MINISTRY OF AGRICULTURE, FISHERIES AND FOOD **CSG 15**

Research and Development

Final Project Report

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Project title	Companion cropping for organic field vegetables
MAFF project code	**OF0181**
Contractor organisation and location	ADAS Consulting Ltd ADAS Terrington Terrington St Clement King's Lynn Norfolk PE34 4PW
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Executive summary (maximum 2 sides A4)

Typical organic crop rotations are extensive with at least one year in four as a fertility building crop. However, the economic viability of organic systems may be compromised by having 75% or less of the farm productive at one time, limited further by the absence of the Arable Area Payments Scheme, particularly Set-aside, for vegetable crops. In addition, the system gives rise to a high fertility/low fertility sequence which is inefficient in terms of nutrient management (particularly nitrogen). To try to address this, the use of permanent beds of companion crop grown alongside the vegetable crops has been developed under various conditions around the world and is perceived as a possible alternative in organic husbandry. Companion crops also have the potential to reduce the impact of pests and weeds. A potential disadvantage of companion crops is competition with crop plants for space, light, water and nutrients. The companion crop, therefore, is likely to have to be mown or grazed to control competition and encourage nutrient transfer. On the positive side, companion crops have the potential to reduce the impact of pests, and weeds. The challenge is, therefore, to develop appropriate crop layouts and machinery to balance these interactions and result in profitable crop production.

Project OF0181 was delivered with Elm Farm Research Centre and was guided by a Steering Group. The core of the project was the further development and evaluation of a seven-crop companion crop system initially developed by Professor Martin Wolfe at Wakelyns Agroforesty, Fressingfield, Suffolk, a Soil Association registered organic farm. The system was based on 1.5 m beds, with three 20 cm vegetable rows alternating with 30 cm leguminous companion strips. Within each bed, there was a seven-course crop rotation: potatoes, alliums, Umbellifers, spring oats, legumes, brassicas and spring wheat. To establish and manage this system, Martin Wolfe and his co-workers (P. J. & M. J. Wards) had by spring 1999 developed a range of purpose-built machinery including a strip rotavator, 3 row precision seed drill, straight tine or L-blade strip cultivator with/without discs, rotary strip mower, strip irrigator and a strip compost spreader. Whilst the basic versions of these machines were completed and working in 1999, development work continued through the life

of the project, particularly aimed at more precise management of the companion crops, and improved seedbed preparation.

Two large experiments were established at Wakelyns in spring 1999; it was planned that these be continued for the full three years of the project. One experiment compared a factorial combination of a) three companion crops: white clover, vetch and nil, b) companion crop mowings left to fall, or deflected onto the vegetable rows, and c) the presence or absence of added composted manure. A second experiment compared factorial combinations of winter cover crops of rye and vetch grown in the vegetable rows with additional approved inputs of phosphorus and potassium. All seven crops were grown but assessments were made only on brassicas, alliums and carrots.

In 1999, persistently wet weather delayed crop establishment and made control of companion crops and weeds difficult. All planned assessments were made but yields were very low (<2.5 t/ha), and none was marketable. In 2000, wet and mild conditions led to strong grass weed and clover growth while limiting possibilities for weeding and mowing. For the second year, there was a very low total yield, and no marketable yield from any of the three test crops. It was therefore again not possible to assess nutrient transfer from the companion to the vegetable crops even though all planned soil and plant sampling and analyses were completed where feasible. These two experiments were discontinued and an alternative programme of work for the final year of the project agreed with DEFRA.

In a glasshouse experiment in 2000, vegetable crops (leeks, calabrese or carrots) were grown in trays in various combinations with two companion crops. They were grown with and without root or aerial barriers to assess competitive mechanisms. The competitive effects varied with vegetable crop. For leeks, both companion crops, but especially vetch, markedly reduced leek growth and yield. In the calabrese experiment, it was the companion crops rather than the vegetable crop that were severely affected by competition. For both of these crops, the lack of a barrier effect suggests that general competitive effects for moisture, light and nutrients were responsible for the reduced growth. In the carrot experiment, reduced carrot growth only when no barriers or root barriers were in place, suggests that competition was largely for light rather than moisture or nutrient factors. Carrots also reduced companion crop growth suggesting that they are intermediate between calabrese and leeks in susceptibility to competition.

Also in 2000, two experiments (carrots and Brussels sprouts) were undertaken on a separate farm to test the Wakelyns system and to allow an assessment of the pest and disease control potential of companion crops in single-species cropping on a large scale. In practice, as described above, it took longer than one year to develop the system at Wakelyns. Therefore, these experiments were done largely using hand-tools and companion crops were sown at the same time as the vegetables. Weeds out-grew the companion crops in the early stages but clover eventually formed a dense canopy. Yields were very low (16 t/ha for carrots and 1.5 t/ha for Brussels sprouts) but there was a trend for a greater yield of carrots without a companion crop, supporting the competitive effects of clover measured in the glasshouse experiment. There was an indication of negative effects of companion crop on common scab on carrots but this was against a background of very low disease pressure. There was no effect on pest or disease incidence on Brussels sprouts.

The revised programme of work for 2001 included a move to a newly established similar companion crop system, free from grass weeds, in an adjacent field at Wakelyns. Two experiments were done with leek transplants to assess the levels of nutrient transfer from clover. Clover grew well with mean accumulated total nitrogen of 260 kg/ha N in the cut foliage. However, leek yield was very low, averaging only 3.3 t/ha fresh weight. The quantity of nitrogen recovered in the leeks at less than 10 kg/ha was only about one quarter of the pre-planting soil mineral nitrogen (SMN). The calculated apparent nitrogen mineralisation (leek N offtake plus post-harvest SMN, minus pre-planting SMN) was therefore negative for all treatments. The “missing” nitrogen, plus nitrogen mineralised from the (up to) 300 kg/ha total N added to vegetable rows as mown clover, was probably competitively taken-up by the clover. This massive effect swamped any effects of previous crop or mowing treatment. This supports the results of the glasshouse experiment and confirms that leeks are not a suitable crop for such an intimate association with a companion crop.

The literature was reviewed (Appendix 1) for nitrogen transfer between companion crops and associated cash crops. There is little direct N transfer (via rhizodeposition and mycorrhizal interactions) that is of agronomic significance in companion cropping systems. The indirect route of nutrient transfer via the mineralisation of dead root and shoot material (following defoliation/suppression) is more important. Much of the N released may be either immobilised within the soil microbial biomass or recycled back to the leguminous crop (which itself may inhibit N fixation). To make some estimates of the likely return of N in clover and its dynamics of release following cutting and mulching, a small modelling exercise was undertaken using early season data from the leek experiments at Wakelyns. Regardless of the cutting frequency, all models suggest that c.70-75% of the residue N will be mineralised within the first year after cutting. The pattern of release will depend on the temperature and moisture regime of the soil, however, and also differs between models.

