MINISTRY OF AGRICULTURE, FISHERIES AND FOOD

Research and Development

CSG 15

Final Project Report

(Not to be used for LINK projects)

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Project title	Testing the sustainability of stockless arable organic farming on a fertile soil
MAFF project code	**OF0145**
Contractor organisation and location	ADAS Consulting ltd, ADAS Terrington Terrington St Clement, King's Lynn, Norfolk PE34 4PW.
Total MAFF project costs	£ 540,901
Project start date	01/04/98
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Executive summary (maximum 2 sides A4)

If organic farming is to expand in the arable east of England, where the knowledge, infrastructure and capital for livestock are not available, viable stockless systems will be needed. The policy relevance to MAFF is to help identify sound methods of organic farming, limiting factors and ways of overcoming them. The aim is to maximise economic performance and in turn encourage conversion. Project OF0112 showed that a stockless arable rotation was consistently more profitable that a comparable conventional rotation on the fertile silty clay loam at ADAS Terrington. Project OF0145 researched challenges to sustaining that level of performance into the second crop rotation. These include management of nutrient supply, perennial weeds and soil borne pests and diseases. The project was a combination of systems comparison, replicated experiments and monitoring of commercial farms. A steering group consisting of representatives of MAFF, Soil Association, Elm Farm Research Centre and three farmer members guided the project.

The core of the project was an unreplicated systems comparison with field-scale plots to allow meaningful study of patchy problems such as perennial weeds and give confidence to farmers that the system could work on a farm scale. Conversion was completed in 1995 and the rotation has since been clover, potatoes, winter wheat, spring beans, undersown spring barley. Ten hectares has been in this rotation throughout. In the remaining 2.5 ha, potatoes were replaced by field vegetables from 1998. There were five plots in each rotation and a different phase of the rotation was grown in each plot. In the commercial Linked-farm study, costings were done to a net farm income level and compared with results for similar conventional farms from Farm Business Study data. Results were compared with the Terrington organic and conventional crop rotations.

The greatest agronomic challenges continued to be with the establishment of fertility-building legumes. Patches of poor clover growth of red clover first seen in spring 1998 were due to stem nematodes, Ditylenchus dipsaci. Red clover has been replaced by broad-leaved white clover which has so far proved resistant to the

race(s) present and has grown well. In 1999, clover was replaced by vetch when poor seedbed consolidation led to a failure to establish. Despite these problems, crop yields have been maintained with good rolling average yields of 25 t/ha for potatoes, 7.5 t/ha for winter wheat, 3.5 t/ha for spring beans and 4.1 t/ha for spring cereals.

Disease levels in cereals have remained low and posed minimum threat to yields. Slugs and blight have affected potatoes in wet years; control of these is particularly difficult in an organic system leading to greater yield variability than would be expected in a non-organic rotation. Calabrese has grown and yielded well with few problems but weed control in onions proved both difficult and expensive and they have been dropped in the successor project OF0301. Weighted rolling-average gross margins show a consistent and large advantage to organic (£912/ha conventional, £1757/ha stockless with potatoes and £1148/ha stockless with vegetables). The advantage to organic has increased with time as yields and prices have been maintained whilst conventional crop prices have fallen.

Soil fertility as measured by carbon and nitrogen contents has shown little change since the start of conversion in 1990. The lack of a marked increase is not unexpected, as returns in crop residues were not significantly greater than in the conventional cropping replaced. Soil available P and K have remained at ADAS Index 1 to 2 despite continued crop offtakes. However both are showing a slow progressive decline, less so with P, perhaps partly due to the rotational applications of Aluminium Calcium Phosphate. Annual weeds are proving relatively easy to control, being worst where crop growth is poor for reasons such as compaction on headlands. However, the perennial weeds couch grass, creeping thistles and docks are an increasing problem. Hand pulling of thistles and docks is containing the problem but the cost of this has risen dramatically in the last two years. Winter cover crops have been replaced with cultivated fallow as an additional control measure and may need to change to wide rows and tractor-hoe cereals if the trend continues.

Crop yields on ten monitored organic Linked-farms were similar to Terrington apart from winter wheat which averaged only 3.9 t/ha. Input costs, crop husbandry and sale prices were also similar to Terrington. However, the overall gross margins of the Linked-farms were lower, principally because of their higher proportion of fertility building crops and the general lower profitability of livestock enterprises. The profitability of the monitored farms relative to conventional has increased with time, largely due to the fall in conventional prices whilst organic prices have remained steady.

In experiments from 1996 to 1999, spring wheat gave an average yield of 4.01 t/ha compared with 4.45 t/ha from spring barley and 4.95 t/ha from spring oats. Generally higher prices for barley versus oats resulted in very similar gross margins from these two crops. All crops were undersown but problems with establishment and stem nematodes meant that only in 1997 could the follow-on performance of the undersown legume be assessed. In the 1997 cereal crops, at harvest there were 174 kg DM/ha of clover under barley compared with 88.5 kg DM/ha under wheat and only 4.5 kg DM/ha under oats, illustrating the greater competitive effect of the denser oats crop canopy. When assessed in May 1998, there were no differences suggesting that having sufficient plants established is more important than how large these plants are at cereal harvest.

Couch grass was mapped on three sites on five occasions from 1999. At two sites there was a high and stable population that showed little change in spatial distribution with time. At Terrington where there was a lower and more variable population, there was a marked decrease in the number of sampling points with couch (from 50 to 20%) following undersown barley. There was little change in mean shoot number during this period but it increased sharply (from 3 to 15 shoots m^{-2}) following the mulching of the clover during the following year. Similar effects were seen at one of the other sites suggesting that it should be possible to derive improved management guidelines for couch control in arable systems. However, these preliminary conclusions need further verification. One field experiment was done in 2000 to compare cutting regimes for clover for the control of creeping thistles. Post-treatment assessments will be made in June 2001 and reported in OF0301. One experiment in 1999/2000 showed that both summer fallow and vetch could reduce perennial grass weed populations.

The distribution of potato cyst nematodes (PCN) was mapped within all five plots in January 1998, 1999 and 2000. Sampling was in 25 m x 25 m sub-plots. In January 2000 viable cysts were found in 7.6 % of sub-plots, all at fewer than 10 eggs per g of soil. There was no evidence of a significant multiplication of PCN following potatoes. Growing a variety other than the resistant Sante may have allowed multiplication.

A manure utilisation booklet was compiled in association with Elm Farm Research Centre. The text was agreed with MAFF in May 2001 and it should be published by July 2001.

Results were presented at a number of conferences, including the National Organic Conference at Cirencester and a Crop Rotation Design workshop in Denmark in 1999, at workshops and in the farming press.

The study has contributed data to several other MAFF studies such as OF0114 - P&K, OF0178 - Nitrogen Use and to economic studies at the University of Wales.

An extension for one year to 31 March 2002 has been agreed with MAFF (as project OF0301). This concentrates the study on basic monitoring of the main stockless rotation (i.e. the rotation previously with potatoes but now also including vegetables) with revised and extended assessments, and continues the Linked-farm study. Milestones include writing refereed papers covering results from the first full crop rotation following conversion.

Continued evaluation of the stockless rotation would maintain the data sets on yield, profit, nutrients, weeds, pests and diseases. This would:

a) Assist DEFRA with policy issues such as conversion aid.
b) Allow evaluation of changes in, and control of, patch problems such as perennial weeds and soil borne pests on a site with a known history and uniform cropping.

Specific challenges deserving further study include:

- The ecology of perennial weeds and agronomic strategies for their control.
- Quantification of net nitrogen fixation by legumes and subsequent release to crops.
- The impact of potato cultivar on PCN multiplication.
- Better and more reliable grain quality.
- Control of slugs and potato blight.

The development of companion and bi-cropping systems for arable rotations (linked to results from OF0181 and OF0173).

Scientific report (maximum 20 sides A4)

Background.

This report covers a three-year part of a longer-term project, which began in 1990 and has recently been extended to 2002.

