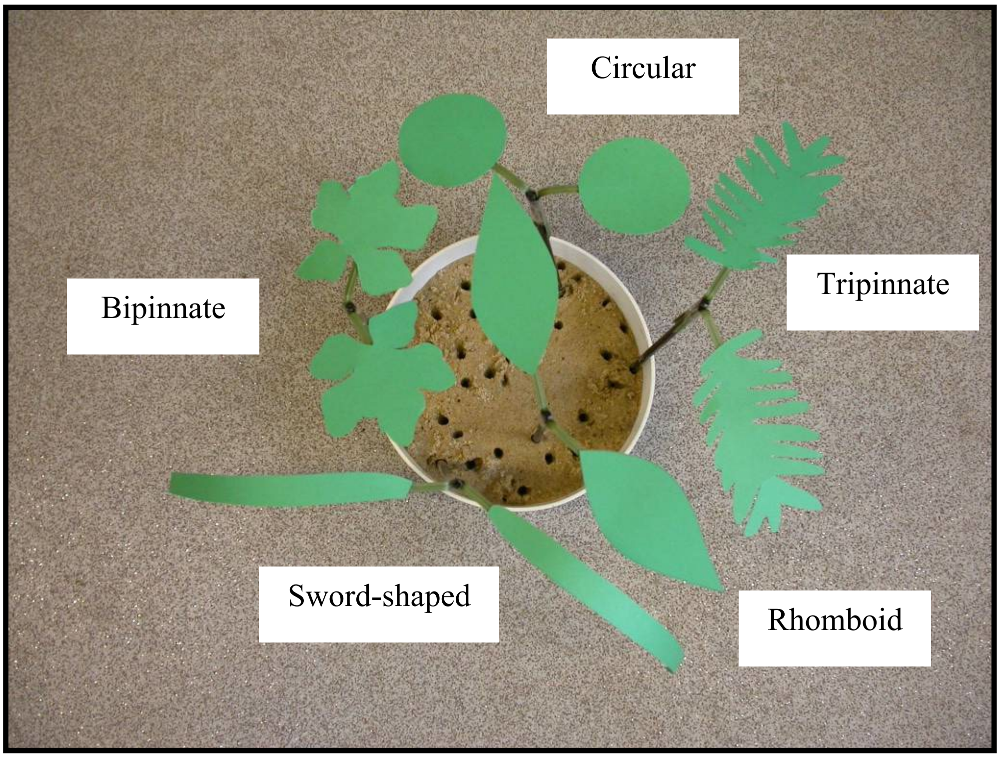
ANOVA indicated a statistically significant difference between treatments (F pr. = 0.001; 54 d.f.). The treatment '*8x0.75_4x0.5'* reduced egg numbers to 26.7 per plant compared with 121.8 per plant for the control treatment (Figure 5).

Figure 5. Effect of the amount and vertical distribution of companion plant foliage on the mean number of eggs laid around cauliflower plants by female cabbage root flies.

Leaf Shape

The aim of this experiment was to determine whether the shape of companion plant leaves affected their efficacy in reducing egg-laying by female cabbage root flies. A range of typical leaf shapes was chosen and each leaf type was photocopied, cut out and weighed to determine its relative size. The photocopier was then used to change the size of each leaf until its area was comparable with a circular leaf with a radius of 2.83 cm. The scaled leaves were used as templates to make leaves of each shape from green card. The leaf shapes were rhomboid, bipinnate, tripinnate, sword-shaped and circular (Figure 6).

Figure 6 Leaf shapes tested.



In each experimental run there was a total of 8 black sticks per pot holding 8 leaves at three-quarter height (18 cm above soil level) and 8 leaves at half height (12 cm above soil level). The cauliflower plants had a mean of 5.8 leaves and were 28.2 cm tall. There were 20 experimental runs and each companion plant treatment was replicated 12 times.

Egg counts required a square root transformation to improve the underlying assumptions of the ANOVA. More eggs were laid on the control treatment than on any of the five companion plant treatments, but no significant differences were evident between the companion plant treatments (Figure 7).

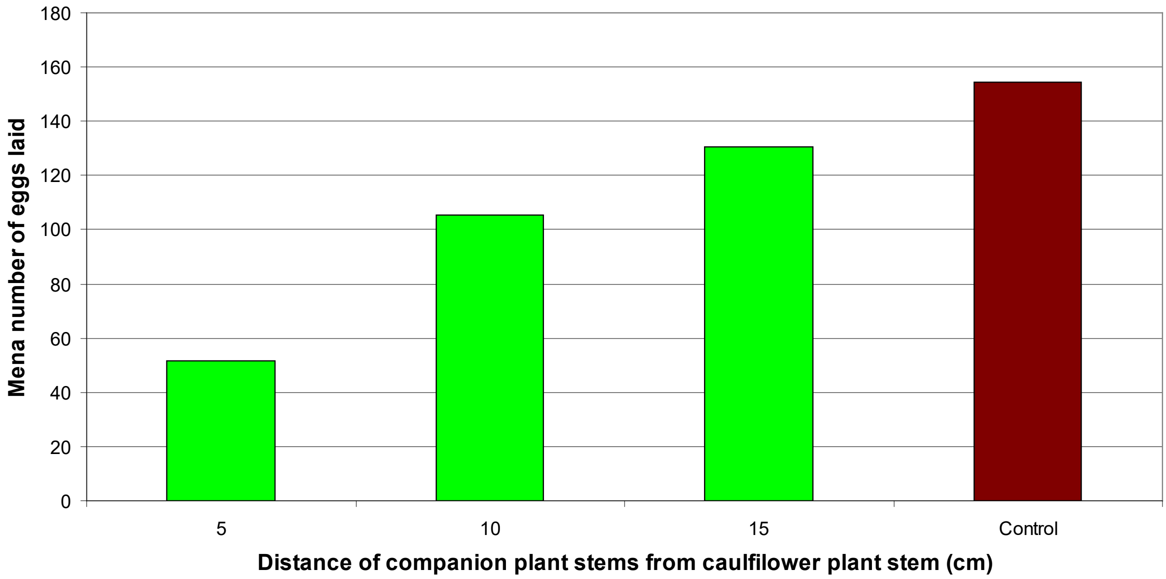
Figure 7. Effect of the shape of companion plant foliage on the mean number of eggs laid around cauliflower plants by female cabbage root flies.

Proximity of companion plants to cauliflower plant

The aim of this experiment was to determine whether companion plants that were close to the cauliflower plant were more effective in reducing egg-laying than those that were further away. All companion plant treatments consisted of 8 black sticks supporting 8 leaves at three-quarter height (18 cm above soil level) and 8 leaves at half height (12 cm above soil level). There were no black sticks in the pots containing the control treatment. The companion 'plants' were composite, consisting of 1 rhomboid, 1 bipinnate, 1 tripinnate and 1 circular leaf at each of the two heights. The sticks holding the companion plant leaves were located at distances of 5 cm (in the pot), 10 cm and 15 cm away from the cauliflower plant stem. The cauliflower plants had a mean of 5.9 leaves and were 27.6 cm tall. There were 12 experimental runs and each treatment was replicated 12 times.

ANOVA showed that proximity of the companion plants had a statistically significant effect on the numbers of eggs laid (F Pr. 0.006; 33 d.f.), approximately three times more eggs were laid on the control plants than on the plants surrounded by companion plants at a distance of 5 cm (Figure 8).

Figure 8. Effect of companion plant proximity on the mean number of eggs laid around cauliflower plants by female cabbage root flies.



3. Identify companion plant species that would reduce cabbage root fly egg laying to the desired level.

In April/May 2006, Elsoms grew over 200 varieties/species of plant in modules. These included a number of edible crops and herbs and other plants identified by the consortium as potential companion plants. A number of plants were selected for further evaluation (Table 1). This was based on their relative size versus cauliflower plants of a similar age and their habit. Four varieties of carrot, with different growth characteristics, were chosen for comparative purposes.

Table 1 Possible companion plants (identified 18 May 2006 at Elsoms)

Caraway
Carrot - Chantenay Red Cored
Carrot - Florida F1
Carrot - Mignon
Carrot - Namur F1
Chard
Chervil
Chicory
Dill
Endive
Fenugreek
Lettuce
Linseed
Lupin
Sorrel - garden
Tarragon

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.*

The 16 selected 'companion' plants and cauliflower cv Skywalker were grown in 308 module trays at Elsoms for transplanting at Warwick HRI (Wellesbourne, Warwicks), Elsoms (Spalding, Lincs) and Marshalls (Boston, Lincs). The cauliflower seed was treated with Gigant (chlorpyrifos) to protect the plants from cabbage root fly attack.

