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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: OF 0332
2. Project title: Organic field vegetable production - baseline monitoring of systems with different fertility building strategies
3. Contractor organisation(s): HDRA
   Ryton Organic Gardens
   Coventry
   CV8 3LG
4. Total Defra project costs: £ 332707
5. Project: start date .... 01 January 2003
   end date .... 31 March 2006

6. It is Defra's intention to publish this form.
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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.

1. OBJECTIVES
The overall aim of this study was to provide continued baseline information on the agronomic and economic performance during the post-conversion period for organic field vegetable production systems. There were the following specific objectives:

1. To complete three more cropping seasons at the established organic HRI units (at Hunts Mill, Wellesbourne and at Kirton).
2. To assess agronomic and economic performance of the systems by quantitative and qualitative monitoring.
3. To make these resources (i.e. the facilities together with their baseline data collected within this and previous projects) available for other organic farming research initiatives and to increase the awareness amongst researchers, advisors and growers of their potential value.

All of these objectives were met, in full, as described below.

2. METHODS
The project was led by HDRA in collaboration with Warwick HRI who conducted all the horticultural operations and provided advice on monitoring methods and statistics. EFRC provided agronomic advice. The project was directed by a steering committee.
The research used a 'case study' methodology, continuing monitoring work that had begun in 1995 as a study of conversion to organic production as part of Projects OF 0126T and OF 0191. There were two sites to provide contrasting case studies; each was cropped with fully stockless field vegetable/arable rotations:
Hunts Mill Field at Warwick HRI Wellesbourne (in the Midlands) – a sandy loam soil with low organic matter, marginal for growing brassicas. The basic rotation was fertility building crop, nutrient demanding vegetable, less nutrient demanding vegetable and cereal (undersown). There were three strategies based on this, which had different proportions of time dedicated to fertility building (A, 2-years; B, 1-year; C, 0.5-years). Green waste compost was applied once in a rotation, primarily as a source of P and K.
Warwick HRI Kirton (in Lincolnshire, close to the Wash) – a deep silty loam, in a prime vegetable growing area. The basic rotation was as Strategy B above but with another vegetable substituted for the cereal crop. There have been no fertiliser inputs since 1995.
Assessments were made of all crop yields (marketable and unmarketable), nutrient removals and inputs (including returns from crop residues and fertility building crops), soil nutrient status, weed incidence, pest and disease damage and economic performance of individual crops. The data collected during this project (2003-2005) were collated with that gathered in earlier years to enable the construction of nutrient and

financial budgets for complete cycles of each rotation.

3. RESULTS OF THE AGRONOMIC AND ECONOMIC MONITORING (Objectives 1 and 2)

Performance of cash crops. At Hunts Mill crops of potatoes, carrots, parsnips leeks, lettuces, sweetcorn and barley were all successfully grown, giving positive gross margins. At Kirton crops of cabbages, lettuces, sweetcorn and seed crops of peas and beans were grown. The main problems at this site were with sometimes poor levels of available nitrogen and bird attacks. Marketing of the crops was sometimes difficult, particularly at Kirton.

Performance of fertility building crops. Leys (pure clover or grass and clover) were established by undersowing in cereal or sweetcorn crops and grown on for six months, 18 months or 30 months. The shorter leys could be very effective but sometimes failed to perform because establishment was hampered by dry weather or pest attack. Winter cover crops (rye, vetch, crimson clover or sweet clover) were used whenever possible – they were particularly important in Hunts Mill Strategy C. It was sometimes difficult to establish them early enough if harvest of the previous crop was delayed by adverse weather.

Soil fertility. There were no measurable changes in organic matter levels at either site (regardless of the cropping strategy) over a ten year period. At Hunts Mill there was little overall change in levels of available P and K, but at Kirton (where there had been no external inputs) both elements had declined since conversion began. At Hunts Mill soil analysis during the cash cropping phase of the rotations indicated greater availability of mineral nitrogen in Strategy A than in Strategy C.

Nutrient budgeting. At Hunts Mill all areas showed a positive balance for N but this was dependant on the compost additions; much of this nitrogen would not have become available in the short term. Phosphorous balances were generally clustered around zero and potassium balances were generally negative; for both these elements the most negative values were occurred in Strategy A where the higher yields (particularly of potatoes) resulted in greater offtakes.

The effect of rotation design on yield. In the first cycle of their rotations, there was no difference between the three Hunts Mill fertility building strategies in terms of total offtakes of carbon or nitrogen in harvested crops. In the second cycle of the rotations, the greatest offtakes were from Strategy A with the longest fertility building periods. The yields of comparable individual crops confirmed this overall trend. At Kirton there was only one fertility building strategy based on a one year ley. This generally performed well but there were problems when a fertility building crop did not perform well due to weed competition, pest damage or water stress.

Weed management. Annual weeds were generally effectively controlled by mechanical means supplemented by hand weeding when necessary. There was a much higher weed pressure at the Kirton site. At Hunts Mill there were less annual weeds in Strategy A (with the longest fertility building periods). Perennial grass weeds were not a particular issue at Kirton but at Hunts Mill there was an increasing problem of grass weeds in all three strategies.

Pest and disease management. A minimum intervention strategy was generally adopted which relied on resistant varieties and timely cultural control rather than the application of permitted inputs. The main pests were birds (particularly affecting brassicas and barley). Carrots were not significantly affected by carrot fly even though they were not covered with fleece and this resulted in a considerable financial saving. The main disease issues were potato blight (necessitating early defoliation in some years), potato scab (which affected marketability) and downy mildew of lettuce. Overall pest and disease management was successful and did not have a significant impact on yields or financial performance.

Economic analysis of crops and cropping strategies. At Hunts Mill the overall economic performance was better in the 2003-2006 period than in the years immediately after conversion; in part this was due to changes in the crops that were grown (cabbages and onions were discontinued and lettuces and sweetcorn were introduced). There was an opposite picture at Kirton but this was mainly due to difficulties of marketing rather than agronomic issues. Analysis was made of the three Hunts Mill fertility building strategies. In the first cycle of the rotation, Strategy A had the highest rotational gross margin but issues specifically related to conversion complicated the results. In the second cycle, there was little difference between the strategies (although C was the best). The third cycle was only completed for the shorter Strategy C – this showed a 13% reduction in performance largely as a result of declining yields.

4. ADDITIONAL WORK USING THE SITES (Objective 3)

It is particularly important that research into organic farming systems is done on sites that have realistic soil fertility levels, weed populations etc; the creation of a resource that could be used for other projects was a key objective of OF 0332. The sites at Hunts Mill and Kirton provide this resource with detailed documentation about past performance and during the course of the project were selected as sites for field trials forming part of a number of projects funded by DEFRA, HDC and the EU.

5. MAIN CONCLUSIONS

At both Hunts Mill and Kirton the basic crop rotations have proved to be agronomically sustainable under organic management for a period of ten years. Available nitrogen was a key factor in limiting the yields of several crops. At Hunts Mill the benefits of Strategy A (with the most time dedicated to fertility building) became much more evident as time progressed. However, in some cases the short-term green manures

of Strategy C would have been more productive if greater priority had been given to establishing them earlier; similar knock-on effects of poor fertility building crop performance were also seen at Kirton. The most intensive strategy can therefore be considered to be more risky although it still has potential. Whilst it is clear that the longest fertility building crops generally have the most impact, several shorter term crops can also be effective and may be a more efficient use of the land under certain circumstances. This is particularly the case in stockless systems when there is no direct economic return from the fertility building leys. Long leys may, however, have other benefits; they can help in the control of weeds and can act as a break to prevent the build up of certain pests and diseases.
The project created, in each site, a resource for organic field vegetable research; this enabled the successful completion of a number of ‘bolt on’ projects.

6. DISSEMINATION ACTIVITIES
Open days for farmers, advisors and scientists were held at both sites throughout the project. Presentations about OF 0332 were also given at other open days and conferences organised by HDRA or organisations. The project was also publicised on the internet. A number of scientific papers are in preparation. A full report containing all the detailed agronomic and economic information at each site is available on request.

7. FUTURE WORK
Both sites have now been monitored for over ten years but long term effects of contrasting management are only now beginning to appear. We propose that this is continued. This will also allow the sites to be maintained in a condition that will permit their use as facilities for additional ’bolt on’ projects. In any future projects there should be more emphasis on the effects of the crop rotations on soil organic matter, soil structure and soil microbiology and novel fertility building approaches.

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).

