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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: OF0318
2. Project title: Assessing the sustainability of a stockless arable organic rotation
3. Contractor organisation(s): ADAS UK Ltd
   Terrington St Clement
   King's Lynn
   Norfolk
   PE34 4PW
4. Total Defra project costs: £ 385,254.00
5. Project: start date .... 01 April 2002
   end date .... 31 December 2005

6. It is Defra's intention to publish this form.
Please confirm your agreement to do so...**YES** ☒ **NO** ☐

(a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.

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(b) If you have answered NO, please explain why the Final report should not be released into public domain

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

The majority of organic conversions have been on upland grass-based livestock farms resulting in a shortage of UK-grown cereals and pulses. Across northern Europe, conventional agriculture has developed a specialised structure with many areas having no livestock, or knowledge or facilities to support livestock. Sustainable organic production on these farms has particular challenges for nutrient supply, for the management of weeds, pests and diseases and for economically viability.

This report covers a three and a half year period (four crop harvests) of a longer-term programme of work, which began in 1990. The overall objective was to identify and overcome factors limiting the sustainability of a stockless arable rotation. Specific objectives were to 1) quantify crop yield and quality, 2) quantify the financial performance of the rotation and contrast with Farm Business Survey data from comparable non-organic arable farms, 3) to monitor and evaluate indicators of sustainability; particularly for nutrients, weeds, pests and diseases and 4) to communicate results, and their implications, to Defra and other stakeholders. These were all achieved.

The study was located on the ADAS Research Centre at Terrington St Clement, Norfolk. The soil is a deep stoneless silty clay loam of the Wisbech series. It is derived from marine alluvium, has a naturally high pH of around 7.5 and is retentive of water and nutrients. The project was an unreplicated study with field-scale plots. There were five plots, each of 2 ha, each in a different phase of a five-year rotation. This design, with no replication within-year, whilst allowing more meaningful crop husbandry and economic evaluation than a conventional small-plot replicated experiment, did limit statistical analysis. This was a deliberate choice as economic evaluation and demonstration were the principal initial objectives of the project. Despite this limitation, it has provided a long-term data-set gathered under realistic conditions that gave useful indicators of crop performance in a stockless rotation, and provided data for other Defra-funded projects, such as economic modelling.

The project was managed by a steering group chaired by the Defra project officer. Other members included Roger Unwin, policy adviser on soil protection and organic farming in the Defra Rural Development Service, three organic farmers, and representatives of the Soil Association and Elm Farm Research Centre (EFRC). Meetings were held twice per year. Detailed written reports were submitted to each meeting for discussion. All changes to cropping and management were agreed by the group.

The crop sequence from 2002 to 2004 was: potatoes and calabrese (split ⅔ potatoes and ⅓ calabrese) → winter wheat → spring beans → spring wheat (undersown) → white clover (fertility building crop). The clover was mown three to four times per year and left as a mulch. Organic registration was with the Soil Association. All crop management operations were done using normal farm machinery; the aim was to simulate typical commercial practice. No fertilisers were applied apart from aluminium calcium phosphate ("Redslaag") once per rotation, at 625 kg/ha. No irrigation was applied.

Undersown white clover thrived only in one year (2002) out of five. Establishment was affected variously by slug grazing, insufficient rain, and excessive rain. It was successfully re-sown in 2003 but had to be replaced by spring sown vetch in 2004 and 2005. Of all the crops grown post-conversion, fertility-building crops have been the most difficult to establish. Over the life of the programme, clover failed to successfully establish in four of the eleven years from 1995 to 2005, even when re-sown in some years. Vetch was sown in spring as a (reputedly) rapidly-growing replacement in three of the years but it was slow to establish, competed poorly with weeds and had a considerably lower accumulated nitrogen in the mulched foliage. The mean accumulated nitrogen in vetch was 102 kg/ha (range 90 to 121), whereas in clover it was 175 kg/ha (range 0 to 274). Despite the poor performance of some of the fertility-building crops, this was not clearly reflected in the performance of following cash crops. This conclusion was supported by results from replicated experiments comparing legume species over different seasons, done at Terrington in the 1990s as part of this programme (and published in a peer reviewed journal), and by results from a stockless arable study on fertile soil in Germany.

Yield of winter wheat was good with an average of 7.0 t/ha; this compares with a typical organic yield of 4.0 t/ha. Yield was relatively consistent, and reflected environmental conditions, with lowest yields in the very dry 1995 and the wet and dull 1997 and 2001. The highest yield of 9.8 t/ha was in 1996 when a dry and sunny early summer was followed by rain in July and August ensuring good grain fill. Grain nitrogen content ranged from 1.7% (1995 and 1997) to 2.2% (2003). This was generally below the 2.2 to 3.3% typically required for bread making and as a result it was sold for organic livestock feed. Potato saleable yield was very variable (from 7 to 40 t/ha) depending on the impact of rainfall pattern, slugs and blight. Beans generally established and grew well with yields of over 3 t/ha in all but two years. Yield was reduced in 1995 by drought, in 1997 by poor pollination and pod set in a very dull June, and in 2004 and 2005 by weeds. The spring cereal yielded considerably less than the winter wheat. This was expected as it was at the end of the crop sequence when nitrogen availability would be least.

Crop prices declined through the programme, particularly from 1999 (e.g. winter wheat price fell from £205/t in 1996 to £129/t in 2005). Non-organic prices also declined, but at a slower rate. The stockless rotation had a substantially greater gross margin than comparable non-organic farms until 2000 (e.g. £1,881/ha vs. £601/ha in 1997). From 2000, the advantage decreased as prices fell. From 2003 to 2005, gross margin was less than for non-organic farms (£561/ha vs. £601/ha in 2005). High margin crops such as potatoes and calabrese made a large contribution to the rotation gross margin and were necessary to balance the low income from the 20% of fertility-building crops in the stockless rotation. The introduction of the Single Payment Scheme in 2005 changed the economic picture making the inclusion of 20% fertility-building crops look even less attractive. New designs of stockless rotation are needed with better integration of fertility-building, and ideally with all crops earning revenue from sales.

Relatively stable crop yields and nitrogen contents suggested that the rotation was in balance for nitrogen. However, crop offtake of nitrogen was substantially greater than the estimate of nitrogen supply from the fertility-building crop mulched foliage, suggesting that this measure was underestimating nitrogen supply. Soil available potassium was consistently in Index 2 despite no additions, showing that the clay minerals were releasing potassium to replace offtake. Soil available phosphorus declined sharply initially and calcium ammonium phosphate was applied annually from 1995. It continued to decline but more slowly, and by 2005 was just in Index 1. Soil carbon showed a slow upward trend. In the longer term, sustainable additions of plant-available phosphorus and potassium will be needed in a stockless rotation, even on nutrient retentive and potassium rich soils as at ADAS Terrington.

Diseases and pests had little impact on cereals and beans. Significant pest issues were slugs on potatoes, calabrese and clover, and stem nematodes and *Sitona* spp. weevils on clover. The lack of an organic control for slugs makes production of root and vegetable crops on such slug-prone soils unreliable. Strategies to avoid stem nematode, such as alternating clover species, should be adopted in stockless systems with a high frequency of clover crops.

Total numbers of weeds did not increase, but the dominant species of annual weeds changed from those of autumn-sown arable crops to those of spring-sown crops. Perennial weeds, particularly creeping thistles, progressively increased from an initial sparse and patchy distribution to cover the whole study area at a dense population. By 2005, it was clear that the creeping thistle population could not be managed without substantial change to the rotation, such as the introduction of a cultivated fallow or a longer fertility building period, both of which would be costly. Strategies to avoid domination by perennial weeds should be put in place at the start of conversion. That would be more likely to succeed in the long term rather that trying to contain a well-established population at a manageable level. Any new rotations designed in response to the introduction of the Single Payment Scheme would also have to be more competitive against perennial weeds.

Two papers were published in peer-reviewed journals, and papers were presented at two Colloquium of Organic Researchers conferences. A web site dedicated to the project was established and maintained.

Further research is needed on:

1) An integrated strategy for the management of perennial weeds, particularly to prevent infestations spreading. This is likely to require research to clarify aspects of weed biology and spread mechanisms, and the interaction of those with crop husbandry practices;
2) Reliable and affordable controls for slugs, particularly to protect product quality in root and vegetable crops;
3) New designs of rotation with fertility building better integrated with cash crops to a) eliminate unproductive and failure-prone dedicated fertility-building crops, and b) offer better competitive ability against perennial weeds.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
   - the scientific objectives as set out in the contract;
   - the extent to which the objectives set out in the contract have been met;
   - details of methods used and the results obtained, including statistical analysis (if appropriate);
   - a discussion of the results and their reliability;
   - the main implications of the findings;
   - possible future work; and
   - any action resulting from the research (e.g. IP, Knowledge Transfer).

BACKGROUND

This report covers a three and a half year period (four crop harvests) of a longer-term programme, which began in 1990. The report also includes a discussion of results over the whole timespan of the programme.

OF0102 - 1990 to March 1995
OF0112 - April 1995 to March 1998
OF0145 - April 1998 to March 2001
OF0301 - April 2001 to March 2002
OF0318 - April 2002 to December 2005 (the subject of this report)

The programme evolved from a study of conversion, to one testing the sustainability of organic production. It has also contributed data to several other Defra organic farming studies such as OF0164 and OF0190.

OBJECTIVES

The overall objective was to identify and overcome factors limiting the sustainability of a stockless arable rotation. Specific objectives were to:

1. Quantify crop yield and quality.
2. Quantify the financial performance of the rotation and contrast with Farm Business Survey data from comparable non-organic arable farms.
3. Monitor and evaluate indicators of sustainability; particularly for nutrients, weeds, pests and diseases.
4. Communicate results, and their implications, to Defra, other research contractors, farmers, advisers and organic certification bodies.

These objectives were met.

METHODS

Site

The study was located on the ADAS Research Centre at Terrington St Clement, Norfolk. The soil is a deep stoneless silty clay loam of the Wisbech series. It is derived from marine alluvium, has a naturally high pH of around 7.5 and is retentive of water and nutrients. Soil organic matter is around 2.5 %. Altitude is uniform at around 2 m and mean annual rainfall is 598 mm which is, on average, evenly distributed throughout the year. The site had been cropped in an arable rotation for at least the previous 50 years.

Design

The project was an unreplicated study with field-scale plots. There were five plots, each of 2 ha, each in a different phase of a five-year rotation. This design, with no replication within-year, whilst allowing more meaningful crop husbandry and economic evaluation than a conventional small-plot replicated experiment, did limit statistical analysis. This was a deliberate choice as economic evaluation and demonstration were the principal initial objectives of the study. Despite this limitation, it has provided a long-term data-set gathered under realistic conditions that gave useful indicators of crop performance in a stockless rotation, and provided data for other projects, such as economic modelling. The study also provided a well-monitored site for replicated experiments (see Section 9: Cormack *et al*., 2003).

Crop rotation

Conversion to UKROFS organic standard was achieved in 1995. A 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 is shown in Appendix 1. From autumn 2001, registration was with the Soil Association. The crop sequence from 2002 to 2004 was:

- Potatoes and calabrese (split ⅔ potatoes and ⅓ calabrese)
- Winter wheat
- Spring beans
- Spring wheat (undersown)
- White clover (fertility building crop)

When a plot was in vegetables, it was split ⅔ potatoes and ⅓ calabrese. The split was in a constant position so that potatoes and calabrese were always grown in the same areas of each plot. The split was first made in 2001; previously the whole plot was planted in potatoes. Therefore there are fewer years' data for crops grown after calabrese than after potatoes.

For potatoes, calabrese and winter wheat, with the aim of consistency, the cultivar grown was the same each year. Cultivars of beans, spring cereals and legumes varied in response to changing availability of suitable varieties of organically produced seed.

Potatoes have been a key crop economically in the rotation. However, since 2000, changed market conditions made it impossible to sell the potatoes as an organic product. This difficulty was created by a general oversupply, and a desire by the multiple retailers to have the same visual blemish-free and uniform size they expect of non-organic product. The soil type and lack of irrigation at Terrington did not allow those standards to be reliably achieved every year. Also, contracts became necessary to secure a market outlet. The quantities grown at Terrington were too small to do that. Potatoes were grown after 2000 for continuity of assessments. However, in 2004 the steering group concluded that it was no longer sensible to grow potatoes and that the crop rotation should be changed. Various options were discussed, and it was agreed that they be replaced by spring wheat in 2005.