OF0102 - 1990 to March 1995
OF0112 - April 1995 to March 1998
OF0145 - April 1998 to March 2001 (the subject of this report)
OF0301 - April 2001 to March 2002

The project has evolved from a conversion study to testing the sustainability of organic production. It has also contributed data to several other MAFF studies such as OF0114 - P&K, OF0178 - Nitrogen Use and to economic studies at the University of Wales.

Full reports (in addition to CSG12s) have been prepared annually for MAFF. Pairs of reports have been written for each of 1997, 1998 and 1999 harvest years. One of each pair covers the linked-farm results (Objective 6) and the other covers the main Terrington systems comparison and replicated experiments (Objectives 1 to 5). As planned, full reports for 2000 harvest year will be presented to MAFF in September and October 2001. To be more meaningful, this CSG15 report includes reference to some of the earlier work done in OF0102 and OF0112, and preliminary results from 2000 for the work at Terrington.

Introduction.

Results from OF0102 and OF0112 showed that a stockless organic arable rotation was consistently more profitable than a conventional stockless crop rotation on the fertile silty clay loam soil at ADAS Terrington, at least when considering the first crop sequence after conversion. However there were a number of challenges to sustaining that level of performance into the second crop sequence:

- The second and subsequent cycles follow only one rather than two years of red clover. This will probably mean less nitrogen available to crops from atmospheric fixation and hence lower crop yields and profitability.

- Plant availability of other nutrients such as potassium and phosphorus may also become a future limitation. These nutrients have until now been available in sufficient quantity not to limit plant growth.

- In common with the experiences of most other organic farmers, weed levels are increasing, particularly creeping perennial weeds such as couch grass (*Elytrigia repens)* and creeping thistle (*Cirsium arvense*). These latter two are spreading and both have the potential to seriously reduce yields and crop quality.

- Pests and diseases have so far not been a major limitation to performance. Slugs in 1993 and blight in 1997 reduced potato yields but the crops were still relatively profitable. However there are a number of possible future limitations, mainly soil borne, that have not yet been encountered. These include Potato Cyst Nematode (PCN) and Sclerotinia *spp*. If these developed they could necessitate a major change in the crop rotation and so affect profitability. If particularly profitable crops such as potatoes could not be grown then the sustainability of the rotation could be in doubt.

Objectives.

The main scientific objective will be to test the sustainability of an arable organic rotation, on a fertile soil, in the absence of grazing livestock or any inputs of animal manure (i.e. a “stockless” rotation).

1. Assess the performance of two stockless organic arable rotations at ADAS Terrington. And compare with the performance of the conventional arable rotation.

2. Assess the performance of ten commercial, largely arable, organic farms and compare with Terrington. (the “Linked-farms”)

3. Evaluate and compare spring-sown wheat, barley and oats as final crops in the sequence and for their characteristics as cover crops for undersown clover.

4. Map the development and spread of perennial weeds at Terrington and on two other linked farms.

5. On a Linked-farm, compare cutting regimes for the clover fertility building crop for control of creeping perennial weeds.

6. Increase monitoring of Potato Cyst Nematode at Terrington to predict changes in PCN population through the rotation.

7. The existing steering group will be continued.

8. A strong programme of technology transfer.

9. To produce for organic growers a booklet on managing nutrients in livestock manures. (as revised from the original CSG7 by agreement with MAFF)

Design of the project.

To deliver the above objectives, the project is a combination of unreplicated large-scale system study unit, replicated small-plot research and monitored commercial farms.

Relevance to MAFF policy.

The policy relevance of this work to MAFF is to help identify sound methods of organic farming, limiting factors and ways of overcoming them. The aim is to maximise economic performance and in turn promote conversion to help realise the environmental benefits that organic methods can deliver.

Objective 1. Assess the performance of two stockless organic arable rotations at ADAS Terrington. And compare with the performance of the conventional arable rotation.

Design and organic crop rotations

The core of the project is an unreplicated systems comparison/demonstration with field-scale plots. Large plots were adopted to allow normal farm machinery to be used to get meaningful costings, to allow real patchy problems such as perennial weeds and potato cyst nematodes to be encountered and researched, to give confidence to farmers that the system could work on a farm scale and to allow space for replicated small-plot experiments to be done in an organic context.

Conversion to UKROFS organic standard was achieved in 1995. Until 1998, the same crop sequence was grown across the project:

- Potatoes
- Winter wheat
- Spring beans
- Spring wheat (undersown)
- Red clover (one year fertility building crop - Set aside)

Since conversion, the majority of the land, approximately 10 ha, has been in this stockless rotation throughout. This was called the "stockless system" in OF0112. A further 2.5 ha was cropped in the same way from conversion but with the addition of 30 t/ha of composted pig manure per rotation. This was called the "FYM" system in OF0112.

From 1998, the "stockless system" was continued unchanged. However, the application of manure to the "FYM system" was discontinued and vegetables replaced potatoes. This was because of the small responses to manure found in OF0112, and to gain data on the performance of vegetables as alternatives to potatoes as a high-value cash crop.

During the life of OF0145, spring barley replaced spring wheat as the final crop, and white clover/lucerne replaced red clover in the fertility building crop. Reasons for these changes are discussed below. The full cropping history is attached as appendix 1.

Layout

Each of the two "systems" is split into five equal plots. The five-course rotation was phased-in over three years so that from 1997, each of the five plots was in a different crop. The full cropping history of all plots is shown in appendix 1.

Conventional crop rotation

To assess a comparable conventional arable rotation, yields of appropriate commercial conventional crops at Terrington have been measured. As for other farmers, the conventional crop rotation has changed since the start of the work in 1993 in response to external market factors. In 2000 the conventional rotation was:

- Sugar beet
- Winter wheat
- Winter wheat
- Winter beans
- Winter wheat

There was no conventional set-aside at the Terrington site from 1998 to 2000.

Yield measurement

Crop yields in cereals and pulses were assessed using a plot combine; potatoes from machine harvested sub-plots; sugar beet in hand-dug sub-plots; calabrese and onions by hand cut and harvested sub-plots. This probably gave slightly higher figures than would be achievable commercially from whole fields. However the relative performance of the systems should be unaffected. All organic crops were sold as organic produce. Onion and potato yields were adjusted to allow for any storage and grading losses measured on the whole crop.

Economic evaluation

All inputs to both organic and conventional crops were recorded and costed. Combined with the yield and crop value, a gross margin was calculated for each crop. Labour and machinery input were also costed to allow the calculation of a Net Margin for each crop. Other fixed costs have been calculated from Farm Business Survey

(FBS) data as the Terrington research farm does not give realistic values for these and they should be similar across farming systems. For comparison, the conventional rotation needs to include set-aside but as this is not in the cropping at Terrington, standard figures have been used. As a final stage, the profitability of a model farm, of 120 ha, was calculated to show overall profitability. All appropriate AAPS payments have been included in the models.

Results

Fertility building crops

Patches of poor growth of up to 10 m across appeared in April 1998 in red clover in plot 3 of the stockless with potatoes rotation, and plot 1 of the stockless with vegetables rotation. The surviving plants in the patches were stunted and microscopic examination confirmed that they were infested with *Ditylenchus dipsaci*, Stem Nematodes. Sampling showed that they were present throughout both crops. Soil sample records showed that free living nematodes were present throughout the experiment from about 1993. The cool wet conditions of spring 1998 probably particularly favoured the nematodes despite it being a full four years since clover was last grown in these two plots (see Appendix 1). Glasshouse tests were run at ADAS Wolverhampton to determine the race(s) of stem nematode present. These showed that it was probably the narcissus race. Tests also showed that lucerne was resistant to the races present. Clearly it would not be sensible to continue growing red clover as the fertility year crop. It was too late to change for spring 1998 undersowing but from spring 1999; a change was made to a large leaved white clover and lucerne mixture. The lucerne was included even though it is not an ideal plant for frequent cutting in the short term. This was because it was resistant the races of nematode at Terrington, and if the white clover failed there would be some insurance.

