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SID 5

Research Project Final Report

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Project identification

1. Defra Project code: OF0363
2. Project title: Fertility management strategies in organic arable and vegetable production
3. Contractor organisation(s):
   Garden Organic (formerly HDRA)
   Warwick HRI
   IBERS
   ORC - EF
   ABACUS
4. Total Defra project costs (agreed fixed price): £ 370001
5. Project: start date .... 01 January 2007
   end date .... 31 December 2009

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 overall aim of the project was to explore the effects of contrasting fertility management strategies in organic stockless systems growing arable and/or vegetable crops. There were six specific objectives:

Objective 1. To continue to monitor the agronomic and economic effects of three established stockless fertility building strategies for arable and vegetable crops at Hunts Mill (Warwick HRI, Wellesbourne).
This field, with a sandy loam soil, has been divided into six areas, each of 0.8ha, each further divided into six strips for monitoring purposes. The cropping at this site has followed three contrasting fertility building strategies since conversion to organic management began in 1995 (Defra Projects OF0126T, OF0191 and OF0332): Strategy A (two year grass ley), Strategy B (one year clover ley), Strategy C (short term green manures only). The cropping has been a mix of field vegetables and arable and is completely stockless. There has been routine monitoring of soil fertility, crop yield (total and marketable), weeds, pests, diseases and economic performance.

Within Strategy A comparisons were made between lucerne, clover/ryegrass mix and a volunteer clover and within Strategy B a replicated experiment was set up to compare seven undersown green manure treatments (red clover, white clover, trefoil, lucerne, sainfoin, sweet clover an clover/ryegrass mix) with an non undersown control. Each was followed, in 2009, with crops of Savoy cabbage and triticale. The best performance of both cash crops was following lucerne plots grown for two years in Strategy A. Within Strategy B the clover/ryegrass mix outperformed the lucerne (in the Strategy A area this mixture became much more dominated by grass in the second year and much less nitrogen was finally incorporated as a result). Economic analysis showed that investment in an effective green manure crop was much more easily justified for the high value cabbage crop than in an arable situation.

In Strategy C two replicated trials were set up. One investigated the potential for 'strip cropping' as an innovative way of increasing diversity in the field by growing green manure and vegetables in alternate beds; there were no significant effects on yield or crop quality. The second experiment was to see if winter soil management could be used to control couch grass (this had built up over the previous ten years on the land which had been in almost continual cropping). There were four treatments: uncultivated bean stubble, a mustard cover crop, regular overwinter shallow cultivations and winter wheat. Couch grass was reduced by the cultivations; although leaching losses were greatest in these plots they did give the highest spring barley yields in 2009.

Objective 2. To capture existing information/knowledge about fertility building crops held by farmers and other experts.
A stakeholder day was held in April 2007 to provide an opportunity to discuss fertility building crops – this was attended by forty people representing farmers, growers, researchers and advisors. A series of workshops

covered forage legumes, grain legumes and novel approaches such as intercropping and fertility building for perennial crops. Issues for future research were identified.

Objective 3. To assess the performance of a range of novel legumes (fertility building crops and cash crops) on several sites and to assess their impact on subsequent crops.
On-farm trials were set up at eight organically managed sites around the country; these included vegetable, arable and stocked systems. In each case the farmer was asked to replace a part of his standard fertility building crop with one or more alternative species (red clover, white clover, yellow trefoil, crimson clover, Persian clover, sweet clover, lucerne and fenugreek). The performance of these was monitored and, when possible, assessments were made of the following crop yields. Each crop had particular strengths and weaknesses but Persian clover, not commonly grown at present, showed particular promise as a fast growing annual that competed well with weeds. At one site there was particular interest in finding a legume into which cereals could be drilled directly without cultivations that could lead to wind erosion – some varieties of white clover combined with 'Dynadrive' cultivation showed promise but more work is needed to develop this idea further.

Objective 4. To determine the usefulness of three computer models developed recently for assessing the nitrogen dynamics of organic rotations, specifically with regard to nitrate leaching.
The EU-Rotate_N model was developed by a consortium of European researchers – it is particularly intended for vegetable production although vegetable crops are also included. Modelling of a range of fertility building crops includes aspects such as nitrogen fixation, the effects of mowing, litter loss and establishment by undersowing. The NDICEA model was developed by the Louis Bolk Institute in the Netherlands to enable the assessment of organic fertilisation strategies using easily obtainable input values. The FBC model was developed to predict yields, soil mineral nitrogen and leaching losses following the incorporation of fertility building crops.

The models were tested using historical datasets. In their current form none of them reliably predicted the actual amounts of nitrogen available in the soil or lost by leaching although the correct patterns were usually indicated. However, they are still useful as planning tools to show what might happen. At present only the NDICEA model is available to the general public in a user-friendly form.

Objective 5. To interpret the new data within the context of whole farm systems to assess the implications of organic farming on soil fertility.
Green manures have been under-utilised by farmers and growers, both organic and conventional. However, there are indications that this is changing as fuel prices rise and there are concerns about changing weather patterns. Much emphasis has been placed on their use to fix or conserve nitrogen – their financial benefits can most easily be quantified by comparing the nitrogen they add with fertiliser prices. However, this overlooks the benefits they can bring to soil structure by additions of organic matter (particularly with regard to better water holding capacity) and to the enhancement of nutrient cycling in the soil. These benefits are recognised to some extent by Environmental Stewardship schemes.

The most common species grown in the UK are red or with clover, often mixed with perennial ryegrass. Many others are available and offer particular advantages in some situations – repeated growing of the same type can lead to a build up of pests and diseases ('clover sickness'). A choice of variety for many legumes is not readily available but differences in performance are likely to exist.