1. OBJECTIVES OF THE WORK

The overall aim of this study was to provide continued baseline information on the agronomic and economic performance during the post-conversion period for organic field vegetable production systems. There were the following specific objectives:

1. To complete three more cropping seasons at the established organic HRI units at Hunts Mill, Wellesbourne and at Kirton.
2. To assess agronomic and economic performance of the systems. To achieve this the individual areas were quantitatively and qualitatively monitored by assessing:
   a) Yield of cash crops
   b) Additions, removals and returns of nutrients and organic matter
   c) Soil nutrient status
   d) Weeds
   e) Pests and diseases
   f) Economic performance
3. To make these resources (i.e. the facilities together with their baseline data collected within this and previous projects) available for other organic farming research initiatives and to increase the awareness amongst researchers, advisors and growers of their potential value.

All of these objectives were met, in full, as described below.

2. METHODS

The project was led by HDRA in collaboration with Warwick HRI who conducted all the horticultural operations and provided advice on monitoring methods and statistics. EFRC provided agronomic advice. The project was directed by a Steering Committee made up of representatives from the industry. The research used a ‘case study’ approach to describe and characterise the cropping systems and their agronomic and economic performance. There were two sites to provide contrasting case studies; each was cropped with stockless field vegetable/arable rotations and in both cases the systems were established on a realistic field scale to reflect farm practice.

2.1. Hunts Mill Site

The organic unit at Hunts Mill (Warwick HRI, Wellesbourne) has been closely monitored since conversion began in 1995 (DEFRA Projects OF0126Tand OF0191). This field, in the Midlands, has a sandy loam soil and is marginal for the growing of brassicas. It was divided into six areas, each of 0.8ha. Each area was further divided into six strips (A to F) for monitoring purposes and to vary the cropping on certain occasions. It was completely stockless and green waste compost was applied with the main aim of replacing P and K removed by the cash crops. Four types of crops were grown:

- Fertility building crops (clover or clover/grass leys or winter green manures)
- Cereals (usually spring barley undersown with a ley)
- ‘Veg 1’ (nitrogen demanding vegetables: potatoes and cabbages)
- ‘Veg 2’ (less nitrogen demanding vegetables: onions, carrots, leeks, lettuces, parsnips and sweetcorn)

Fertility building is a particular challenge in stockless systems (because there can be no direct economic return from leys). In order to address this issue three different fertility building strategies were investigated in which different species were grown for different lengths of time:

- Strategy A (Area 1 and 4). Two year grass/clover ley
- Strategy B (Area 2 and 5). One year clover ley
- Strategy C (Area 3 and 6). A reliance on short term green manures only; this strategy gives opportunities for more novel species and techniques to be used.

2.2. Kirton site

The organic unit was also stockless and occupied Lane field at Warwick HRI, Kirton. The soil was a deep silty loam in a prime vegetable growing area in Lincolnshire close to The Wash. Conversion began in 1997 and it was also monitored as part of DEFRA Projects OF0126T and OF0191. The fertility building approach mirrored that of Strategy B at Hunts Mill (based on a one year ley) but no cereals were grown. The 3.2ha site was divided into eight plots (A to H). Difficulties with marketing potatoes and carrots meant that they were not grown in later years.

2.3. Monitoring methods

A computerised field diary was kept of all operations, growing practices, observations and scientific monitoring at both sites. All the parameters listed below were monitored at both sites but this was done in greater detail at Hunts Mill.

Yields. Marketable and unmarketable yields were recorded. When appropriate, sub samples of unmarketable produce were categorised according to the reasons for their failure.

Nutrient removals and inputs. Fertility building crops were assessed at incorporation and whenever they were mown (using quadrats). Above and below ground biomass was measured and estimates of the proportion of the nitrogen that had been fixed were made from literature values. The off-takes and returns of nutrients by cash crops were measured either using quadrat sampling as for the fertility building crops or by taking samples from the larger harvested areas used for determination of pests/diseases and unmarketable produce. Samples of milled material were analysed for nitrogen phosphorus and potassium. The green waste compost was analysed for organic matter, total and available nutrients and potentially toxic elements. Nitrate leaching and deposition of nutrients were estimated from literature values.
Soil fertility. Soil was analysed routinely once a year in late February/early March (0-30 cm depth). Standard ADAS protocols were used to determine available nutrient levels but samples were also sent Natural Resource Management Ltd (Bracknell) for analysis according to the EFRC methodology. This service employs extraction techniques, which give results considered to be particularly useful to the organic farmer (EFRC, 1985). At strategic times in some areas samples were also analysed for soil mineral nitrogen.
Weed incidence. The emerged weed flora was monitored using quadrats. Weeds were identified and counted and the percentage cover of each species estimated. Percentage cover of crop and bare ground were also recorded.
Pest and disease assessment. Crop walking was performed regularly throughout the growing season, with general agronomic comments noted for each strip. Pest and disease assessments were made at various times, targeted when the crops were at peak pest or disease pressure.
Economic assessment. In order to calculate gross and net margins, the variable costs, labour and machinery costs of all cultivation operations were recorded. Rotational costs (not allocatable to any specific crop in the rotation, e.g. green manures, sub-soiling, compost or lime spreading) are included in the rotational gross and net margins. Contractor rates and casual labour rates were extracted from the Organic Farm Management Handbook 2nd-6th editions (Lampkin *et al*. 1996-2004) or other published standardised figures (Nix, 2003). For the calculation of output real obtained prices and marketed produce were used.
Statistical analysis. The monitoring at the sites at Hunts Mill and Kirton was using a case-study research methodology. Neither of the sites were set up as replicated trials and so there are limitations as to the type of formal statistical analyses that are appropriate. Values presented in this report are the means of measurements taken in similarly treated strips. Where appropriate the coefficient of variation (%cv) and the standard deviation (SD) are given.

3. RESULTS OF THE AGRONOMIC AND ECONOMIC MONITORING (Objectives 1 and 2)

The results described here focus on the period of the Baseline Monitoring Project (OF 0332) but, particularly where long-term trends are important, reference is made to results gathered during the preceding 'conversion' projects (OF 0126T and OF 0191). Because a case study approach was taken there were limitations with the comparisons that could be made and the conclusions which could be drawn.
Providing baseline data about the performance of the different strategies was also an important part of creating the 'resources' to be uses in other projects to fulfil Objective 3.

3.1. Agronomic and economic performance of individual cash crops

Table 1 summarises the yields and gross margins of all the cash crops grown at Hunts Mill between 2003 and 2005.

Potatoes: These were one of the easier crops to grow although yields were low in Strategy C as there was lower soil fertility. Skin finish, due to diseases such as scab, meant that the tubers were often not of good enough quality for supermarket retail specifications.
Carrots: These performed well. Late sowing was used to mitigate the effects of carrot fly and so there were few outgrades due to this despite the crops not being fleeced. Flame weeding, steerage hoeing and hand weeding effectively controlled annual weeds but there were problems with perennials (horsetails and couch grass).
Parsnips: Good yields and profitability were achieved with few problems. Misshapen roots were the main reason for outgrading.
Leeks: This was an expensive crop to grow, requiring a lot of hand weeding and trimming before sale. The yield was relatively low as a result of poorer soil fertility in Strategy C.
Lettuce (Crisphead, Cos and Little gem types): There were few difficulties with actually growing lettuces. The key issue was harvesting at the optimal time.
Sweetcorn: This was a relatively trouble-free crop. The main problems appeared to be linked to poor establishment; once the plants got off to a poor start, they never recovered. Weed management was another issue and undersowing with red clover was successfully tried.
Barley: Yields were very variable. Although they could sometimes be linked to the fertility building strategy (eg low yields in Strategy C), there were also seasonal effects and problems with crows and poor soil structure where the wheelings of the previous vegetable crop had been.

Table 1. *Summary of yields and financial performance of Hunts Mill crops. Values are the means of measurements taken from strips (A-F) with the same past cropping.*

Crop	Year	Strategy	*Area and strip*	Marketable yield sold (t/ha)	Crop gross margin (£/ha)
Potatoes	2003	**A** **C**	*1 A-F* *6 F*	33 23	6949 4968
	2004	**A** **C**	*4 A-F* *6 A-F*	28 18	5521 3816
	2005	**B** **C**	*2 A-E* *3 A-E*	31 18	5598 2762
Carrots	2003	**B**	*5 A-F*	30	6223
	2004	**A**	*1 A-F*	42	6633
	2005	**A**	*4 A-F*	51	6299
Parsnips	2004	**A**	*1 A*	19	8815
	2005	**A**	*4 E-F*	24	9123
Leeks	2005	**C**	*6 A-E*	9	941
Lettuce	2003	**C**	*6 A-B*	10	3601
	2004	**C**	*3 A and 3 F*	22	7104
Sweetcorn	2003	**C**	*6 C-E*	5	4345
	2004	**C**	*3 B-D*	5	4615
Barley	2003	**B** **C**	*2 B-F* *3 B-F*	4.5 4.6	892 928
	2004	**B**	*5 A-F*	3.5	698
	2005	**A** **C**	*1 A-F* *6 F*	3.2 2.1	637 479

Table 2 summarises the yields and gross margins of all the cash crops grown at Kirton between 2003 and 2005. For the calculation of the crop gross margin at Kirton only the actually sold marketable yield was used. With more time devoted to harvesting and marketing a higher percentage of the yield could have been marketed and hence higher gross margin would have been achievable.