Crop management

All crop management operations were done using normal farm machinery; the aim was to simulate typical commercial practice. Primary cultivations were by ploughing to 15 cm. Seedbed preparation was by powered and unpowered harrows. The exception was post-potatoes where non-inversion tined cultivations were used to prepare the winter wheat seedbed, leaving tubers near the surface to allow frost to kill them over winter. Cereals and beans were sown using a combination power harrow and drill. Clover was established by undersowing into the spring cereal.

The main weed control strategy was to grow competitive crops. In addition, mechanical and some hand weeding were done. A tined weeder ('Harrow Comb') was used in cereals and beans when weeds and crop were at an appropriate growth stage and soil moisture content was suitable. Weed control in potatoes was by inter-row harrows and ridging machines. Perennial weeds were hand-pulled in early summer in most crops. This was affordable with the lower population of creeping thistle (*Cirsium arvense*) and higher crop prices of the 1990s. However, by 2003 the cost of this job would have been unaffordable in a commercial situation and the project steering group decided that hand weeding would be limited to pulling wild oats (*Avena fatua*) and docks (*Rumex* spp.).

The fertility-building crops were mown between one and three times per year in response to growth rate, and the mowings were left as a mulch.

All seed, apart from an approved proportion of the white clover, was organically grown. The calabrese plants were grown organically, by a Soil Association approved plant raiser, from non-organic seed.

Aluminium calcium phosphate (14% P) ("Redslaag") was applied once per rotation, after harvest of the beans, starting in plot 1 in 1995, at 625 kg/ha. This product is approved for use on high-pH soils only. No manures, composts or other fertilisers were applied. No irrigation was applied apart from water applied by hand on one occasion in each of 2004 and 2005 to ensure post-planting establishment of calabrese transplants. Hosepipes fed from a mobile tank were used.

The aim was to sell all crops as organic produce and use the actual prices realised in the economic evaluation. This was achieved except for potatoes, as discussed below. Cereals, beans and calabrese were sold at harvest. Potatoes were stored in the refrigerated box store at ADAS Terrington.

Assessments

Above-ground dry matter and nitrogen accumulation of the fertility-building crops was assessed by analysing foliage cut from four randomly sited quadrats, each of 0.25 m^2, immediately before each mowing. Yields of cereals and beans were assessed by taking the average from six cuts, each of 20 m by 2 m, with a Sampo Rosenlew 2010 plot combine harvester. Grain dry matter content and specific weight (Dickey-John Grain Analysis Computer, model GAC 2000), nitrogen concentration, and Hagberg Falling Number were measured on sub-samples taken at harvest. For potatoes, at crop maturity, six randomly selected areas, each of 7.5 m by 2 rows, were harvested to assess tuber yield and size distribution. For calabrese, yield was taken as the total amount sold from the whole sub-plot. For all crops, samples of harvested produce were analysed for nitrogen, phosphorus and potassium content, and offtake calculated. Soil was sampled twice each year, in spring and post-harvest. Soil was taken from 0-15, 15-30, 30-60 and 60-90 cm. It was analysed for available P (Olsen's method), available K (ammonium nitrate extraction), mineral nitrogen and carbon.

OBJECTIVE 1. QUANTIFY CROP YIELD AND QUALITY.

Fertility-building crops

Undersown white clover thrived only in one year (2002) out of five. Establishment was affected by slug grazing, insufficient rain, and excessive rainfall.

A mixture of large leaved white clover, cv. Alice, Aberdai & Aran, at 2.0 kg/ha of each, was undersown in 2001 for the 2002 fertility building crop in plot 1. It established and grew well. It was cut and left as a mulch on 20 May, 28 June, 22 August, 8 October and finally on 19 December prior to ploughing. Dry matter yield was reasonable at 6.75 t/ha and total nitrogen accumulation was good at over 242 kg/ha (Table 1).

The same mixture of large leaved white clover was undersown in 2002 for the 2003 fertility building crop in plot 3. The clover emerged well but was almost completely eaten by slugs during a wet spell in mid-May. The clover was successfully re-sown with the same seed mixture after harvest of the barley. It was cut and left as a mulch on 20 May, 10 July, 29 August, 23 October and finally on 12 December prior to ploughing. Dry matter yield and total nitrogen accumulation were modest with averages of 4.61 t/ha and 170 kg/ha respectively (Table 1).

A mixture of large leaved white clover, cv. Alice, Aberdai & Aran, at 2.0 kg/ha of each, was undersown on 1 May 2003 for the 2004 fertility building crop in plot 2. The clover emerged but suffered severe plant loss from slug grazing in a wet June. The clover was re-sown with a mixture of cv. Alice (2.4 kg/ha), Aberdai (1.8 kg/ha) & Menna (1.8 kg/ha) on 8 Sept 2003 post cereal harvest, and rolled, but failed to emerge, probably due to a very dry September. Vetch (cv. Early English) was sown, followed by rolling, on 13 April 2004 at 50 kg/ha. The vetch emerged slowly, and was slower to grow than the weeds, achieving only 9% ground cover by 14 May. The vetch did not show vigorous growth until June, by which time thistles were growing well above the crop across the plot. The tall weeds were mown with a flail mower on 4 June 2004. This caused some damage in the wheelings but the vetch then grew well through June and July. The vetch was mown on 20 July and left as a mulch. Dry matter yield and total nitrogen accumulation were modest with averages of 2.6 t/ha and 90 kg/ha respectively (Table 1).

Undersowing of plot 4 was not attempted in spring barley in 2004 due to a very dense growth of charlock. White clover (cv. Aberconcord (3 kg/ha), Alice (1.5 kg/ha) and Menna (1.5 kg/ha)) was direct-sown in September after harvest of the barley. Only a few plants establish in a very wet autumn (over 110 mm of rain fell in October). The plot was re-sown with vetch (cv. Early English) in March 2005. The vetch was well established by late April but there was also a high population of charlock. The plot was mown on 13 June to remove flowering stems of charlock and creeping thistle, and mulched to ground level on 29 July as it was starting to set seed. Dry matter and nitrogen accumulation were similar to 2004 (Table 1).

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

	2002 White clover undersown	**2003** White clover re-sown in spring following failure of under-sowing	**2004** Vetch replacing failed under-sown and re-sown white clover	**2005** Vetch replacing failed white clover
Dry Matter (t/ha)	6.75	4.61	2.60	3.25
Nitrogen (kg/ha)	242	170	90	97

Of all the crops grown post-conversion, fertility-building crops have been the most difficult to establish. Over the life of the project, clover failed to successfully establish in four of the eleven years from 1995 to 2005, even when re-sown in some years (Table 2). Vetch was sown in spring as a (reputedly) rapidly-growing replacement in three of the years but it was slow to establish, competed poorly with weeds and had a considerably lower accumulated nitrogen in the mulched foliage. The mean accumulated nitrogen in vetch was 102 kg/ha (range 90 to 121), whereas in clover it was 175 kg/ha (range 0 to 274). Until 1995, clover was direct-sown in autumn after harvest of the preceding cereal crop. From 1996, with establishment of full crop rotation on all five plots, clover was undersown in a spring cereal. Each method suffered particular problems; direct sown crops start growth well in autumn but were susceptible to damage from *Sitona* spp. weevils and frost. Undersown crops were more susceptible to drought and slug damage. Growth of established crops was affected by variation in rainfall, and by attack from pests such as *Sitona* spp. weevil and stem nematode (*Ditylenchus dipsaci*). The appearance of stem nematode damage in red clover in 1998 prompted the change to white clover as tests showed it was resistant to the races present. The two highest dry matter yields (in 1998 and 1999) were from red clover, but a generally higher nitrogen content in white clover foliage resulted in less difference in accumulated nitrogen.

Table 2. Fertility building-crop species, yield and nitrogen accumulation, 1995 to 2005.

Year	**Plot**	**Legume species**	**Accumulated dry matter yield of mulched foliage (t/ha)**	**Accumulated nitrogen content of mulched foliage (kg/ha)**
1995	4	Red clover	3.07	95
1996	5	Red clover (failed to establish)	0.00	0
1997	1	Red clover	9.41	274
1998	3	Red clover	9.76	199
1999	2	Vetch in place of failed red clover	5.84	121
2000	4	White clover plus lucerne	6.78	238
2001	5	White clover	4.67	184
2002	1	White clover	6.75	242
2003	3	White clover	4.66	169
2004	2	Vetch in place of failed white clover	2.59	90
2005	4	Vetch in place of failed white clover	3.38	97

Despite the poor performance of some of the fertility-building crops, this was not clearly reflected in the performance of following crops. For instance, the failed clover in plot 5 in 1996 was followed by above-average yields of potatoes in 1997, and of winter wheat in 1998. This illustrates both the nutrient retention capacity of the soil at Terrington and the over-riding impact of environmental conditions on organic crop performance, particularly on a fertile soil. Replicated experiments comparing legume species over different seasons, done at Terrington in the 1990s as part of this programme (Cormack *et al*., 2003)), showed little correlation between above-ground dry matter and nitrogen accumulation with the yield of a subsequent wheat crop. It was concluded that effects of weather and soil on the growth and nitrogen fixation of legumes, on mineralisation of the legume residues, and on the nitrogen uptake, growth and yield of the subsequent wheat crops, were likely to be much greater than those of legume species and management. This conclusion was supported by results from a stockless arable study on fertile soil in Germany. (Schmidt *et al*., 1999).

2002 cash crops

Total rainfall in 2002 was well above average (598 mm) at 750 mm. Only 1993 had been wetter in the previous 53 years. Most of the excess rain fell in July, October November and December. February rain was slightly above average but all other months were drier than average, particularly March, June and September. Sunshine hours were below average, reflecting the wet weather. The result was generally good growing conditions but problems with slugs and blight in potatoes, slugs in undersown clover and an increased risk of over-winter nutrient leaching.

Winter wheat grew well although there was some indication of poor growth where there was soil compaction following the previous potato crop. Annual weeds were at an acceptable level and not judged bad enough to justify the use of the “Harrow Comb” tined weeder. Foliar disease, primarily *Septoria tritici*, was at a low level throughout. Grain yield was reasonable at 7.1 t/ha after potatoes and 6.4 t/ha after calabrese (Table 3). Hagberg Falling Number, at 225 after calabrese and 213 after potatoes, was acceptable for bread making. Grain protein was 9.3% after potatoes and 9.5% after calabrese.

Potatoes were planted on 6 April in good soil conditions, inter-row cultivated on 15 June to control weeds, and ridged on 7 June. Control of annual weeds was acceptable, but docks and thistles grew strongly. These were hand-pulled in May. Foliar symptoms of blight (*Phytophthora infestans*) were not recorded until 18 July, probably because June was drier than average. Despite a very wet July, blight increased only slowly to reach 2% leaf affected on 31 July. Soil conditions were too wet to allow application of copper and lime fungicide (‘Bordeaux mixture’). Blight increased rapidly to 10% leaf area affected on 5 August. Foliage was flailed-off on 6 August and harvest was on 14 September. Total yield was good at 39.5 t/ha. Saleable yield, assessed at harvest, was 24.0 t/ha (Table 3). The main reason for rejection was slug damage (10.2 t/ha) (Figure 1). Tuber size tended to be small (Figure 2). Skin quality at harvest was excellent with the only blemish recorded as common scab (*Streptomyces scabies*) at an average of 1.2% of surface area affected. As in earlier years, there were minimal losses in store, even following significant levels of foliar blight in the crop. The only significant post-storage disease present was silver scurf (*Helminthosporium solani*). When assessed on 14 March, there was an average surface area blemish from silver scurf of 4.2%; common scab was recorded as 0.4%.

Table 3. Saleable crop yields (t/ha). P = after potatoes and C = after calabrese in the rotation.

	2002		**2003**		**2004**		**2005**		**Programme mean 1993 to 2005**	
	P	**C**	**P**	**C**	**P**	**C**	**P**	**C**	**P**	**C**
Potatoes, cv. Sante	24.0	-	26.0	-	18.0	-	-	-	23.2	-
Calabrese, cv. Marathon	-	4.9	-	4.1	-	5.7	-	6.2	-	4.2♠
Spring wheat after fertility-building crop (replacing potatoes in 2005)	-	-	-	-	-	-	5.7	-	5.7	-
Winter wheat, cv. Hereward	7.1	6.4	7.6	7.4	7.4	7.7	5.1	7.0	6.9	7.1
Spring beans*	3.8	-	2.8	3.1	0.0	0.0	2.0	1.8	3.1♣	1.6♣
Spring cereal**	3.4	-	4.7	-	2.0	2.6	7.6	6.7	4.2♦	4.6♦

* Beans cv. Meli in 2002 and 2003, cv. Victor in 2004, cv. Compass in 2005.