Trial 1 – 3 sites

Trial 1 was done at all three sites. The cells in the 308 trays were sown with the following combinations of each companion plant species:

Single companion plant
Cauliflower + 1 companion plant
Cauliflower + 2 companion plants
Cauliflower + 4 companion plants

Three sets of these plants were grown – for transplanting at the three sites. These plants were transplanted on 14 (Spalding), 19 (Butterwick) and 26 (Wellesbourne) July. The plots were irrigated at two sites (Spalding & Wellesbourne) and grown without irrigation at Butterwick. Although there was replication across sites there was no replication at individual sites and there was a maximum of 24 'plants' of each combination at each site, planted in a 3 x 8 block (Figure 9).

Samples of cauliflower and their associated companion plants were taken at transplanting and approximately 6 weeks after transplanting. These included plant counts and measures of fresh and dry weights. Further assessments were made as the cauliflowers matured.

Figure 9 Layout of Trial 1 at each of the three sites.

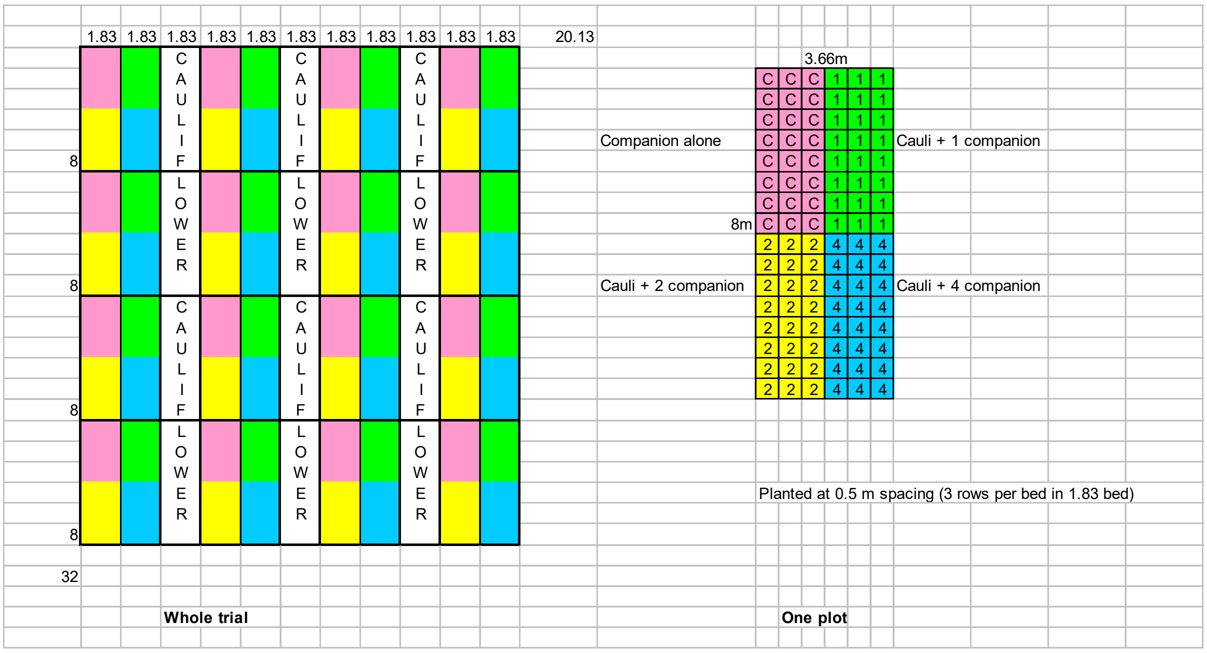


Figure 10 summarises the survival, from sowing until transplanting, of companion plants and cauliflower plants sown in a 1:1 ratio per cell (assessment made on the set of trays transplanted at Wellesbourne).

Figure 10 Plant survival in cells sown with 1 companion plant and 1 cauliflower.

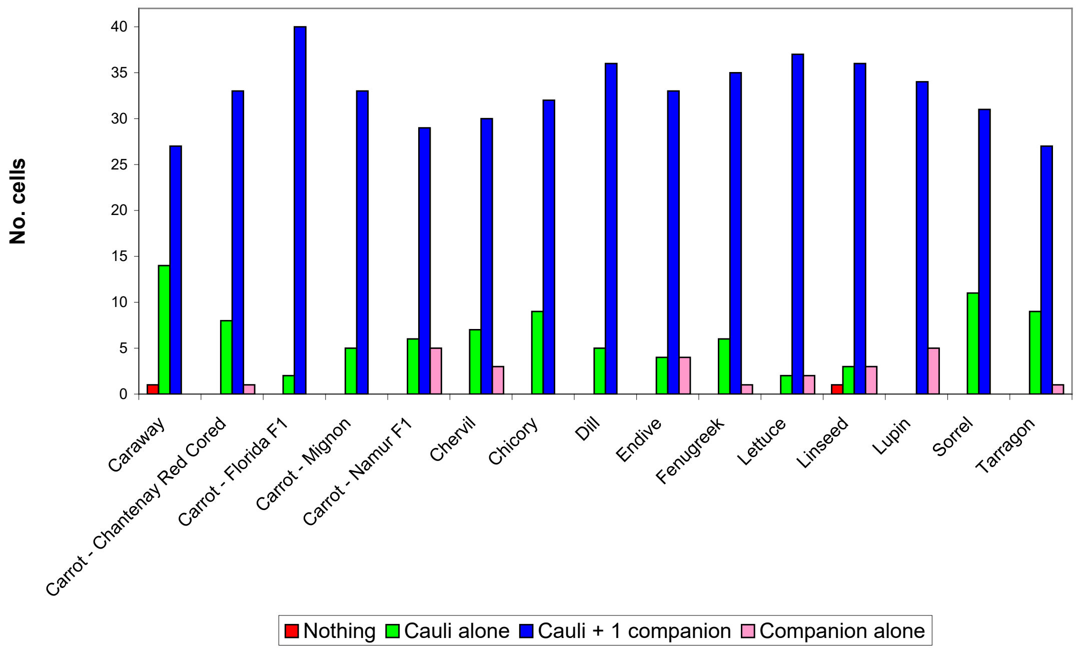


Figure 11 shows the dry weights at transplanting time of plants sown in a 1:1 ratio. At this stage, lupin was the most competitive companion plant and caraway was the least competitive. The lupin seeds were very large and proved to be unsuitable for this method of propagation.

Figure 11 Dry weights of cauliflower and companion plants (1 of each per cell)