Table 2. *Summary of yields and financial performance of Kirton crops. Values are the means of measurements taken from plots with the same past cropping.*

Crop	Year	Strategy	Plot	Marketable yield sold	Crop gross margin (£/ha)
Cabbages	2003 2004 2005	**B** **B**	*E and G* *B and D* *A and C*	4953 heads/ha 15080 heads/ha 13385 heads/ha	143 2214 436
Lettuces	2003 2004	**B** **B**	*F and H* *E and G*	1123 doz/ha 203 doz/ha	269 -1890
Sweetcorn	2003 2004 2005	**B** **B**	*A* *F and H* *E and G*	10539 cobs/ha None sold 1787 cobs/ha	429 -1268 -1142
Courgettes	2005	**B**	*D*	3.4 t/ha	228
Peas (seed) Beans (seed)	2003 2003	**B** **B**	*D* *D*	Crop failure 2.5 t/ha	-553 2257

Cabbages (Savoy type): These were grown under fleece, mainly to protect them against pigeons – this made timely weeding more difficult. The main problem was with nitrogen availability; crop performance was very good when they followed a successful green manure but very poor when the preceding ley did not establish well.
Lettuces (Cos and Little gem types): The crops grew well (under fleece) but problems with tipburn, downy mildew and aphids did affect their marketability, especially in 2004. The short growing period of the lettuce crops meant that weeding could be minimised without compromising yields but this approach did risk building up the weed seed bank. There were problems with marketing.
Sweetcorn: All the crops were undersown with either trefoil or red clover. This failed to establish in 2003 because of the dry autumn but in the other years, it was successful and helped suppress weeds that were difficult to control mechanically in such a tall crop with the given equipment. Several varieties were tried that had different growth characteristics but all produced satisfactory yields of cobs although marketing was difficult and not all yield was sold.
Courgettes: The crop performed very well with few problems – a higher yield would have easily been obtained with more regular picking as many fruits were rejected for being oversized.
Peas and broad beans (grown for seed): These were devastated by birds and had to be re-sown. The peas were a complete failure, however the beans grew well and fetched good prices.

3.2. Fertility building crop performance

One and two year leys: At Hunts Mill these were established by undersowing the spring-barley crops and maintained by cutting and mulching as necessary to control weeds and maintain a vegetative state. Two-year grass/white clover ley was used in Strategy A and one-year pure red clover was used in Strategy B. In the period covered by this project only the Strategy A leys were due for incorporation (11.6t/ha dry matter containing 266kg N in Area 1 in March 2003 and 7.1t/ha dry matter containing 127kg N in Area 4 in March 2004). These values do not account for additions of biomass and nitrogen to the soil as a result of litter loss and mowing during the overall period of growth. Two-year leys were not used at Kirton. Here both red clover and trefoil leys were established by undersowing in the sweetcorn crops. The red clover was more successful as the trefoil was less able to compete with weeds and less able to tolerate the mowing necessary to control them.
Six to nine month over-wintered leys: At Hunts Mill these were the main fertility building crop in Strategy C. Pure legumes were used (red or white clover or trefoil) established by undersowing in barley or, on one occasion, sweetcorn and incorporated in the following spring. They were generally very effective (at incorporation averaging 4.6t/ha dry matter containing 92kg N/ha) were productive but the dry weather in 2004 severely limited those sown in that year. These crops were not grown at Kirton.
Winter cover crops: These were used whenever possible and were generally successful when they could be sown sufficiently early. At Hunts Mill, they were particularly important in Strategy C but it was often difficult to sow them early enough (e.g. after harvesting potatoes). Rye and vetch (alone or mixed) were mainly used. One crop of vetch, sown in September and allowed to grow until June, accumulated over 200kg N/ha. In 2003, crimson clover and sweet clover were also tried; although in this year they were less productive than the average for vetch they are worthy of further investigation. At Kirton, the relatively early harvesting of the cabbages, lettuces and courgettes meant that there were good opportunities for vetch to be used. However, establishment was sometimes poor (often due to bird damage) and this was reflected in the final biomass produced and the yield of the following crop.

3.3. Soil fertility

Table 3 gives, as an example of the data available, a summary of the soil nutrient status at each site in spring 2005. At Hunts Mill there were no significant differences between the individual strips that could be attributed to the cropping strategy. The organic matter content of the soil was low for this soil type (and had not changed since conversion to organic management began in 1995); this may have contributed to soil structural problems (surface capping and compaction). Using the standard Olsen extraction P levels were satisfactory but the three EFRC-method extractions (EFRC, 1985) suggested that they were borderline for horticultural production. In contrast, both approaches suggested that levels of K were rather low. There had been little overall change in the available levels of either element since conversion began. Levels of iron were high, manganese normal, zinc was low and copper levels were normal. Green waste compost applications were made once per rotation at a rate of 30 to 40t/ha; with the rotations that were used here slightly greater applications may be needed to prevent a decline in available P and K.

At Kirton calcium and pH were high as is characteristic of this soil type. Only the Olsen analysis for P is considered suitable for use with alkaline soils; it showed satisfactory levels. Levels of K were lower than at Wellesbourne but Mg levels were higher. Both P and K had declined at this site (with no inputs) since conversion began. This mirrors changes seen in other stockless systems in the UK (Cormack 1999, Rayns & Sumption 2004).

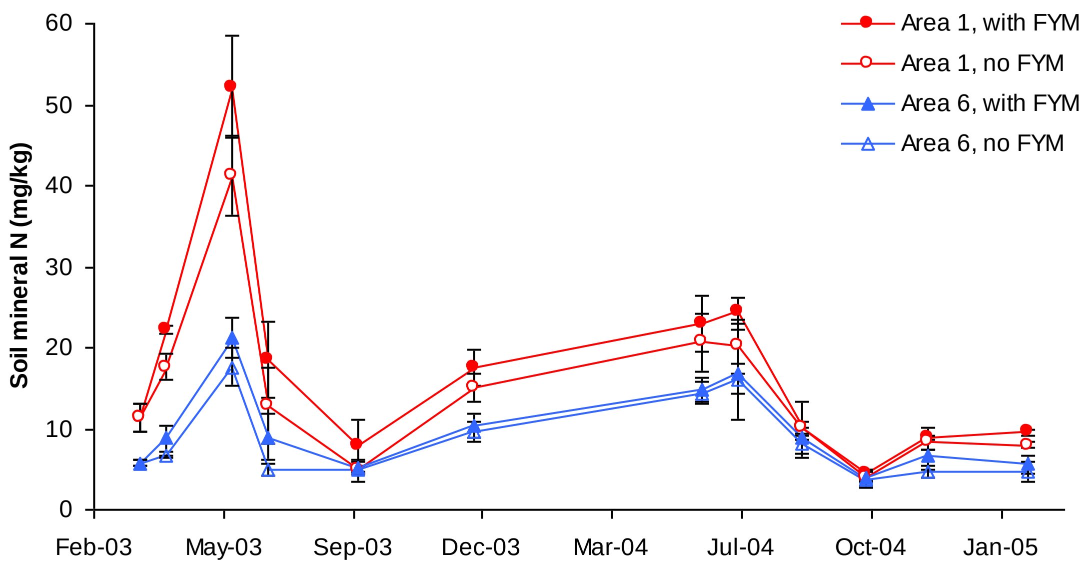
Figure 1 shows an example of mineral N measurements (nitrate and ammonium) made at Hunts Mill. This indicates that much more nitrogen was available in the first two years after incorporation of the long ley in Area 1 (Strategy A) than after the short ley in Area 6 (Strategy C). This was correlated with the potato yields (see Table

1). This was the only occasion in which FYM applications (to supply 250kg/ha N) were made to small replicated plots; the effect of the FYM was much less significant than the preceding fertility building crop. These experiments were set up at Hunts Mill to provide data for the validation of the EU-Rotate_N computer model; more information will be available in the final report for this project (see www.hri.ac/eurotate).