Observations and data collected through 2001 were collated (Appendix 2) to give an overview of the performance of the companion crop system in the second season of production in North Field at Wakelyns. Plant establishment was often low, at least partly due to the late, wet spring. It may have been improved by a wider use of transplants but that would have increased costs. Alliums, carrots, legumes and some brassicas such as Brussels sprouts performed poorly in both 2001 and 2000, with nil or very low harvestable yields. Beta species, swede, some cabbages, parsnips, turnips and lettuce performed well with the yields of the best varieties similar to organic expectations in conventional growing systems. Some crops produced a positive return against production costs, others did not, mostly because of low crop yields. A simple gross margin analysis on a best case scenario, calculated using the best cultivars of the most suited crops, indicated a return similar to average production of organic field vegetables in more conventional cropping systems.

An Expert Group of researchers, advisers and growers met at Wakelyns in August 2001 to assess the commercial potential for the system (Appendix 3). In general, the group considered that, at present, companion cropping was better suited to small-scale production serving local markets. The large-scale producers were concerned about the level of input required to manage the clover and crops. Mechanised harvesting would be essential for large-scale enterprises but would be difficult with individual species sown on a single row or single bed basis.

Conclusions

Companion cropping has the potential to improve economic viability, and pest, disease and annual weed control in organic cropping systems, particularly in field vegetables which are not supported by the Arable Area Payment Scheme. However, in practice, in project OF0181 these benefits were not realised:

- Grass weeds were favoured and were difficult to control once established.
- There were problems with seedbed preparation and crop establishment; these may be less on lighter soils.
- Some crop species were better suited to companion cropping. In 2000 and 2001, there was:
  - a high yield in both years from beetroot, spinach, chard and kale;
  - a high yield in one year from Brassicas (some cabbage, swede, turnip), endive, lettuce, parsley and parsnip;
  - a low yield in both years from Allium crops (leeks, onions), Brassica (sprouts, some cabbage, calabrese), carrots, celeriac, broad and dwarf beans.
- Clover used soil available nitrogen in preference to fixed nitrogen, starving less competitive crops such as alliums of the nutrient and resulting in very low yields.
- Even with reliable yields, companion cropping in the form tested may only be suited to small-scale labour-intensive production.
- A system with greater spatial separation of companion and vegetable crops, with vegetables and companion crops grown alone in separate beds or strips, may give the reported benefits of companion cropping with less competition and be practical for large scale production.

Scientific report (maximum 20 sides A4)

Background

Vegetables are grown on a range of soils from naturally fertile peats and silts to less fertile sands. In organic systems, the nutrients come from fertility-building ley crops, farmyard manure, or from green manures. Typical organic rotations are extensive with at least one year in four as a fertility building crop. The economic viability of organic systems may be compromised by having 75% or less of the farm productive at one time, limited further by the absence of Arable Area Payment Scheme, particularly Set-aside, for vegetable crops. In addition, the system gives rise to a high fertility/low fertility sequence which is inefficient for nutrient management (1). The disturbance of soils by ploughing leys also reduces the colonisation of certain beneficial organisms such as earthworms and mycorrhizae that flourish in undisturbed soils. The use of permanent beds of companion crop grown alongside the vegetable crops has been developed under various conditions around the world and is perceived as a possible alternative in organic husbandry. Companion crops also have the potential to reduce the impact of pests and weeds (2, 3 & 4). The companion crop is likely to have to be mown or grazed to control competition and encourage nutrient transfer. The disadvantage of companion crops is competition with crop plants for space, light, water and nutrients. Therefore, the challenge is to develop appropriate crop layouts and machinery to balance these interactions and result in profitable crop production.

Objectives (as in the contract, ref: CSA 4956)

1. To appraise the economic viability of producing two major representative vegetable crops within a six-course rotation using permanent companion crop strips when compared with a standard organic farm system and conventional husbandry using standard yields and costs.

2. To compare the competitiveness of three companion crops with three vegetable crops in a glasshouse pot experiment undertaken in one season.

3. To evaluate the use of two leguminous overwintered cover crops and applied approved P and K nutrients in the vegetable crop strips for additional nutrition in two seasons.

4. To determine the effects of a fertility-building companion crop, grown on a permanent bed/strip system on the nutrient accumulation, and incidence of damage caused by pest and disease in three major vegetable crops over three seasons.

Revised objectives for 2001 as agreed with DEFRA. These were agreed following site problems, described below, encountered in achieving objectives 1 and 3 in 1999 and 2000.

5. To assess nutrient transfer and crop yield in leeks grown in a white clover companion cropping system.

6. To review the literature on nutrient transfer in companion cropping and construct a model to predict nutrient transfer and crop productivity.

7. To assess the economics of an established companion cropping system in North Field at Wakelyns Agroforestry.

8. To form an Expert Group to review progress and to consider the role of companion cropping systems in organic farming. To include manager of project OF0173.

Relevance to DEFRA (MAFF) policy

DEFRA (and MAFF) policy is to encourage the uptake of organic farming systems, primarily for their environmental benefits. Research into systems of companion cropping for organic field vegetables should help develop systems which are sustainable and economically viable and so encourage the expansion of organic horticulture which continues to lag behind consumer demand with around 70% of retail sales from imports.

Approaches and acknowledgements

The project was delivered in conjunction with Elm Farm Research Centre (EFRC) who were sub-contracted to provide and manage the sites for the field experiments in Objectives 1 and 3. These field experiments were sited at Wakelyns Farm, Fressingfield, Suffolk; a Soil Association registered organic farm owned by Professor Martin Wolfe, Research Director of EFRC. The companion cropping system used in Experiments 1, 3 and 5 was developed by Martin at Wakelyns pre-OF0181.

For objective 2, we are grateful to Jill Vaughan of Delflands Nursery for providing a site for the experiment in their glasshouses. For objective 4, we are grateful to Donald Morton for providing sites for experiments on his Norfolk organic farm.

The work was directed by a Steering Group that met twice yearly. Besides ADAS and EFRC staff, the group included Peter Rickard, independent vegetable consultant, and Christopher Stopes, independent organic consultant. We are grateful for their contributions to the project. MAFF (now DEFRA) staff attended some meetings and received minutes of all meetings.

Objective 1. To appraise the economic viability of producing two major representative vegetable crops within a six-course rotation using permanent companion crop strips when compared with a standard organic farm system and conventional husbandry using standard yields and costs.

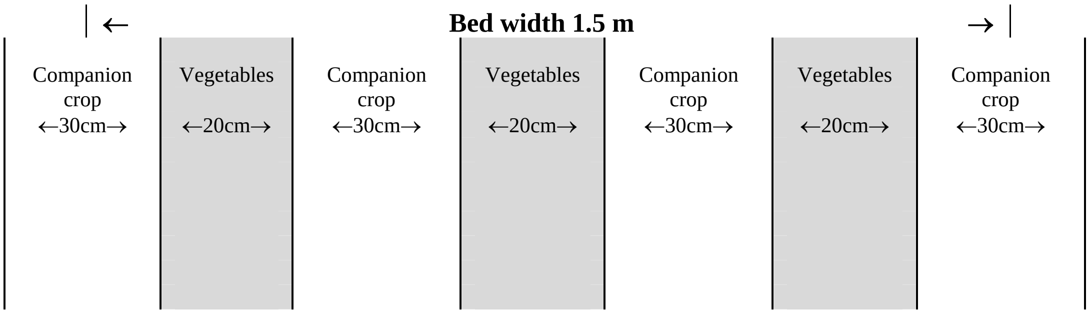
Experiment 1

For objective 1, a field experiment in Home Field at Wakelyns Agroforestry, Fressingfield, Suffolk compared white clover (AberHerald, AberCrest, AberDai, Alice and Riesling in equal proportions), vetch (Common vetch) and nil companion crop in a seven-course crop rotation. Seven rather than the intended six courses suited the final site layout at Wakelyns. Soil texture was sandy clay loam. Previous cropping was long term grass/clover ley.