**Barley cv. Dandy in 2002 and 2003, Wheat cv. Paragon in 2004 and Chablis in 2005.

♠ Mean of five crops. Includes failed crop in 2001.

♣ Mean of eleven crops after potatoes and three crops after calabrese. Includes failed crops in 2004.

♦ Mean of ten crops after potatoes and two crops after calabrese.

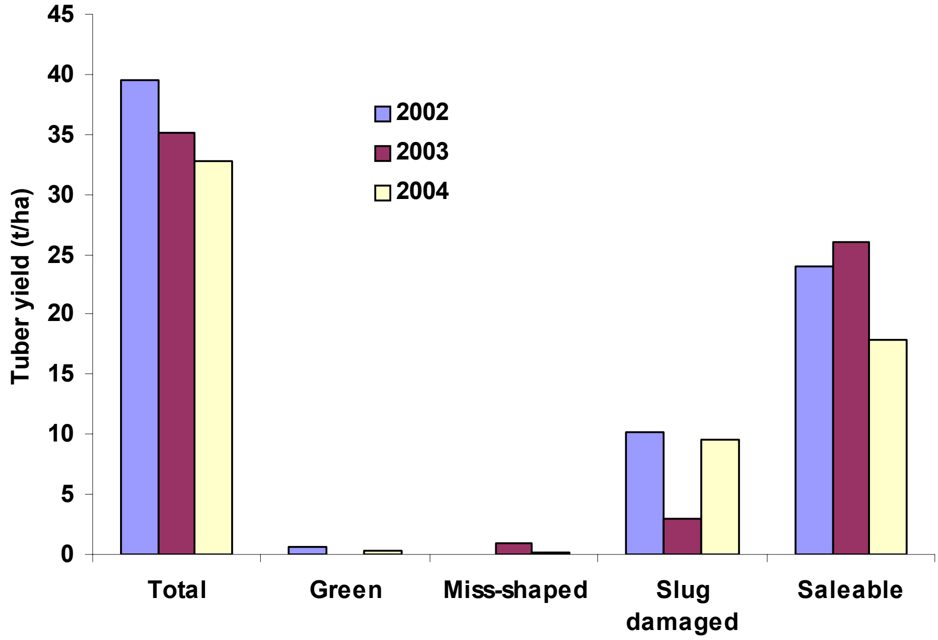

Figure 1. Yield of reject and saleable potato tubers, 2002 to 2004.

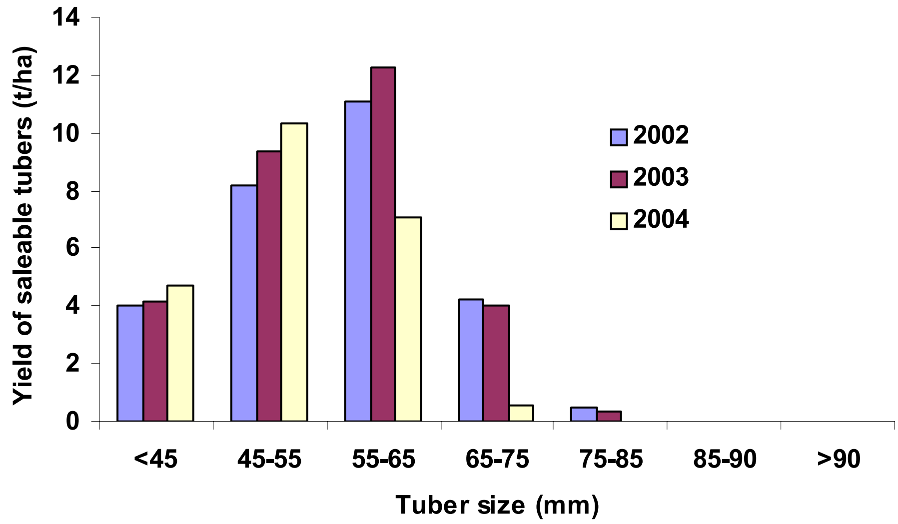

Figure 2. Potato yield distribution by tuber size, 2002 to 2004.

Calabrese was planted on 3 May (40,365 plants/ha). A woven mesh cover ("Enviromesh") was put on immediately post planting. The aim of using this was as a physical barrier to flying pests. This cover was removed only for weed control and harvest. There was adequate rainfall following planting and watering was not necessary for establishment. The calabrese was tractor hoed and hand-weeded on 11 June. Slugs were encouraged by the damp conditions caused by rain during May leading to moderate feeding damage to leaves and some plant loss. Harvests were on 12 July, 17 July and 19 July. Total yield sold was 4.9 t/ha (Table 3).

Spring beans were sown on 5 March at 300 kg/ha. Emergence was good with 75 plants/m^2 established. No pest or disease problems were evident and harvest was on 30 August. Yield was 3.8 t/ha (Table 3).

Spring barley was sown at 200 kg/ha on 5 March. The crop established well and white clover was under-sown into the growing barley on 27 April. Plant population, at 134 plants per m^2 was modest. Creeping thistles were present across the plot, at about 4% ground cover overall, and were hand pulled in July. Foliar diseases were almost absent at GS 31 on 17 May; by GS 59 on 14 June rhynchosporium (*Rhynchosporium secalis*) was present on leaves 2 and 3 at 10% incidence. By GS 75 on 11 July, rhynchosporium had increased to 70 % incidence on leaf 2 and brown rust (*Puccinia recondita*) was present at 20% incidence on leaf 1. The barley was harvested on 13 August. Yield was 3.8 t/ha (Table 3).

2003 cash crops

Total rainfall in 2003, at 585 mm, was close to average. January and June were very wet with twice the long-term average for those months. In contrast, early spring and late summer were dry with February, March, April, August and September having less than half the long-term average rainfall. Sunshine hours were well above average. The result was generally good spring planting and growing conditions, and good opportunities for post-harvest cultivations. However, a wet spell in early June was ideal for slugs which resulted in a substantial (approx. 50%) loss of calabrese plants.

Winter wheat was sown on 25 October 2002. The crop established well but there was some loss of plants from slug grazing early in 2003. Levels of foliar disease were again very low. Weeds, primarily creeping thistles, and a few docks and wild oats, were hand-pulled on 9 June. Grain yield was reasonable at 7.6 t/ha after potatoes and 7.4 t/ha after calabrese (Table 3). Hagberg Falling Number was 227 after calabrese and 244 after potatoes. Grain protein was 10.7% after potatoes and 10.8% after calabrese.

Potatoes were planted on 11 April in good soil conditions. The crop was inter-row cultivated and ridged on 4 June. Control of annual weeds was acceptable but, as in previous years, docks and thistles grew strongly, but as agreed by the steering group, thistles were not hand-weeded. Despite a very wet June, foliar symptoms of blight were not recorded until 17 July. Levels increased slowly to 7% leaf area affected on 18 August. Soil conditions were too wet to allow an application of fungicide. Foliage was flailed-off on 18 August and harvest was on 4 September. Total yield was modest at 35.1 t/ha. Saleable yield, assessed at harvest, was 26.0 t/ha (Table 3). The main reasons for rejection were tubers smaller than 45mm (4.2 t/ha) and slug damage (3.0 t/ha). Skin quality at harvest was good; disease was limited to black scurf (*Rhizoctonia solani*) and silver scurf at an average of 0.4% and 0.8% of surface area affected respectively. As in earlier years, there were minimal losses in store, even following significant levels of foliar blight in the crop. The only significant post-storage disease present was again silver scurf. When assessed on 25 November, there was an average surface blemish from silver scurf of 1.1%; black scurf was still 0.4%.

Calabrese was planted and covered with mesh on 3 May. Dry weather followed planting, but rain fell on 13 May reviving the plants which then grew-on well. The start of June was wet, particularly 1, 6 and 8 June, when over 12 mm fell each day. This encouraged slug activity, leading to extensive grazing and loss of plants, particularly in areas of the plot where soil was less compacted. Damage to plants on the headland was much less. This effect was also observed in earlier years, but attempts to plant into a firmer seedbed caused problems in getting sufficient planting depth, and also resulted in poor establishment. The calabrese was tractor-hoed between the rows, and hand-weeded in the row, on 12 and 13 June. Harvest was on 18, 22 & 28 July, and 1 August. Yield sold was 4.1 t/ha (Table 3).

Spring beans were sown on 28 February at 300 kg/ha. Emergence was good with 68 plants/m^2 established. No particular pest or disease problems were evident and harvest was on 18 August. Yield was 2.8 t/ha after potatoes and 3.1 t/ha after calabrese (Table 3).

Spring barley cv. Dandy was sown at 200 kg/ha on 17 March. Foliar diseases were almost absent at GS 31 on 17 May. At GS 59 on 16 June, Rhynchosporium was present on leaf 3. By GS 75 on 16 July, it had increased to 50% incidence (i.e. half of the plants sampled had the disease) and 1.0% severity (percentage of leaf area affected) on leaf 1, and 30% incidence, 2.5% severity on leaf 2. The barley was harvested on 9 August. Yield was 4.7 t/ha (Table 3).

2004 cash crops

The 2004 cropping year was the most challenging year weatherwise since the project started. Total rainfall in 2004 was 758 mm, the wettest year at Terrington since 1951. The wettest months were November and December 2003, January, August and October 2004. The latter two were particularly wet, both with around double the average rainfall. Sunshine hours were slightly below average. Persistently wet soil and the lack of prolonged dry spells made it a very difficult year for sowing both autumn and spring crops. Timely weed control and potato blight spraying were impossible, harvest of beans and potatoes was affected, and cereal grain quality was impaired.

Winter wheat was sown on 27 October 2003. It was sown in wide rows (34 cm (13.5 inches)) for the first time, to allow inter-row hoeing for weed control. Seed was sown at 160 kg/ha, the maximum that could be sown using the Moore drill set to wide rows. Winter wheat established and grew well in the wet spring, but soil was consistently too wet to allow tractor hoeing. Levels of foliar disease were higher than in earlier years, probably due to the wet season. At GS31 on 30 April, disease levels were similar after potatoes and calabrese. *Septoria tritici* was recorded at a mean incidence of <1% on leaf three, severity 0.6%. When re-assessed at GS59 on 07 June

Septoria tritici had developed further although levels remained low. On leaf 3 there was a mean incidence of 60% and severity of 5% after potatoes, a mean incidence of 40% and severity of 5% after calabrese. Brown rust was present on leaves 2 and 1 in both areas. Occasional docks and wild oats were hand-pulled on 8 June. Creeping thistles were widespread across the plot but they were not hand-pulled. The move to wide rows was intended to reduce weeding costs and improve management by allowing tractor hoeing, but the persistent wet conditions made it impossible to hoe. August was very wet and harvest was not possible until 4 September. Grain yield was good, given the disease and weed pressure, at 7.4 t/ha after potatoes and 7.7 t/ha after calabrese (Table 3). Grain protein was 10.2% after potatoes and 10.0% after calabrese. Hagberg Falling Number was very low (73 after potatoes and 74 after calabrese) reflecting the delayed harvest due to wet weather.

Potato planting was delayed until 17 May by wet soil conditions. The crop was ridged on 8 June, and inter-row cultivated and ridged again on 17 June. It established well, reaching 90% ground cover by mid-July. Control of annual weeds was acceptable but, as in previous years, docks and thistles grew strongly. Foliar symptoms of blight were first seen on 2 August. Blight developed rapidly in the wet conditions (111 mm of rain fell in August) reaching 7% of leaf area affected on 6 August and 25% by 16 August. The soil was too wet to travel on with the tractor and sprayer, particularly after 23 mm fell on 9 August, so it was impossible to treat with fungicide even though permission had been granted by the Soil Association. The soil was not dry enough to travel on until 30 August when the foliage that remained was flailed-off (blight was at 90% leaf area affected). Harvest of hand-dug test-plots was on 28 September. Total yield was modest at 32.8 t/ha; saleable yield was 18.0 t/ha (Table 3). The main reasons for rejection were slug damage (9.5 t/ha) exacerbated by the wet conditions, and tubers smaller than 45 mm (4.7 t/ha) probably due to the late planting. The tuber sample was not bold, with only 0.7 t/ha of saleable tubers larger than 65 mm (Figure 2). Small size has been a feature of most potato crops due to a combination of growing an early maturing cultivar to minimise the impact of blight, the absence of irrigation and early defoliation due to blight. This contributed to difficulties in marketing the crop. Tuber disease at harvest was limited to silver scurf and common scab at an average of 0.9% and 0.1% of tuber surface area affected respectively. As in earlier years, there were minimal losses in store, even following significant levels of foliar blight in the crop. When assessed again post-storage (18 January 2005), the incidence of silver scurf had increased to 3.5%, no other diseases were recorded.