Objective 6. To disseminate the findings of the project through a number of channels.
Three events were held during the project to disseminate its findings (in 2007 at HRI Wellesbourne, Warwickshire, in 2008 at G's Marketing Ltd, Cambridgeshire, in 2009 at Duchy College, Cornwall). Papers have also been presented at several conferences and articles about the project have appeared in the farming press and on http://www.gardenorganic.org.uk/organicveg. Scientific papers are in preparation.

Possible future work
The established cropping strategies at the Hunts Mill site should continue to be monitored to determine long term implications of the various rotations. Further work is needed to evaluate more species (and varieties) of green manures under various soil and climatic conditions. This could include examining the degree to which pests and disease limit their growth. Computer models to simulate green manure growth can be an invaluable aid for rotation planning but more parameterisation of different crops needs to be done and tested against measured values. Green manures could be used in more innovative ways, for example in intercropping systems in vegetable production (where they could aid in pest control) and as feed for anaerobic digesters; this could be more efficient way to use material that would otherwise be cut and mulched.

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. BACKGROUND

Fertility management remains one of the most crucial aspects of organic production systems; there is a reliance on legume derived nitrogen but long-term fertility building leys are expensive, particularly in stockless systems when they give no direct economic return. Soil nutrient management and improvement of fertility building strategies has been identified as priority for research (ACOS, 2006). Because of their multifunctionality the choice of fertility building cropping has implications on soil structure and subsequent weed, pest and disease problems as well as on soil nutrient dynamics. Long term monitoring work is essential if the full effects of contrasting approaches are to be evaluated. Many Defra projects have investigated aspects of fertility building cropping, most recently OF0316 and this projects built on this work. It particularly utilised the Hunts Mill field at Warwick HRI where contrasting fertility building strategies have been monitored in detail since 1995 (OF0126T, OF0191 and OF0332).

This project was led by HDRA in collaboration with Warwick HRI who conducted all the horticultural operations at the Hunts Mill site and provided input on statistical interpretation and computer modelling. IBERS worked on computer modelling, specifically with regard to the FBC model. EFRC and ABACUS provided agronomic advice and assisted with capturing information from stakeholders. The project was directed by a Steering Committee made up of representatives from the industry.

2. OBJECTIVES

The overall aim of the project was to explore the effects of contrasting fertility management strategies in organic stockless systems growing arable and/or vegetable crops. There were six specific objectives:

1. To continue to monitor the agronomic and economic effects of three established stockless fertility building strategies for arable and vegetable crops at Hunts Mill (Warwick HRI, Wellesbourne).
2. To capture existing information/knowledge about fertility building crops held by farmers and other experts.
3. To assess the performance of a range of novel legumes (fertility building crops and cash crops) on several sites and to assess their impact on subsequent crops.
4. To determine the usefulness of three computer models developed recently for assessing the nitrogen dynamics of organic rotations, specifically with regard to nitrate leaching.
5. To interpret the new data within the context of whole farm systems to assess the implications of organic farming on soil fertility.
6. To disseminate the findings of the project through a number of channels.

All these objectives and associated milestones were fully met and details of the work done are described in the following sections.

3. PROGRESS DURING THE PROJECT

Objective 1: To continue to monitor the agronomic and economic effects of three established stockless fertility building strategies for arable and vegetable crops at Hunts Mill (Warwick HRI, Wellesbourne).

General methods

Hunts Mill field, in the English Midlands, has a sandy loam soil which is marginal for the growing of brassicas. It has been monitored since conversion to organic management began in 2005; six areas, each of 0.8ha were 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, once per rotation, with the main aim of replacing P and K removed by the cash crops.

Until 2006 a vegetable/arable rotation was used in all the strips:

Fertility building crop => Veg 1 (e.g. potatoes) => Veg 2 (e.g. carrots) =>Cereal (usually spring barley)

This was continued, in each area, in strips A, B and C but in Strips D, E and F a purely arable rotation was established from 2006 onwards; the vegetable crops were replaced with a cereal (wheat or triticale) or with field beans. In either case the final spring barley crop was undersown with a fertility building ley to complete the rotation.

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 giving opportunities for more novel species and techniques to be used.

Because of limitations of funding for this project only three of the six areas could be used; Area 2, Area 4 and Area 6 were selected as being at the most favourable stage of their rotations to give useful information during the life of the project. A computerised field diary was kept of all operations, growing practices, observations and scientific monitoring at both sites. The following general parameters were assessed:

Crop yield. Both 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. In 2007 70 ceramic cups were installed and samples of water taken at fortnightly intervals were analysed for their nitrate content; the total amounts of nitrate leached were determined by integration with net drainage figures. Nitrate leaching in earlier years 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).
Weed, 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. Percentage ground cover of weeds and crop were regularly assessed and measurements of weed biomass formed part of the assessment of the fertility building crops.
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 (unable to allocate 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*. 1996-2009) or other published standardised figures (Nix, 2005-2009).
Statistical analysis. The monitoring at the Hunts Mill sites was largely done using a case-study research methodology. The site overall sites was not set up as a replicated trial 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.

Within this structure specific replicated trials were set up to explore in more detail the effects of undersowing barley with a wider range of fertility building crops, the effects of a green manure on perennial weed control and the effects of strip cropping (alternate beds of vegetables and green manures) on system performance.

Results – fertility building crop performance

In Area 4 (**long term fertility building strategy**) three green manure treatments were established after the barley harvest in August 2006; 20kg/ha lucerne, 23kg/ha Cotswold Seed Ltd 'Fertility Builder mix' (red and white clover and ryegrass) and volunteer clover (these were not replicated in each strip because sowing had to be done before funding for the project was confirmed and so the time input had to be minimised). Because of poor establishment in the autumn the lucerne had to be resown in the spring of 2007. It was originally intended to sow another grass/clover ley as well as the 'Fertility Builder Mix'. However, such a good crop of volunteer clover emerged in the autumn of 2006 that the land was left undisturbed in Strips B and E. The green manures were allowed to grow on (cut and mulched as appropriate) until spring 2009 (ie for over two years).