In spring 1998, red clover was undersown in the spring wheat. Due to the very wet soil conditions we could not roll clover after undersowing, as there was concern that soil capping could result and impede seedling emergence. In the event, the weather became very dry and the clover failed to emerge, most probably because of inadequate seed to soil contact. In spring 1999, vetch was sown as a replacement fertility crop. It was sown on 17 February but was slow to emerge and early growth was slowed by pigeon and weevil grazing. It was less competitive against weeds than overwintered clover. It was lightly topped in June to cut flowering heads of creeping thistle. The vetch was mulched to ground level in late July before seed could be set. Gross N in the cut material was about half that we have recorded in red clover (Table 1). The spring 1999, and spring 2000 undersowings of white clover and lucerne in spring barley were both successful.

Clearly these pest attacks, crop failures and crop species changes will have impacts on nitrogen fixation, availability and hence on crop yields. However there is no indication that there has been any immediate dramatic effect when crop yields in 1999 and 2000 are considered. We have measured above-ground gross accumulated nitrogen in mulched legumes (Table 1) but this takes no account of re-cycling, of below-ground accumulation or of pattern of release of nitrogen to following crops. The overall performance of the clover in 1998 was reasonable despite the nematodes, however the distribution was patchy and was particularly bad along the south side of the 5 ha plot. In 1999, the growth of potatoes was visibly poorer in that area, and the growth of weeds stronger as a result of reduced crop competition. A better understanding of net N fixation by legumes, and how the nitrogen in these crops is subsequently mineralised would contribute to better rotation planning and better advice on how growers should respond to poor fertility crop performance.

Table 1. Gross total annual accumulation of nitrogen in mulched legume fertility crops.

	1998	**1999**	**2000**
	red clover	vetch	White clover/lucerne
Stockless with potatoes	199	121	238
Stockless with vegetables	234	128	234

Crop yields

Yields of all crops have been maintained through the three years of OF0145 with no sign of any decrease as we progress into a second full crop cycle (Tables 2 and 3).

Table 2. Saleable crop yields (t/ha) stockless with potatoes rotation

	1998	**1999**	**2000**
Potatoes, cv. Sante	14.66	19.26	28.77
Winter wheat, cv. Hereward	7.93	7.07	6.66
Spring beans, cv. Scirocco	3.16	4.96	4.15
Spring cereal*	3.95	2.98	5.32

* Wheat cv. Axona in 1998, barley cv. Derkado in 1999 and cv. Dandy in 2000.

Table 3. Saleable crop yields (t/ha) stockless with vegetables rotation

	1998	**1999**	**2000**
Calabrese, cv. Marathon	4.83	8.83	8.95
Onions*	15.61	26.51	20.51
Winter wheat, cv. Hereward	8.55	6.16	7.20
Spring beans, cv. Scirocco	3.31	3.39	3.47
Spring cereal**	4.35	3.63	4.11

* onions cv. Centurion in 1998 and 1999, cv. Turbo in 2000.
** wheat cv. Axona in 1998, barley cv. Derkado in 1999 and cv. Dandy in 2000.

Disease levels in cereals continue to be well below that which would be expected to respond to fungicide treatment in conventional systems with low levels of *Septoria tritici* in winter wheat and of brown rust and Rhychosporium in spring barley. The only crop protection products applied to any crop were sprays of copper-based fungicide to the potatoes. Three applications were made in both 1998 and in 1999. In both years blight did not exceed 1% leaf area affected. In 2000, weather conditions were more conducive to blight development and despite three applications of fungicide blight increased to 7.5 % leaf area by 24 July and 25 % by 11 August when the foliage was flailed-off. Despite this, harvestable yield was greatest in 2000, probably due to a combination of late planting and high rejections (13.7 t/ha) due to slug damage in 1998 and poor growth in 1999 following the 1998 red clover affected by stem nematode. Potatoes were stored in a refrigerated box store until sale in late winter when demand was stronger. There was no incidence of tuber blight in any year. Quality out of store has been acceptable although some reduction in appearance was found in 2001 to modest levels (< 5%) of silver scurf. This has been similar in earlier years but the increasing supply of organic potatoes is probably resulting in more choosy buyers.

Vegetables were grown for the first time in 1998. Calabrese grown from transplants has been successful with good yields and good quality heads each year. As a protection from insect pests, it has been grown covered with a woven mesh cover from transplanting to harvest. This adds a substantial fixed cost but it should last for at least five seasons and has worked well. It has also proved invaluable in preventing damage from birds after planting. Areas not covered were eaten beyond recovery in 1999 and 2000, although the relatively small area grown probably exaggerated this problem. Onions were grown from sets and were more difficult to manage, particularly for weed control. In wet conditions there are few suitable days to hoe on the silty clay loam soil and once well established weeds were difficult and costly to control by a combination of tractor and hand hoeing.

Yields were modest and costs high. As a result, from 2001 in OF0301, only calabrese will be grown.

Economic performance

Where we have a direct comparison of yields at Terrington, organic saleable yields were only 22% lower for winter wheat but 41% lower for potatoes (Table 4). This difference was mainly the result of potato crop losses from blight and slugs that were difficult to control organically; on average only 71% of potato harvested yield was saleable.

Table 4. Organic *vs.* conventional yields, 1993 to 2000 harvests.

	2000 harvest			**Rolling average**		
	Organic (t/ha)	**Conventional (t/ha)**	**Diff.**	**Organic (t/ha)**	**Conventional (t/ha)**	**Diff.**
Potatoes	25.8	-		25.0	42.4	-41%
Calabrese	9.2	-		7.6	-	
Onions	20.5	-		19.1	-	
Winter wheat	6.6	10.2	-36%	7.5	9.6	-22%
Spring cereal$^{\alpha}$	4.7	-		4.1	-	
Spring beans	3.8	-		3.5	-	
Winter beans	-	4.1		-	4.1	
Sugar beet	-	75.7		-	58.4	

α excludes data on spring cereals grown following two-year red clover conversion crop during the phasing-in of the rotations.

The market for organic crops has held over the period while conventional prices have fallen, notably for supported crops. This has led to a widening of the 'premium' for organic crops (Table 5).

Table 5. Organic *vs.* conventional crop prices, 1993 to 2000 harvests.

	2000 harvest			**Rolling average**		
	Organic (£/t)	**Conventional (£/t)**	**Diff.**	**Organic (£/t)**	**Conventional (£/t)**	**Diff.**
Potatoes	300	-		284	107	165%
Calabrese	870	-		953	-	
Onions	225	-		285	-	
Winter wheat	183	61	200%	186	84	121%
Spring cereal	170	-		178	-	
Spring beans	185	-		181	-	
Winter beans	-	85		-	85	
Sugar beet	-	29		-	32	

Every year since 1993 the conventional rotation had the lowest overall gross margin. On rolling average figures it was only 79% of the organic rotation with vegetables, and 52% of the organic rotation with potatoes (Table 6). The mean figures for the rotations were weighted to allow for the proportions of each crop in the totals. For the organic rotations it was 20% for each crop, for conventional it was 20% sugar beet, 12% linseed, 40% first wheat, 20% second wheat and 8% set-aside. In practice, of course, an organic rotation is likely to include both potatoes and vegetables so the advantage over conventional would be intermediate between these figures.

Table 6. Organic *vs.* conventional crop gross margins (rolling average figures)

	Organic crops (£/ha)		Conventional crops (£/ha)
	Stockless with potatoes	**Stockless with vegetables**	
Potatoes	5,490		-
Vegetables (mean of calabrese and onions)		2,443	-
Winter wheat	1,573	1,573	900
2nd winter wheat	-		882
Spring cereal	851	851	-
Beans*	821	821	521
Sugar beet	-	-	1,495
Set-aside	50	50	179
Weighed average	1,757	1,148	912

* Spring beans in organic rotation, winter beans in conventional

When these gross margin data were put into the 120 ha model farms, the higher allocated fixed costs from the two organic rotations reduced the difference at net margin level. However, there still remained a substantial advantage to organic when potatoes were grown; the modest profit for the vegetable rotation highlights how vulnerable organic returns are where a high margin cash crop is not grown. (Table 7).