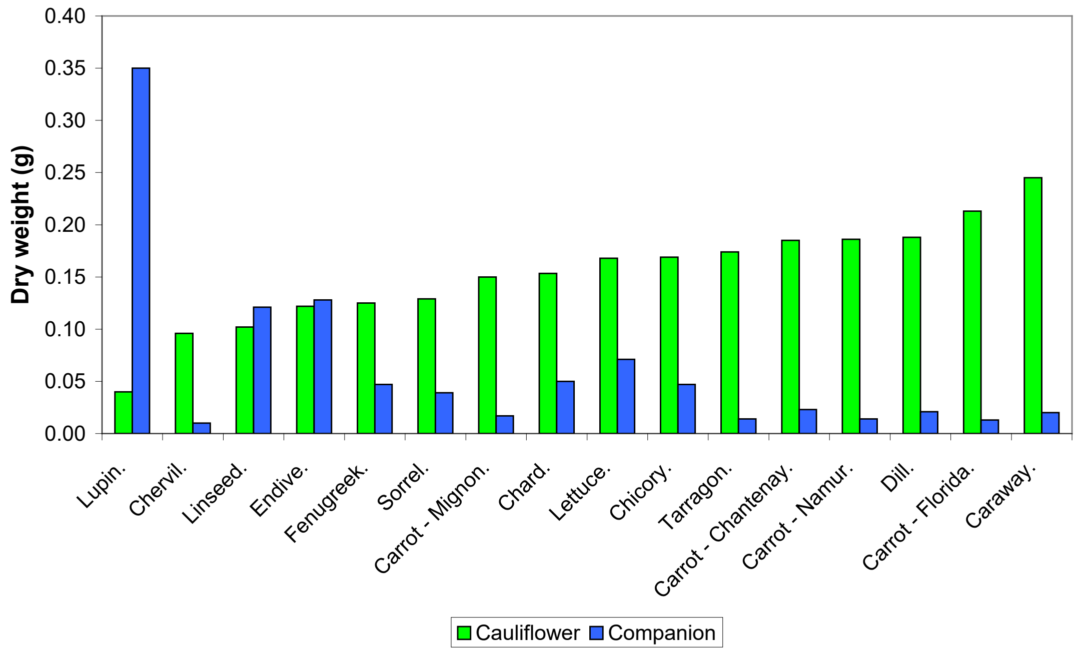
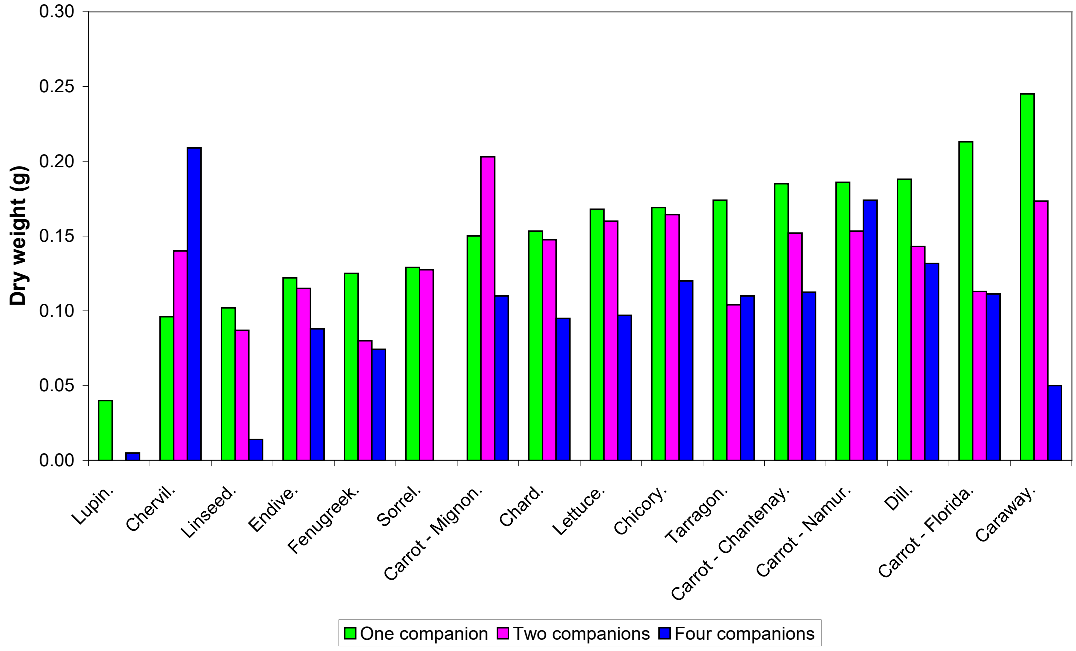


Figure 12 summarises the dry weights of cauliflower plants grown with 1, 2 or 4 companion plants per cell. In most cases, the dry weight of the cauliflower plant decreased as the number of companion plants per cell increased; chervil was a notable exception.

Figure 12 Dry weights of cauliflower in cells with 1, 2 or 4 companion plants.



Figures 13-15 show various combinations of cauliflower and companion plant in the trial at Wellesbourne on 10 August 2006, two weeks after planting.

Figure 13 Cauliflower and carrot (Chantenay red cored) at Wellesbourne on 10 August 2006.

Figure 14 Cauliflower and lettuce at Wellesbourne on 10 August 2006.

Figure 15 Cauliflower and chard at Wellesbourne on 10 August 2006.

Samples of cauliflower plants and their companion plants were removed from the plots at Spalding (23 August) and Wellesbourne (30 August) to take measurements of plant growth. This period, the first 5-6 weeks after planting, is the time when cauliflower plants are likely to be most susceptible to cabbage root fly damage, before their roots have started to develop extensively. Samples of 9 'plants' per plot were taken at Spalding and 6-9 'plants' at Wellesbourne. The cauliflower plants were weighed and their companion plants were weighed and counted. Sub-samples were taken to estimate the ratio of dry weight to fresh weight of all plant types.

Figure 16 shows the number of cauliflower plants that were associated with the correct number of companion plants 5 weeks after planting at Spalding (maximum possible = 9). There was considerable variation and relatively few cauliflower plants still had four companion plants.

Figure 16 Number of cauliflower plants associated with the 'correct' number of companion plants 5 weeks after planting at Spalding. Ranked by number of plants with one companion plant.

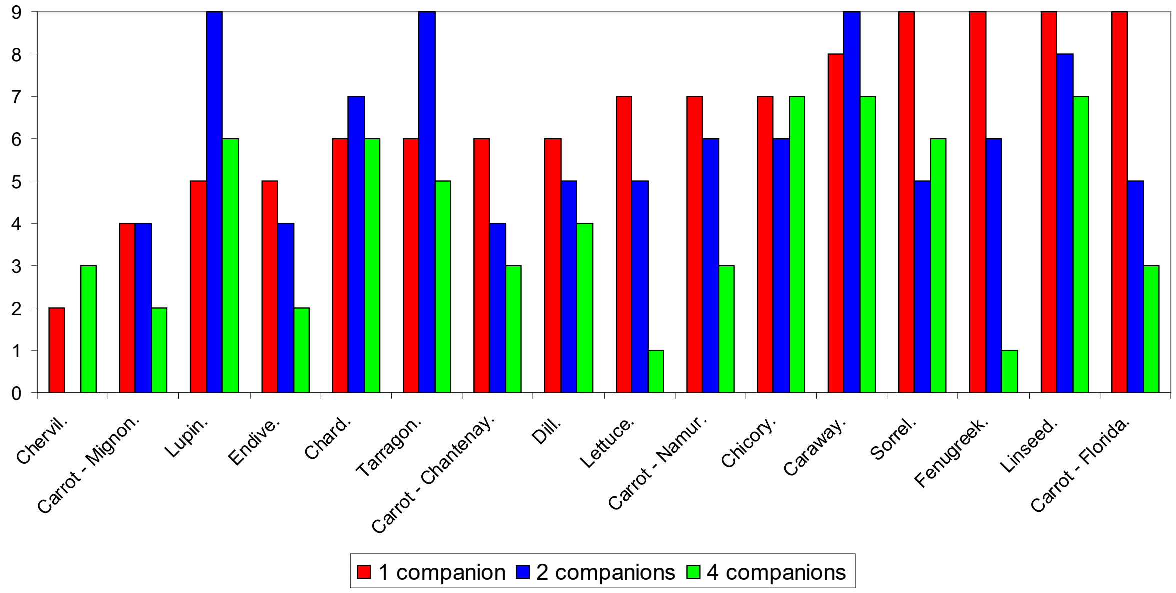
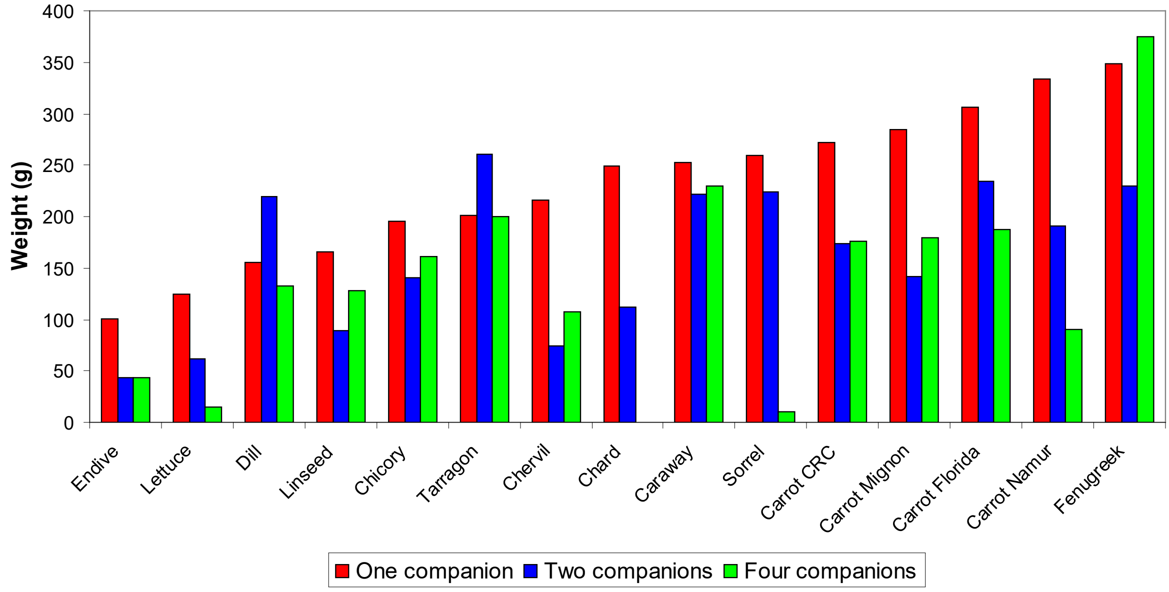


Figure 17 shows the mean fresh weights of cauliflower plants with 1, 2 or 4 companion plants (other combinations were ignored in the calculation) at Wellesbourne and Spalding. In general, cauliflower plants with just one companion plant were heavier than those with 2 or 4 companion plants. The rankings differed between the two sites, but this is to be expected, as the sample size was relatively small.