Table 3. *Soil nutrient status (top 30cm) of the Hunts Mill and Kirton sites in 2005. Values are averages for each site. Analysis using standard 'ADAS' methods is shown in italics; other analysis was done using 'EFRC' methodology.*

Parameter	**Method and unit**	**Hunts Mill**	**Kirton**
pH		7.0	7.7
Organic matter	%	1.2	2.4
Extractable P	Olsen's (mg/L)	*50 (Index 4)*	*31 (Index 3)*
	Sodium acetate (mg/kg)	33	pH too high for this test
	Double lactate (mg/kg)	148	pH too high for this test
	Citric reserve (mg/kg)	331	pH too high for this test
Extractable K	Ammonium nitrate (mg/L)	*160 (Index 2-)*	
	Double lactate (mg/kg)	118	88
Extractable Mg	Ammonium nitrate (mg/L)	*106 (Index 3)*	
	Double lactate (mg/kg)	139	459
Extractable Ca	Double lactate (mg/kg)	1733	4356
Extractable Fe	(mg/kg)	165	146
Extractable Mn	(mg/kg)	72	98
Extractable Zn	(mg/kg)	5.4	5.3
Extractable Cu	(mg/kg)	1.7	2.1

Figure 1. *Soil mineral nitrogen (top 60cm of soil) in two contrasting areas of Hunts Mill (Area 1 had just grown a two year ley and Area 6 a six month ley). Potatoes were grown in 2003 (either with or without FYM), carrots in 2004 and spring barley in 2005.Values are the means of three replicate plots, vertical bars represent standard deviations.*

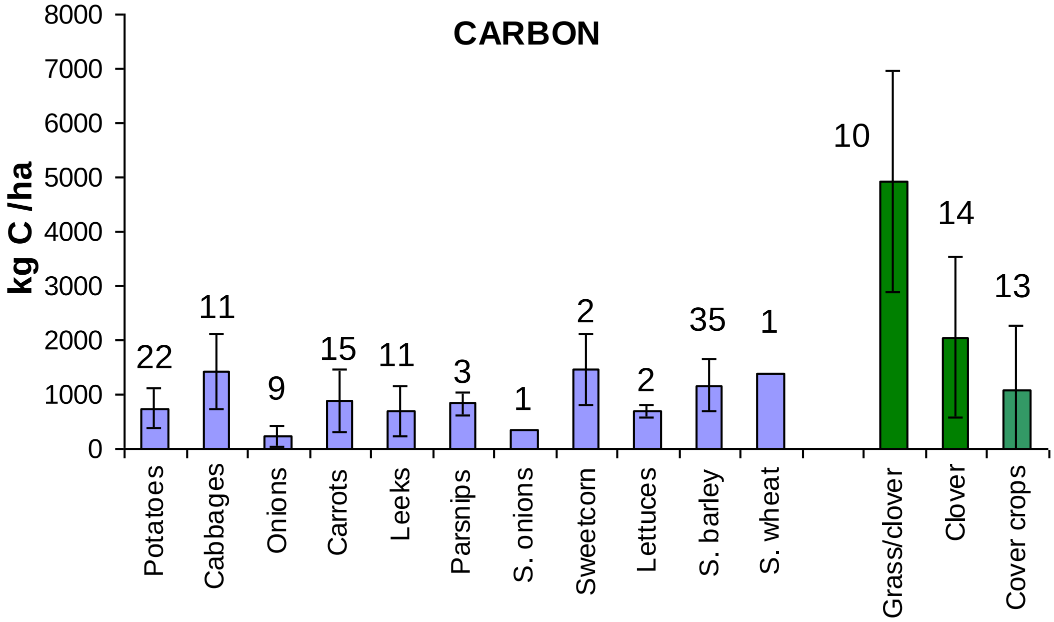


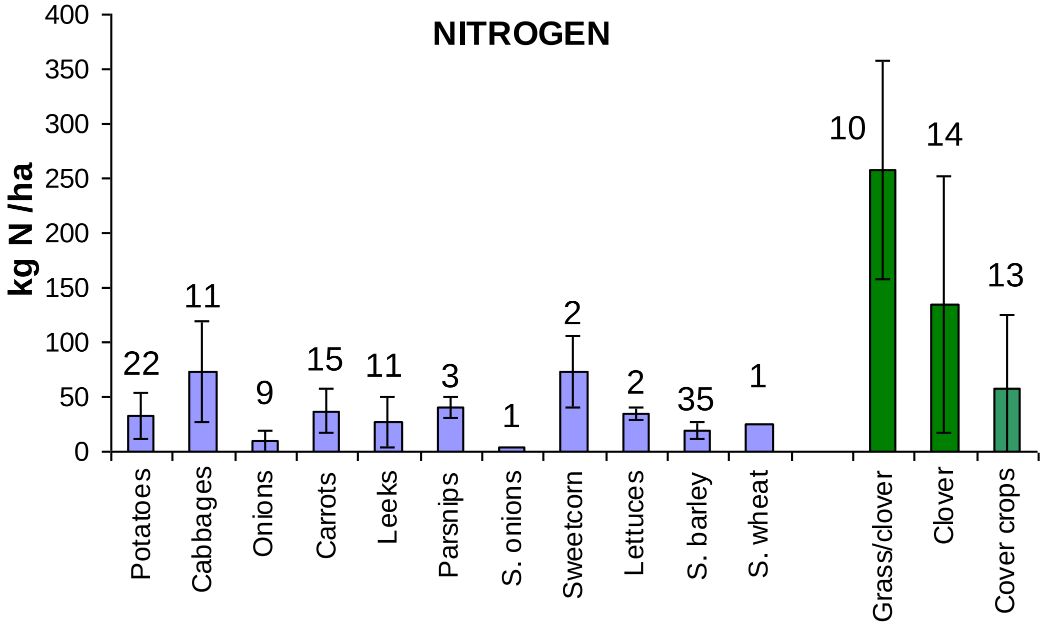
3.4. Nutrient budgeting

Nutrient off-takes at Hunts Mill were calculated using the weight of material, which actually left the field – in some cases (when grading was done in the packing shed) this was rather more than the marketable yield. One important result was the large amounts of P and K removed by potatoes and carrots. For crops with particularly variable yields the nutrient off-takes covered a large range; expressing the data as a proportion of fresh weight yield greatly reduced its variability. In most cases there was quite good agreement between the measured values of P and K and data in tables commonly used by organic farmers. The Hunts Mill crops generally contained less nitrogen (especially the carrots and potatoes) and this may be a reflection of the fact that conventional crop information is generally used to derive the 'standard' figures.

Figure 2 summarises the additions of carbon and nitrogen to the soil. Although this is the main purpose of fertility building crops (leys, undersown clovers and winter cover crops) it is obvious that the cash crops also make a significant contribution. Most soil carbon is originally derived from the atmosphere as a result of plant photosynthesis. Much of it is in a very stable form and makes up the bulk of the organic matter in the soil. Recent crop residue returns generally make up a more labile pool. In the process of decomposition soil microorganisms use the carbon as an energy source and often make other nutrients available to plants in the process. Some of the residues will not be fully decomposed and will become part of the permanent soil organic matter – this is important for improving soil structure (Shepherd *et al*, 2002). At Hunts Mill both carbon and nitrogen were also added to the soil in the compost applications. It is generally accepted that compost provides these elements in a very inert state (HDRA, 2001). They are likely to become part of the stable soil organic matter rather then becoming rapidly mineralised – this is borne out by the fact that fragments could be detected visually over a year after application. At Hunts Mill, the total measured addition of carbon in crop residues was between 1 and 3 t/ha/year. In practice, this is likely to be an underestimate because of the difficulty of accurately measuring the contribution of roots and because many crop residues are returned to the soil before harvest (e.g. cabbage leaves and potato tops). Much of this added C, however, will have been lost quite rapidly as a result of microbial respiration. There were scarcely any changes in total soil organic matter levels since monitoring began in 1995.

Figure 2. *Measured C and N returns from fertility building (green) and cash crops (blue) at Hunts Mill. The numbers refer to the number of crops of each type making up the average and the lines are SD to give an idea of the degree of variability. Note that some of the nitrogen, even from the legumes, is recycled from the soil.*





Some of the measured returns of nitrogen in crop residues (even by the legumes) are just a recycling of nitrogen and not true additions to the system. It was not within the remit of this project to measure nitrogen fixation. The amount of nitrogen fixed by legumes is notoriously variable, being dependent on the climate, soil pH, available nutrients, age of legume, cultivar and strain of symbiotic rhizobia. Estimates of the amounts of nitrogen fixed average 150 kg/ha/year (with a range of 80- 250) for 1-2 year old leys and 85 kg/ha/year (with a range of 50-130) for older leys (Kristensen *et al,* 1995). It is generally believed that forage legumes will fix approximately 90% of their nitrogen requirements and grain legumes 50% (Watson *et al*, 2002).