In 2007 the lucerne got off to a slow start – there was insufficient biomas to justify mowing in June when the other plots were first topped. The volunteer clover plots had looked very good in the autumn and early spring (which is why they were not resown). They had an almost complete cover of white clover. However, this gradually became dominated by coarse weed grasses. The 'Fertility Builder Mix' plots also became more sparse and grassy as they leys aged. The lucerne, however, improved markedly during 2008, needing to be mowed three times in contrast to two for the other treatments. During the two years of mowing 439kg N/ha were returned from the lucerne, 186kg N/ha from the sown grass/clover ley and 143kg N/ha from the volunteer clover.

For each crop there were two incorporation dates in 2009 (February, before a triticale crop and May, before a cabbage crop). Plant biomass is shown in Figure 1.These was little difference, in terms of total nitrogen added to the soil, between the different treatments in February (average 116kg N/ha) but by May the lucerne was clearly the best (over 400kg N being incorporated in comparison to only 85kg N form the Fertility Builder mix). In the Fertility Builder mix plots only a small proportion of the legume content (less than 10%) was actually the red clover that was sown – most was volunteer white clover.

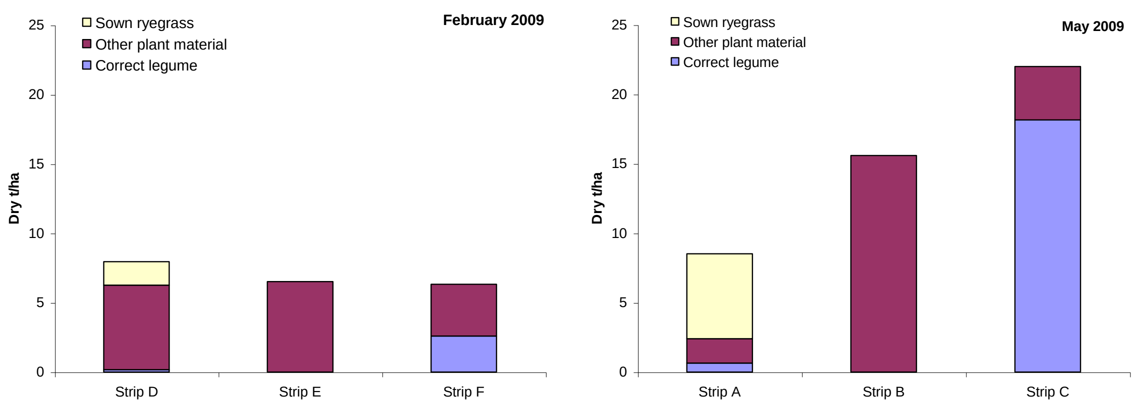

Figure 1. *Incorporated material in Area 4 in spring 2009 (shoots and recoverable roots). At each of the two incorporation dates only one strip was available for sampling.*

In Area 2 (**medium term fertility building strategy**) spring barley was undersown, by broadcasting in June 2007, with seven different green manures (15kg/ha red clover, 5kg/ha white clover, 8kg/ha yellow trefoil, 20kg/ha lucerne, 70kg/ha sainfoin, 6kg/ha sweet clover and 23kg/ha Cotswold Seed Ltd 'Fertility Builder mix' including red clover, white clover and perennial ryegrass) in comparison with a non-undersown control. Overall there was a general decline in legume ground cover throughout the first winter period but some species had consistently higher cover than others. The red clover, especially in combination with the ryegrass in the Fertility Builder mixture, most effectively suppressed the weeds. Perennial grass weeds (couch and bent) were particularly a problem in Strips D, E and F which had been used to grow barley in 2006 and so had missed out on the extra cultivations needed for the vegetables in A, B and C. These grass weeds effectively competed with the legumes whilst they were still beneath the cereal. Annual broad leaved weeds were less of a problem. There was a high incidence of volunteer legumes (mainly white clover) across the trial. These accounted for up to 40% ground cover in some plots on some dates

The area was managed by a cutting and mulching three times in 2008. All the plots were mown together – to some extent the timing of this had to be compromise between the needs of the different species. Some (eg the sweet clover) would probably have performed better if they had not been cut at all. The greatest returns of nitrogen (over 220kg N/ha) were from the red clover, lucerne and 'Fertility Builder mix' plots but even the control plots returned 60kg N/ha over the course of the year (much of in the form of volunteer white clover).

The fertility building crops were incorporated in spring 2009. Strips D, E and F were ploughed in earlier to permit the sowing of the spring cereal. The dry matter and nitrogen contents of shoots and recoverable roots was measured – this is obviously an underestimate of the true biomass present (Figure 2). At both incorporation dates, but particularly the February one, the sown legumes accounted for a relatively small proportion of the total biomass – in most plots grass weeds accounted for the bulk of the samples but there were also significant quantities of volunteer legumes (in the control plots an average of 85 kg N/ha were incorporated in February and 104 kg N/ha were incorporated in May). The greatest amount of incorporated nitrogen was measured in the sainfoin plots in May (211kg/ha) but only 64% of this was actually in the form of sainfoin.