Table 7. Organic *vs.* conventional Net Farm Income (120 ha model farms)

	Organic rotation with potatoes (£)	**Organic rotation with vegetables** (£)	**Conventional** (£)
Farm Gross Margin	210,840	137,760	109,440
Allocated fixed costs	52,080	49,320	29,640
Farm Net Margin	158,760	88,440	79,920
Other fixed costs **	67,080	67,080	67,080
	91,680	21,360	12,840
Net Farm Income			
Difference from conventional	+78,840	+8,520	

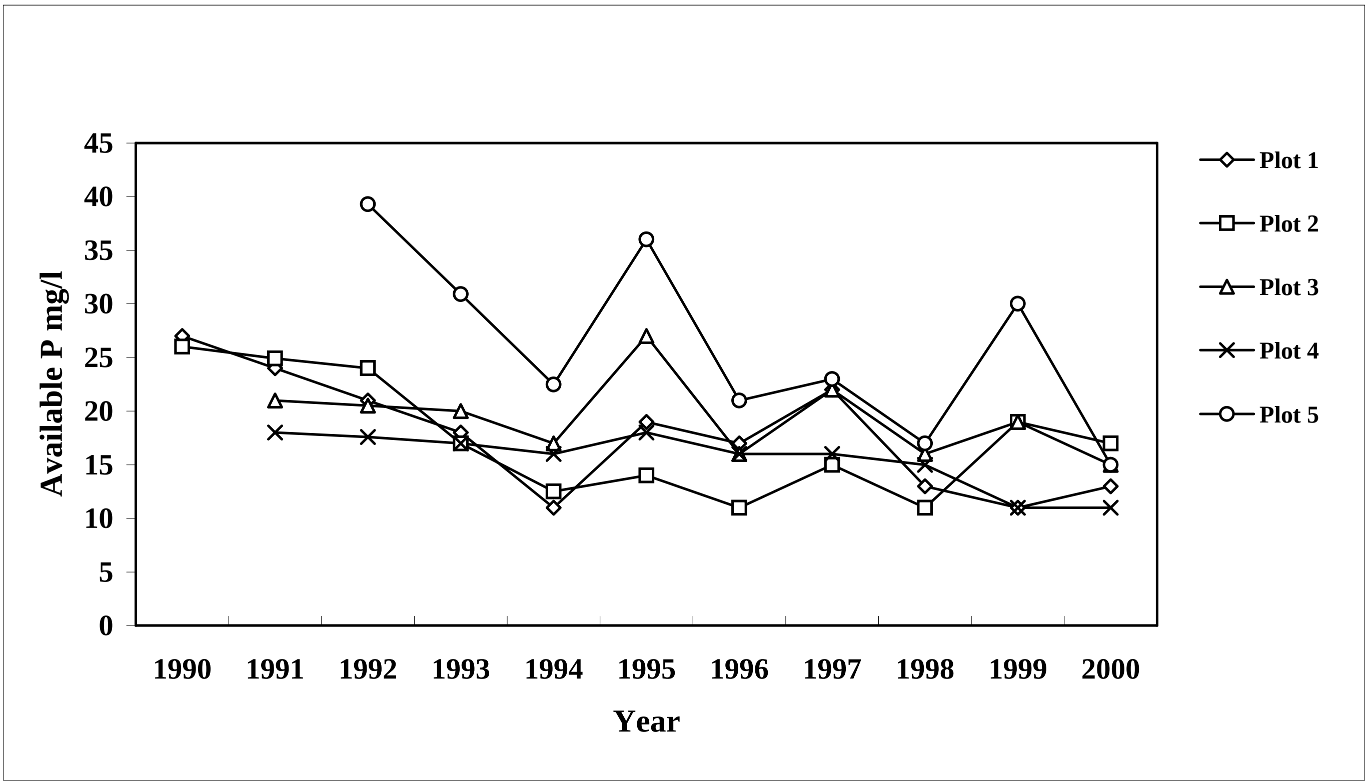
** Cambridge University FBS data.

Changes in soil fertility

Data from the stockless rotation with potatoes are presented, as this rotation has been consistent since 1990.

In response to the decline in soil available phosphorus (Olsen's method) seen from 1990 to 1994, phosphorus fertiliser has been applied once per crop rotation, as Aluminium calcium phosphate (14 % P) at 625 kg /ha. However, since 1995, soil available phosphorus has not continued to fall but has tended to level out but with large seasonal variations (Figure 1). There has been no obvious effect of the fertiliser applications on soil available P level. By autumn 2000, soil available P was at around 15 mg/l which equates with the top end of ADAS Index 1, well above deficiency levels. A full nutrient balance has been done as part of project OF0114. This predicted a near balance in P so the rotational application of P has been continued.

Figure 1. Soil available P, stockless with potatoes.



Soil available potassium levels (Ammonium nitrate method) have also shown some very marked variations between seasons, although there has been a general downward trend (Figure 2). Levels in autumn 2000 were between 120 to 170 mg/l, the lower end of ADAS Index 2. The nutrient balance done in OF0114 shows a large annual average negative balance of 53 kg/ha. Soil available K remains adequate and crop yields are being sustained but if the decline in available K continues despite release from clay minerals, there will soon be a need for supplementary potassium.

Soil organic Carbon showed an apparent large increase following the two conversion years but this was is too large to be accounted for by the organic matter accumulated by two years of clover. It was probably due to errors in sample taking and preparation despite appropriate protocols being followed (Figure 3). This emphasises the benefit of sampling and analysis over a period of years to avoid such anomalies causing misleading conclusions to be drawn. Following conversion, Carbon has stabilised at around 1.3 to 1.5 %, similar to the starting levels in 1990. This is not unexpected, as the returns of organic matter will not be a lot greater than in the previously practised conventional arable rotation. The clover fertility crops are a new source but these will be to some extent balanced by lower crop yields and hence smaller crop residue returns to the soil.

Figure 2. Soil available K, stockless with potatoes.