For nutrient balance calculations to be of value, these must be done over a 'complete' rotation. The average annual balances for the first two turns of the rotations with the three contrasting fertility building strategies at Hunts Mill were calculated. This was done using measured removals in harvested crops, estimates of leaching losses (based on DEFRA project OF 0178), measured inputs of nutrients in compost additions, literature estimates of deposition (Mitchell *et al* 1998 and Shepherd *et al* 1999), and estimated fixation (75% of the N in legume-containing residues).

- **Nitrogen**. All the areas generally showed a positive balance (-12 to +119 kg/ha/year) but this was completely dependant on the compost applications; much of this compost-nitrogen will not be readily available. Leaching losses generally exceeded removals in the crops. The negative balances in the second rotation cycle in area 4 were associated with a very poor ley.
- **Phosphorus**. The balances were clustered around zero (ranging from -6 to +12 kg/ha/year). Areas where root crops (carrots and potatoes) had been grown had the most negative values.
- **Potassium**. The balances were generally negative (ranging from –72 to +50 kg/ha/year). As with K where there were differences between the strips the most negative values were associated with cropping with carrots and potatoes.

The nitrogen balance was most positive in Strategy B, associated with the good productivity of the one year leys. The phosphorous and potassium balances are most negative for Strategy A, associated with greater offtakes as a result of its generally better yields.

3.5. The effect of rotation design on yield

A critical question is whether, overall, extra time dedicated to fertility building results in better crop yields. There were limited opportunities to make direct comparisons between the crops grown at Hunts Mill because the site was not set up as a replicated trial. Sometimes different crops were grown (especially in Strategy C) and often different varieties and management were used. Potatoes and barley were the most standardised crops. Although, in some years, the yields were lowest in Strategy C overall analysis of their yields showed no relationship to the cropping strategy.

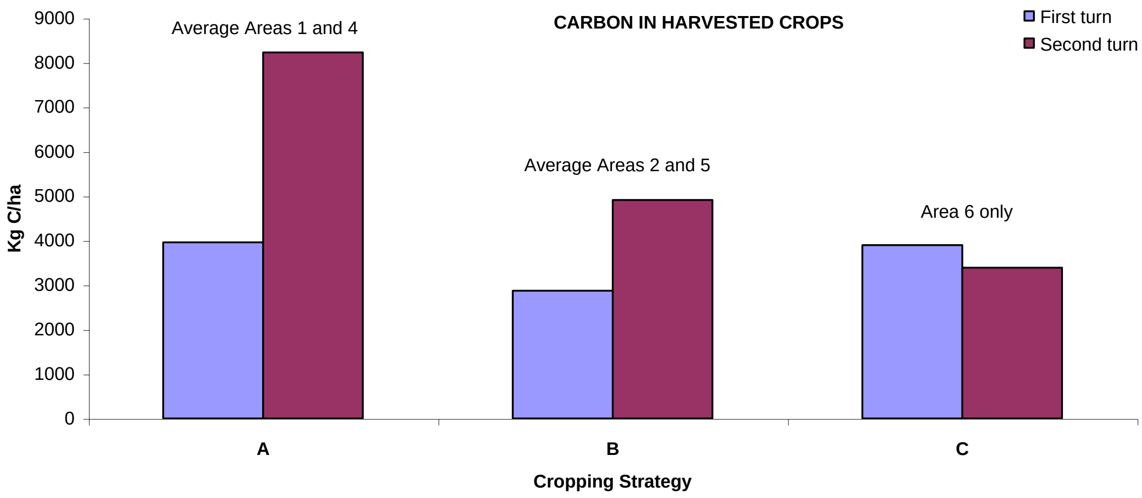
Another approach is to consider the overall removal of carbon or nitrogen in all harvested crops (Figure 3). A similar pattern is shown for both elements. In the first cycle of the rotations there was little difference between the strategies. However, in the second cycle Area 6 (Strategy C) was clearly the least productive. A third approach is compare the financial performance of the cropping strategies – this is discussed in Section 3.8.

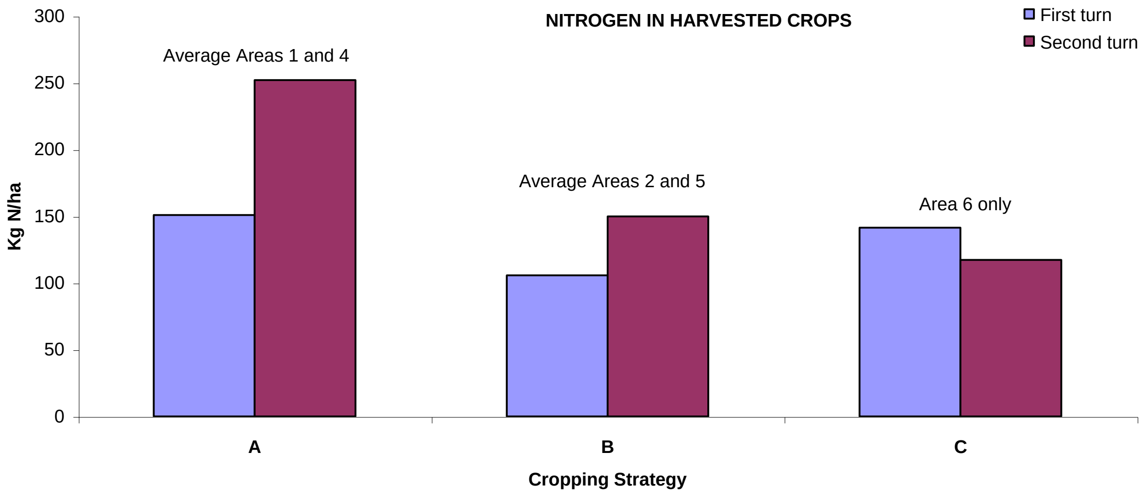
In order to directly compare the effect on yields of the two most contrasting strategies at Hunts Mill replicated trials were set up within Area 1 (following a two year ley – Strategy A) and Area 6 (following a six month ley – Strategy C). The crops grown were potatoes (in 2003, with or without an application of Farm Yard Manure), carrots, beetroot, French beans, calabrese and leeks (in 2004), spring barley (in 2005). This work was done jointly with the EU-Rotate_N project (see www.hri.ac/eurotate). In almost every case, the yields were significantly higher in Area 1 (i.e. preceded by the longer fertility building period) whilst the effect of FYM applications was relatively insignificant. These yields effects were clearly related to mineral N levels in the soil (see Figure 1).

It is clear that levels of fertility at Hunts Mill have fallen in Strategy C, which relies on short term green manure crops. However, this is partly due to the failure to establish some of these fertility building crops successfully (e.g. in 2006 the potatoes in Area 3 were harvested too late to enable a vetch crop to be sown even though an early maturing potato variety was used). This is a reflection of real farm practice in which Strategy C is recognised to be a more risky one (if a long term ley fails there is always time to resow it). As well as direct effects on nitrogen availability, the different fertility building strategies also have effects on soil structure and weeds (and thus crop yields).

At Kirton, there was only one fertility building strategy, based on a one year ley (although winter green manures were also grown when possible). Crop observation showed that, in most cases, adequate nitrogen was available – although there were occasions when the preceding fertility-building crop was not able to supply crop demand (e.g. cabbages struggled in 2003, when the preceding fertility crop had not performed well due to weed competition, pest damage and water stress).

Figure 3: *Overall average removal (kg/ha) of carbon and nitrogen in harvested crops in the first two completed crop rotations in the various areas of Hunts Mill. Area 3 was excluded because it had an arable rotation in the early years.*