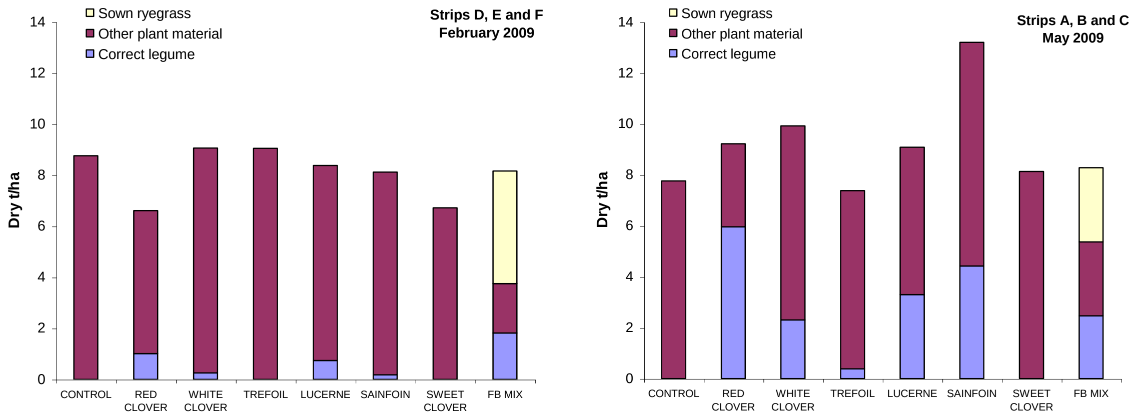

Figure 2. *Incorporated material in Area2 in Spring 2009 (shoots and recoverable roots). The values shown are the average of three individually sampled strips.*

In Area 6 (**short term fertility building strategy**) different trials were set up in the 'vegetable' (Strips A, B and C) and 'arable' (Strips D, E and F) rotation sections to evaluate ways of making the best use of short term green manures. In the 'vegetable section' an intercropping approach was evaluated. This focussed on the use of strip cropping – alternate beds of vegetables and red clover (cut and mulched). The aim of this was to avoid the excessive competition that can come from growing green manures immediately adjacent to vegetable crops. Performance of the red clover was similar to that in Area 2; growth of the vegetables is covered in the cash crop section below.

In the 'arable section' of Area 6 the use of cropping to control perennial weeds was explored. Since 1995 the incidence of grass weeds (particularly couch grass) had increased in Area 6 where there were no ley periods of extended fertility building to the extent that there were significant management difficulties. This work was done in conjunction with Defra project OF 0367 (*The control of perennial weeds in organic and low input farming systems*) After a crop of field beans grown in 2007 four overwinter treatments (replicated in the three strips but not randomised) were established: uncultivated been stubble, mustard winter cover crop (Caliente mustard was sown at 15kg/ha), land kept bare overwinter.by spring tine harrowing and winter wheat (cv Claire). Spring wheat (cv Paragon) was sown on the other three plots in April 2009.

The cultivations after the bean harvest brought a lot of couch grass roots to the surface – many of these were dragged off by the harrowing but this probably had little impact on the infestation. By late November on the uncultivated plots there was almost complete ground cover – mainly grass but also volunteer beans and annual weeds. The mustard had achieved 75% ground cover by late November but the plants were small (less than 10cm tall) and there was sea of new shoots of couch grass. Plant biomass was measured on 12/3/08 (Figure 3). Unsurprisingly there was most couch grass in the uncultivated plots and least in the cultivated ones; the Caliente mustard was not more competitive than the winter wheat – it had itself accumulated approximately 4.5t/h fresh weight.

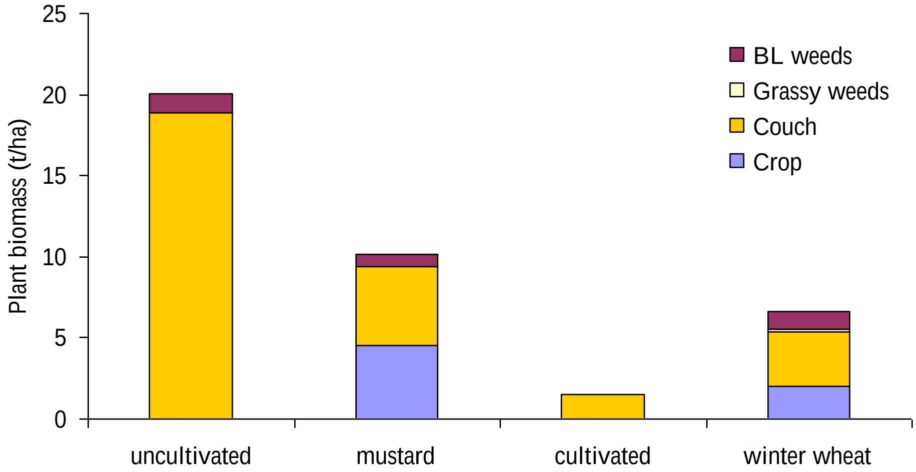

Figure 3. *Plant biomass (shoots and recoverable roots) in Area 6 (average of Strips D, E and F) as assessed on 12/3/08, shortly before cultivations for establishment of a spring wheat crop.*

Results – cash crop performance

In Area 4(**long term fertility building strategy**) strips D, E and F were incorporated in mid February and followed by a crop of spring triticale (cv Somtri, sown at 200kg/ha on 9/4/09) and strips A, B and C were incorporated in late May and followed by a crop of Savoy cabbages (cv Cantassa, planted three rows to a bed at a spacing of 33cm between the plants in early July). Cabbage yields were assessed early (8/12/09) in order to collect the data before the end of the project. The best performance (34t/ha) was from Strip C where lucerne had been grown with the greatest addition of nitrogen to the soil. The triticale was a vigorous crop which established well and suppressed the weeds despite a relatively late sowing. Again, the best yield followed lucerne (4.0t/ha).

In Area 2 (**medium term fertility building strategy**) spring barley (cv Dandy) was grown in 2007 but there were no differences in yield as a result of any of the eight undersown treatments; grain yield averaged 2.7t/ha.