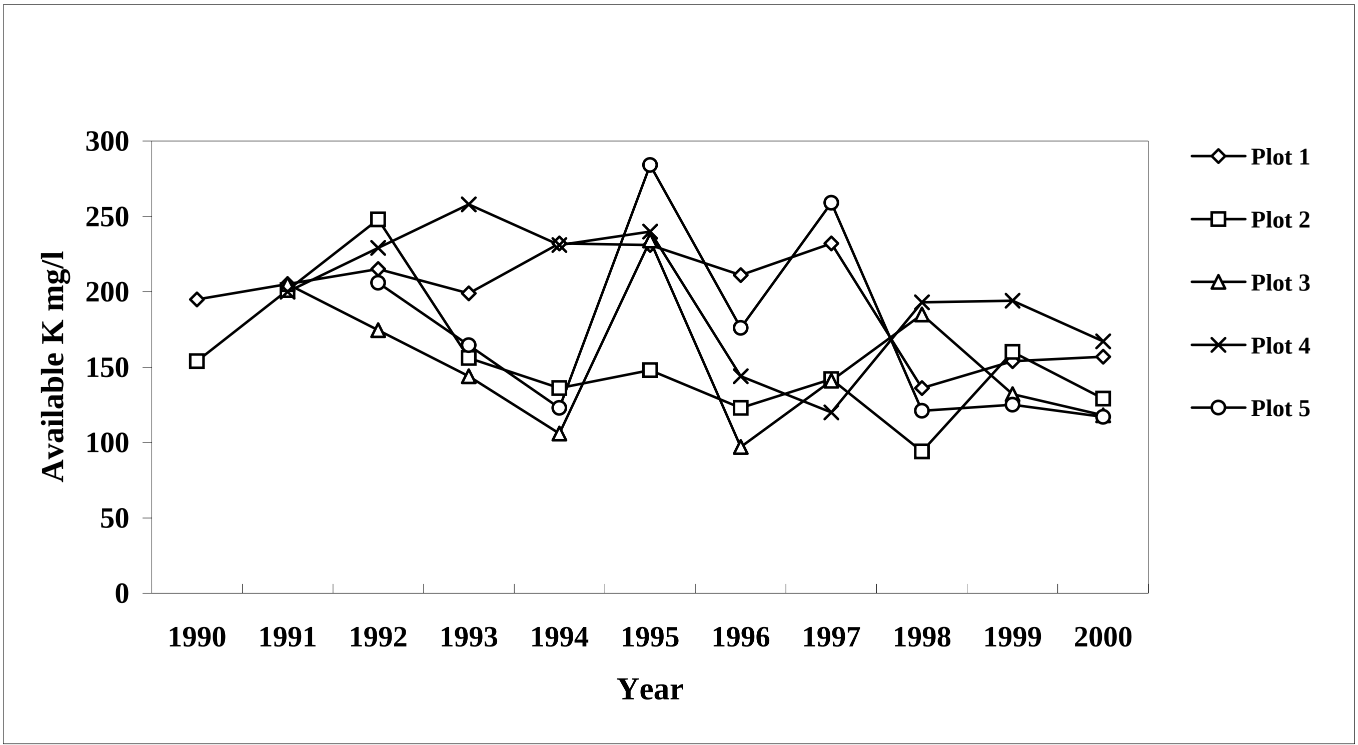
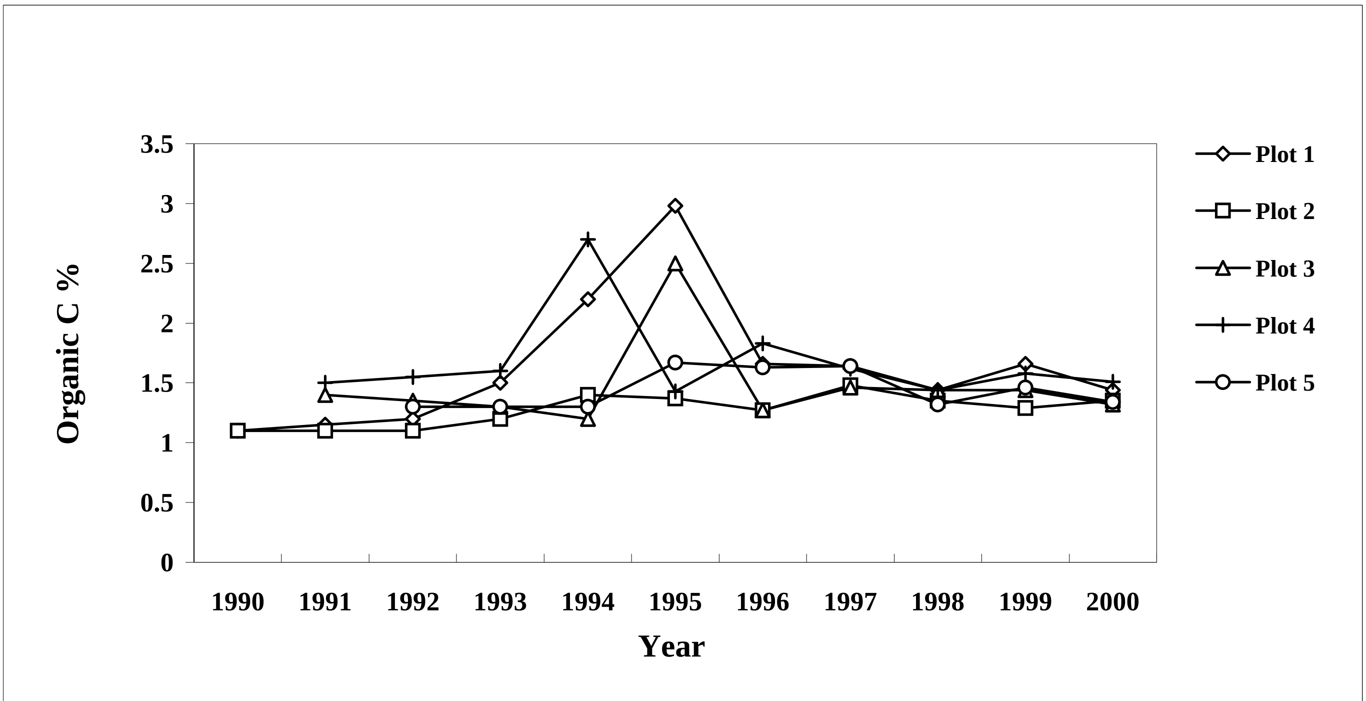


Figure 3. Soil Organic Carbon %, stockless with potatoes.



Nitrogen balance is more difficult to predict due to the difficulty in knowing what the net N fixation by leguminous crops has been. MAFF project OF0178 has reviewed this and calculated the balance for the Terrington rotation using the latest published data. Using actual data for crop N offtakes and legume dry matter production, this showed that the rotation was very close to a balance. The lack of any progressive decline in crop yields would support this calculation. There will be variation as when stem nematode affected growth in 1998 and a failed clover crop was replaced by vetch in 1999, but essentially the rotation is in balance for nitrogen.

Weeds

Annual weeds are becoming more prevalent each year but it was difficult to quantify the changes due to effects of season and crop on weed species and number. Generally they have been controlled successfully. A Harrow comb weeder was available for use in cereals and pulses but opportunities for use were often limited by soil moisture and crop growth. In most years it was not used. Good crop establishment and growth provided the best weed control with annual weeds a problem only where crop growth was poor, for example on headlands where soil had become compacted. Control in potatoes and vegetables was satisfactory but difficult to do in a timely manner in wet seasons.

Perennial weeds have increased since conversion, particularly creeping thistle, and to a lesser extent docks and couch grass. The increase was most apparent in 1999. A measure of the problem was in the time spent hand-pulling these weeds which has increased from an average of less than one hour per hectare in 1994 to 40 hours per hectare in 2000. This cost can be borne by current crop prices but in many areas labour to do this job is not available and we must aim to have a system with minimum handwork. Without introducing a summer fallow, opportunities for mechanical control are limited to post-harvest and over-winter. There is a conflict here with the need to get over-winter catch crops sown as soon as possible after harvest. In 1999, weed control was deemed more urgent that leaching minimisation so no winter cover crops were grown and the soil cultivated several times over winter to help control perennial weeds. It is too early to say whether this has been successful. A change to wider cereal rows to allow inter-row mechanical hoeing may become necessary. Objective 4 is assessing perennial weeds in more detail.

Objective 2. Assess the performance of ten commercial, largely arable, organic farms and compare with Terrington. (the “Linked-farms”)

Ten farms were costed in 1995 and 1996 in project OF0112, and all ten agreed to continue into project OF0145. Only two were stockless farms as very few existed to choose from. Most were largely arable mixed farms, with beef or sheep enterprises. Cropping on the Linked-farms has changed in response to market conditions with the introduction of potatoes and vegetables onto most of the farms. Of the ten, six were costed to a net farm income level; four could be costed only to farm gross margin level due to the incorporation of unrelated businesses in their accounts. The results were compared with equivalent conventional farms from the Nottingham University Farm Business Survey (FBS), and with organic results from Terrington.

Yields of spring cereals, potatoes, pulses and vegetables were similar to those at Terrington, as were husbandry practices, cultivars and variable costs and crop prices realised. The greatest difference was in winter wheat yield with the Linked-farm average of 3.9 t/ha almost half the Terrington average of 7.7 t/ha; this was probably due to the lower nitrogen retention on the lighter soils of the Linked-farms. The overall farm margins were of course also influenced by their proportionate mix of enterprises and fertility building crops. The most profitable farms were those growing the higher gross margin crops such as potatoes and/or vegetables. Low prices caused by BSE and a limited demand for organic livestock products caused relatively poor financial performance from livestock enterprises although there were signs of improvement in 1999.