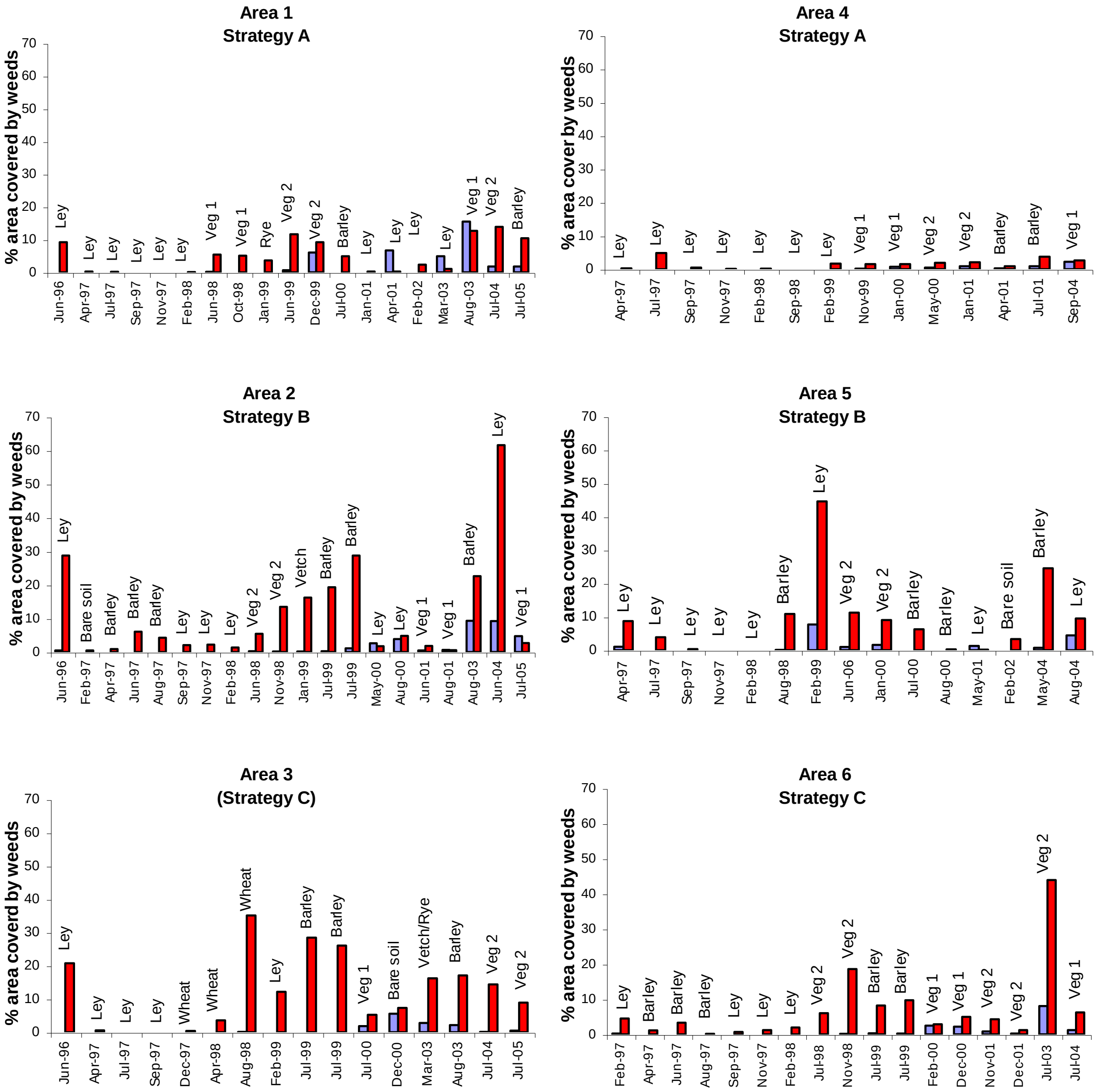


3.6. Weed management

At both sites weeds in the vegetables were controlled primarily by mechanical inter-row cultivations (using steerage hoes, brush or finger weeders) followed by hand weeding if this was necessary. Crops were often established in stale seedbeds; flame weeding was usually done before carrots emerged. Weeds in the leys were controlled by mowing. There was no weed control in the cereal crops but the undersown legumes provided some competitive inhibition.

Figure 4 shows a summary of the trends in weed incidence at Hunts Mill - note that the assessments were made at peak weed pressure or harvest of the crop and so the dates in the different areas do not always correspond. The main annual weeds were mayweed (*Matricaria* spp.), common field-speedwell (*Veronica persica*), common chickweed (*Stellaria media*), shepherd's purse (*Capsella bursa-pastoris*), fat hen (*Chenopodium album*), poppy (*Papave*r spp.) and groundsel (*Senecio vulgaris*). The control measures used were generally sufficient to suppress annual weed competition enough to enable satisfactory crop yields. However, there was sometimes a mis-timing of mechanical operations and much additional (and costly) hand weeding was necessary (e.g. the leeks and carrots grown in 2005). There were greater problems with the control of perennial grass weeds - couch (*Elitrigia repens*) and black bent (*Agrostis tenuis*). Levels of these weeds had increased since conversion to organic management began in 1995 (represented by blue bars in Figure 4). This was despite attempts to specifically control them by cultivations designed to dry out the rhizomes (even at the expense of taking the worst affected strips out of production in some years). These grasses were even present within the fertility building leys where they could have been expected to be outcompeted by the other grass species in this situation. There were also long standing patches of horsetail (*Equisetum* spp.) that were not effectively controlled; in 2004 an area of carrots had to be abandoned because of this weed. Potato volunteers were a persistent problem in the following carrot crops; parsnip volunteers were also common but did no great harm in the following cereal crops although they were very visual. Weeds were generally less of a problem in the Strategy A where the long ley gave a better break from the vegetable and arable cropping.

***Figure 4**. An overall summary of the weed status in the six areas of Hunts Mill between 1996 and 2005. At each date the figures are the average of ten quadrats placed in each of the six strips of each area. Broad-leaved weeds are shown in red and grass weeds in blue. Note that in Area 3 only potatoes and cereals were grown prior to 2004 and so the rotation in this area did not follow the norm for Strategy C.*



At Kirton the weed pressure was much greater. The main weeds were common chickweed (*Stellaria media*), nettles (*Urtica* spp.), speedwell (*Veronica* spp.), sowthistle (*Sonchus* spp.), shepherd's purse (*Capsella bursa-pastoris), redshank (Polygonum spp.),* mayweed (*Matricaria* spp.), fat hen (*Chenopodium album*) and groundsel (*Senecio vulgaris).* Perennial grass weeds were not generally a problem; they occurred sporadically but with no evidence of increase. The shortness of the lettuce crops were an advantage at this site, because they could often be harvested before hand weeding was necessary; in contrast the taller weeds sometimes interfered with the pollination of the sweetcorn even when they were not present in particularly high numbers. The greater use of crop covers at this site sometimes made timely weeding operations more difficult.

3.7. Pest and disease management

The main problems affecting the various crops grown at Hunts Mill and Kirton were identified in Section 3.1. At both sites a minimum intervention strategy was adopted; this reflected common farm practice and relied on resistant varieties and timely cultural control rather than the application of permitted inputs. This approach was helped by the diversity of cropping that limited spread.

At Hunts Mill the major disease 'problem' limiting yield was potato late blight *(Phytopthora infestans*), but this was effectively managed by timely defoliation of the crop. Scab (*Streptomyces scabies*) affected a large number of tubers, making them largely unsuitable for supermarket retail although it was possible to sell them to other outlets. Irrigation was only used for crop establishment and not to main potato crops - this exacerbated the scab problem. The main pest problems were with birds; rooks (*Corvus frugilegus*) were particularly damaging to the barley crops immediately after sowing and just before harvest. Carrots were not significantly affected by carrot fly (*Psila rosae*) even though they were not covered by fleece (since the sowing dates were chosen to minimise damage). Avoiding the use of fleece represented a considerable financial saving. Weevil damage was often observed on the clover leaves and whist this may have delayed the establishment of crops it was unlikely to have a significant impact on their biomass accumulation.

At Kirton, birds (mainly pigeons, *Columba palumbus*) were also a major problem. They made establishment of vetch crops difficult – this had knock on effects on the yields of subsequent cash crops. The cabbages had to be grown under fleece to protect them and birds completely devastated pea and bean crops that had to be resown. Lettuces also needed protection from fleece but in one year, its late removal exacerbated damage from tipburn. The marketability of the lettuces was also affected by downy mildew (*Bremia lactucae*) and aphids (*Nasonovia ribisnigri* and *Myzus persicae*).

3.8. Economic analysis of crops and cropping strategies

Crops and whole farm analysis. The individual agronomic and economic crop results were described in section 3.1. Table 4 shows the average gross margins for all crops at Hunts Mill. Results for net margins were also calculated but are not presented here as they show very similar patterns to the gross margins. Overall economic performance increased from the time of Conversion Projects (1997 to 2001) to the time of the Baseline Monitoring Project (2002 to 2005). This was mainly due to changes in the crops grown: cabbage and onions were discontinued and lettuce and sweetcorn were introduced. The whole farm gross margin average of £2067/ha/year from 1997 to 2001 increased to an average of £3130/ha/year from 2002 to 2005. Key crops suited to the soil conditions at Hunt Mill (like potatoes and carrots) slightly increased their performance while leeks struggled, mainly because they were only grown in the last year of the intensive short-term fertility building Strategy C. The gross margins of fertility building crops decreased, mainly due to lower subsidies (set-aside) and higher seed costs for the organic seed required in more recent years (due to changes in the Organic Standards).