Figure 17 Fresh weights of cauliflower with 1, 2 or 4 companion plants – sample taken 5 weeks after planting at Wellesbourne (upper) and Spalding (lower). Ranked by weight of cauliflower plants with one companion plant.



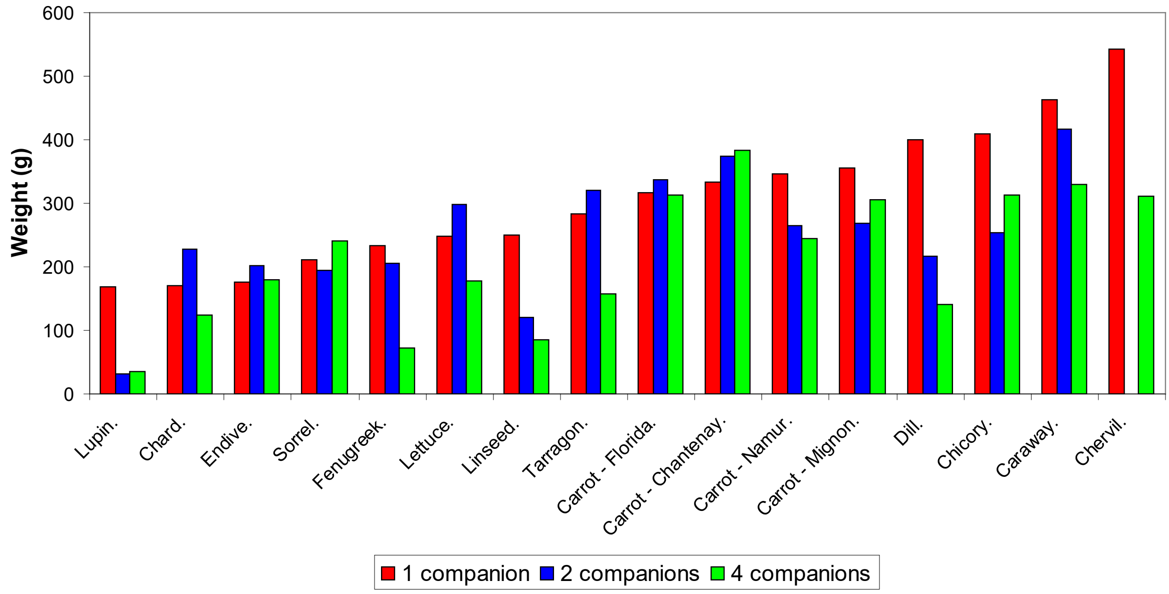
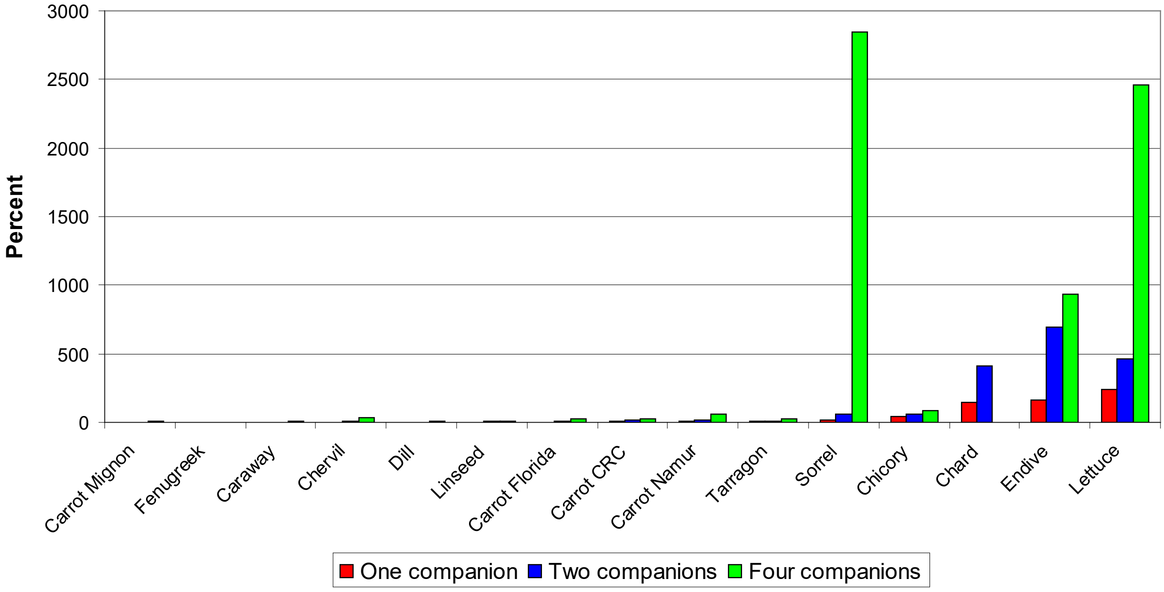


Figure 18 summarises the fresh weight of the companion plants (all the plants around a single cauliflower plant) as a percentage of the fresh weight of the cauliflower plant they surrounded. Chard, endive, lettuce, lupin and sorrel were relatively large plants, whilst most of the umbellifers were relatively small.

Figure 18 Fresh weight of companion plants as a percentage of fresh weight of cauliflower plants grown at Wellesbourne (upper) and Spalding (lower)). Ranked by weight of plants with one companion plant.