Commercial harvest of the crop using farm-scale machinery was not possible through September and October because of continuing wet soil conditions. Because of the delay this was causing in sowing of winter wheat, the potential soil damage from harvest machinery, the low saleable yield from the test-plots and the expected inability to sell the tubers, it was decided not to attempt a full harvest but to cultivate the ridges and establish wheat with minimal cultivations.

Calabrese was planted, watered and covered with mesh on 21 May. No rain fell until 29 May but the plants survived and grew-on well. Slugs did not cause the damage seen in some earlier years, as conditions during the susceptible phase of growth were too dry for slug activity in this generally very wet year. Harvests were made on 27 and 30 August. Yield was 5.7 t/ha (Table 3).

Spring beans were sown in wide rows (34 cm (13.5 inches)) at 250 kg/ha on 14 April. Sowing was delayed by the wet soil conditions. Emergence was excellent with 78 plants/m^2 established. The plot was inter-row tractor-hoed on 14 May. Despite the successful tractor hoeing, growth of annual weeds was prolific in the wet summer and by late July there were high populations of sow thistle (mean 12.4 plants/m^2), fat hen (mean 22.8 plants/m^2) and black bindweed (mean 11.4 plants/m^2). Harvest was attempted on 8 September, but proved impossible due to the tough dead stems of black bindweed which blocked the combine harvester.

Spring wheat was sown at 200 kg/ha on 17 April. The wheat emerged well, but there was also a very dense growth of charlock (mean of 77 plants/m^2 on 14 May) which seemed particularly favoured by the late sowing and wet season. Foliar diseases were absent at GS 31 on 8 June. Soil remained too wet to allow use of the harrow-comb weeder although the early and well-established tap-rooted charlock would have been resistant to harrowing, and the majority would probably have survived. Therefore, although not done, it is very unlikely that harrowing would have made any significant impact on weed competition. At GS 59 on 7 July there was no disease present apart from traces of *Septoria tritici* on leaf three. Harvest was on 4 September. Yield, at 2.0 t/ha in the potato area and 2.6 t/ha in the calabrese area of the plot (Table 3) was poor, almost certainly adversely affected by the high weed population.

2005 cash crops

Rainfall in 2005 was 585 mm. The winter of 2004/05 was relatively dry and was followed by a cold dry spring. June, July, August and September all had average or above average rainfall.

Winter wheat was sown on 19 November 2004; establishment was good. Crop vigour was noticably better following calabrese rather than after potatoes. The dry spring allowed inter-row hoeing on 5 April. This gave good control of annual weeds, but thistles and docks quickly recovered. Thistles were present at high levels at harvest, averaging 5.8 shoots/m^2 in July. Very few volunteer potatoes were present despite the preceding crop having been unharvested. Foliar disease was again only present at very low levels. Harvest was on 30 August. The higher plant population and vigour after calabrese resulted in an apparently higher yield at 7.0 t/ha compared with 5.1 t/ha after potatoes (Table 3). Grain specific weight was greater after calabrese (75.6 vs. 72.1 kg/hl) but grain protein (10.0 vs. 9.9 %) and Hagberg Falling Number (265 vs. 287) were similar.

Calabrese was planted on 12 May. Plants were watered before covering with mesh, and established well with very few plants lost. Little rain fell until 24 June (15 mm) and 28 June (30 mm). This limited weed growth and hoeing was not necessary. The calabrese grew well after the rain, and matured evenly needing only one harvest on 19 July. Sold yield was 6.2 t/ha (Table 3), the highest of the four years.

Spring wheat grown in place of potatoes was sown at 200 kg/ha on 23 March in good conditions. It emerged and established well. Foliar disease was limited to low levels of *Septoria tritici* and mildew (*Blumeria graminis)*. Creeping thistles were the dominant weed, averaging 12.6 shoots/m^2 on 18 July. Harvest was on 30 August. Yield was 5.7 t/ha (Table 3), protein content was 9.5% and Hagberg Falling Number was 364.

◄ Thistles in spring wheat following potatoes - August 2005

Beans were sown at 270 kg/ha in wide rows on 24 March. They emerged well and were inter-row hoed on 3 May. This was successful, but by mid-July there was a very dense growth of creeping thistles (10.2 shoots/m^2), docks (3.4 plants/m^2) and annual sow thistle (20.8 plants/m^2). Harvest was on 9 August. Yield was 2.0 t/ha after potatoes and 1.8 t/ha after calabrese; it was probably reduced by the high weed population (Table 3).

◄ Creeping thistles in beans - June 2005

◄ Creeping and sow thistles in beans - August 2005

Spring wheat was sown 23 March at 200 kg/ha. It emerged well and white clover was under-sown on 5 May. Both wheat and clover established well. Foliar disease was limited to low levels of *Septoria tritici* and Mildew. Weed numbers were high, the dominant species present in July were black bindweed (7.6 plants/m^2), creeping thistle (6.4 shoots/m^2) and chickweed (10.4 plants/m^2). Harvest was on 30 August. Yield was excellent at 7.6 t/ha after potatoes and 6.7 t/ha after calabrese (Table 3). The crop was vigorous and competed well with the large population of weeds. The beans in 2004 in this plot could not be harvested and the significant nitrogen return in the bean seed (mean of 133 kg/ha (Table 7)) would have contributed to a higher than normal nitrogen supply for this crop at the end of the rotation and was probably the main reason for this relatively high yield (Figure 6).

Longer-term trends in crop yield and quality

Winter wheat

Autumn sowing of winter wheat was achieved every year apart from for the 1994 crop when sowing was delayed by persistently wet soil. Yield was good with an average of 7.0 t/ha (Figure 3); this compares with a typical organic yield of 4.0 t/ha (Lampkin *et al*., 2004). Yield was relatively consistent, and reflected environmental conditions, with lowest yields in the very dry 1995 and the wet and dull 1997 and 2001 (Figure 3). The highest yield of 9.8 t/ha was in 1996 when a dry and sunny early summer was followed by rain in July and August ensuring good grain fill. Grain nitrogen content ranged from 1.7% (1995 and 1997) to 2.2% (2003). This was generally below the 2.2 to 3.3% typically required for bread making (Berry *et al*., 2005) and as a result it was sold for organic livestock feed. Foliar disease was limited to low levels of *Septoria tritici*, and also mildew and brown rust (*Puccinia recondita)* in the hot dry summer of 1995. No fungicides were applied in any year, as they were not considered necessary due to the low levels and late development of disease.

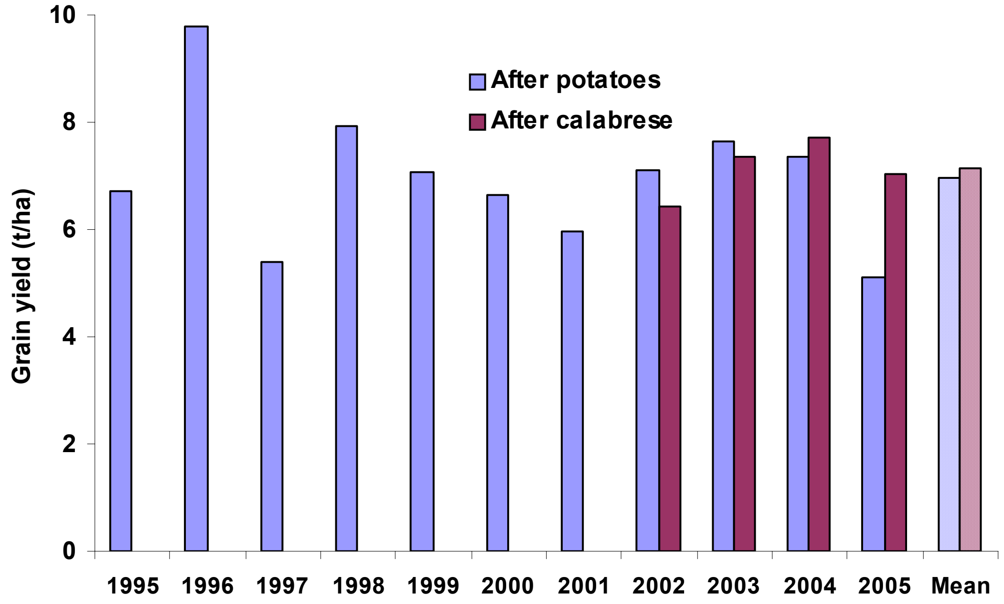

Figure 3. Winter wheat grain yield, 1995 to 2005 (excludes the 1994 crop which was spring sown).

Potatoes

Total and saleable yields of potatoes were very variable (Figure 4), reflecting effects of rainfall both directly on growth and yield, and indirectly on the activity of slugs and blight. The low yields of saleable tubers in 1993, 1998, 2001 and 2004 were due to a large proportion of rejects from slug damage in those wet seasons. The very dry summer of 1995 restricted both total and saleable yields. The summer of 1996 also started dry and sunny but rain in late July resulted in the highest total and saleable yields. No blight was seen in the dry conditions in 1995 or 1996 and no fungicide was applied. Meteorological conditions were favourable for, or foliar blight was present, in all other years. A copper-based fungicide was applied between 1 and 5 times, but in the absence of an untreated control, it is not possible to say how effective this was. No tuber blight was recorded in any year. In the absence of irrigation, variation in rainfall led to a large variation in tuber size distribution (Figure 2). This contributed to the lack of a market for the crop from 2000.

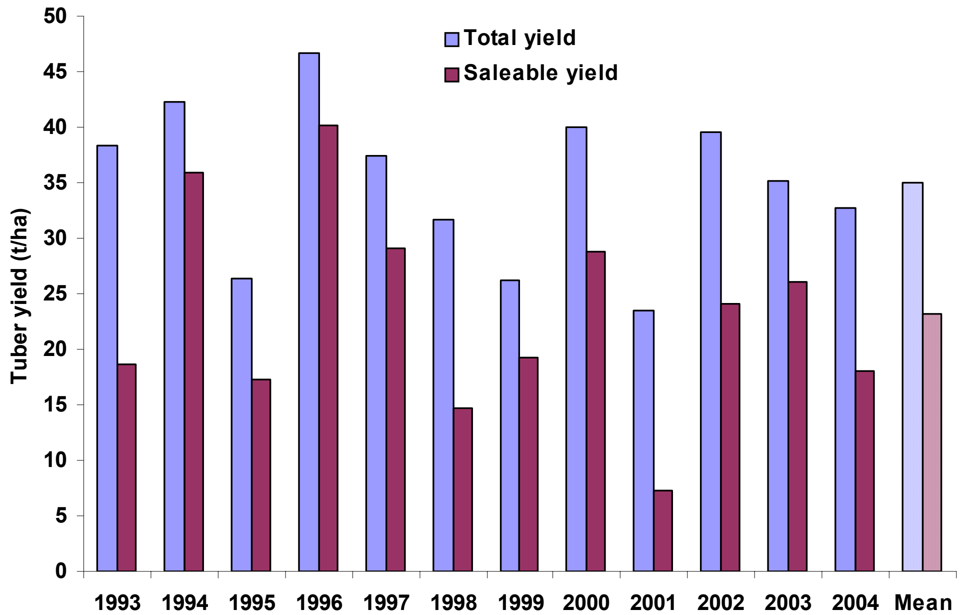

Figure 4. Yield of potatoes, 1993 to 2005.

Spring beans

Beans generally established and grew well with yields of over 3 t/ha in all but two years (Figure 5). Establishment was variable, ranging from 22 to 71 plants/m^2. Yield was reduced in 1995 by drought, in 1997 by poor pollination and pod set in a very dull June, and in 2004 and 2005 by weeds.