Layout, design and treatments

Home Field was divided into 9 'alleys', each 12 m wide. Longitudinally, each alley was further divided into seven beds each 1.5 m wide. Each bed contained three rows of crop, 20 cm wide, separated by companion crop strips of 30 cm width. A single bed thus had 3 x 20 cm crop rows alternating with 30 cm wide companion crop strips (Figure 1). The companion crop strips were permanent except in the beds assigned to potatoes. Here, the companion crops were ploughed-in and two rows of potatoes grown alone in the plots; companion crops were re-sown in autumn after harvest of the potatoes.

Figure 1. Experiment 1: layout of a single bed. The outer strips of companion crop are shared with the adjacent beds and also act as a wheelway for the tractor and machinery, all designed to operate within one bed.



The experiment was of a split-split-plot design with three replicates.

Main plots: Companion crops

* White clover
* Common vetch
* No companion crop (mown and cultivated to control weeds)

Sub-plots: Methods of nutrient transfer were compared in a two-by-two factorial combination on sub-plots.

* Companion crop mowings were either left to fall on the companion crop rows
* Companion crop mowings deflected to fall on the vegetable rows.

* Composted livestock manure applied at 60 t/ha to potatoes, 15 t/ha to leeks and 30 t/ha to the other crops.
* No manure.

Sub-sub-plots: Seven crop rotation in the sequence:

Potatoes, alliums, umbelliferous crops, spring oats, legumes, brassicas and spring wheat. A range of varieties were grown.

There were 252 plots in total. Plot size at the lowest level was one bed wide, by 30 m long.

Figure 2. Cultivating crop strips in the companion cropping system at Wakelyns. North Field 2001.

Duration

Companion crops were sown in spring 1999 at the same time as the first vegetable crops. It was intended to continue the experiment for three crop harvest years, ending in 2001.

Machinery development

To establish and manage this system Martin Wolfe and his co-workers (P. J. & M. J. Wards) had for spring 1999 developed a range of purpose built machinery. (Table 1)

Table 1. Machinery developed at Wakelyns for managing the companion crop system.

Strip rotavator
3 row precision seed drill
Seed broadcast unit for rotavator
Straight tine strip cultivator with/without discs
L blade cultivator with vertical discs for cutting clover
Rotary strip mower with deflector for mowings
Strip irrigator
Strip compost spreader with deflectors

Whilst the basic versions of these machines were completed and working in 1999, development work continued through the life of the project, particularly aimed at more precise management of the companion crops, and improved seedbed preparation. Horizontal growth of clover stolons into the vegetable rows was better controlled by the development of lifting fingers and vertical cutting discs. This gave improved control of clover competition in the crop seedling stages. Seedbed preparation was improved by the development of a range of tines for the rotavator and cultivator. Photographs of the range of equipment as at August 2001, are included in Appendix 3, the Expert Group Report.

Assessments

Assessments were made on three crops; brassica, leek and carrot. To assess nutrient transfer, it was intended to measure vegetable total yield and nutrient uptake, soil mineral nitrogen at three times through the year and compost nutrient content. To assess economics, it was intended to measure vegetable marketable yield.

Results

In 1999, companion crops were sown on 17-18 March, and vegetable crops from 15 April (leeks) to 10 June (swedes). Wet weather in winter/spring led to difficulties in establishing the companion and vegetable crops due to delayed sowing, wet and cloddy seedbeds and soil compaction. Companion crops took most of the year to establish properly. Clover grew and survived much better than vetch. Difficulties of establishment were exacerbated by the discovery of areas of poor drainage resulting from a previously unknown old blocked-off tile drainage system, and by prolific weed growth in the wet conditions. Compost application was not possible as planned due to the wet conditions. As a result of these difficulties, the vegetable crops did not grow well. Total yields were very low (e.g. carrot 2.05 t/ha, leek 0.5 t/ha and swede 1.25 t/ha with clover companion crop). Plants were small and none was large enough to market. Insufficient crop was harvested to allow analysis for nutrient transfer.

In 2000, growth of weeds, particularly grass weeds and self-sown clover, in the vetch and nil treatments proved impossible to control adequately. Vetch did not persist and re-sowing was unsuccessful. The companion crop strips in the vetch and nil treatments became populated largely by grass weeds and self-sown white clover. At the July Steering Group meeting, it was agreed to discontinue further assessments on these two treatments.

Grass weeds, particularly creeping bent (*Agrostis stolonifera*) and couch grass (*Elytrigia repens*), were variably present in the white clover but, it was thought at that time, at a level that could be tolerated and managed using the improved machinery then available. Vegetable crops were planted on 8 April (leek seed), 9 May (carrot seed, delayed by wet conditions in April/May) and 23 June (cabbage transplants). However, the wet and mild conditions led to strong grass weed and clover growth while limiting possibilities for weeding and mowing. The leek and carrot suffered competition from the weeds and clover over large parts of the trials and the cabbages were affected by mammalian pest damage. For the second year, there was a very low total yield, and no marketable yield from any of the three test crops. It was therefore again not possible to assess nutrient transfer from the companion to the vegetable crops even though all planned soil and plant sampling and analyses were completed where feasible. As the whole site was affected by grass weeds, it was not feasible to switch the assessments to one of the other crops in the rotation.

At the December 2000 Steering Group meeting, after considering several options, it was decided to recommend to DEFRA that Experiment 1 be discontinued. This recommendation, along with an alternative programme of work for the final year of the project, was accepted by DEFRA.

Objective 2. To compare the competitiveness of four companion crops with three vegetable crops in a glasshouse pot experiment undertaken in one season.

Hypothesis

Companion crops can inhibit the growth of adjacent vegetable crops such that specific companion crop/vegetable crop associations will be required to make the system viable.

Treatments

In each of three glasshouse tray experiments, one vegetable crop was grown in various combinations with two companion crops. They were grown with and without root or aerial barriers to assess competitive mechanisms. To investigate possible allelopathic effects, a foliage extract of each companion crop was applied to the soil, at sowing, to vegetables grown alone. A full list of treatments is given in Tables 2 to 4.

Materials and methods

Three tray experiments were conducted in a glasshouse at Delflands Nurseries, Doddington, Cambridgeshire (Soil Association certificated). Each experiment compared one vegetable crop (Calabrese cv. Marner Large White, Carrot cv. Rothschild and Leek cv. Tadorna) with two companion crops (White clover: cv. AberHerald, AberCrest, AberDai, Alice and Riesling, and Vetch: cv. Winter Vetch). Trays were of dimensions 61 cm length x 41 cm width x 10 cm depth. Each tray was filled with 3 kg Vapogro organic peat compost. There were three rows of vegetable crop per tray alternated with two rows of the companion crop, with a spacing of 10 cm between rows and 10.5 cm between the outside rows and tray sides. Rows were parallel with the longest side of the tray. The crops were sown densely, then thinned after emergence to give a plant spacing of 2 cm.