In 2009, after the fertility building period, Savoy cabbages (cv Cantassa) were grown in strips A, B and C and spring triticale (cv Somtri) in strips D, E and F; these were planted at the same time as those in Area 4. Total and marketable yields followed the same pattern; the best performance was on plots which had grown red clover (pure or with ryegrass) and the worst following either the unsown or sweet clover. The yield following lucerne (22t/ha) was considerably less than that where this crop had been grown for longer in Area 4.The greatest yield of triticale (3.5t/ha) was from the 'fertility building mix' plots and the least (1.7t/ha) was from the control plots which had only grown volunteer legumes during the fertility building phase. Control plots also had the lowest grain nitrogen content. These yield difference were much more striking than measured differences in the nitrogen added by the various fertility building crops.

In Area 6 (**short term fertility building strategy**) the strip cropping trial was conducted in Strips A, B and C. This was intended to be an innovative way of integrating the use of green manures with cash cropping by growing vegetables in alternate beds with green manures – this should bring benefits in terms of pest control as a result of land diversity and could build fertility without the need to set aside a dedicated period of fertility building. Eight treatments were replicated three times (Table 1). Cabbages (cv Tundra in 2007, January King in 2008) and carrots (cv Berlicum) were grown in various combinations with red clover as a green manure in alternate beds.

Table 1. *Cropping in the strip cropping trial set up in the 'vegetable rotations section of Area 6 (Strips A, B and C).*

Treatment	Cropping in 2007	Cropping in 2008	Cropping in 2009
1	Cabbages	Carrots	Spring barley
2	Cabbages	Red clover	Spring barley
3	Red clover	Cabbages	Spring barley
4	Red clover	Carrots	Spring barley
5	Cabbages/ red clover	Red clover/cabbages	Spring barley
6	Cabbages/ red clover	Carrots/red clover	Spring barley
7	Cabbages/ red clover	Carrots/cabbages	Spring barley
8	Cabbages/ red clover	Red clover/ carrots	Spring barley

There were no significant differences in yield between any of the treatments in any crop in any year. Levels of cabbage root fly damage (a pest that was expected to be affected by the intercropping) were particularly low overall; cabbage yields were poor mainly because of pigeon attack. The main reason for outgrading the carrots was for misshapen roots rather for pest damage.

In Strips D, E and F wheat was grown in 2008. Spring wheat (cv Paragon) was sown after three of the overwinter treatments (uncultivated bean stubble, mustard, regularly cultivated) and the winter wheat (cv Claire) was allowed to grow on. All the wheat was undersown with red clover at the end of May. It was a very poor crop; the best yield (only 1.5t/ha) was from the winter wheat with only 1.1t/ha of spring wheat where the stubble had not been disturbed overwinter. There remained significant competition from couch grass and other weeds – more couch grass seed heads were counted in the winter wheat plots than in any of the others which received a spring cultivation. Spring Barley (cv Dandy) was grown in 2009; the best yield was from the plots that been regularly cultivated to keep them bare in the 2007/2008 winter and the worst yield followed winter wheat. Soil fertility was an issue but so was weed competition. More detail of crop yields is given the economics section below (Tables 3, 4 and 5).

Results – soil fertility and nitrate leaching

Average soil organic matter in the top 30cm of the three monitored areas increased from 1.3% in 2007 to 1.7% in 2009 – there were no significant differences between the areas with contrasting fertility building regimes. These levels were actually lower than those measured at the start of the conversion project at this site (1.8% in 1996). Similarly there was no overall trend in levels of available P, K or Mg, or effects of fertility building strategy, during the period of study.

Nitrate leaching was measured over the winters of 2007–2008 and 2008–2009 using ceramic cups installed to a depth of 80 cm. Samples of the water were collected from the ceramic cups every fortnight and the concentration of nitrogen in the water measured. The amount of drainage was calculated using figures provided by MORECS. This allowed the amounts of nitrogen leached over each winter to be calculated. Leaching was measured in Areas 2 and 4, and the arable section of Area 6 where different overwinter treatments were applied to control couch grass. Leaching occurs when the soil reaches field capacity and water drains out of the soil. During the winter of 2007–2008, most drainage occurred during the period 19th November 2007 to 6th February 2008. In 2008–2009, this occurred between 16th September 2008 and 26th February 2009. The amounts of nitrogen leached over each winter are presented in Table 2.

Table 2. *Nitrate leaching at Hunts Mill calculated from ceramic cup measurements.*

Area	Overwinter crop 2007/2008	Amount of N leached (kg/ha) 2007/8	Overwinter crop 2008/2009	Amount of N leached (kg/ha) 2008/9
Area 2	Red clover	3	Red clover	5
Area 4	Volunteer clover	2	Volunteer clover	0.3
	'Fertility builder' mix	11	'Fertility builder' mix	2
	Lucerne	3	Lucerne	4
Area 6	Uncultivated bean stubble	13	Stubble/undersown clover	1
	Mustard	14	Stubble/undersown clover	9
	Regular cultivations	40	Stubble/undersown clover	7
	Winter wheat	21	Stubble/undersown clover	1

In the winter of 2007/8 less nitrogen was leached form the established green manures in Areas 2 and 4 than from Area 6. The greatest losses were from the plots that were cultivated regularly over the winter to keep them bare in an attempt to control couch grass.

In the winter of 2008/9, the amounts of nitrogen leached in Area 6 were generally much less than in 2007 - 2008. This was because the cereal crops had taken up much of the nitrogen and also, as the clover was undersown, no cultivations had to be made which would have mineralised nitrogen and increased leaching.