In every year, overall farm gross and net margins were lower than those from Terrington (Table 8). The reasons for this are differences in soil texture and crop rotation. The silty clay loam soil at Terrington has better nutrient retention characteristics than the lighter textured soils of the Linked-farms. This allows crop yields at Terrington to be maintained with a lower proportion of fertility building crops in the rotation, and the soil is also particularly suited to winter wheat growing. The crop rotation difference is the absence of less profitable livestock enterprises which are necessary on the lighter soils of the Linked-farms. They need a higher proportion of fertility building crops and it is uneconomic for this to be set-aside as at Terrington, hence the inclusion of grass/clover leys and grazing ruminants.

Table 8. Farm gross margins (£/ha) for Linked-farms, Terrington and FBS conventional farms.

	1995	1996	1997	1998	1999
Linked-farms	1022	915	834	1147	1397
Terrington*	1680	2271	1818	1748	1708
FBS conventional	1049	851	680	768	696

* Average of the two organic rotations.

Fluctuations in margins between years were due to a combination of differences in crop yields and prices, particularly of potatoes and vegetables. Dry conditions in 1995 led to low yields, particularly of unirrigated crops, but prices were good and margins relatively high. Yields were higher in the wetter 1996 but prices were down. Potato blight reduced saleable yield of potatoes in 1997. Yields were lower in 1998 and 1999 but, on average, higher prices more than compensated giving similar margins to 1995.

The Linked-farms are a small sample of organic farms and are of differing sizes and enterprises so these average data need to be used with caution. However, they also show that whilst Linked-farm and Terrington gross margins were sustained, conventional farm profitability fell sharply over the five year period, mainly due to falling prices. Whilst 1995 Linked-farm and FBS gross margins were similar, by 1999, Linked-farm gross margin was nearly double that of the FBS farms. Conventional margins have fallen to an unsustainable level. For example, by 1999 the FBS Net Farm Income was only £71/ha. Linked-farm Net Farm Income was much healthier (Table 9). As not all Linked-farms could be costed to Net Income level, these data are not directly comparable with the gross margin data above.

Table 9. Linked-farms Net Farm Income.

	1995 (£/ha)	1996 (£/ha)	1997 (£/ha)	1998 (£/ha)	1999 (£/ha)
Output	1571	1351	1291	1641	1744
Variable costs	343	387	366	346	346
Gross Margin	1228	964	925	1295	1397
Fixed costs	637	688	736	780	820
Net Farm Income	591	276	189	515	576

Fixed costs varied greatly between farms reflecting the different levels of capital investment for different enterprises. There was limited variation between similar types of businesses but these were often associated with the individual nature of the businesses and priorities of the owner. The average level of fixed costs was higher than the comparative group of conventionally managed FBS farms but the sample was too small and varied to draw firm conclusions.

Objective 3. Evaluate and compare spring-sown wheat, barley and oats as final crops in the sequence and for their characteristics as cover crops for undersown clover.

This experiment has compared spring wheat, barley and oats for the final phase of the crop rotation. The two main objectives were to determine which of these crops is the most profitable and which is the best host for undersown legumes for the following fertility building year. The legume was either red clover or a mixture of red clover, lucerne and perennial ryegrass. Experiments were completed for 1996, 1997, 1998 and 1999 harvest years. There was a significant effect of cereal species on grain yield every year (Table 10). Spring wheat gave the lowest average yield, and oats the greatest.

Table 10. Cereal grain yield (t/ha at 85% DM), mean over cultivars and undersowing mixture.

	Wheat	Barley	Oats	F test probability	SED
1996	4.53	5.74	5.32	<0.001	0.108
1997	3.65	4.24	5.07	<0.001	0.100
1998	3.84	4.31	5.17	<0.001	0.265
1999	-	3.50	4.24	<0.001	0.113
Mean	4.01	4.45	4.95	-	

A full assessment of legumes was possible only in the 1997 experiment. This was due to problems with crop establishment in 1996 and 1998, and a severe attack of stem nematode in 1999. Lucerne and grass generally failed to establish; therefore differences in growth of the legume treatments were largely due to differences in the sowing rate of the red clover. In 1997, there were 174 kg DM/ha of clover under barley compared with 88.5 kg DM/ha under wheat and only 4.5 kg DM/ha under oats (Table 11). However, when assessed in May 1998, there was no effect of cereal species on clover dry matter yield. This suggests that as long as a sufficient number of plants survive after harvest of the cereal cover crop, growth and hence N fixation in the subsequent year should be unaffected by the size of those plants after cereal harvest.

Table 11. Clover biomass (kg/ha DM) at cereal harvest, 6 August 1997.

Undersown legume	Cereal species and cultivar						
	spring wheat		spring barley		spring oats		
	Axona	Canon	Hart	Derkado	Melys	Dula	mean
red clover	113.7	63.3	205.7	142.7	4.0	5.0	89.1
red clover/lucerne/ grass	15.3	8.3	31.7	27.3	2.0	3.3	14.7
mean	64.5	35.8	118.7	85.0	3.0	4.2	

F probability for cereal species <0.001, undersown species <0.001 and interaction <0.001.
SED cereal species (5 df) 17.44, undersown species (1 df) 10.07 and interaction (5 df) 24.66.

A similar, but less marked, effect on clover dry matter yield was recorded at cereal harvest in the 1999 experiment. However the failure of this clover in early 2000 due to stem nematode damage prevented follow-up assessments.

Objective 4. Map the development and spread of perennial weeds at Terrington and on two other linked farms.

Changes in the spatial distribution of perennial weeds were mapped at three sites over three years. There was one site at Terrington and two on Linked-farms – at Long Whatton and CWS Quenby, both in Leicestershire. A nested sampling plan was designed for each site. There were 118 sampling points on each of the Linked-farms and 101 sampling points at Terrington. Each point was located by GPS and also physically on the site. At each sampling point, shoots of couch were counted in a 1 m^2 quadrat. Couch grass was mapped on five occasions from 1999. At the two Linked-farm sites there was a stable population that was persistently present in over 70% of quadrats (Table 12). At Terrington, couch was persistently present in less than 10% of quadrats.

Table 12. Summary of persistence of couch in quadrats at each site

Site	Number of sampling occasions	% of quadrats with couch grass:		
		Persistently present	Persistently absent	Variable
CWS Quenby	4	79.6	0.9	19.5
Long Whatton	4	71.8	2.6	25.6
Terrington	5	8.3	27.8	63.9

At the two Linked-farm sites there was a high stable population (up to 100 shoots m^{-2}) that showed little change in spatial distribution with time. The was an apparent decrease in points with couch grass at CWS Quenby but this was probably because the site had been recently ploughed before the final assessment. (see appendix 3 for details)

At Terrington where there was a lower and more variable population, there was a marked decrease (from 50 to 20%) in the number of sampling points with couch present following undersown barley (Figure 4). There was little change in mean shoot density during this period but it increased sharply (from 3 to 15 shoots m^{-2}) following the mulching of the clover during the following year (Figure 5). This suggests that it should be possible to derive improved management guidelines for couch control in arable organic systems although further data is needed to confirm this tentative conclusion.

Figure 4. Percentage of sampling points with couch grass present – Terrington.