Root barriers made of correx (corrugated plastic) were placed between the rows of vegetable and companion crop and were held in place by the compost. Aerial correx barriers (11 cm high) were placed between the crop rows by slotting into a correx lining placed along the sides of the tray, with the base of the barrier buried 1 cm below the compost surface.

To make the extract for treatments 16 and 17, clover and vetch were grown in pots in a glasshouse. For each species, 30 seeds were planted in each of 10 pots containing soil. The clover and vetch were harvested when they reached a height of 25 cm. The plants were washed, then placed in a food processor with de-ionised water and liquidised. The blended material was left to soak overnight to allow exudates to pass into the water, then filtered through muslin. The companion crop extract was applied using an Oxford precision sprayer fitted with 03 F110 even fan nozzles. The application rate of 1 litre per minute at a pressure of 2 bar equated to 20 sec per vegetable row.

For each experiment, treatments were arranged in a randomised block design with three replicate blocks of eighteen treatments including a double replication of the control (treatments 1 and 18). Seed was sown on 15 August; harvest was on 8 November.

Assessments

Vegetable and companion crop height, and vigour score were recorded fortnightly. At harvest, the centre vegetable row and both companion rows in each tray were harvested by cutting at compost level. The number of plants harvested was counted and the fresh weight recorded. A sub-sample was dried at 100^{o}C for 18 h and the dry matter yield calculated.

Results

In all three experiments, the vegetable and companion crops emergence and grew well.

Leeks

At the final vigour assessment, leeks were shorter when grown in combination with vetch than when grown alone, irrespective of barrier type (Table 2). At harvest, significantly lower weights recorded for leeks grown with vetch or clover compared with leeks grown alone, independent of barrier type. Dry weights for leeks plus companion crop extracts were similar to those recorded for leeks alone. No clear trends emerged for the effect of treatments on companion crop growth.

Table 2. Effect of companion cropping on leek and companion crop height (cm) and yield (g from centre row).

		Crop height (cm) 6 November		Fresh Weight (g)		Dry Weight (g)	
	Treatment	Leeks	Companion crop	Leeks	Companion crop	Leeks	Companion crop
1	Vegetable grown alone without restriction	46.0	-	86	-	8	-
2	Clover grown alone without restriction	-	22.3	-	457	-	62
3	Vetch grown alone without restriction	-	23.7	-	465	-	63
4	Clover and vegetable together	40.7	22.0	43	278	4	41
5	Vetch and vegetable together	35.3	23.7	19	458	2	65
6	Vegetable grown alone with root barriers	45.3	-	69	-	6	-
7	Clover grown alone with root barriers	-	23.0	-	324	-	44
8	Vetch grown alone with root barriers	-	25.3	-	572	-	80
9	Clover and vegetable together with root barriers	42.3	25.3	43	352	4	50
10	Vetch and vegetable together with root barriers	38.7	24.0	21	479	2	75
11	Vegetable grown alone with aerial barriers	53.7	-	86	-	7	-
12	Clover grown alone with aerial barriers	-	29.3	-	410	-	53
13	Vetch grown alone with aerial barriers	-	36.0	-	491	-	78
14	Clover and vegetable together with aerial barriers	45.3	25.7	33	241	4	33
15	Vetch and vegetable together with aerial barriers	35.7	36.7	16	531	2	81
16	Clover extract applied to vegetable grown alone	47.0	-	65	-	6	-
17	Vetch extract applied to vegetable grown alone	41.7	-	52	-	5	-
18	Vegetable grown alone without restriction	47.7	-	73	-	7	-
sed (df=22)		3.40	2.00	11.6	57.8	0.9	8.1
P		<0.001	<0.001	<0.001	0.001	<0.001	<0.001

Calabrese

There was no effect of treatment on the height or vigour of calabrese, or of fresh weight at harvest (Table 3). There was a significant treatment effect on dry weight at final harvest (P<0.05) but no clear treatment trend was apparent. In contrast, there was a marked effect of treatment on height, vigour and dry weight of the companion crops. Both companion crops, when grown with calabrese, were around 50% shorter, showed less vigour and yielded as little as 10% of the dry weight of clover or vetch grown alone; this trend was apparent irrespective of barrier type.

Table 3. Effect of companion cropping on calabrese and companion crop height (cm) and yield (g from centre row).

		Crop height (cm) 6 November		Fresh Weight (g)		Dry Weight (g)	
	Treatment	Calabrese	Companion crop	Calabrese	Companion crop	Calabrese	Companion crop
1	Vegetable grown alone without restriction	36.3	-	483	-	55	-
2	Clover grown alone without restriction	-	25.7	-	398	-	54
3	Vetch grown alone without restriction	-	23.3	-	606	-	78
4	Clover and vegetable together	39.3	8.7	641	16	72	3
5	Vetch and vegetable together	39.7	11.0	514	27	60	6
6	Vegetable grown alone with root barriers	42.7	-	619	-	67	-
7	Clover grown alone with root barriers	-	23.7	-	340	-	45
8	Vetch grown alone with root barriers	-	25.7	-	508	-	68
9	Clover and vegetable together with root barriers	39.6	11.7	543	24	55	4
10	Vetch and vegetable together with root barriers	40.7	28.7	644	69	76	12
11	Vegetable grown alone with aerial barriers	44.7	-	693	-	86	-
12	Clover grown alone with aerial barriers	-	27.3	-	274	-	35
13	Vetch grown alone with aerial barriers	-	36.0	-	459	-	62
14	Clover and vegetable together with aerial barriers	40.3	10.7	614	22	67	3
15	Vetch and vegetable together with aerial barriers	40.7	27.0	445	88	54	17
16	Clover extract applied to vegetable grown alone	36.0	-	561	-	58	-
17	Vetch extract applied to vegetable grown alone	38.0	-	530	-	57	-
18	Vegetable grown alone without restriction	35.7	-	511	-	56	-
sed (df=22)		3.52	3.21	77.8	56.4	8.4	1.7
P		NS	<0.001	NS	<0.001	0.014	<0.001

Carrots

Carrots grown with clover or vetch, with no barrier, or root barrier, were shorter and had a lower dry weight than carrots alone (Table 4). Companion crop heights and dry weights were lower when grown with carrot, compared with companion crops grown alone.

Table 4. Effect of companion cropping on carrot and companion crop height (cm) and yield (g from centre row).