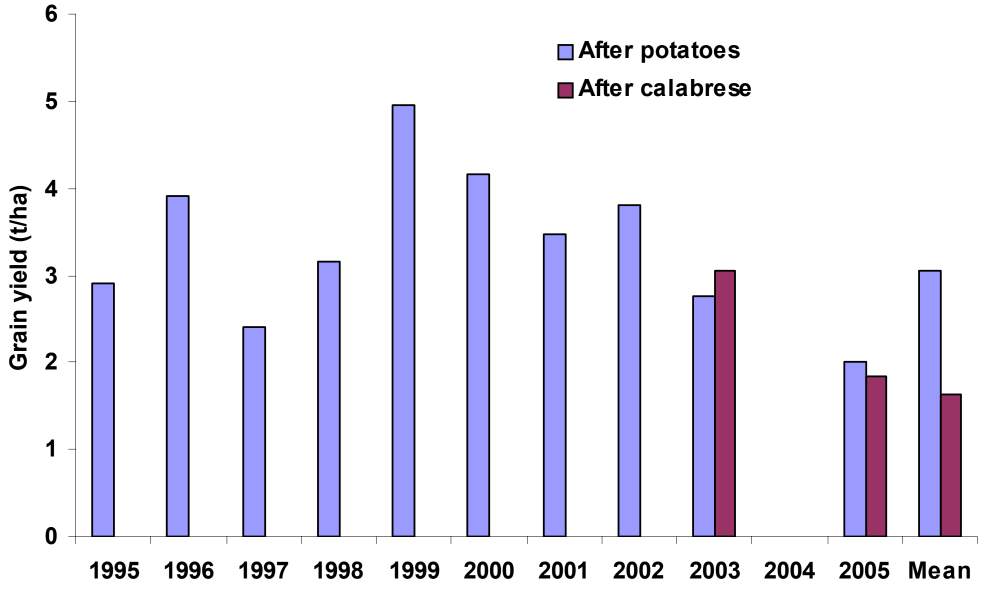

Figure 5. Yield of beans, 1995 to 2005 (mean includes zero yield in 2004).

Spring cereal

Apart from in 2005, the spring cereal yielded considerably less than the winter wheat (Figure 6). This was expected as it was at the end of the crop sequence when nitrogen availability would be least. Foliar disease levels were low, and as for winter wheat, were unlikely to have been significantly limiting to yield. The low yield in 2004 was probably mainly due to weed competition, particularly charlock. The 2005 crop had the greatest yield, probably because of a greater N supply as the preceding bean crop was not harvested resulting in all the seed nitrogen being returned to the soil rather than removed at harvest. This is supported by the soil mineral nitrogen (SMN) to 90 cm results. This averaged 178 kg/ha in April 2005, compared with 115 kg/ha in 2004 in plot 4, 104 kg/ha in 2003 in plot 2, 76 kg/ha in 2002 in plot 3 and 92 kg/ha in 2001 in plot 1, all in spring after beans.

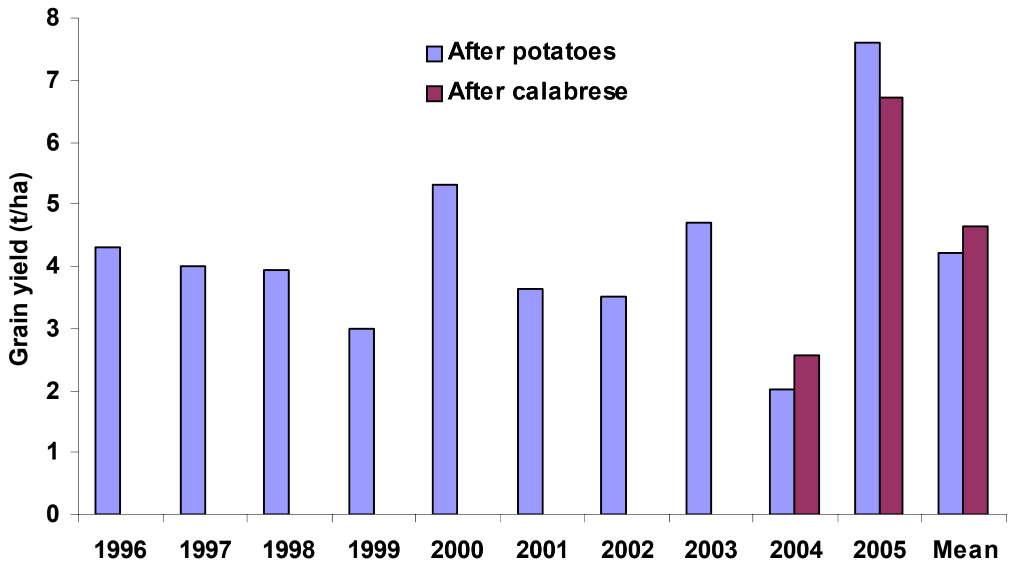

Figure 6. Yield of spring cereal following beans, 1996 to 2005.

Effect of potatoes vs. calabrese on yield of following crops

There was no consistent difference in the mean yields of crops grown following either potatoes or calabrese. If there were to be an effect, the greatest impact would be expected in the immediately following crop of winter wheat. Of the four wheat crops grown immediately after either potatoes or calabrese, the data suggest that in two years yield was higher after potatoes and in two it was higher after calabrese (Figure 3). This magnitude of this apparent difference was greatest in 2005. However, there was no replication of treatment within-year to confirm whether these apparent differences were real. To give some indication of confidence, a standard deviation was calculated from the six separate plot-combine yield assessments making up each mean. Confidence limits (95%) were calculated by multiplying the standard deviation by the statistic "t" (value 2.57 for 5 degrees of freedom). This showed that in all years, the confidence limits (the mean, plus or minus the standard deviation multiplied by t) overlapped showing that at the 95% confidence level, we cannot say that there is a real difference in wheat yield after potatoes or calabrese. Similarly, for beans and spring wheat (Figures 5 & 6), the recorded means were not significantly different.

OBJECTIVE 2. QUANTIFY THE FINANCIAL PERFORMANCE OF THE ROTATION AND CONTRAST WITH FARM BUSINESS SURVEY DATA FROM COMPARABLE NON-ORGANIC ARABLE FARMS.

As ADAS Terrington is a research farm, fixed costs (such as machinery and labour) can not be realistically measured. Therefore data are presented to the gross margin level only, i.e. crop output (yield × price) minus variable costs (such as seed, and approved fertiliser and pesticide).

Crop gross margins

The gross margins of individual crops are principally a function of crop yield and price, as variable costs for organic crops are much lower than in non-organic production due to the omission of most pesticides and fertilisers. As discussed above, there has been considerable variation in saleable yield between years and crops (Table 3).

Cereals, beans and calabrese were sold as organic produce each year (Table 4). However, no organic market could be found for potatoes from 2001 due to a more discerning market as a result of a significantly increased supply. To allow calculation of economic performance, a market price was estimated for the sample produced each year using information from commercial producers gathered in related project OF0322. The apparent rise in the calabrese price in 2003 was due to changes in the operation of the company purchasing the crop. Until 2002 this was a net harvested price with the buyer harvesting the crop; from 2002 ADAS staff harvested the crop.

Table 4. Actual prices achieved for the sale of organic crop produce, 2002 to 2005.

	2002 (£/t)	**2003 (£/t)**	**2004 (£/t)**	**2005 (£/t)**
Potatoes $^{\alpha}$	160	150	150	not grown
Calabrese	700	1050	800	800
Winter wheat	165	155	120	129
Spring cereal	120	105	120	129
Spring beans	165	155	not harvested	140

α *Estimated prices*

In common with most farms, the prices obtained for crops have fallen over recent years. The price achieved for organic winter wheat grown at Terrington declined progressively from 1999 to 2004, as imports of organic cereals at competitive prices became more available (Figure 7). There was a slight improvement in 2005, probably in response to increased demand for animal feed. The decline in the price of non-organic wheat has been less marked, reducing the advantage to the organic system.

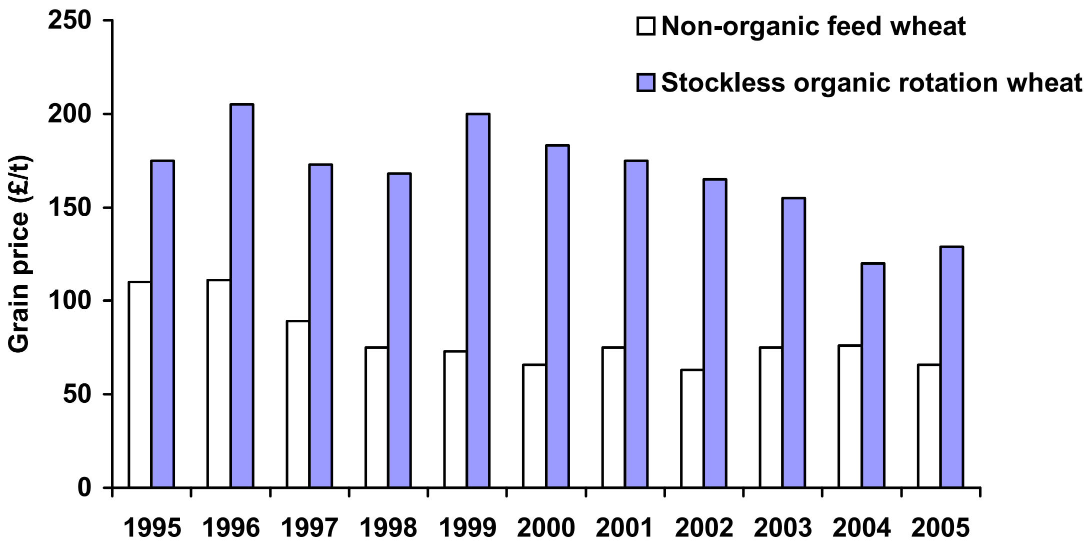

Figure 7. Winter wheat grain price achieved in the study compared with the non-organic price, 1995 to 2005.
(Non-organic price source: Anonymous, 2005)

The value of support under the Arable Area Payments Scheme (AAPS) has been very significant for combinable crops (ranging from £230-250 per hectare for cereals) and was included as an income in crop gross margins up to 2004. However, from 2005, support payments were de-coupled from individual crops under the Single Payment Scheme. The effect of decoupling will be to allow more flexibility in cropping, but this advantage cannot be realised in a stockless organic rotation. Commercial farms which are 100% organic have no requirement to set land aside and the 20% fertility building crop in the stockless organic rotation represents a major opportunity cost.

To allow fair comparison between years, support payments, including set-aside payable on the fertility-building crops, have been excluded from all of the crop gross margins presented in Table 5. Also, no payments for organic conversion have been included in any of the margins.

Table 5. Organic gross margins (excluding AAPS), 2002 to 2005.

	2002 (£/ha)	**2003 (£/ha)**	**2004 (£/ha)**	**2005 (£/ha)**
Potatoes	3100	2875	1741	not grown
Calabrese	1017	609	936	1822
Winter wheat	994	1047	819	681
Spring cereal	300	385	178	721
Spring beans	461	288	-120	133
Fertility crop	-170	-128	-195	-146
Rotation gross margin $^{\alpha}$	**728**	**667**	**404**	**561**

$^{\alpha}$ *Weighted by the proportion of each crop in the rotation.*

Key conclusions are:

- High margin crops such as potatoes and calabrese made a disproportionately large contribution to the rotation gross margin and are necessary to balance the low or negative income from the 20% of fertility-building crops.
- The fertility-building crop represents a major opportunity cost. This is particularly so as non-organic farmers could grow industrial crops on set aside land to generate income. On stocked organic farms there would be income from associated livestock enterprises.
- Spring cereals have generally performed poorly relative to winter wheat (with the exception of 2005 when nitrogen supply was higher following the non-harvested bean crop).
- Competition from weeds in spring-sown crops can reduce margins significantly; for example in beans in 2004 and 2005, and in spring wheat in 2004.