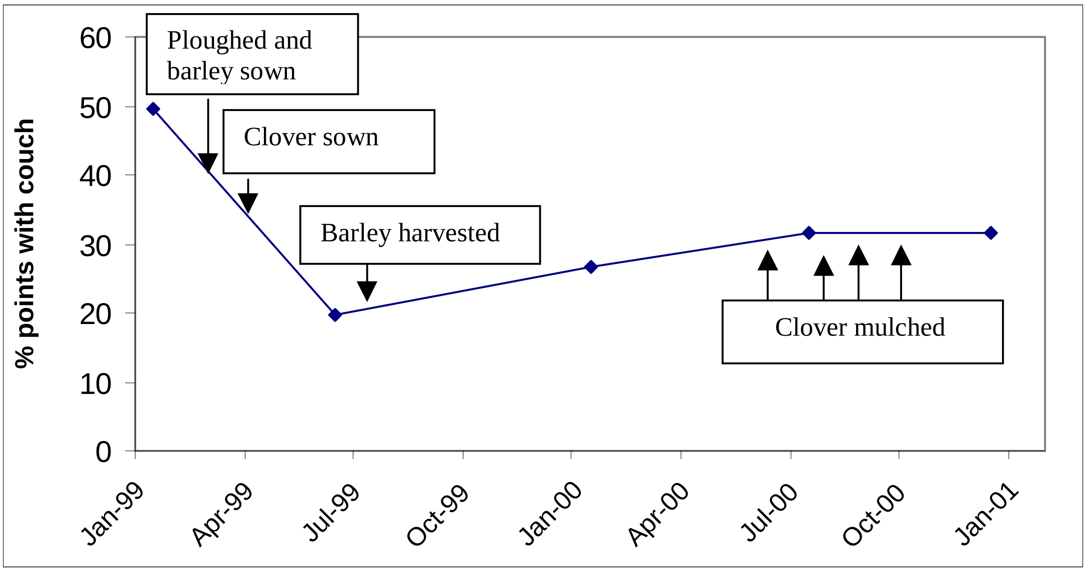
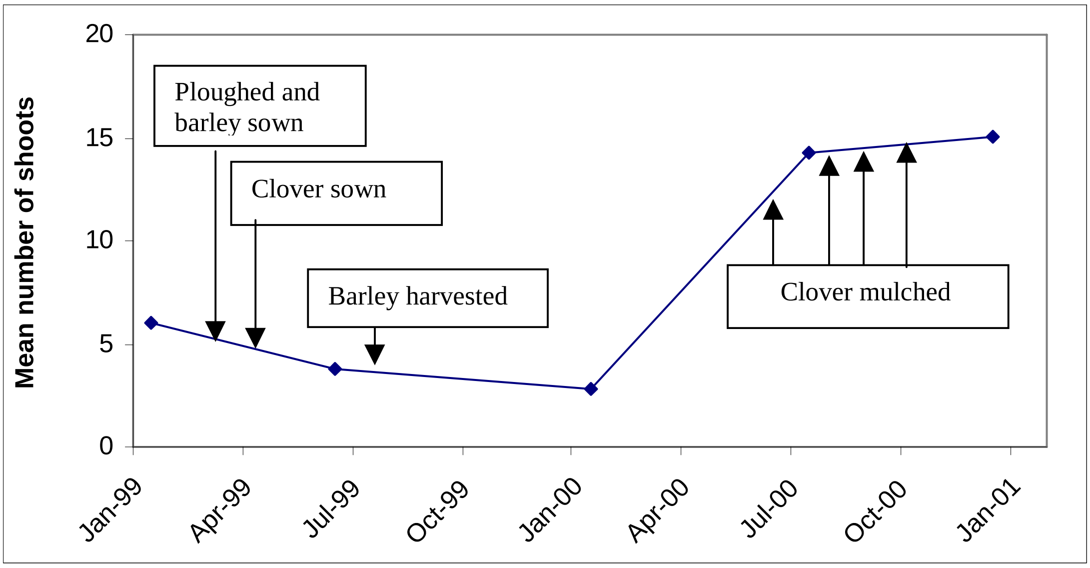


Figure 5. Mean number of couch grass shoots per square metre – Terrington.



Objective 5. On a Linked-farm, compare cutting regimes for the clover fertility building crop for control of creeping perennial weeds.

Two experiments have been done under this objective.

1. *Effect of Vetch cover on the control of perennial grass weeds.*

An experiment was done in a stockless rotation on a commercial organic farm in Leicestershire. The experiment compared a vetch crop with summer fallow and cultivations for the control of perennial grass weeds. Plot size was large at 0.5 ha to allow use of farm machinery. There were two replicates of the two treatments. Previous cropping was a cereal. The dominant weed was *Agrostis stolonifera* (creeping bent) with, with patchy *Elytrigia repens* (couch) populations and occasional *Rumex* spp. (docks), *Ranunculus repens* (creeping buttercup) and *Cirsium* spp. (thistles). Weeds were assessed in a series of fixed quadrats. Baseline counts were done in February 1999. The field was then ploughed and Vetch sown in late April. Populations of creeping bent and couch grass were too high to count so they were assessed by recording their presence and absence in a series of nested quadrats. The vetch was allowed to grow and die after setting seed. The fallow treatment was cultivated on several occasions during summer. The field was ploughed and red clover sown in autumn 1999. Unfortunately, profuse growth of volunteer vetch from the shed seed made it impossible to assess weed growth until January 2001. Results show that both treatments were effective at reducing the populations of perennial grass weeds but there was no clear difference between the two treatments (Table 13). However, populations were still very high (over 70% abundance on average).

Table 13. Mean abundance values (based on nested quadrat scores) and % frequency of occurrence for *E. repens* and *A. stolonifera* in baseline and final years. Treatment 1 = cultivated fallow, treatment 2 = vetch.

		Abundance (max = 120)				Frequency (%)			
		E. repens		*A. stolonifera*		*E. repens*		*A. stolonifera*	
Trt.	Rep.	Baseline	Final	Baseline	Final	Baseline	Final	Baseline	Final
1	1	15	0	110	63	42	0	100	83
1	2	41	10	97	75	67	25	100	100
2	1	8	7	104	84	25	17	100	96
2	2	32	2	94	64	67	8	100	79

2. *Influence of cutting frequency on the control of perennial weeds in the fertility building phase of a stockless rotation.*

This experiment was within plot 4 of the stockless with vegetables rotation at Terrington. The site was chosen as it had an even population of creeping thistle and was in clover/lucerne in 2000. There were three treatments:

1. Cut twice - when thistle flower buds visible.
2. Cut four times - when clover/lucerne reaches 45 cm height in June, July, August and September.
3. Cut every 2 weeks from June until end September.

Design was five replicates of three treatments in a randomised block design. Plots size was 23 m × 4 m (width to fit in with two passes of a 2 m wide tractor rear-mounted flail mower). Ten permanent quadrats per plot were located on two lines along the length of each plot and 0.5 m from the each edges of the plot to avoid the tractor wheelings from mowing. The number of shoots (or rosettes) of *Cirsium arvense* and any other perennial species was counted in each permanent 1 m^2 quadrat. There was an average of 9.5 creeping thistle stems per m^2 in April 2001. Cutting treatments were applied as planned and the final weed count will be in June 2001 in the following calabrese crop. Results will be reported as part of OF0301.

Objective 6. Increase monitoring of Potato Cyst Nematode at Terrington to predict changes in PCN population through the rotation.

The distribution of potato cyst nematodes (PCN) within the five plots of the stockless organic rotation at ADAS Terrington was mapped in December 1998, January 2000 and January 2001. Each of the five plots was divided into sub-plots of approximately 625 m^2 (25 x 25 m). The corners of each sub-plot were geo-referenced using a GPS (Global Positioning System) to record actual location and aid relocation. On each sampling occasion, 30 soil cores were taken to 15 cm depth from each sub-plot and bulked to make one representative sample. PCN cysts were extracted and egg counts made using standard assessment methods.

The PCN population levels observed over the three cropping years covered by the sampling occasions remained at low levels (Table 14). Variations in the percentage plots infested and PCN eggs/g of soil in individual plots were within the range of sampling errors that would normally be encountered when assessing low PCN populations. Critically, there was no evidence of a significant multiplication in the PCN population in plots cropped with potatoes prior to a sampling occasion (Table 15). None of the PCN populations found were sufficiently numerous or viable for a PCN species test to be done. Nonetheless, the fact that the potato variety grown in all plots was Santé, which has full resistance to both yellow PCN (*Globodera rostochiensis*) and partial resistance to white PCN (*G. pallida*), would have contributed significantly to suppressing the build-up of PCN populations. Use of non-PCN resistance varieties may well have resulted in significant population build-up in plots 1, 2 and 3, and future work should consider the impact of variety choice on the sustainability of organic potato cropping on PCN-infested land.

Table 14. Percent sub-plots infested and range of PCN populations found on each sampling occasion.