	Treatment	Crop height (cm) 6 November Carrots	Crop height (cm) 6 November Companion crop	Fresh Weight (g) Carrots	Fresh Weight (g) Companion crop	Dry Weight (g) Carrots	Dry Weight (g) Companion crop
1	Vegetable grown alone without restriction	48.3	-	242	-	28	-
2	Clover grown alone without restriction	-	21.7	-	404	-	50
3	Vetch grown alone without restriction	-	20.7	-	509	-	72
4	Clover and vegetable together	42.7	18.3	156	142	19	21
5	Vetch and vegetable together	41.3	19.7	120	197	16	31
6	Vegetable grown alone with root barriers	52.0	-	260	-	30	-
7	Clover grown alone with root barriers	-	23.7	-	379	-	50
8	Vetch grown alone with root barriers	-	22.3	-	440	-	60
9	Clover and vegetable together with root barriers	38.0	16.0	161	111	19	16
10	Vetch and vegetable together with root barriers	34.0	19.0	128	188	17	32
11	Vegetable grown alone with aerial barriers	46.7	-	224	-	31	-
12	Clover grown alone with aerial barriers	-	32.3	-	356	-	45
13	Vetch grown alone with aerial barriers	-	36.3	-	489	-	68
14	Clover and vegetable together with aerial barriers	50.3	18.7	216	78	29	13
15	Vetch and vegetable together with aerial barriers	45.0	26.3	161	149	22	25
16	Clover extract applied to vegetable grown alone	46.0	-	251	-	30	-
17	Vetch extract applied to vegetable grown alone	46.7	-	248	-	29	-
18	Vegetable grown alone without restriction	42.7	-	213	-	28	-
sed (df=22)		3.90		2.16		38.7	
P		0.007	<0.001	<0.001	<0.001	<0.001	<0.001

Discussion

The competitive effects observed in the three experiments varied with vegetable crop. For leeks, both companion crops, but especially vetch, exerted a competitive effect that markedly reduced leek growth and yield. Since leek yield reduction was irrespective of barrier type, it is likely that there was competition both above ground for light and also in the soil for moisture and/or nutrients. Conversely, companion crop development was not inhibited by the association with leeks. These results are in agreement with comments from a NIAB feasibility study (5) suggesting that since leeks and alliums are slow to emerge and establish when direct drilled, they could experience serious competition from companion crops, particularly well-established swards. In the calabrese experiment, it was the companion crops rather than the vegetable crop that were severely affected by competition. Again, the lack of barrier effect suggests that general competitive effects for moisture, light and nutrients were responsible for the negative effect on companion crop development. In the carrot experiment, reduced carrot growth only when no barriers or root barriers were in place, suggests that competition was largely for light rather than moisture or nutrient factors. Carrots reduced companion crop growth suggesting that they are intermediate between calabrese and leeks in susceptibility to competition.

The results support the hypothesis that companion crops can inhibit the growth of adjacent vegetable crops such that specific companion crop/vegetable crop associations will be required to make field-scale companion cropping systems viable.

The lack of a response to the companion crop extracts suggests that, at least for the combinations tested, there was no allelopathic effect. However, shoot extracts are unlikely to function in the same way as natural root exudates and it is feasible that these latter could have played a role in reducing influencing vegetable and companion crop growth but it was not possible to differentiate this from other competitive effects in these experiments.

Objective 3. To evaluate the use of cover crops and applied approved nutrients in the vegetable crop strips for additional nutrition in two seasons.

For Objective 3, a field experiment was established in Home Field at Wakelyns. This was due to run for two cropping seasons; 2000 and 2001.

Layout, design and treatments

The layout and general management was as for the adjacent experiment 1 as described previously.

The experiment was a randomised block split-split-split plot, with two replicates.

Main plots: Companion crops

* White clover
* Common vetch

Sub-plots: Winter cover crops in the vegetable strips

* Nil
* Rye
* Common vetch
* Rye and vetch mixed

Sub-sub-plots: The same seven course crop sequence was grown as in experiment 1 but assessments were made on only two crops:

* Brassica
* Allium

Sub-sub-sub-plots: Additional nutrients

* Nil
* Phosphate at 90 kg/ha as Reddzlaag
* Phosphate at 180 kg/ha as Reddzlaag
* Potash at 125 kg/ha as Kali Vinasse
* Potash at 250 kg/ha as Kali Vinasse

This gave a total of 160 plots.

Assessments

Intended assessments included vegetable total yield and nutrient uptake, and soil mineral nitrogen at three times through the year.

Companion crops were established in 1999.

Vegetable crops were sown in spring 2000. The experiment was adjacent to Experiment 1 described above and vegetable establishment and growth was severely affected by competition from grass weeds and clover. As for Experiment 1, there was a very low total yield and no marketable yield from the vegetables. It was therefore again not possible to assess nutrient transfer from the companion to the vegetable crops even though all planned soil and plant sampling and analyses were completed where feasible.

At the December 2000 Steering Group meeting, after considering several options, it was decided to recommend to DEFRA that Experiment 3 be discontinued. This recommendation, along with an alternative programme of work for the final year of the project, was accepted by DEFRA.

Objective 4. To determine the effects of a fertility-building companion crop, grown on a permanent bed/strip system on the nutrient accumulation, and incidence of damage caused by pest and disease in three major vegetable crops over three seasons.

The intention of Objective 4 was to apply the system developed at Wakelyns on a farm scale to allow an assessment of the pest and disease control potential of companion crops in single-species cropping on a large scale.

In practice, as described above, it took longer than one year to develop the system at Wakelyns. As a result, only one set of machinery was available by 2000 and it could not leave Wakelyns for use on a remote site as it was needed there almost daily, therefore these experiments were done largely using hand-tools. Also, for the same reason, companion crops could not be established in advance and were sown at the same time as the vegetables.

Materials and methods

Two experiments (carrots and Brussels sprouts) were done at Bagthorpe Farm, Bagthorpe, King’s Lynn, Norfolk on land registered with the Soil Association.

For the carrot experiment, three rows of carrots cv. Nairobi were drilled per 1.8 m bed, at 56 cm apart, using a Singulaire (Stanhay) drill to give a seed rate of 1.6 million seeds/ha. The carrots were sown late (16 May) following normal organic practice, to avoid the first generation of carrot fly. On the same day, companion crops were sown by hand in 20 cm strips between the carrot rows. For the Brussels sprout experiment, two rows per 1.8 m bed, at 90 cm apart, were transplanted using a Vegrow planter. The Brussels sprouts were planted late (19 June) due to delays in the supply of plants from the propagator. On the same day, 30 cm-wide strips of companion crops were sown, as for the carrot trial, between the sprout rows.

The clover comprised a mixture of five white clover varieties (AberHerald, AberCrest, AberDai, Alice and Riesling) in equal proportions by weight and was sown at a rate of 10 kg/ha to give a target population of 500 plants/m^2. The vetch was sown at 100 kg/ha to give a target population of 100 plants/m^2. The aim was to mow the companion crops to 5 cm each time they grew to 15 cm using a petrol mower or strimmer.

Each experiment was established as a randomised block design with seven replicates per treatment. Each plot comprised five beds, each of 1.8 m width, by 12 m length.

Treatments

1. Vegetables grown with a white clover companion crop.
2. Vegetables grown with a vetch companion crop.
3. Vegetables grown alone with no companion crop.

Assessments:

Carrots

The incidence of pest and disease damage, and other disorders was recorded. At harvest, 4.5 m of the middle row of one bed in each plot was lifted and washed. The number and weight of marketable and unmarketable roots in each size grade (<19, 19-25, 26-32, 33-44 and >44 mm), were recorded.

Brussels sprouts

The incidence of pest and disease damage, and other disorders was recorded. At harvest, all the Brussels sprout plants from two rows (6 m length) were harvested. The fresh weight of whole plants per plot was recorded. The buttons were removed, and the number and weight per size grade (<11, 11-22, 22-30 and 30-40 mm) was recorded.