Results – economic performance

Area 2 experiment (comparison of medium term undersown green manures)

For this experiment is shown the total fertility building costs for the green manure crops that were undersown in barley in 2007. The costs consist of seed costs (at the time organic seeds could be sourced for red clover, white clover and the fertility building mix), broadcasting, harrowing and mowing in 2007 and 2008. For the cash crops following in 2009 the marketable yield are shown. For cabbage this is heads over 200 g in dozens per ha. For the cereal (spring-triticale) the yield is shown in t/ha. A partial budget is shown in Table 3 to compare the treatments (the net margin of the cash crop minus the total fertility crops in £/ha). The partial budget accounting technique assumes that besides fertility building costs all other costs where identical for each cash crop. The net margin includes machinery costs.

Table 3. *Economic effects of the various undersown green manures in Area 2 (medium term fertility building strategy).*

Green manure treatments (undersown in barley in 2007)	2007/8 Total fertility building cost	2009 vegetable cropping Cabbages over 200g		2009 arable cropping Triticale grain	
	£/ha	**dozens/ha**	**£/ha**	**t/ha**	**£/ha**
Control (volunteer clover only)	81	241	-1827	1.7	172
Red clover	227	3639	7270	2.5	235
White clover	160	1459	1406	2.7	353
Trefoil	148	1258	872	3.2	495
Lucerne	204	2381	3870	3.0	387
Sainfoin	275	1808	2241	2.7	238
Sweet clover	133	390	-1474	1.9	172
'Fertility builder' mix	192	2260	3553	3.5	529

The results show that fertility-building costs are almost insignificant for vegetables. The main success factor is the fertility delivered to the vegetable, which enables a large marketable yield. Only red clover, lucerne and the fertility builder mix were able to secure marketable yields above 2,000 dozens/ha or above £3,000/ha net margin. Only red clover was able to deliver a very high net margin. White clover, trefoil and sweet clover, although cheap to grow, were disappointing in this experiment. If cereals are following the fertility phase the economics are very different. Here the fertility building costs are important although the 'Fertility Builder' mix (rather expensive to grow) still provided the highest yield and highest net margin.

Area 4 experiment (comparison of long term green manures)
Here only 'Fertility building mix' and lucerne were compared to volunteer clover. There are higher mowing costs (2 or 3 times mowing per year depending on crop). Lucerne had particular high establishment costs as the first crop was a failure and seed and broadcasting costs were incurred again. The second also received some irrigation (a cost of £116/ha) to aid its success in the spring of 2007.

The results (Table 4) are particular interesting as cabbage following lucerne was able to produce a high marketable yield due to the fertility delivered. Even the large fertility building costs of £550/ha (more then three times above average costs) are well compensated in the partial budget and produced good economic results. In contrast to this the 'Fertility builder mix' and the volunteer clover, which did not grow well, resulted in a very small amount of marketable cabbages and on a farm-scale this negative net margin would be a financial disaster. As in Area 2 the financial assessment of cereals is very different. Here marketable yield and outgrading are not an issue. Lucerne also produced the highest triticale yields but the partial budget was the lowest - the high costs of the crop failure work against lucerne. The volunteer clover, which only incurred mowing costs, produced a slightly lower yield with a much higher partial budget.

Table 4. *Economic effects of the various undersown green manures in Area 4 (long term fertility building strategy).*

Green manure treatments	2006/8 Total fertility building cost	2009 vegetable cropping Cabbages over 200g		2009 arable cropping Triticale grain	
	£/ha	**dozens/ha**	**£/ha**	**t/ha**	**£/ha**
'Fertility builder' mix Red and white clover and ryegrass	237	465	-1318	3.1	380
Volunteer clover	129	533	-1081	3.7	644
Lucerne (sown twice because of crop failure in autumn of 2006)	547	3707	7134	4.1	330

Area 6 experiment (comparison of winter cropping to manage couch grass and fertility building)
The economic benefit was again measured by using the partial budget method to show net margin after costs of the various treatments (Table 5). For the interpretation of the results it is important take account of the very low yields of the wheat and barley in 2008 and 2009; at those levels differences between the treatments are likely to be small. The results did show that the regular winter cultivations did increase yields in both years - the net margin as an average of 2008 and 2009 was 5% higher. As expected winter wheat produced higher yields then spring wheat, but the subsequent barley yield was reduced and overall net margin was below the control. The

mustard treatment was clearly unsuccessful having no effect on yields and incurring high costs due to high seed costs (Caliente mustard seeds were £11/kg or £165/ha at a 15kg/ha seed rate). Even if seed costs were halved the net margin would increase to only 60% of control. Measuring yields and economics of two subsequent crops may not be enough to capture the long-term benefits of weed control, but the research funding was terminated in 2009.

Table 5. *Economic effects of the over winter treatments in Area 6 (short term fertility building strategy).*

Green manure treatments	**Yield of wheat 2008**	**Yield of barley 2009**	**Net margin 2008 plus 2009**
Control – uncultivated stubble	1.1t/ha	1.8 t/ha	£125/ha
% of control			
Mustard	90%	106%	29%
Regular cultivations	110%	128%	105%
Winter wheat	143%	72%	94%

Conclusions

From the experiments it can be concluded that the choice of fertility crop is very important. In addition, cost-benefits of fertility crops are very different if the fertility building is for a high-value vegetable crop, or for a commodity arable crop. Even irrigation and a second sowing can be well justified to avoid disaster in the following vegetable. On the Hunts Mill site during the 2007-2008 period red clover and lucerne produced considerably better 'fertility crop economics' when compared to trefoil, sweet clover or white clover. A cost saving strategy using volunteer clover can be sufficient for a cereal crop but is very risky for a high-value vegetable crop with high demands on soil fertility.

Objective 2: To capture existing information/knowledge about fertility building crops held by farmers and other experts.