Financial performance compared with non-organic farms

The economic performance of the stockless rotation has been compared with non-organic farm data from Cambridge University Farm Business Survey (FBS) fen-arable group (Table 6). On non-organic farms, the cost of weed control using herbicides would be included in the gross margin as part of the variable costs of production. As discussed under objective 3 below, with the increasing populations of perennial weeds, the time spent hand weeding increased sharply at the end of the 1990s (Figure 14). This weeding was done by ADAS staff rather than contract labour, so the cost was not included in the crop gross margins. Therefore, to give a more realistic comparison, this cost has been included in the gross margin in Table 6. There was a small gross margin advantage to organic in 2002 despite the very high weeding costs that year. After 2002, creeping thistles were not hand-weeded, only docks and wild oats. This reduced weeding costs significantly, but was more than balanced by lower crop output resulting in a lower gross margin than in the FBS non-organic farms every year. AAPS payments have been retained in the gross margin calculations for both FBS and stockless organic rotation data for 2002, 2003 and 2004 because they cannot be readily identified in the FBS data.

Table 6. Stockless organic whole-rotation gross margin (GM) compared with Cambridge University FBS non-organic fen-arable farms, 2002 to 2005.

	2002 (£/ha)	2003 (£/ha)	2004 (£/ha)	2005[β] (£/ha)
Stockless organic GM	920	875	601	561
Hand weeding cost	150	41	20	20
Stockless organic GM (including hand weeding cost)	771	834	581	541
FBS fen arable non-organic GM	744	848	734	601 [α]
Advantage to organic	**26**	**-14**	**-153**	**-60**

[α] *Estimated from 2004 and adjusted for yields and prices from national statistics.*
[β] *Both non-organic and organic margins for 2005 exclude support payments. Other years include appropriate AAPS payments.*

Over the whole life of the project, the decline in relative profitability of the stockless organic rotation becomes more apparent (Figure 8). As discussed above, there has not been a decline in crop yield over this period, and crop variable costs have remained stable, therefore the decline in relative profitability was principally due to a decline in crop prices. Higher weeding costs in some years had a small impact on relative profitability.

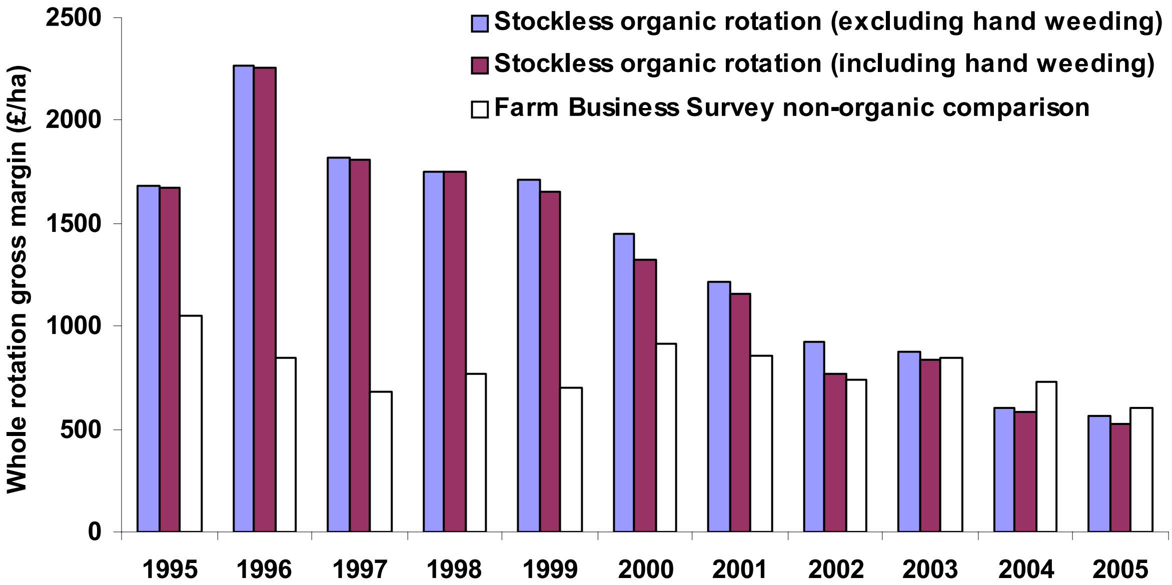

Figure 8. Stockless organic whole-rotation gross margin compared with Cambridge University FBS non-organic fen-arable farms, 1995 to 2005.
(Both non-organic and organic margins for 2005 exclude support payments, other years include appropriate AAPS payments).

OBJECTIVE 3. MONITOR AND EVALUATE INDICATORS OF SUSTAINABILITY; PARTICULARLY FOR NUTRIENTS, WEEDS, PESTS AND DISEASES.

Nutrients

Mean nitrogen offtake was highest for beans and least for Calabrese (Table 7). Potassium offtake was much higher for potatoes than for any other crop.

Table 7. Nutrient offtake in harvested crops, excluding failed crops (kg/ha).

	Nitrogen		Phosphorus		Potassium	
	Mean	Range	Mean	Range	Mean	Range
Potatoes	118	69-156	13	8-24	141	94-200
Calabrese	25	22-28	3	3-4	18	15-21
Winter wheat	114	78-157	19	12-24	26	18-33
Spring beans	133	73-193	19	8-27	37	17-54
Spring cereal	62	37-95	12	6-19	17	7-28

Cereal and bean data are for crops grown after potatoes in the rotation.

Nitrogen

The relative stability of yield, and the lack of any drop in crop N% over two crop rotations, suggests that the nitrogen supply was in balance. The total mean offtake of nitrogen over a rotation with potatoes was 427 kg/ha and with calabrese 338 kg/ha. Net nitrogen fixation was not measured, so that cannot be confirmed. However, this does suggest that the measure of gross nitrogen accumulation in the fertility-crop mulched foliage (which ranged from 0 to 274 kg/ha) considerably underestimated the net nitrogen fixation, even allowing for a small contribution from the bean crop.

Phosphorus

There were marked variations in available phosphorus (P) in the soil between plots and seasons (Figure 9). Because of a sharp fall in available P from 1990 to 2004 in all five plots, aluminium calcium phosphate (14% P) was applied once per rotation, after harvest of the beans, starting in plot 1 in 1995, at 625 kg/ha. Available P tended to continue to decline from 1995, but at a slower rate and with marked seasonal fluctuations. Changes in level were not related to applications of fertiliser, confirming that it is a slow-release material. By 2005, levels were between 10 and 16 mg/l, in Index 1 for Olsen's P (Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209)), and unlikely to be limiting to plant growth. However, values were close to Index 0, and if cropping was to continue, a supplementary, more available source of P would probably have to be introduced.

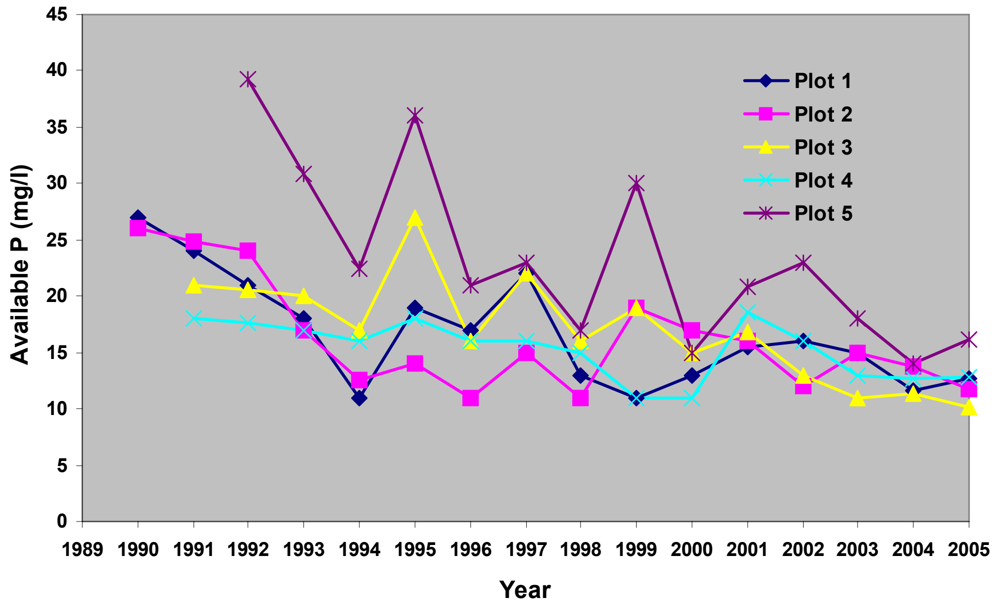

Figure 9. Available phosphorus in soil (0-15 cm).

Potassium

In contrast to phosphorus, available potassium (K) did not show a decline post-conversion (Figure 10). By 2005, available K ranged from 171 to 195 mg/l (Index 2 for ammonium nitrate extraction). This was similar to the levels in 1990, and was well above levels limiting to crop growth. As no K has been added, the substantial offtake, particularly from potatoes, has presumably been replaced by release from clay minerals in the soil. There was a very marked seasonal effect showing the importance of using changes over time rather than spot measures to make decisions on changes in soil fertility.

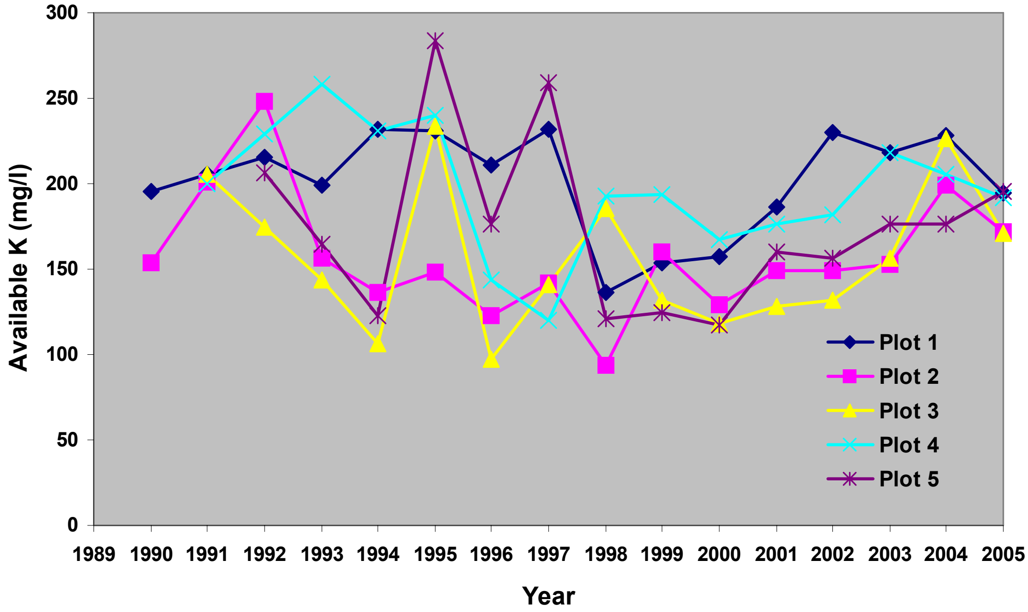

Figure 10. Available potassium in soil (0-15 cm).

Soil carbon

Soil carbon showed, on average, a trend for a progressive small increase (Figure 11). This is probably mainly a response to the additional organic matter returned in fertility-building crops. The rotation and crop residue management were otherwise similar to that practised before conversion. Straw would have been baled and removed pre-conversion, but would have been returned as manure. This increase is also despite a probable lower overall return in crop residues as crop yield would have been less than previously, although we do not have data to confirm that.

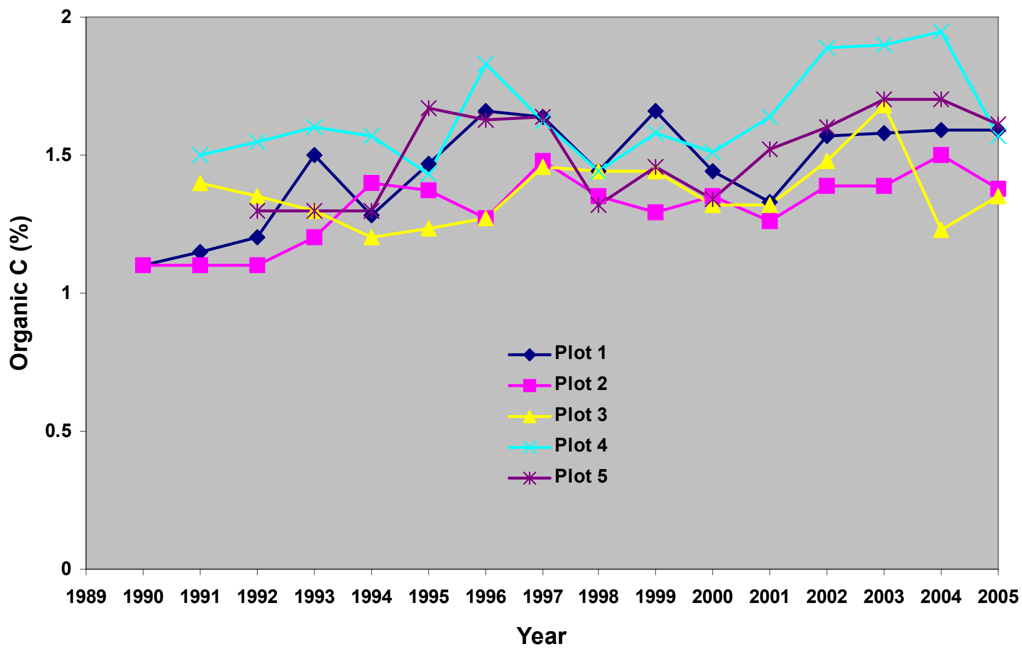

Figure 11. Carbon in soil (0-15 cm).