Statistical analyses

The results were analysed using analysis of variance (Genstat) using angular transformations when data did not conform to the assumptions of ANOVA.

Results and discussion

Companion crop establishment was very slow, probably not helped by the relatively late sowing into dry conditions in the sandy soil at Bagthorpe. Weeds out-grew the companion crops in the early stages; they were difficult to control adequately with strimmers and hand-weeding and there was probably some yield reduction in both experiments from weeds. Clover eventually developed a dense canopy, but the final plant stand for vetch was lower than anticipated with a mean of 80 rather than 100 plants/m^2.

Carrots

There was a tendency for yields in the larger size grades to be higher for carrots grown with no companion crop compared with carrots grown with clover (Table 5). A similar trend was observed for the total yield; at P=0.052 this was only just outside the conventional minimum 95% probability of there being a real treatment effect.

Table 5. Yield (t/ha) of carrots at harvest

Companion crop	Size grade <19 mm	 19-25 mm	 26-32 mm	 33-44 mm	 >44 mm	Total
Clover	0.06	0.56	3.14	4.63	2.96	11.4
Vetch	0.03	0.48	2.53	6.04	4.11	13.3
Nil	0.06	0.32	2.94	7.08	5.69	16.1
SE (12 df)	0.023	0.082	0.294	0.665	0.749	1.22
P	0.581	0.148	0.357	0.068	0.069	0.052

The incidence of common scab (*Streptomyces scabies*) was significantly higher ($P<0.05$) at harvest on roots from the clover companion crop; 0.4% compared with nil or vetch companion crops, both at 0.0%. The mechanism for this is unclear. It is possible that the dense clover cover may have altered the soil environment in such a way that facilitated scab infection, which is known to proliferate under dry conditions at higher pH levels. However, the levels were very low and this may not be a substantive result. There was a trend for higher numbers of roots scoring class 2 cavity spot (*Pythium violae*) damage from the nil companion crop treatment. Overall, there was a higher cavity spot damage index for the nil companion crop treatment compared with the clover and vetch treatment ($P=0.054$). Although marginal, the slight suppression of cavity spot on roots cropped with clover and vetch was in agreement with previous research by Theunissen & Schelling (6) who observed a more dramatic suppressive effect over four consecutive growing seasons. They suggest two possible mechanisms for the observed effect; firstly, a change in the crop plant physiology may render the crop less suitable to pathogen attack; alternatively, a shift in the soil microflora due to the presence of companion crops may enhance endophyte activity and thus plant defence mechanisms. The same authors report that clover companion cropping can also significantly reduce carrot fly attack. There was no significant effect of treatment on carrot fly damage, but overall levels were very low so may have masked any effect.

<u>Brussels sprouts</u>

There was no effect of treatment on the number of leaves per plant, button size or the total plant weight at harvest. Button total yields were very low, averaging only 1.5 t/ha, probably mainly due to the delayed planting. There was no effect of treatment on the yield of buttons by size grade or in total. There was no effect of treatment on numbers of caterpillars present on the crop, on caterpillar damage, on mean aphid damage or on cabbage root fly damage during the growth. There was also no effect of treatment on button damage at harvest due to cabbage mealy aphid, caterpillars, cabbage moth, slug/snail, cabbage root fly, *Alternaria* spp., ringspot, or white blister.

Conclusions

The very late development of the companion crop canopy, late planting and difficulties in adequately controlling weeds meant that these experiments were not a meaningful assessment of the pest and disease suppression potential of a companion crop. However, there were effects of companion crop on carrot yield and quality that could be of commercial significance. Further experiments in an established companion crop are needed to verify these effects.

Objective 5. To assess nutrient transfer and crop yield in leeks grown in a white clover companion cropping system.

Objectives

1. To accurately assess the levels of nutrient transfer from a clover mulch in an intercropping system.

2. To compare mulching *in situ* with transfer to vegetable rows at two mowing frequencies.

3. To accurately measure vegetable crop yield, companion crop yield and nutrient transfer. Leeks were chosen as they are relatively nutrient-responsive and from observations in 1999 and 2000, relatively resistant to bird and mammal damage.

Site

The experiment was in North Field at Wakelyns Farm in 2001. The intention was to have two identical experiments; one on a bed where lettuce was grown in 2000, representing an established system (Experiment A) and one on a bed where potatoes were grown in 2000, representing an annual cropping system (Experiment B). In contrast to the other crops, potatoes are grown after ploughing-in the clover which is then re-established post-harvest. Hence this is more similar to an annual rather than perennial clover companion crop. Unfortunately, the clover failed to establish after the potatoes. In its place, Experiment B was grown after red beet. Red beet was higher yielding than lettuce in 2000 so this should have given a contrast in residual fertility.

Treatments

1. Control - clover removed mown and cuttings removed (complete removal of plants was intended but found to be impractical)
2. Clover cut and placed back in the clover rows at weekly intervals.
3. Clover cut and placed back in the clover rows at monthly intervals.
4. Clover cut and placed back in the vegetable rows at weekly intervals.
5. Clover cut and placed back in the vegetable rows at monthly intervals

Design was a factorial of two mowing frequencies and two methods of placement of mowings, plus a control. There were five replicates. The plots were 6m long, and one bed wide (1.5 m). Each bed comprised 3 rows of the vegetable crop (20 cm wide) and 3 rows of companion crop (30 cm wide). The companion clover crop was established from a seed mixture of the five white clover varieties detailed in Objective 4, sown at 8-10 kg/ha, to give a target plant population of 500 plants/m^2. Clover was mown using an electric rotary lawn mower. All mowings were collected.

The Leeks were cv. Carentin 3, transplanted on 4 May at 12.5 plants per metre of row.

Assessments

Soil was sampled within the vegetable rows and analysed for soil mineral nitrogen both pre-planting and post harvest of the leeks.

At each mowing, the total fresh weight of mown clover per plot was recorded. A sub-sample of 100g of mown material was taken from each plot and dried at 100^{o}C to assess dry matter and total N, P and K content. The remainder of the mown clover was spread either on the vegetable rows or clover rows, dependent on the treatment.

At harvest on 9 October, all leeks in 2 rows by 5 m length were harvested from each plot. The whole plants were transported to ADAS Arthur Rickwood where the roots and soil were removed and the total number and weight recorded. A sub sample of 400g of clean dry leeks was taken. The leeks in the sub-sample were chopped and dried at 100 ^{o}C for 18 hours. Dry matter yield was calculated and sub-samples analysed for total N, P and K.

Results and discussion

Clover was uniform across the experiments and there were few weeds. It grew well with mean accumulated total nitrogen of 220 kg/ha N in experiment A and 260 kg/ha N in experiment B. Leeks established well with few losses but were subject to rabbit grazing, particularly in early growth when there were few other vegetables emerged. In Experiment B, with weekly mowing, clover yield increased almost linearly, at an average of 350 kg DM/ha per week, from the first mowing on 15 May until late August. In September, yield declined to around 100 kg DM/ha per week. Accumulated clover dry matter was greater from weekly than monthly mowing

(Table 6). At the first mowing, clover N content were similar; at all later cuts N content was higher in weekly compared with monthly mowing. As a result accumulated nitrogen was around 50% greater from weekly mowing. Results were similar in Experiment A.