Table 4. *Average crops gross margins (£/ha) and average whole farm gross margins (£/ha/year) of all crops grown at Hunts Mill during the conversion and baseline-monitoring project. As and indication of variability the coefficient of variation is given. The % change for the conversion to the baseline period is also shown.*

Project:	**Conversion**		**Baseline**			**Total**
Time:	1997-2001		2002-2005			1997-2005
Crops gross margins	£/ha	cv	£/ha	cv	*%-change*	£/ha
Cabbage (n=12)	3815	1.04	Not grown			3815
Onions (n=10)	829	3.09	Not grown			829
Lettuce (n=5)	Not grown		5703	0.80		5352
Sweetcorn (n=6)	Not grown		4480	0.44		4480
Potatoes (n=36)	5526	0.22	5583	0.30	*1%*	5568
Carrots (n=33)	6046	0.65	6335	0.25	*5%*	6230
Leeks (n=13)	2298	0.84	941	0.90	*-59%*	1776
Parsnips (n=4)	14925		8379	0.16	*-44%*	10016
Cereal/Barley (n=97)	545	0.27	688	0.28	*26%*	600
Fertility crops (n=17)	266	0.20	179	0.24	*-33%*	236
Whole farm gross margin						
	£/ha/year		£/ha/year		*%-change*	£/ha/year
	2067		**3130**		***51%***	**2358**

The situation at Kirton was rather different. Before conversion, in 1996, the average annual farm gross margin was £1218/ha/year. During conversion (1997 and 1998) the annual farm gross margin decreased to £390/ha/year and in the four years following the conversion period it averaged £1017/ha/year. A high of £3318/ha/year in 2000 and a low of -£862/ha/year in 2001 indicates the great variability of this system. Rotational gross and net margins showed that the two rotations with in-conversion vegetables produced lower gross margins of £42/ha/year after six years, while the other six rotations with two years of grass/clover ley during conversion had, on average, margins of £1119/ha/year and hence 'paid' for the fertility delivered and the reduced cropping risk in subsequent vegetable crops.

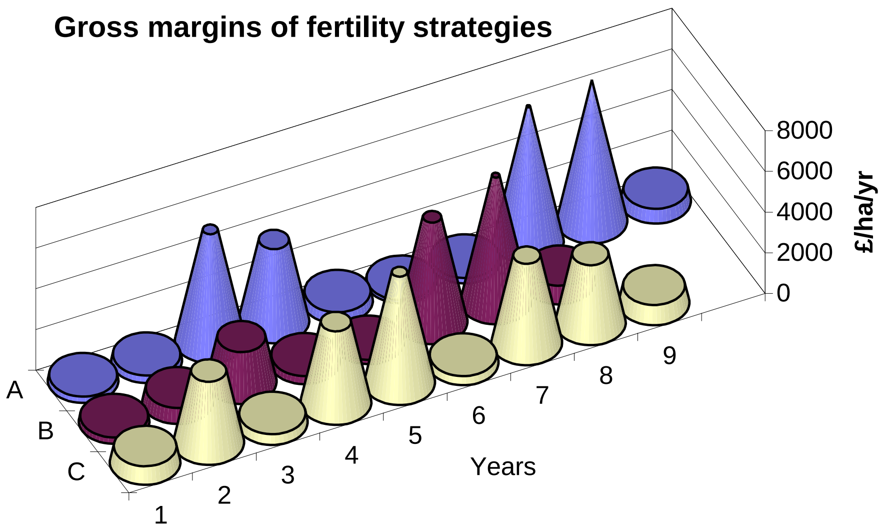
It was difficult for staff at Kirton to market the produce at the scale it was produced. Although good yields were achieved (Table 5), they were often not fully marketed. Therefore, the measured low gross and net margins in the later years of the rotation during the period of the baseline monitoring project (2002-2005) are real although not representative of truly commercial growing conditions. The agronomic performance of the crops was, however, similar to standard organic figures. Table 5 shows a comparison for the crops grown in Kirton in more then 3 years; the results indicate slightly above average results for potatoes and cabbage with a low coefficient of variation. Carrots were not grown as successfully and, with a high coefficient of variation, they were discontinued in later years.

Table 5. *Marketable yields of organic vegetable cash crops grown at Kirton in more then 3 years. Yields are shown in tonnes per ha, cv% is coefficient of variation and %-OFMH percentage provides a comparison with Organic Farm Management Handbook standard data (Lampkin et. al. 1996-2004).*

Crop	t/ha	cv%	% of OFMH
Potatoes (n=4)	29.3	39%	105%
Carrots (n=3)	28.8	94%	78%
Dutch White Cabbage (n=3)	30.6	50%	102%

Effect of fertility building strategies. As explained in Section 3.5 comparisons between the strategies must be made with caution. Figure 5 shows that the performance of each rotational year is very much dependant on the crop type grown (fertility, cereal or vegetable crop).

Figure 5. *Hunts Mill rotational gross margins (£/ha/year) for each rotational year of the three fertility building strategies A, B and C (n=12 for Strategy A and B, n=6 for Strategy C). The graph shows performance for up to 10 years after the start of conversion.*



The economic analysis of the three contrasting fertility building strategies at Hunts Mill shows, as with the crop-by-crop analysis, that the 2nd and 3rd cycle of the rotational strategies had an increased performance compared to the 1st cycle of the rotation by 39% for A, 248% for B and 109% for C, respectively (Table 6). Although the short-term fertility building strategy (C) had a much higher proportion of vegetable crops in the rotation (67% in C versus 40% in A) the average rotational gross margin (£2558/ha/year) was not very different (£2512/ha/year) from that of Strategy A with its long-term fertility period (Table 6). The %-coefficient of variation is similar in all three strategies (Strategy A 25%, Strategy B, 31% and Strategy C 30%, respectively). Only the medium-term fertility building strategy had a low average gross margin of £1989/ha/year; this was largely due to a bad start in the first four rotational years. If only the most recent cycles of each rotation are compared Strategy A and B show similarly good performance. It will be interesting to see if the rotational gross margin of the most intensive rotation, Strategy C, continues to decrease in performance.

Table 6. *Average rotational gross margins (£/ha/year) for the three fertility building strategies with a comparison of the averages of the first, second and third cycles of the rotation (n=12 for Strategy A and B, n=6 for Strategy C).*

Strategy	Average 1st cycle	Average 2nd cycle		Average 3rd cycle		Average All
	£/ha/yr	£/ha/yr	*% change*	£/ha/yr	*% change*	£/ha/yr
A	2106	2919	*39%*			**2512**
B	888	3091	*248%*			**1989**
C	1561	3266	*109%*	2847	*-13%*	**2558**

Further detail can be extracted if the efficiency of each strategy is compared. Efficiency in this case, is defined as the gross margin (in £/ha) achieved for each percentage point of vegetable crops in the rotation. For rotational planning, it is relevant information if the same gross margin can be achieved with fewer vegetable crops, which will free management time and resources. Table 7 shows this comparison for the 2nd cycle of the rotation. Although there is little difference in the rotational gross margin of all strategies in their second cycle, there is a significant ranking in efficiency. Strategy A has the highest efficiency, generating £73/ha gross margin for each % of veg crops, followed by Strategy B and Strategy C.

Table 7. *Efficiency (£/ha gross margin per percentage point vegetable crops in the rotation) and average rotational gross margins (£/ha/year) for the three fertility building strategies (n=12 for Strategy A and B, n=6 for Strategy C, Student's t-test).*

Strategy	Average 2nd cycle	% veg crops in rotation	Efficiency
	£/ha/yr	%	£/ha per % veg
A	2919	40%	**73** (a)
B	3091	50%	**62** (b)
C	3266	67%	**49** (b)

Changes in outputs, variable and allocated fixed costs. As already discussed the rotational gross margin of all three strategies were increased during the 2nd cycle of the rotation (Table 8). This is due to an increase in output and a slower increase in variable costs. In Strategy B, the variable costs were even decreased resulting in a much larger response in the gross margin increase. The same is true for the allocated fixed costs. Their increase was moderate or negative as for Strategy A, resulting in even better results for the rotational net margin. The moderate increase of variable and allocated fixed costs can be seen as an efficiency gain in the second cycle of the rotation.

Table 8. *%-Change of rotational output, variable costs, gross margin, allocated fixed costs and rotational net margin form the 1st to the 2nd cycle of three fertility building rotations (n=12 for Strategy A and B, n=6 for Strategy C, raw data not shown for gross margin see Table 6).*

Strategy	Output	Variable costs	Gross margin	Allocated fixed costs	Net margin
A	*23%*	*8%*	*39%*	*-17%*	*50%*
B	*34%*	*-21%*	*252%*	*13%*	*421%*
C	*64%*	*38%*	*105%*	*26%*	*135%*

Casual labour costs – A comparison with data for casual labour hours published in the Netherlands (Geven 1999) shows that casual labour costs (using UK labour rates of 7.29 €/h) are similar for some crops like leeks and onions, higher for potatoes and carrots and lower for cabbage. On average the casual labour costs where 151% of the Dutch data, which give no indication of variation.