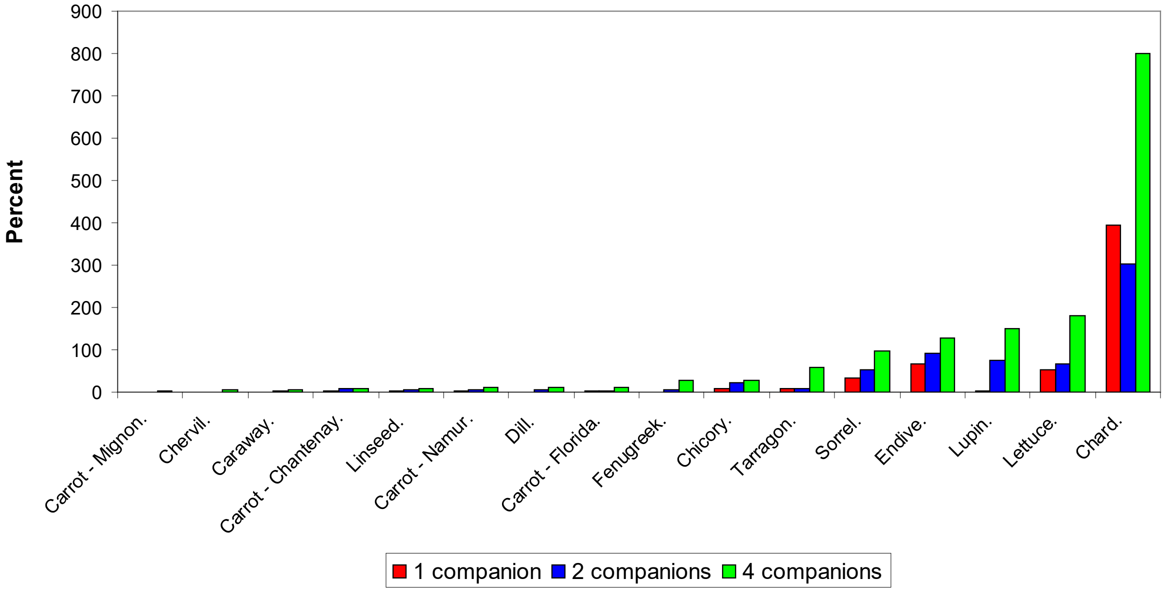
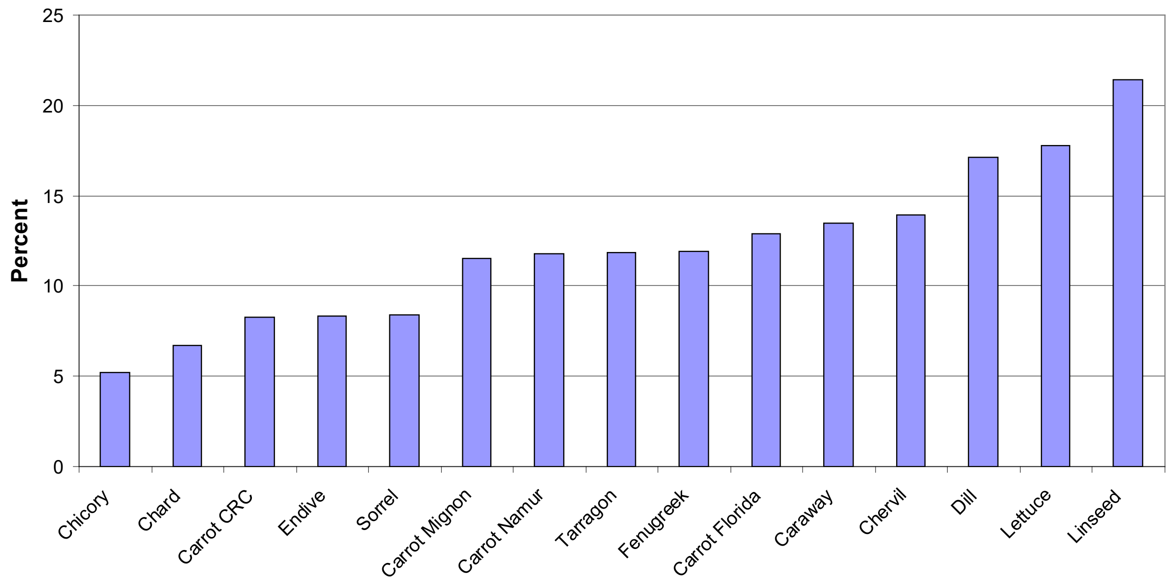
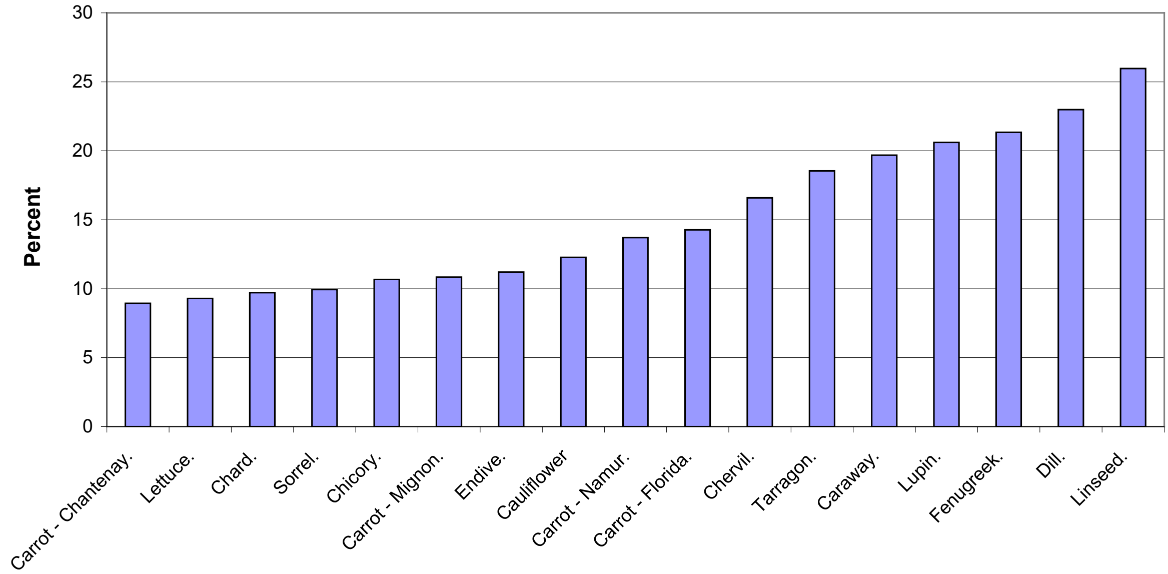


Figure 19 shows the dry weight as a percentage of fresh weight for all the plant types grown.

Figure 19 Dry weight as a percentage of fresh weight (plants grown at Wellesbourne (upper) and Spalding (lower))





Further assessments were made as the cauliflowers matured and included the date of maturity (estimated as the plots were not visited every day), the diameter of the mature curd and quality (Class1 and lower quality). At Wellesbourne, the data presented in Figures 21-23 are based on the plants that were still associated with the correct number of companion plants at maturity (Figure 20). Consequently, some of the means are based on very low numbers of plants. At Spalding, the data presented in Figures 24-26 are based on all the plants remaining in the plot, regardless of whether they were associated with the correct number of companion plants.

Figure 20 Number of cauliflower plants at Wellesbourne associated with the correct number of companion plants at maturity.

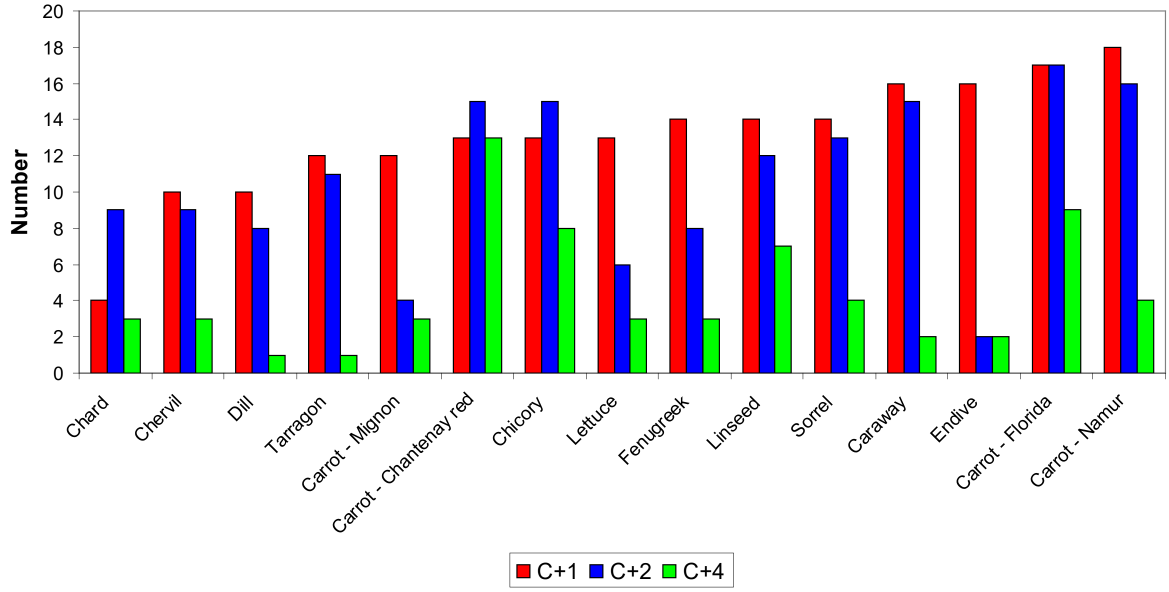


Figure 21 Mean cutting date at Wellesbourne – data for cauliflower alone consists of 18-plant samples from each of 2 separate blocks.