Table 6. Effects of mowing frequency on accumulated clover yield and nitrogen content (Experiment B).

	Weekly	Monthly	P
Accumulated yield t DM/ha	5.8	4.6	<0.001
Nitrogen % in clover DM*	5.5	4.6	<0.001
Accumulated nitrogen kg/ha	323	200	<0.001

* Average excluding the first mowing on 15 May.

Leek fresh weight yield was similar from the two experiments (3.2 t/ha from experiment A and 3.4 t/ha from Experiment B). There was no effect of treatment on leek yield or nitrogen uptake in Experiment B. In Experiment A, placement of mowings had no effect but there was a greater yield and nitrogen uptake of leeks when clover was mown monthly compared with weekly, irrespective of placement of mowings (Table 7). Observations suggested that this was probably not a direct treatment effect but as a result of less rabbit grazing of leeks in the monthly mown clover as the leeks in the weekly mown strips were more obvious and accessible to rabbits.

The very low yields suggest that factors other than residual fertility were dominant. The quantity of nitrogen recovered in the leeks was less than 10 kg/ha and was significantly less than the pre-planting SMN (38 kg/ha N 0-90 cm in Experiment A and 46 kg/ha N 0-90 cm in Experiment B). The calculated nitrogen mineralisation (leek N offtake plus post-harvest SMN, minus pre-planting SMN) was therefore negative for all treatments in both experiments. The missing nitrogen, plus N mineralised from the total N added (up to 300 kg/ha) to vegetable rows as cut clover, was probably competitively taken-up by the clover. This massive effect swamped any effects of previous crop or mowing treatment.

Table 7. Effect of mowing frequency on leek yield, N uptake and N mineralisation (Experiment A)

Treatment	Leek fresh yield t/ha	Leek dry matter yield t/ha	Leek N offtake kg/ha	N mineralisation kg/ha
1 Control	2.3	0.31	5.0	-24
2 Clover mown weekly	2.7	0.32	6.1	-21
3 Clover mown monthly	4.2	0.51	9.0	-19
SE (13 df)	0.49	0.061	1.05	1.1
P	0.009	0.006	0.014	0.028

Conclusions

Competition from clover for SMN led to very poor growth and yield of transplanted leeks. This supports the results of the glasshouse experiment described above (Objective 2) and confirms that leeks are not a suitable crop for such an intimate association with a companion crop.

Objective 6. To review the literature on nutrient transfer in companion cropping and construct a model to predict nutrient transfer and crop productivity.

Literature review

The literature was reviewed for effects for nitrogen transfer between companion crops and associated cash crops. Possible mechanisms reviewed for the transfer of nutrients from the companion ('donor') to cash ('receptor') crop included: mineralisation of foliage cuttings and crop residues (above ground); mineralisation of root material (below ground); rhizodeposition, the loss of organic materials from roots as they grow through the soil; and direct transfer via mycorrhizal connections between the plants (below ground). In summary, the conclusions were:

- There is little direct N transfer (via rhizodeposition and mycorrhizal interactions) that is of agronomic significance in companion cropping systems.
- The indirect route of nutrient transfer via the mineralisation of dead root and shoot material (following defoliation/suppression) is more important.
- Forage legumes have the greatest potential as a companion crop as they obtain over 90% of their N from atmospheric fixation compared to just 50% by grain legumes. This provides a greater net N contribution to the system by 'freeing' more soil N for the associated crop.
- There is little quantitative information on nutrient transfer in companion cropping systems. Many factors will affect the amount available for transfer including legume species, age and management, soil nutrient supply, soil microbial mineralisation and immobilisation and residue quality.
- Much of the N released may be either immobilised within the soil microbial biomass or recycled back to the leguminous crop (which itself may inhibit N fixation). This makes the accurate quantification of the amount transferred difficult to assess.

Modelling of N mineralisation

To make some estimates of the likely return of N in clover and its dynamics of release following cutting and mulching, a small modelling exercise was undertaken. This used early season data on clover dry matter and % N content collected from the leek experiments at Wakelyns (Objective 5). Using these data, three models were used to estimate the amounts and patterns of N release from the applied plant material: SUNDIAL, WELLN and the Jenkinson equation. Only data from the plots where the mown clover was returned to the leek rows were used (i.e. avoiding any possibility of double accounting for N in clover from previous cuts that may have been re-collected). In summary, the conclusions were:

- Measurements of clover (above-ground) dry matter returns showed that weekly cutting and mulching returns more N than monthly cutting and mulching.
- Regardless of the cutting frequency, all models suggest that c.70-75% of the residue N will be mineralised within the first year after cutting.
- The models showed reasonable general agreement in these estimates.
- The pattern of release would depend on the temperature and moisture regime of the soil, however, and also differs between models.
- The models assume the residue is ploughed into the soil: they have not been validated for surface applications and the pattern and rate of mineralisation could be different for mulched residues.
- Using this approach, it was not possible to account for below ground release and transfer.
- As a first step, however, the desk study has given some useful information on amounts and timescale of N release.

A copy of the full literature review, and detail of the modelling, is attached as Appendix 1. A key point, however, is that this modelling exercise did not take any account of the potential recycling of released N back through the clover: clearly the field experiments showed that this competitive effect was overwhelming.

Objective 7. To assess the economics of an established companion cropping system in North Field at Wakelyns Agroforestry.

Observations and data collected through 2001 were collated to give an overview of the performance of the vegetable-clover inter-crop system in the second season of production in North Field. Records used include yield and sales data collected by those involved in harvesting and marketing (M Gaze, A Wolfe), cultivation costs from P J and M J Wards, contracting data and other observations and sampling completed during the season (M S Wolfe with assistance).

1. Plant establishment was often low, at least partly due to the late, wet spring. It may have been improved by a wider use of transplants but that would have increased costs.

2. Alliums, carrots, legumes and some brassicas such as Brussels sprouts performed poorly in both 2001 and 2000, with nil or very low harvestable yields. Beta species, swede, some cabbages, parsnips, turnips and lettuce have performed well with the yields of the best varieties similar to organic expectations in more conventional growing systems.

3. For most species, there were considerable differences in the performance between varieties, but it was not clear whether this variation was related to soil, site or system or to interactions among these factors.

4. Pest problems were limited to larger animals – hares, rabbits and pheasants.

5. A range of vegetable crop diseases was present, but none was of significance for vegetable quality or yield.

6. Clover occupied much of the space that would otherwise have been occupied by weeds. Hand weeding was confined largely to onion sets and to restriction of thistles and broomrape. Mechanical cultivation was used regularly both for weeding and soil nutrient mineralisation.

7. Some crops produced a positive return against production costs, others did not, mostly related to low crop yields. The major cost, as with all vegetable enterprises, was the labour involved in harvesting and marketing. The use of seed rather than transplants reduced costs. Cultivation costs were a relatively small proportion of overall costs, but they could be further reduced.

8. A simple gross margin analysis based on a best case scenario, calculated using the best cultivars of the most suited crops, indicated a return similar to average production of organic field vegetables in more “conventional” cropping systems.