Weeds

Weeds were counted in twenty fixed-quadrats in each plot. These were of 1 m^2 and set out along a diagonal across each plot. Weeds were counted three times per year; in spring (April), summer (July) and in late autumn (November/December). Weed numbers and species varied depending on crop grown, and on season. Overall, total numbers of weeds did not increase post-conversion (typical data, for plot 1, are presented in Figure 12). Greatest numbers were associated with spring-sown cereals and beans, and with failed fertility-building crops, where crop competition was least. Lowest numbers were in winter wheat and well established clover crops.

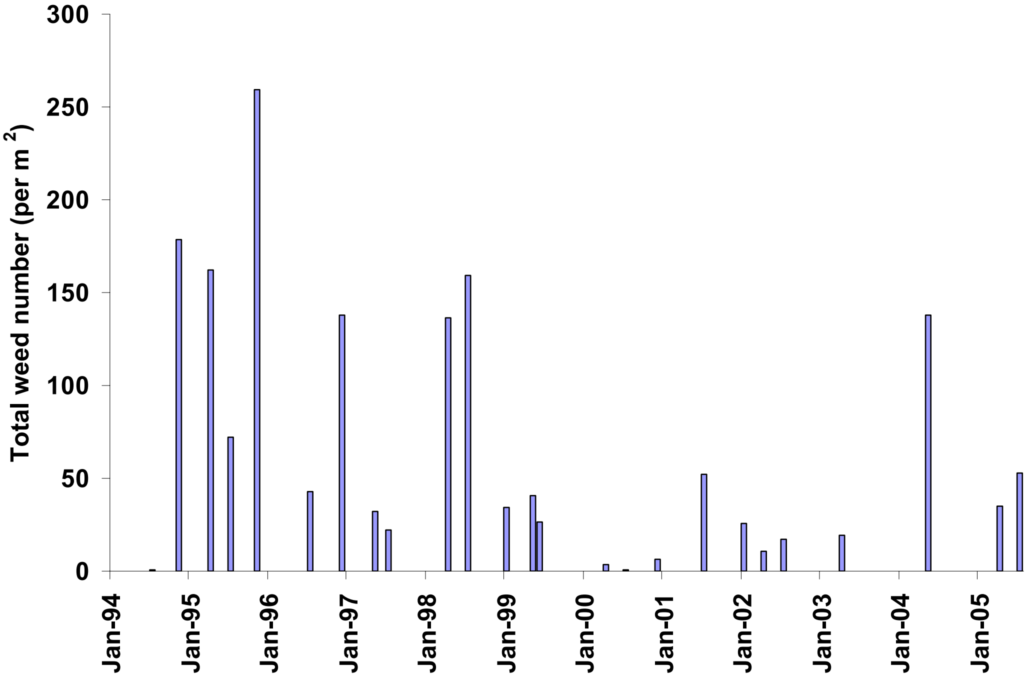

Figure 12. Total number of weeds in plot 1, 1994 to 2005.

There were some marked changes in the dominant weed species. The most common annual weeds were chickweed (*Stellaria media*), field speedwell (*Veronica persica*) and annual meadow grass (*Poa annua*). These were present every year, sometimes at very high levels. Typical weeds of spring cropping, such as redshank (*Polygonum persicaria*), black bindweed (*Polygonum convolvulus*) and charlock (*Sinapis arvensis*) were rare in the earlier years. However they increased in later years and became a serious problem. Black bindweed prevented harvest of beans in plot 5 in 2004, and a very high population of charlock developed in plot 4 affecting the spring cereal in 2004 and vetch in 2005.

Much more obvious were the increases in the perennial species creeping thistle (*Cirsium arvense*) and docks (*Rumex* spp.), particularly the former. Creeping thistle was present at low levels at the start of conversion but was not recorded in the fixed quadrats until 1999 in plot 2. It spread progressively across all plots until in 2005 it was present across the whole study area, particularly in plots 1 and 2 which completed conversion first. The data for plot 1 (Figure 13) illustrate the impact of crop on shoot numbers with the lowest numbers in potatoes, which can be easily cultivated, and in well-established, dense, mown clover. The reduction in shoot numbers during a clover crop was also recorded in a replicated experiment at Terrington in 2000, and presented at the 2002 COR Conference (see section 9). In that experiment, shoot numbers were reduced by 75% by a one-year dense clover fertility-building crop.

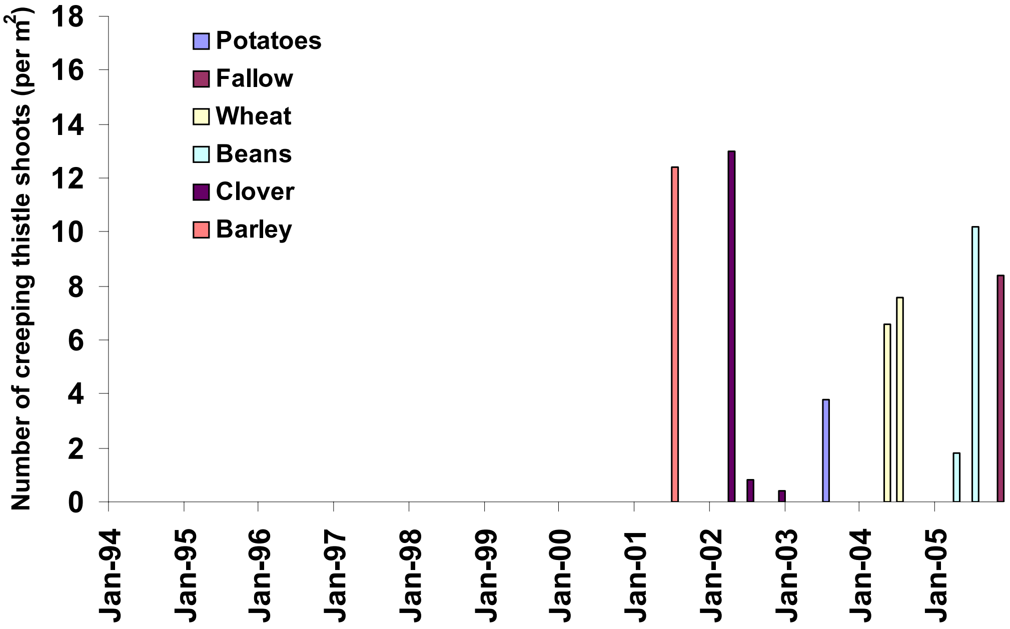

Figure 13. Number of creeping thistle shoots in plot 1, 1994 to 2005.

The impact of the increase in creeping thistles was seen in a sharp rise in the time spent hand-weeding at the end of the 1990s (Figure 14). As discussed above, to be commercially representative, hand weeding was limited to docks and wild oats after 2002.

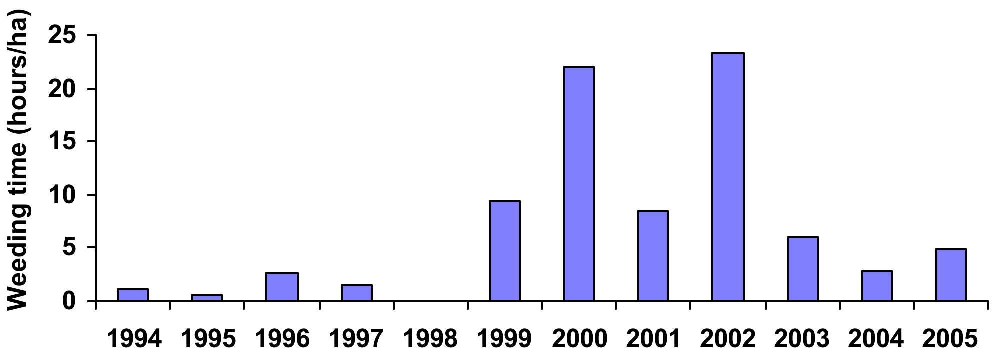

Figure 14. Time spent hand-weeding organic crops, 1994 to 2005.

Couch grass (*Elytrigia repens*) was present in patches in plot 3. Although it was very obvious in some crops, it did not spread significantly.

The relentless increase in creeping thistle shoot numbers suggests that the crop rotation is inherently favourable to them. Effective hoeing was usually not possible due to the soil being too dry or too wet when weeds and crop were at a suitable growth stage. In any case, mechanical weeding using hoes and tined harrows has only a temporary effect by removing young shoots. It has little impact on the large root structure, and shoots rapidly re-grow. Hand pulling is also not an effective solution. The observation of the decline of shoot numbers under dense clover discussed above suggests that the main encouragement for thistles is a lack of effective crop competition inherent in the crop sequence. This lack of competition was exacerbated by a number of poorly established, and non-competitive, fertility-building crops. Extending the duration of the fertility-building crop would increase competition with thistles. However, that would not be sustainable financially without the introduction of livestock to utilise those crops and would not be a viable option on many farms. An alternative approach could be to seek better overall crop competition through the rotation by better integrating fertility-building crops as undersown, inter-cropped and over-wintered crops rather than as separate crops. Such a strategy is also needed to improve overall rotation profitability in response to the introduction of the Single Payment System.

Until 1998, stubble turnip catch crops were grown between wheat and beans, and between beans and spring cereal (Appendix 1). They were discontinued as establishment and growth was slow. They were not effective at either nitrogen recovery or weed suppression. In a new design of rotation, sowing and establishment of cover crops would have to be pre-harvest of the main crop.

Pests and Diseases

Significant pest issues were slugs on potatoes, calabrese and clover, and stem nematodes and *Sitona* spp. weevils on clover.

The soil type at Terrington is particularly favourable to slugs when wet. Slugs damaged potato tubers when soil remained wet for prolonged periods post tuber-initiation; the longer it remained wet, the greater the damage. They caused significant rejection of tubers in 1993, 1998, 2001 and 2004 and the presence of damage was a deterrent to buyers because of worries about consumer acceptance. In other crops, they were a problem when excessive rainfall co-incided with susceptible growth stages, such as immediately post-planting of calabrese, and at clover emergence. Damage varied from nothing in dry years to total plant loss in calabrese in 2001 and in under-sown clover in 2002 and 2003. There are no commercially-available and affordable controls for slugs on a field scale and they remain a serious pest of vegetable and legume crops on heavy soils.

Stem nematode damage symptoms were seen only in 1998 in red clover. No symptoms have been seen since the switch to white clover that year, but the population is likely to comprise more than one race and be capable of adjusting to the new host in time. Strategies to avoid stem nematode, such as alternating clover species, should be adopted in stockless systems with a high frequency of clover crops.

Evidence of *Sitona* spp. leaf grazing was present on clover every year but it caused serious damage only when heavy autumn grazing of summer-sown crops was followed by hard winter frosts, as in 1996.

The only significant disease problem was blight in potatoes. The incidence and severity of blight is driven by the presence of wind-borne inoculum and by suitable meteorological conditions. These are not influenced by organic status, and the potential for blight infection is similar on organic and non-organic farms. Resistance to foliar blight of even the best commonly-grown cultivars is not high, and in the correct meteorological conditions blight can reach high levels in only a few days. Bordeaux mixture was applied in some years. How effective it was is not known as we did not have control plots, but observations suggest it had little effect when conditions were highly favourable for blight. Blight infection led to early defoliation, yield reduction and a less bold tuber sample – i.e., a higher proportion of smaller tuber sizes.