A stakeholder day was held at Ryton Organic Gardens on 3/4/07 to provide an opportunity to discuss experiences with fertility building crops in organic systems and decide how research should be taken forward. The day also provided the opportunity for growers to be identified for participatory trials of novel green manures on their farms (Objective 3). Forty people attended the day, including a mixture of farmers, growers, researchers and advisors.

After a series of introductory talks three workshops were held for farmers and growers to discuss their experiences with forage legumes, grain legumes and other fertility building approaches. They also prioritised issues that they thought were important for research.

Most of those growing forage legumes had used the standard red or white clover, often in a grass mix. However, a range of other species had been tried including lucerne, rye and vetch, sanfoin and yellow trefoil. Strong interest was expressed in growing yellow trefoil and lucerne as new crops. Many issues that warranted further research were raised, including mineralization patterns of N, how to hold on to the N fixed, how P and K can be maintained when a silage cut is taken and how the clover content of a ley can be maintained.

The most common grain legume crops grown were field beans or peas. It was generally agreed that growing these crops provided very little N benefit to the subsequent crop but that they were useful as an N neutral crop that extended the rotation. Weed control was the most difficult problem in these crops and had, in some cases, led to a perennial weed problem. Lupins had sometimes been grown successfully as an alternative high protein crop but were generally found to be very poor competitors against weeds. There was also considerable interest in growing new grain crops especially lentils and perhaps also soya.

Other novel approaches were discussed including growing legumes such as crimson clover, subterranean clover and sweet clover and other non-legumes such as mustard and phacelia. Improving undersown crops attracted interest particularly the use of subterranean clover or yellow trefoil in cereals. Fertility building in perennial crops such as vines, orchards or asparagus is also an area that has had little work and warrants further investigation.

Objective 3: To assess the performance of a range of novel legumes (fertility building crops and cash crops) on several sites and to assess their impact on subsequent crops.

Methods
Farm trials were set up at a range of locations and farm types (see Table 6). In each trial field up to five test crops were established using normal farm machinery. They were sown in unreplicated bands up to 10m wide and replaced some of the farmers normal fertility building crop. A range of species were trialled: red clover (*Trifolium pratense*), white clover (*Trifolium repens*), yellow trefoil (*Medicago lupulina*), crimson clover (*Trifolium incarnatum*), Persian clover (*Trifolium resupinatum*), sweet clover (*Melilotus officianalis*), lucerne (*Medicago sativa*) and fenugreek (*Trigonella foenum-graecum*). Each site was visited twice per year for assessment of green manure growth, development and final incorporated biomass; the crops were mown, by the farmer, as appropriate but it was not possible to make measurements of the mowings. The performance of the following crops could only be assessed at four of the sites; at the others the farms had either been sold or the farmers had changed their plans and left the fertility building crop in place for a further season beyond the end of the project.

Information from the replicated trials done at Hunts Mill within Objective 1 is also relevant here.

Table 6. *Characteristics of the on-farm trial sites:*

Location	Type	Soil Type	Sowing date
Somerset	Arable /Livestock	Clay loam	13Oct 07
Cheshire	Arable /Veg	Sandy loam	13Apr 08
Herefordshire	Arable/Veg /Livestock	Clay loam	13 Aug 07
Cambridgeshire	Arable /Veg	Organic sandy	22 Apr 08
Sussex	Arable /Livestock	Clay loam	27 May 07
Cambridgeshire	Veg	Clay	03 Sep 07
Cornwall	Veg	Clay loam	21 May 08
Cornwall	Arable/Veg/Livestock	Clay loam	18 May 08

Results - current practice on the farms
Prior to doing the trials, the farmers were interviewed to ascertain their current usage of fertility building crops. All the farms except one currently grew green manures, the majority growing red and white clover and perennial ryegrass mix. Other species that had been tried included lucerne, grazing rye, mustard, stubble turnips, vetch and alsike clover. There was a wide range of sowing times between spring and autumn, to fit in with cropping patterns. Most of the farms had few problems with the establishment, except two that cited dry conditions as a challenge. This was particularly a problem on one of the farms in Cambridgeshire, a dry region of the country, where green manures were sown throughout the summer, following harvesting of sequentially planted salad crops. Generally autumn or spring sowings are recommended for reasons of soil moisture and establishment. Pests and diseases were not cited as a challenge, but controlling weeds was identified as a medium to high priority challenge on half of the farms.

The cutting regime varied considerably between farms ranging from 1-2 times per season to once every ten days. Cutting was required most frequently on the high organic matter soils in the fens both to control the high inherent weed pressure and to keep the rapid growth of the green manure under control. Just under half of the farms reported some difficulties with turning in the green manures, especially if the crop had become too advanced before the time of incorporation.

Results - canopy development
The development of the crop canopies is summarised in Table 7.

Table 7. *Summary of crop canopy development of eight green manure species tested in the on-farm trials*.

Species	Number of farm sites observed	Maximum ground cover observed (%)	Maximum ground cover of weeds before crop senesced (%)
Red clover	7	21 – 100	0 – 54
White clover	3	70 – 100	0 – 62
Yellow trefoil	6	23 – 98	3 – 92
Crimson clover	6	11 – 73	27 – 63
Persian clover	4	68 – 96	5 – 35
Sweet clover	4	30 – 55	38 – 69
Lucerne	4	37 – 96	24 – 63
Fenugreek	2	6 – 17	82 – 94