9. Observations from the two seasons suggest that some crops are competitive with clover and therefore intercrop well, while others are less competitive. The range of useful crops and varieties could be extended by agronomic modification of the interaction and by selection (and ultimately by breeding) for crop varieties adapted to clover intercropping.

A copy of the full report is attached as Appendix 2.

Objective 8. To form an Expert Group to review progress and to consider the role of companion cropping systems in organic farming. To include manager of project OF0173.

Objectives

1. To consider the applicability of companion cropping in its present form to commercial production at a range of enterprise scales (from small box schemes to large field scale units).
2. To consider future development that needs to be made in order for this approach to be commercially viable.

Membership

The group members were selected to include a wide range of expertise, including commercial growers, advisers, researchers, policy makers and research funders. In total, the group comprised thirteen members:

Dr. Bob Clements (IGER). Researcher.
Dr. Bill Cormack (ADAS). Researcher and Project Leader.
Mr. Andrew Dennis. Commercial Grower (large scale).
Mr. Guy Donaldson (IGER). Researcher.
Mr. Roger Hitchings (EFRC). Adviser.
Ms. Lorna Jackson (HDRA). Researcher.
Mr. Mark Measures (EFRC). Adviser.
Mr. Mel Myers (Marshalls of Butterwick). Commercial Grower (Large scale).
Mrs. Marina O'Connell. Lecturer and grower (small scale).
Dr. Mark Shepherd (ADAS). Soil Scientist.
Dr. Roger Unwin (DEFRA). Policy and research.
Dr. James Welsh (EFRC). Researcher.
Prof. Martin Wolfe (EFRC). Researcher and grower (small scale).

The group met at Wakelyns on 31 July 2001. The meeting comprised a briefing on the background to the work, a visit to the field and machinery used followed by a discussion.

Discussion and conclusions

1. Is there potentially too much nitrogen in the system?

This is a function of the ratio of clover to crop in the system. The reason for the current proportions are to maximise the confusion of pests. This could be adjusted to take account of the crops' nitrogen requirements, but there is no information available to determine what the optimum should be. Clearly, a range of factors including soil type, soil fertility and climatic conditions will affect this. The other issue relating to the proportion of clover is that of competition for water and other nutrients. It was suggested that certain clover varieties (e.g. small-leaved) might be better suited to this type of system than others. Also, other species such as trefoil could be considered as companion crops. Further work is needed to address these issues.

2. Would transplants be better than growing from seed?

The large-scale commercial growers considered that transplants would perform much better than crops grown from seed. This would be particularly important on silt soils that tend to cap, as emergence can be seriously inhibited. Also, the transplants would be much more competitive. The difficulty with transplants relates to cost as they are much more expensive than seed, although this may be more than compensated for by better crops.

3. Choice of Species

It was clear that some species and varieties were better suited to this type of system than others. For example, the beets appeared to be performing well, whilst onions seemed to be suffering from competition with the clover. Therefore, if this approach is to succeed, it is important to establish which species and varieties should be included, and more importantly, which should not.

4. Soil type and seedbed conditions

There was some concern over seedbed quality. Many of the group thought that the seedbed tended to be too coarse. This could be partly due to the problems associated with cultivating narrow strips. However, another reason could have been the very wet weather that was encountered during cultivations. Again, using transplants could overcome this problem, as they would be more tolerant of a range of seedbed conditions. The experiments at Wakelyns were conducted on clay soils, but a number of the group felt that the system may work better on lighter soil types where it would be easier to establish small-seeded crops and also better suited to growing root crops.

5. Slugs

A number of the group were very concerned about the potential for serious slug damage, since the clover provides an excellent habitat for the slug population to multiply. This, however, had not been a problem, as the slugs appeared to be happy to stay in the clover strips rather than venturing out into the crop rows.

6. Commercial viability

In general, the group considered that, at present, companion cropping was better suited to small-scale production serving local markets. The large-scale producers were concerned about the level of input required to manage the clover and crops. Individual species are sown on a single row basis, but this would present major difficulties for large-scale enterprises in terms of harvesting. To overcome this, single species would need to be established either on a bed system or in larger scale blocks. However, this moves away from the concept of increasing diversity to minimise pest, disease and weed problems. Also, the crops are being harvested by hand so mechanisation of this process would be important for field-scale production.

A copy of the full report is attached as Appendix 3.

Conclusions

Companion cropping has the potential to improve economic viability, and pest, disease and annual weed control in organic cropping systems, particularly in field vegetables which are not supported by Set aside payments for fertility-building crops under the Arable Area Payment Scheme. However, in practice, in project OF0181 these benefits were not realised:

- Grass weeds were favoured and were difficult to control once established.
- There were problems with seedbed preparation and crop establishment. These could be more reliable on a lighter soil type.
- Some crop species were better suited to companion cropping. In 2000 and 2001, there was:
  - a high yield in both years from beetroot, spinach, chard and kale;
  - a high yield in one year from Brassicas (some cabbage, swede, turnip), endive, lettuce, parsley and parsnip;
  - a low yield in both years from Allium crops (leeks, onions), Brassica (sprouts, some cabbage, calabrese), carrots, celeriac, broad and dwarf beans.
- Clover used soil available nitrogen in preference to fixed nitrogen, starving less competitive crops such as alliums of the nutrient and resulting in very low yields.
- Even with reliable yields, companion cropping in the form tested may only be suited to small-scale labour-intensive production.
- A system with greater spatial separation of companion and vegetable crops, with vegetables and companion crops grown alone in separate beds or strips, may give the reported benefits of companion cropping with less competition and be practical for large scale production.

Possible future work

Following the review of DEFRA organic farming research in July 2001, a concept note was submitted to DEFRA jointly by ADAS, EFRC and HDRA. This proposed a grower-participative study comparing a range of options for mixed species cropping including more spatially-separated strip cropping which may realise some of the advantages of companion cropping without the severe competition encountered with several crop species in OF0181. Such a system would not need specialised machinery and so could be more attractive to larger-scale growers.

Implications for DEFRA policy

The results of OF0181 show that companion cropping cannot yet be a recommended commercial technique for reliable production of field vegetables. Further research along the lines suggested above may result in practical and reliable systems. Until that work is done, improved economics of production will have to be achieved by other routes.

Publications and press articles arising from this project

'Crop diversity as an essential tool for productivity' by **M. S. Wolfe**, presented at Soil Association event at Sheepdrove Farm, 9 March 2000.

'Functional biodiversity in organic agriculture' by **M. S. Wolfe**, contribution to 'Organic Farming: towards a benign environment', SAC, Edinburgh, 5/6 April 2000.

'Companion cropping for organic field vegetables' **M. S. Wolfe and W. F. Cormack**, poster presentation at IFOAM 2000, Basel, August 2000.

'Opportunities for managing plant diseases in organic farming through functional diversity' Finckh, M. R., Mundt, C. C**., Wolfe, M. S.** presented at IFOAM 2000, Basel, August 2000.

'The missing chapter in the development of organic agriculture' by **M S Wolfe**, presented at Advanta Seeds Day at Chilford Hall, Linton, 16 November 2000.

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Appendices

1. Nitrogen transfer from companion crops: a literature review and computed modelling exercise.
2. Production data and economic analysis of the companion cropping system in North Field at Wakelyns Agroforestry.
3. Report of the Expert Group.

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