Measure of infestation	Sampling date		
	December 1998	**January 2000**	**January 2001**
% sub-plots with no cysts found	87.9%	92.4%	87.3%
% sub-plots with very low PCN levels (non-viable cysts)	5.7%	2.5%	5.1%
% sub-plots with low PCN levels (viable cysts)	6.4%	5.1%	7.6%
Range of eggs/g soil	0.03 – 4.1	0.05 – 4.6	1.0 – 7.0

Table 15. Differences between plots in the percentage of sub-plots containing viable PCN cysts for each sampling occasion in relation to potato cropping history (bold figures for plots 1, 2 and 3 indicate samples taken in the winter immediately following a potato crop).

Plot	Number of sub-plots	Last potato harvest year	% sub-plots with low PCN levels (viable cysts)		
			December 1998	**January 2000**	**January 2001**
plot 1	32	1998	**6.3%**	0%	9.4%
plot 2	31	2000	6.5%	0%	**3.2%**
plot 3	33	1999	0%	**6.1%**	3.0%
plot 4	26	1996	19.2%	15.4%	19.2%
plot 5	35	1997	2.9%	5.7%	5.7%
Mean	31.4	-	7.0%	5.4%	8.1%

Small differences were seen in the PCN counts between different plots (Table 15), with plot 4 having a higher population than the other four plots. The distribution of plots where PCN was found at low levels showed evidence of a distinct, and largely temporally persistent, spatial distribution in the eastern part of Block 4 and the north-west and south-west corners of Blocks 1 and 2 respectively. These infested areas probably reflect the general location of initial foci of PCN infestation rather than an impact of the recent cropping history. The appearance/disappearance of infestations in other sampling plots is largely due to sampling error associated with low PCN populations. Maps showing the spatial distribution of the cysts on each sampling occasion are included in appendix 6.

Objective 7. Steering group.

The steering group met in June and November each year. The group was chaired by Dr David Cooper, MAFF CSG, and included representatives of MAFF RMED, Elm Farm Research Centre, Soil Association and three organic farmers. All reports to MAFF were seen in draft and commented on by the group and all changes to the project work plan were agreed by the group before implementation.

Objective 8. A strong programme of technology transfer.

Highlights are detailed below, in addition there were presentations to various visiting farmers groups and regular contact with Elm Farm advisory service through annual visits by Mark Measures and Stephen Briggs.

1998/99

- Terrington hosted a Soil Association Arable Conversion Seminar on 20 April 1998. The visit was reported in a half-page article in the Eastern Daily Press, April 22.
- A presentation was given at an Elm Farm Research Centre Arable Organic Conversion seminar/open day at Luddesdown Farm, Kent - 20 May 1998.
- Dudley Coates, MAFF Head of Environment Group, visited Terrington on 2 June 1998 to see and discuss the project.

1999/00

- Results were presented at a Nutrients in Organic Farming Group (NOAG) workshop at Henry Doubleday Research Association on 14 April 1999.
- Terrington hosted a Soil Association Arable Conversion Seminar on 1 June 1999. Around forty farmers considering conversion attended.
- Results from OF0145 were presented on the ADAS stand in the Organic Food and Farming Centre at the Royal Show, Stoneleigh, July 1999.
- There were visits on 22 July by Andrew Woodend of MAFF Economics Division, and on 5 November by David Hunter, Head of MAFF Agriculture Group.

2000/01

- Elm Farm Research Centre OAS advisers and researchers visited Terrington on 1 March 2000.
- Participated in Elm Farm Research Centre Colloquium of Organic Researchers meeting on 11 April 2000, including a presentation of OF0145 results.
- Terrington hosted a Soil Association Arable Seminar group on 22 June.
- HDRA researchers visited Terrington on 26 June.
- There were visits by Peter Cleasby, MAFF RMED, on 14 July, and John Sherlock, MAFF CSG, on 8 September 2000.
- Results were presented to a Soil Association meeting on crop rotation design at Duxford, Cambs., on 31 October 2000.

Objective 9. To produce for organic growers a booklet on managing nutrients in livestock manures.

The objective was to produce, in collaboration with Elm Farm Research Centre, an A5, four-colour booklet covering all aspects of manure management as relevant to organic farmers. This would include, where available, revised data on nutrient contents of manures. There was also a need to acknowledge the existing data in the EU Livestock regulations. Organic certifying bodies were consulted on the technical content, and drafts commented on by the certifying bodies, MAFF RMED and CSG, and a number of organic farmers. A final text was agreed with MAFF in May 2001 and 1500 copies should be printed and distributed by July 2001. An electronic copy will be made freely available in PDF format for inclusion on web sites.

Publications and press articles resulting from the project.

Anon (1998) New Organic System is a Winner. *Arable Farming*, 16 May 1998, 52-54.

Anon (1999) All-Arable Can Work - But Soil Must be Right. *Farmers Weekly*, 12 February 1999.

Anon (1999) Siltland Trial Puts Organic Margin Ahead. *Potato Review***,** November 1999, 24-26.

Anon (1999) Beetle Banks for Beneficial Beasties. *Lynn News,* Friday November 26 1999, 10.

Caspell N (2001) Organic Vegetables at Terrington – the good, the bad and the ugly. *The Grower*, February 15 2001, 18-20.

Cormack W F (1998) Organic Farming Makes Sound Financial Sense*. Environmental R&D Newsletter*, MAFF, Volume 4, Autumn 1998, 3.

Cormack W F (1999) The Terrington arable organic project. In *Abstracts and Biographies of the 11th National Organic Farming Conference*, Cirencester, January 1999, pages not numbered.

Cormack W F (1999) Testing a stockless arable rotation on a fertile soil. *Proceedings of an International Workshop on Designing and Testing Crop Rotations for Organic Farming*, Borris, Denmark, June 1999, Danish Research Centre for Organic Agriculture (DARCOF) Report 1/1999, 115-123.

Cormack W F (1998) Stem Nematodes - a Warning. *Organic Farming,* Issue 62, Summer 1999, 19.

Cormack W F (1998) Stem Nematode - a Warning. *Elm Farm Research Centre Bulletin*, No 44, August 1999, 12.

Christine A Watson, Younie D, Elizabeth A Stockdale and **Cormack W F**, (2000) Yield and nutrient balances in stocked and stockless organic rotations in the UK. *Aspects of Applied Biology No 62, Farming systems for the new millennium,* 261-268.

Two refereed papers are in preparation as part of project OF0301.

Possible future work

An extension for one year to 31 March 2002 has been agreed with MAFF (as project OF0301). This concentrates the study on basic monitoring of the main stockless rotation (i.e. the rotation previously with potatoes but now also including vegetables) with revised and extended assessments, and continues the Linked-farm study. Milestones include writing refereed papers covering results from the first full crop rotation following conversion.

Continued evaluation of the stockless rotation would maintain the data sets on yield, profit, nutrients, weeds, pests and diseases. This would:

c) Assist DEFRA with policy issues such as conversion aid.
d) Allow evaluation of changes in, and control of, patch problems such as perennial weeds and soil borne pests on a site with a known history and uniform cropping.

The study has contributed data to several other MAFF studies such as OF0114 P&K, OF0178 Nitrogen and to economic studies at the University of Wales.

Specific challenges deserving study include:

- The ecology of perennial weeds and agronomic strategies for their control.
- Quantification of net nitrogen fixation by legumes and subsequent release to crop plants.
- The impact of potato cultivar on PCN multiplication.
- Better and more reliable grain quality.
- Control of slugs and potato blight.
- The development of companion and bi-cropping systems for arable rotations (linked to results from OF0181 and OF0173).

Appendices

Appendices presented to MAFF with this report:

1. Details of the organic crop rotations at ADAS Terrington.
2. Couch grass assessments at long Whatton.
3. Couch grass assessments at CWS Quenby.
4. Mapping of couch grass presence at ADAS Terrington.
5. Mapping of couch grass shoot density at ADAS Terrington.
6. Mapping of Potato Cyst Nematode at ADAS Terrington.
6. Paper presented to crop rotation design workshop at Borris, Denmark, June 1999.

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