The mesh cover was very effective at excluding flying pests, both birds and insects, from calabrese. There were no rejections of crop due to pests or diseases in any year. However, mesh is expensive and needs a large labour input to remove and replace it for weeding and harvest. It is unlikely to be suitable for larger-scale growing where other methods of pest management would be necessary.

Cereals were the most reliable crops grown, with no failures or serious pest or disease problems. Foliar diseases were present, levels varying between years with meteorological conditions, but always at levels well below those likely to be damaging to yield. This was partly due to the use of resistant cultivars but also probably a response to lower levels of available nitrogen than in a comparable non-organic crop rotation.

OBJECTIVE 4. COMMUNICATE RESULTS, AND THEIR IMPLICATIONS, TO DEFRA, OTHER RESEARCH CONTRACTORS, FARMERS, ADVISERS AND ORGANIC CERTIFICATION BODIES

Regular contact was maintained with the Defra project officer, particularly through the steering group meetings.

Project Steering Group Meetings

The project was managed by a steering group chaired by Dr David Copper of Defra. Other members included Roger Unwin, policy adviser on soil protection and organic farming in the Defra Rural Development Service, three organic farmers, and representatives of the Soil Association and Elm Farm Research Centre (EFRC). Meetings were held twice per year and were minuted. Detailed written reports were submitted to each meeting for discussion. All changes to cropping and management were agreed by the group.

Contact with, and promotion of the resource for use by other researchers

At the November 2003 steering group meeting, Professor Martin Wolfe gave an overview of current arable research by EFRC and Wakelyns Agroforestry (Martin's own farm). He covered:

- Bi-cropping work, showing progress in thinking since Defra project OF0181 was completed.
- Variety evaluation by participative methods.
- The value of cereal mixtures in giving greater yield stability.
- Genetically diverse wheat populations that respond to local selection for productivity and quality.
- Management of potato blight.

There was discussion as to how the stockless rotation at Terrington could be developed, particularly on how fertility building legumes could be better incorporated into the rotation rather than being primarily as dedicated year-long crops.

At the June 2004 steering group meeting, Dr Margi Lennartsson, Research Director at HDRA, gave an overview of the work of HDRA, particularly the field vegetable conversion and post-conversion studies, and the organic weeds project (OF0153). Data have been exchanged between the Terrington and HDRA studies.

Economic evaluation data were passed to the Institute of Rural Studies, University of Wales, Aberystwyth, for use in other Defra-funded economics studies, and in compiling the Organic Farm Management Handbook (Lampkin *et al*., 2004).

Results and experiences from the project were fed into OF0315, the HDRA-led participative weeds project in which ADAS is a partner. (http://www.gardenorganic.org.uk/organicweeds/index.php)

Other meetings attended

A presentation was made at a Colloquium of Organic Researchers (COR) workshop "Developing research opportunities in organic horticultural and arable systems" held at Warwick HRI on Wednesday 13 October 2004. This was organised by HDRA in collaboration with Warwick HRI and ADAS. The aim of this day was to develop novel ideas that could form the basis of research proposals, encourage collaboration and promote the use of three Defra-funded established organic research sites at HRI Warwick, HRI Kirton and ADAS Terrington. Extensive data about crop performance, soil fertility, weeds, pests, diseases and economics have been collected from the three sites. Both contractors were asked by Defra to maximise the use of these well-monitored sites for other studies. This meeting was part of the effort to meet that goal.

The expert group meeting, "What should Defra organic farming research & development deliver?" on 21 June 2005 at the Holiday Inn Birmingham Airport was attended (Defra project OF0350). The meeting reviewed draft organic farming research and development needs for the UK. Issues arising from OF0318 were fed into the consultation.

Wider dissemination of results

Two refereed papers were accepted for publication, and papers were presented at the COR conferences at Aberystwyth in 2002 and Harper Adams University College in 2004 (details in section 9 below).

A dedicated website was established and managed, giving an overview of the project, summary results and news. This, and other publicity, resulted in personal contact for researchers and farmers in the UK, and wider.

CONCLUSIONS

- The good water and nutrient holding characteristics of the silty clay loam soil were well suited to a stockless organic rotation, particularly for autumn sown wheat.

- The soil was less suited to the establishment of small-seeded and spring-sown crops. Fertility-building clover crops were the most difficult to establish, and failed completely in some years despite one or two re-sowings.

- Because of the soil texture, it was often too wet to travel when crops and weeds were suitable for mechanical weeding. This contributed to the increased weed problems in later years.

- Crop yield was not strongly influenced by the performance of the preceding fertility-building crop. Crop yields varied in response to environmental conditions.

- Vetch was a poor substitute for clover, It was slow to establish and competed poorly with weeds.

- Crop yield through the project did not show any particular trend with time. There was no evidence of either a post-conversion adjustment period, or a fall in yield due to declining fertility.

- Crop yields were good in comparison with organic standard yields, particularly for cereals. Yields of potatoes and calabrese were similar to standard yields, probably reflecting the absence of the capacity to irrigate these more drought sensitive crops in dry years. Winter wheat was the most consistently yielding crop with a project average of 7 t/ha, but grain protein was low and the grain was sold for animal feed.

- Potato saleable yield was very variable depending on the impact of rainfall pattern, slugs and blight. Potatoes were readily sold for high prices until 1999. Thereafter, due to issues of tuber quality and scale of production, it was not possible to sell them as organic produce.

- High margin crops such as potatoes and calabrese made a large contribution to the rotation gross margin and were necessary to balance the low income from the 20% of fertility-building crops in the stockless rotation.

- Crop prices declined through the project, particularly from 1999. Non-organic prices also declined but at a slower rate.

- The stockless rotation had a substantially greater gross margin than comparable non-organic farms until 2000. From 2000, the advantage decreased as prices fell. From 2003 to 2005, gross margin was less than for non-organic farms.

- The introduction of the Single Payment Scheme in 2005 changed the economic picture making the inclusion of 20% fertility-building crops look less attractive. New models of stockless rotation are needed with better integration of fertility-building, and ideally with all crops earning revenue from sales.

- Crop offtake of nitrogen was substantially greater than the estimate of nitrogen supply from the fertility-building crop mulched foliage, suggesting that this measure of nitrogen supply is underestimating nitrogen fixation.

- Soil available potassium was consistently in Index 2 despite no additions, showing that the clay minerals were releasing K to replace offtake. Soil available phosphorus declined sharply initially and calcium ammonium phosphate was applied annually from 1995. It continued to decline but more slowly, and by 2005 was just in Index 1. Soil carbon showed a slow upward trend. In the longer term at Terrington, and on different soils, sustainable additions of plant-available P and K would be needed in a stockless rotation.

- Diseases and pests had little impact on cereals and beans.

- Significant pest issues were slugs on potatoes, calabrese and clover, and stem nematodes and *Sitona* spp. weevils on clover. The lack of an organic control for slugs makes production of root and vegetable crops on such slug-prone soils unreliable.

- Strategies to avoid stem nematode, such as alternating clover species, should be adopted in stockless systems with a high frequency of clover crops.

- Total numbers of weeds did not increase, but the dominant annual species changed from weeds of autumn-sown arable crops to weeds of spring-sown crops.

- Perennial weeds, particularly creeping thistles, progressively increased from an initial sparse and patchy distribution to cover the whole study area at a dense population. By 2005 it was clear that the creeping thistle population could not be managed within the rotation without substantial change such as the introduction of a cultivated fallow or a longer fertility building period, both of which would be costly.

- Strategies to avoid domination by perennial weeds should be put in place at the start of conversion. That is more likely to succeed that trying to control a well-established population.

- Any new rotation designed in response to the Single Payment Scheme must be more competitive against perennial weeds.

RESEARCH NEEDS

To allow the viable continuation of existing stockless farms, and encourage more conversion in arable areas, we need:

- An integrated strategy for the management of perennial weeds, particularly to prevent infestations spreading. This is likely to require research to clarify aspects of weed biology and spread mechanisms, and the interaction of those with crop husbandry practices.

- Reliable and affordable controls for slugs, particularly to protect product quality in root and vegetable crops.

- New designs of rotation with:

    1. fertility building better integrated with cash crops to eliminate unproductive and failure-prone dedicated fertility-building crops, and

    2. better competitive ability against perennial weeds.

Appendix 1. Organic rotation cropping sequence.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
1991	Red clover	Red clover			
1992	Red clover	Red clover	Red clover	Red clover	
1993	Potatoes	Spring wheat	Red clover	Red clover	Red clover
1994	Winter wheat Turnip catch crop	Red clover	Potatoes	Spring wheat	Red clover
1995	Spring beans Turnip catch crop	Potatoes	Winter wheat Turnip catch crop	Red clover	Spring wheat
1996	Spring wheat u/s	Winter wheat Turnip catch crop	Spring beans Turnip catch crop	Potatoes	Red clover Turnip catch crop[2]
1997	Red clover	Spring beans Turnip catch crop	Spring wheat u/s	Winter wheat Turnip catch crop	Potatoes
1998	Potatoes	Spring wheat u/s	Red clover	Spring beans Turnip catch crop	Winter wheat Turnip catch crop
1999	Winter wheat *	Vetch[1]	Potatoes	Spring barley u/s	Spring beans *
2000	Spring beans *	Potatoes	Winter wheat *	White clover	Spring barley u/s
2001	Spring barley u/s	Winter wheat *	Spring beans *	Potatoes & calabrese	White clover
2002	White clover	Spring beans *	Spring barley u/s	Winter wheat *	Potatoes & calabrese
2003	Potatoes & Calabrese	Spring barley u/s	White clover	Spring beans *	Winter wheat *
2004	Winter wheat *	Vetch[1]	Potatoes & Calabrese	Spring wheat u/s	Spring beans *
2005	Spring beans	Spring wheat & Calabrese	Winter wheat	Vetch[1]	Spring wheat u/s

[1] Sown in spring in place of failed clover.
[2] Sown in summer in place of failed clover.
* Catch crops not grown – cultivated for weed control.
u/s Undersown.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

PUBLISHED MATERIAL GENERATED BY THE PROJECT

Refereed papers

Cormack, W.F., Shepherd, M. & Wilson, D.W. (2003). Legume species and management for stockless organic farming. *Biological Agriculture and Horticulture* **21**, 383-398.

Cormack W.F. (2006). Crop performance in a stockless arable organic rotation in eastern England. *Biological Agriculture & Horticulture* **24** (1), in press.

Conference papers

Welsh, J. P., Philipps, L. & Cormack, W. F. (2002). The long-term agronomic performance of organic stockless rotations. In: Powell, J. [ed.] Proceedings of the UK Organic Research 2002 Conference, 26-28 March 2002, Aberystwyth, pp. 47-50. http://www.organic.aber.ac.uk/conference/proceedings.shtml

Cormack, W. F. (2002). Effect of mowing a legume fertility-building crop on shoot numbers of creeping thistle (Cirsium arvense (L.) Scop.) In: Powell, J. [ed.] Proceedings of the UK Organic Research 2002 Conference, 26-28 March 2002, Aberystwyth, pp. 225-226.
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Cormack, W.F., Riding, A.E. & Parker, W.E. (2004). Potato cyst nematode populations and spatial distribution: temporal variation within a stockless organic rotation. In: Hopkins, A. [ed.] Organic Farming: Science and practice for profitable livestock and cropping, Proceedings of the BGS/AAB/COR Conference, Harper Adams, Shropshire, Occasional Symposium No. 37, British Grassland Society, p. 232-235.

Project Website

The background to the project, summary results, news and publications are described on a project website (http://www.adas.co.uk/stockless/).

OTHER PUBLISHED MATERIAL QUOTED IN THIS REPORT

Anonymous (2005). *Agriculture in the UK 2004*, Defra, London, U.K.
(http://statistics.defra.gov.uk/esg/publications/auk/2004/chapter6.pdf)

Berry, P.M., Sylvester-Bradley, R., Philipps, L., Hatch, D.J., Cuttle, S.P., Rayns, F. W. & Gosling, P. (2002). Is the productivity of organic farms restricted by the supply of available nitrogen? *Soil Use and Management*, **18**, 248-255.

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Schmidt, H., Philipps, L., Welsh, J.P. & Von Fragstein, P. (1999). Legume breaks in stockless organic farming rotations: nitrogen accumulation and influence on following crops. *Biological Agriculture and Horticulture*, **17**, 159-170.