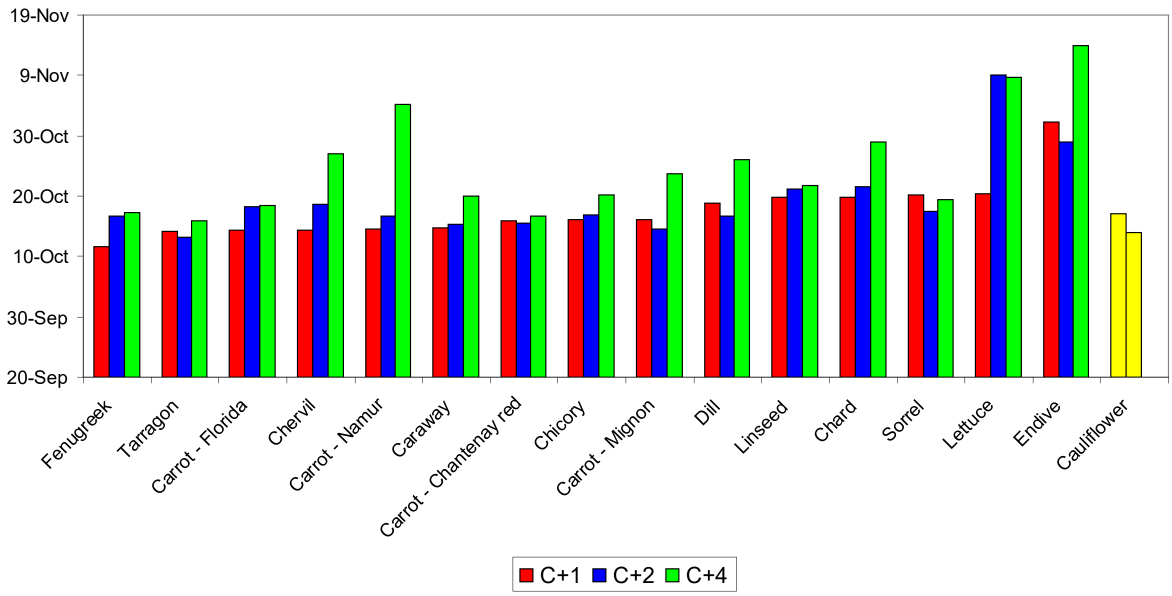


Figure 22 Mean curd diameter at Wellesbourne – data for cauliflower alone consists of 18-plant samples from each of 2 separate blocks.

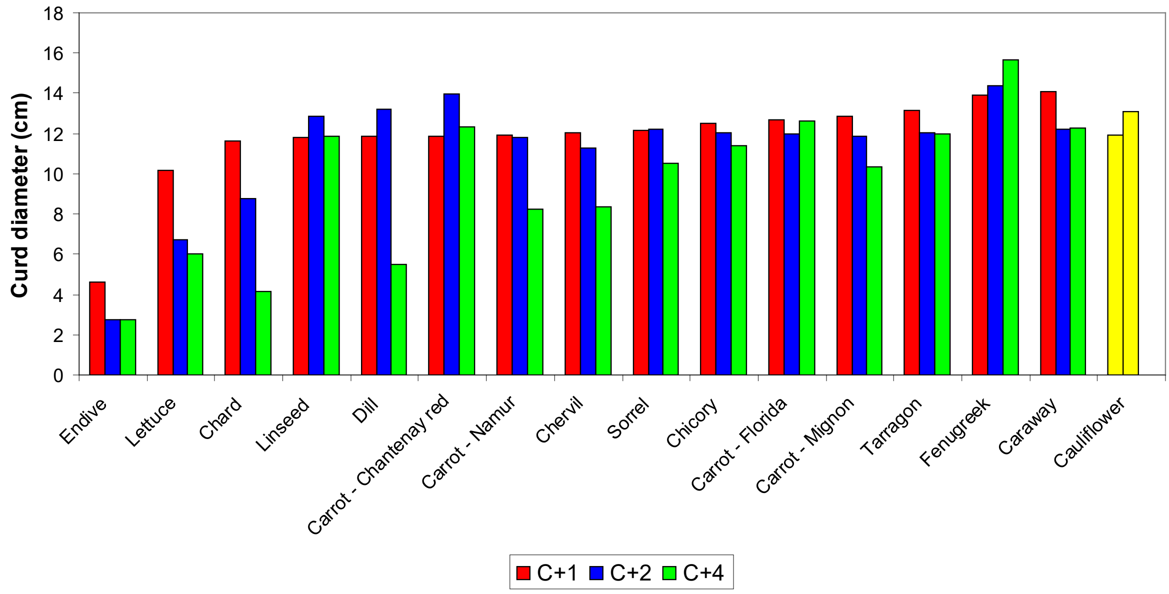


Figure 23 Percentage of Class 1 curds at Wellesbourne.

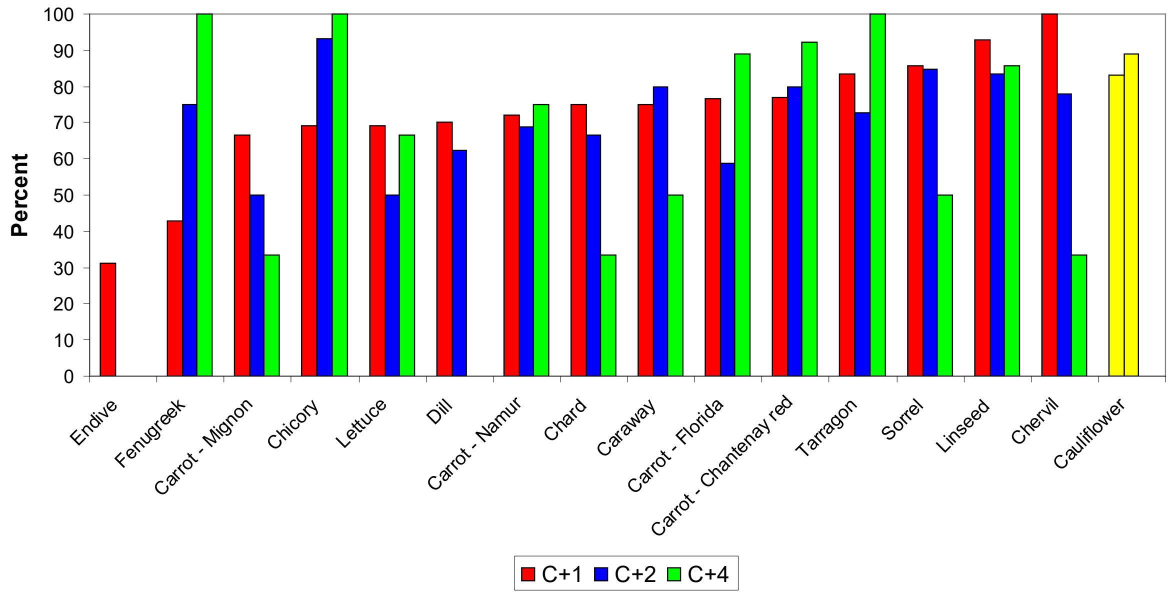


Figure 24 Mean cutting date at Spalding – data for cauliflower alone consists of 15-plant samples from each of the 3 separate blocks.

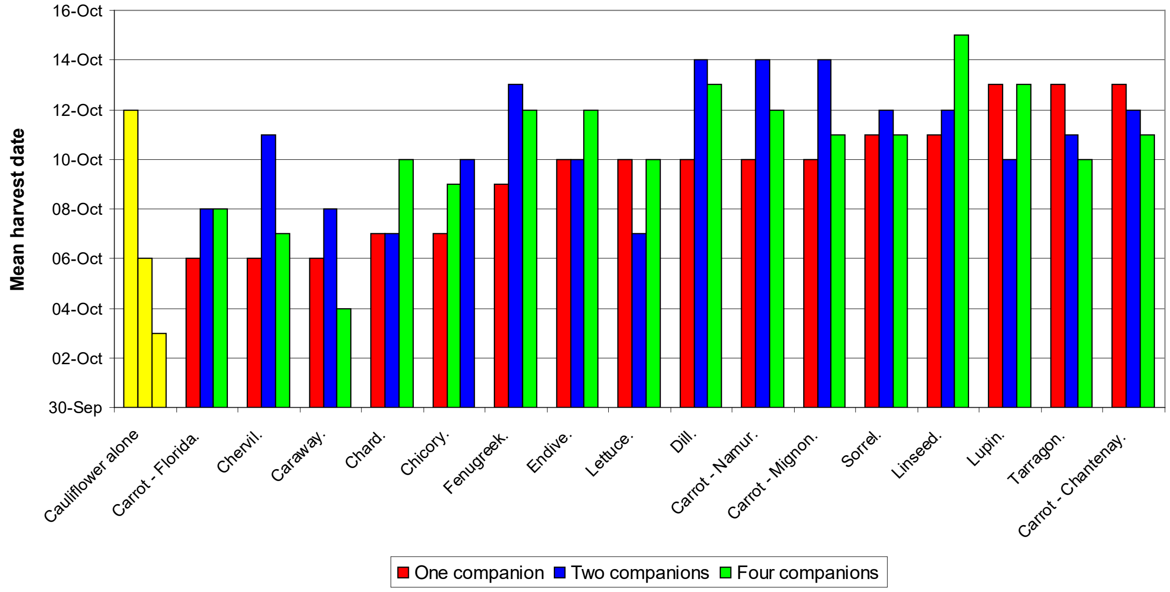


Figure 25 Mean curd diameter at Spalding – data for cauliflower alone consists of 15-plant samples from each of the 3 separate blocks.