Rotational costs - Variable costs as shown in Table 6 refer only to the crop-related costs as, usually published in farm management handbooks (Lampkin et al. 2004). Costs applicable to the whole rotation, like short-term fertility building crops or weeding and sub-soiling not allocable to a certain crop are not included. At Hunts Mill this rotational cost varied between 35 and 140 £/ha/year depending on rotation and were 100 £/ha/year on average.

Costs of fertility management - Costs of green waste compost and spreading were low (20-30 £/ha/year) within a rotation, accounting for 0.5% of the average variable costs of a vegetable crop. Variable and allocated fixed costs of fertility building crops (seeds, sowing, power-harrow and plough, rolling, mowing, spring-tine were necessary) varied between 50 -350 £/ha/year, or 1 - 5% of the average variable costs of a vegetable crop. Further cost analysis is published elsewhere (Schmutz et al. 2006a and 2007).

Risk analysis – A risk analysis (coefficient of variation) of five main vegetable crops (potatoes, cabbages, onions, carrots, leeks) grown in multiple years at Wellesbourne, Hunts Mill showed highest output risk in marketable yield variations (29% cv), above prices (10% cv). The most variable crop yields were measured in onions and cabbage (42% cv). Overall, variable cost variations were on average also below marketable yield variations. The riskiest crop in terms of variation was cabbage (42% cv). Further analysis into the different variable cost showed highest risk introduced by variations in general casual labour and especially casual labour for weeding (59% cv). Crop protection cost were also highly variable (82% cv) reflecting different whether conditions in different years. Further details are found at Schmutz et al. 2005.

4. ASSOCIATED PROJECTS THAT HAVE USED THE SITES (Objective 3)

The creation of a resource that could be used for other projects was a key objective of OF 0332. It is particularly important that research into organic farming systems is done on sites, which have realistic soil fertility levels, weed populations etc. The sites at Hunts Mill and Kirton provide this with detailed documentation about past performance and during the course of the project were selected as sites for field trials forming part of the following projects:

At Hunts Mill:

EU-Rotate_N (EU Project QLK5-2002-01110). This project aimed to develop a new computer model to help farmers manage nitrogen better; the site was used to conduct specific validation trials and other information concerning marketable yields and economics of production has been built into the model. Hunts Mill was particularly suitable for this because areas with contrasting histories of fertility building were available side by side.

Seed treatments for organic vegetable production –STOVE (EU Project QLK5-2002-02239). This project aimed to evaluate and optimize existing methods (physical, chemical and biological) and develop new methods for the control of seed-borne diseases in vegetable crops for organic farming. Hunts Mill was used as a site to evaluate the effectiveness of some of these approaches.

Arbuscular mycorrhiza in organic systems (DEFRA Project OF0333). The site was used to sample soil for microbial analysis.

Improving the sustainability of crop nutrition in horticultural soil (DEFRA Project HH35 08 SFV). The site was used to sample soil for microbial analysis.

Varieties of Field Vegetables and Potatoes for Organic Production and Marketing (DEFRA Project OF0346). A range of salad and maincrop potato varieties and carrot varieties were tested in 2005.

Achieving an optimal balance between machine vision capability and weed treatment effectiveness using competition models (BBSRC funded project). The organic crops were used for image capture.

Using weeds to reduce pest insect numbers in organic vegetable crops - a desk study (DEFRA Project OF 0329). The site was used to set up a trial to evaluate the effect of weeds on pest incidence in a cabbage crop.

Growth & competition model for organic weed control (DEFRA Project OF 0177). The site was used to grow organic cabbage, cauliflower, broccoli and leek for model validation.

At Kirton:

In 2003, the site was used for a NIAB leek variety trial and a demonstration of cabbage varieties.

5. MAIN CONCLUSIONS

Specific conclusions from Wellesbourne, Hunts Mill

All three rotational strategies produced a much higher per ha return then compared to conventional arable (before conversion started) or organic arable production. Even after 10 years of monitoring a final conclusion on the economic performance of the three different rotational strategies is not yet possible. This is because the longer two rotations (5-year, Strategy A and 4-year, Strategy B) have had only two full rotational cycles. In both cases there were improvements in the agronomic and financial performance in the second cycle. In the intensive 3-year, Strategy C a decline of performance was measured in the 3rd rotation. Again, more time is required to see if this decline is a temporary one or if this intensity of cropping is not sustainable in the long run.

Specific conclusions from Kirton

Generally results from 10 years of monitoring at the Kirton site have shown that stockless organic vegetable production on this fertile soil can be economically viable and agronomically manageable. There was a great variability in yields and marketing results and therefore various management interventions and adjustments to the rotation were necessary. It was possible to maintain soil fertility and yield levels with 67-75% vegetable cropping in the rotation and a mixture of long and short-term fertility building crops. No external inputs of animal manures or composts were necessary during the period of study. Although designed as a case study and demonstration site with no replications or a fixed rotation, the unit provided a valuable resource for growers and scientists alike. The data have been used in the European network of long-term field experiments in organic farming (Raupp et al., 2006) and in the modelling of crop rotations and N dynamics (Schmutz et al., 2006b).

General conclusions from both sites

At both Hunts Mill and Kirton, the **basic fertility building strategies and crop rotations** have proved to be agronomically sustainable under organic management for a period of ten years. **Available nitrogen** was a key factor in limiting the yields of several crops. At Hunts Mill the benefits of Strategy A (with the most time dedicated to fertility building) became much more evident as time progressed. However, in some cases the short-term green manures of Strategy C could have been more productive if it had been possible to establish them earlier; similar knock on effects of poor fertility building crop performance were also seen at Kirton. Reliance on only short term fertility building crops can therefore be seen as a risky strategy. Whilst it is clear that the longest fertility building crops generally have the most impact, several shorter term crops can also be effective and may be a more efficient use of the land under certain circumstances. This is particularly the case in stockless systems when there is no direct economic return from the fertility building leys (apart form subsidy payments). Long leys may however have other benefits; they can help in the control of weeds and can act as a break to prevent the build up of certain pests and diseases. Over a ten year period there was no change in total soil organic matter regardless of fertility building strategy. **Annual weeds** were generally effectively controlled by mechanical means supplemented by hand weeding when necessary. There was a much higher weed pressure at the Kirton site. At Hunts Mill there were less annual weeds in Strategy A (with the longest fertility building periods). **Perennial grass weeds** were not a particular issue at Kirton but at Hunts Mill there was an increasing problem of grass weeds in all three strategies. A minimum intervention strategy was generally adopted for **pest and disease management,** which relied on resistant varieties and timely cultural control rather than the application of permitted inputs. The main pests were birds (particularly affecting brassicas and barley). Carrots were not significantly affected by carrot fly even though they were not covered with fleece and this resulted in a considerable financial saving. The main disease issues were potato blight (necessitating early defoliation in some years), potato scab (which affected marketability) and downy mildew of lettuce. Overall pest and disease management was successful and did not generally limit yields or financial performance.

The combination of organically managed land with well defined rotations and a fully documented history created resources at both Hunts Mill and Kirton that were used as field sites forming part of a number of additional projects, funded by DEFRA, HDC and the EU.

6. FUTURE WORK

Projects OF 126T, OF 0191 and OF 0332 have together collected detailed information about the performance of field vegetable production systems at two different sites over a ten-year period. This was invaluable as we have been able to record the effects of the change to organic management and the differences between contrasting fertility building strategies. We propose that this basic monitoring work is continued to see if the trends observed so far continue in the longer term. This will allow the sites to be maintained in a condition that will permit their use as facilities for additional 'bolt on' projects.

In any future projects there should be more emphasis on the effects of the crop rotations on soil organic matter, soil structure and soil microbiology. There should also be opportunities to investigate more novel fertility building approaches (such as intercropping vegetables with legumes) and the benefits of a wider range of fertility building crops (particularly the effect of different grass species).

7. KNOWLEDGE TRANSFER

Detailed reports including all the agronomic and economic information concerning the Wellesbourne and Kirton sites are available on request from HDRA. These contain all data from the monitoring work at each site since 1995.

An open day for farmers and advisors was held at Warwick HRI Kirton in each year of the project. These were focussed on a tour of the experimental area and the findings from OF 0332 but also included presentations by scientists working on related projects. Events were also held at Warwick HRI Wellesbourne but these were more aimed at scientists although practical farmers also attended. In 2005, a special stakeholder day was held to explore the value of long term experiments and to identify potential areas of collaboration between the various organic rotational work currently underway. In addition, presentations about OF 0332 were given at other open days and conferences organised by HDRA or other organisations. The project was also publicised on the internet.

A number of scientific papers with material sourced in this project have been published, more are in preparation. There are also publications arising from the associated projects that have used the sites.

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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.

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