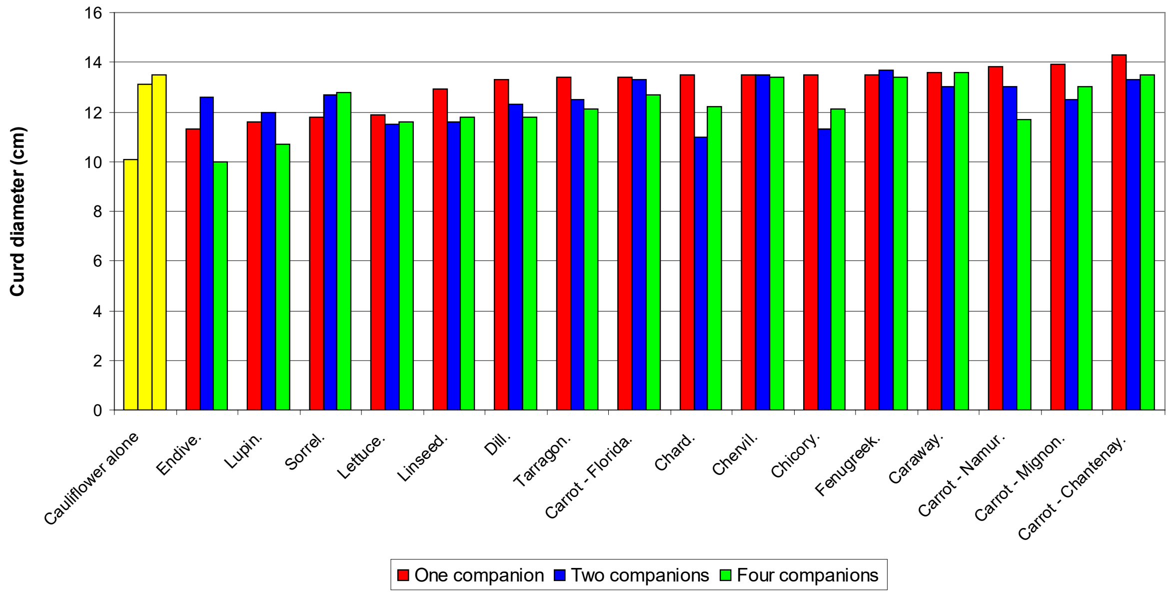
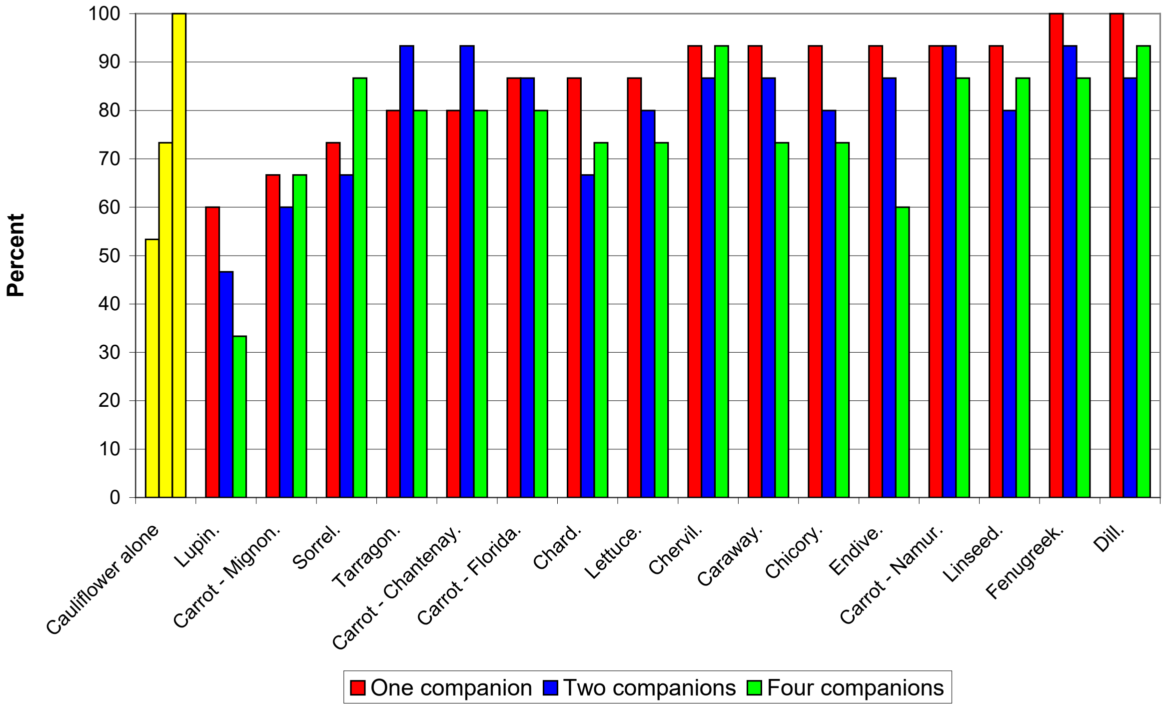


Figure 26 Percentage of plants producing Class 1 curds (maximum 15) at Spalding – data for cauliflower alone consists of 15-plant samples from each of the 3 separate blocks.



The plots at Butterwick were transplanted on 19 July, which was one of the hottest days of the year and when the land was extremely dry. No irrigation was available and indeed this was a good test of the plants' ability to survive. To determine levels of survival an assessment was made of the total numbers of each plant combination surviving. Figure 27 shows the total number of cauliflowers surviving for each companion plant type, across all treatments.

Figure 27 The total number of cauliflowers surviving at Butterwick for each companion plant type, across all treatments.

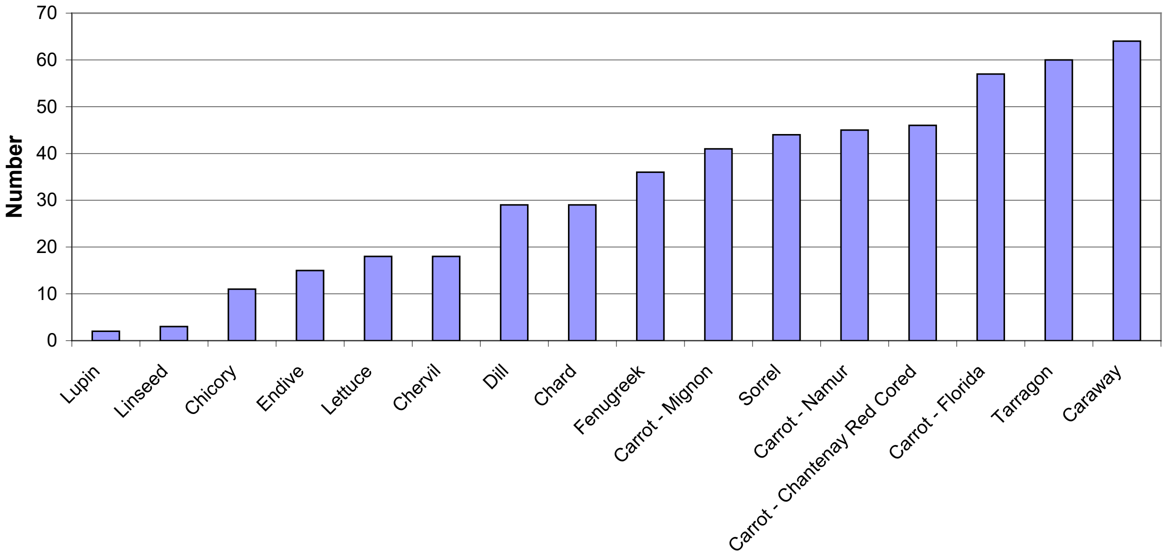


Figure 28 shows the total number of companion plants surviving across all treatments.

Figure 28 The total number of companion plants surviving at Butterwick across all treatments.

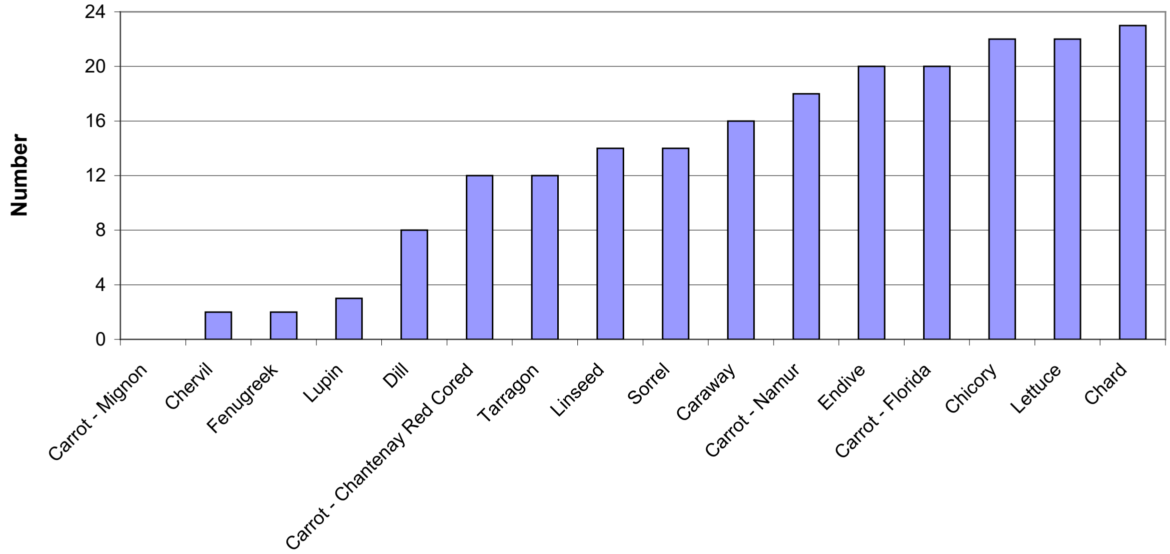
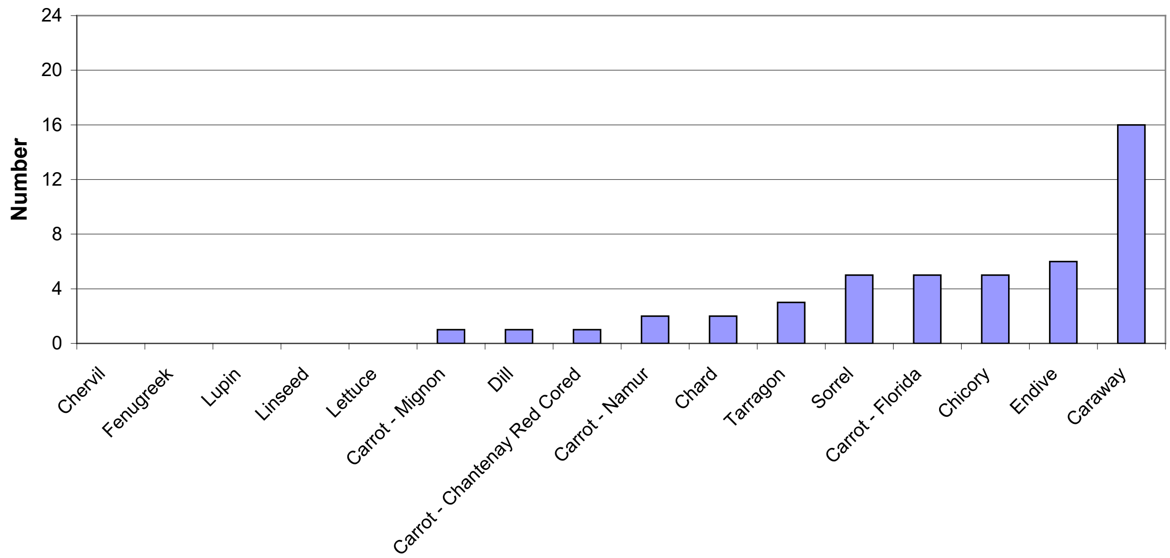


Figure 29 shows the total number of combinations of 1 cauliflower + 2 companion plants surviving at Butterwick.

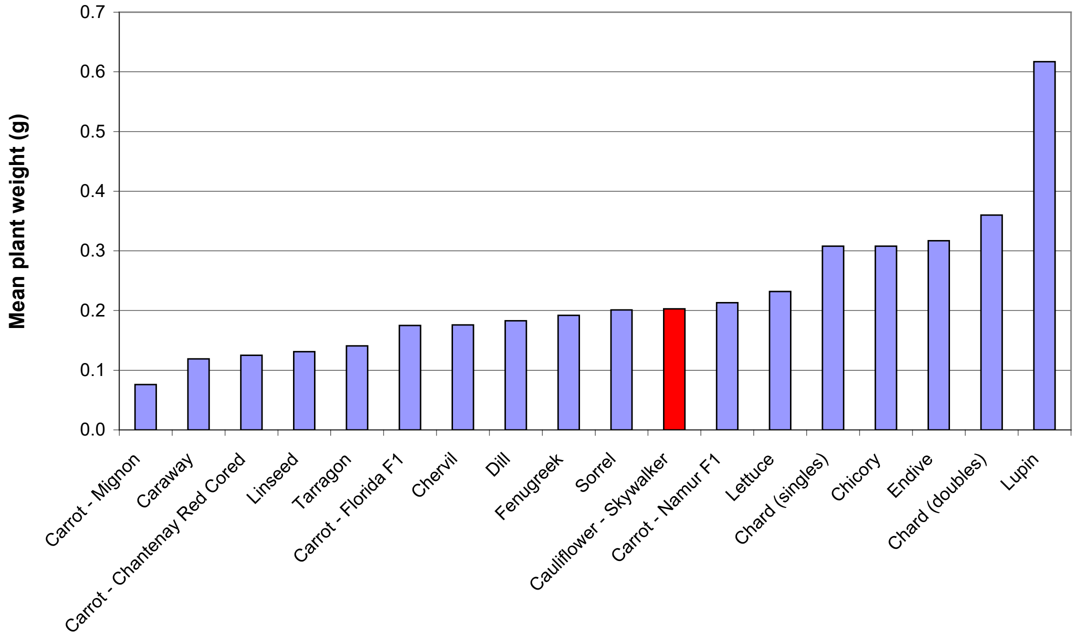
Figure 29 The total number of combinations of 1 cauliflower + 2 companion plants surviving at Butterwick.



Trial 2

Companion plants were sown (1 per cell) into 308 trays at Elsoms and transplanted at Wellesbourne. These plants were used to collect data to parameterise a plant competition model. The records taken consisted of dry weights at transplanting and regular samples to determine foliage cover, crown zone area, leaf area and dry weight. Figure 30 shows the dry weights of each companion plant type and cauliflower at transplanting. The remaining data are yet to be analysed and will be summarised in the next Annual Report.

Figure 30 Dry weight of companion plants and cauliflower at transplanting (one plant per cell).



DISCUSSION

The laboratory tests confirmed that companion plants made from green card reduced the numbers of eggs laid by female cabbage root flies on cauliflower plants. Although the companion plant leaf area, its vertical distribution and the proximity of the companion plants were critical, leaf size and shape were not. The size of the reduction in egg laying varied from one experiment to another and is likely to be determined by the 'effectiveness' of each treatment and also by the effectiveness of the other treatments with which it was presented – as these were essentially 'choice' tests. The information from this study, backed up by data from other studies, indicates that an 'ideal' companion plant should be green, situated close to the plant it is protecting and that it should have a certain leaf area and leaf distribution relative to the crop plant. It appears from the tests reported here that neither the size nor the shape of individual leaves is critical.

The results of the first field trial was extremely encouraging since several of the cauliflower/companion plant combinations produced marketable (Class1) curds and there was no apparent effect on curd size or maturity time. A few of the companion plants were extremely competitive (e.g. lupin, endive) and would not be suitable for a commercial situation. Obviously these were relatively small, unreplicated trials but they should help guide the consortium in the choice of companion plants to pursue in more detail in 2007.

TECHNOLOGY TRANSFER

The project was summarised in a poster presented at a Horticulture LINK event on 23 February 2006.

ACKNOWLEDGEMENTS

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