- *Red clover* is grown as a short to medium term perennial clover. It generally performed reliably, attaining rapid ground cover and producing a large canopy that was effective at competing against the weeds. There was one site where it performed poorly, only attaining a canopy cover of 21 %. This was on a sandy fen soil with high organic matter, and it is likely that the high nitrogen content of the soil suppressed nitrogen fixation, so that the clover had less of an advantage over the rapidly growing weeds.
- *White clover* is a perennial normally grown in longer term leys. It was a consistent performer and although its canopy growth was slow initially, it achieved good even canopy growth (70 – 100% ground cover) that was effective at suppressing weeds at all sites.
- *Yellow trefoil* can grow as an annual or a perennial. Its performance was highly variable in these trials. It performed well on the clay fen soil, where it was topped regularly (maximum ground cover 98%), but at a site with high weed pressure and no topping it was overrun by weeds, only attaining a maximum ground cover of 23%.
- *Crimson clover* is a short term annual. It grew rapidly in some cases, but establishment was unreliable: on a sandy fen soil with high weed pressure, it only achieved a maximum ground cover of 11%. Even under favourable conditions, the largest ground cover achieved was only 73%. Its canopy was short lived and had senesced and set seed by the time of incorporation at all sites.
- *Persian clover* is also a short term annual, not commonly grown in the UK. It grew rapidly at all sites, and its large leaves were very effective at competing against weeds, even at the sites with the highest weed pressure. Being an annual, its canopy was relatively short lived, but longer than crimson clover; it did not start to set seed at any of the sites. This species may make a good alternative to crimson clover if a short lived annual is required.
- *Sweet clover* is a biennial species. Its establishment was uneven at all the trial sites observed, subsequently giving rise to a canopy comprising of widely and unevenly spaced tall plants. This led to a high degree of weed infestation at all sites.
- *Lucerne* is a perennial, normally grown as a longer term crop. It was slow to establish, but generally produced a dense canopy with good persistence and good competitiveness against weeds. The only site where it did not grow well, it was damaged by rabbit grazing (the lucerne plots were next to woodland on this trial). Lucerne had also been grown three years ago in this field, which may have also contributed to its poor performance.
- *Fenugreek* is an annual species, not commonly grown as a green manure in the UK. It was the by far the most rapid to establish of all the species, but unfortunately the topping regime applied killed it off at an early stage (the same topping regime had to be applied to all treatments for practical reasons). This species may be useful for building soil fertility when there is a short window of opportunity between crops.

Results - pests and diseases

The key pest was the sitona weevil (*Sitona discoideus*). It attacked all legumes to some extent, but caused most damage to lucerne, sweet clover and yellow trefoil. The damage was most apparent when the crop was emerging and establishing, but it did not appear to seriously affect the productivity of the green manure crops. Downy mildew (*Peronospora trifolioruma)* was present at low severity and incidence in sweet clover and lucerne in the autumn; it did not appear to affect productivity.

Results - nitrogen incorporation and following crop yield

This was measured at only four of the sites, as some of the growers changed their cropping plans throughout the course of the trial. The key points were:

- Nitrogen incorporated varied widely both between sites and species (from 27 kg N/ha to 194 kg N/ha).
- Most nitrogen was incorporated by the perennial species (red clover, white clover and lucerne) as these were growing and fixing nitrogen for a longer period. There was also more live legume present at the time of incorporation.
- There was much less nitrogen incorporated in the annual species (crimson clover and Persian clover) as all or most of the legume had died off by the time the crops were turned in. Some nitrogen may have been lost as the ground was bare for some period of time. This demonstrates the importance of choosing the right green manure for the time period available.
- Some nitrogen from the weeds growing in the plots was also incorporated but this was generally much less than that of the legumes.
- Generally, yields of the following crop reflected the amount of nitrogen incorporated: best yields were achieved from red clover, white clover and lucerne.

Results - using oats and vetch as an alternative forage and fertility building crop

Peas and barley were normally grown as a forage crop on the Somerset farm, but this was leaving behind insufficient nitrogen resulting in poor yields in the subsequent triticale crop. The key aims of the trial at this site were to test the performance of oats and vetch as an alternative forage crop and the effect on soil fertility for the subsequent cereal crop. There were three treatments: over winter mustard followed by spring peas and barley – standard farm control (PB), autumn sown oats and vetch (AOV), over winter mustard followed by spring oats and vetch (SOV). The key points from the trial were:

- The majority of the nitrogen was removed with the forage cut (80 – 90%) just leaving 20 – 30 kg N/ha of nitrogen incorporated in the residues.
- The AOV mix left behind slightly more nitrogen (30 kg/ha) than the other two mixes (20kg/ha)
- The SOV mix was much easier to harvest as the AOV mix had lodged by the time of cutting.
- Yields of the subsequent triticale crop were largest following the SOV mix. Although this incorporated slightly less nitrogen, it may have been in a more readily available form as the plant material was younger and less woody than the AOV mix.

Results - sowing spring wheat into an established green manure crop

The objective of this trial set up on one of the Cambridgeshire farms was to test the feasibility of sowing spring wheat into an established green manure crop. At this site there were particular concerns about wind erosion and a desire by the farmer to keep the soil covered as much as possible. Nine species and varieties of green manure were tested: five small leaved white clovers, two medium leaved white clovers, yellow trefoil and birdsfoot trefoil. Additionally, three different culivation treatments were applied to the green manures prior to sowing the cereal in order to reduce the competitiveness of the green manure: no pass, one pass and two passes with a Dynadrive cultivator. The following conclusions could be drawn from the trial:

- The small leaved white clovers (AberPearl, AberCrest and AberDale) resulted in the least competition and the best cereal growth.
- The larger leaved white clovers (AberDai and AberHerald) were more competitive against the cereal, reducing its growth.
- Yellow trefoil and birdsfoot trefoil were far too competitive, resulting in very little cereal growth.
- One pass of the Dynadrive resultedin the optimum balance of cereal growth and legume growth and the fewest weeds. Two passes reduced the legume content but increased the weed content so there was no benefit to the cereal.

Objective 4: To determine the usefulness of three computer models developed recently for assessing the nitrogen dynamics of organic rotations, specifically with regard to nitrate leaching.

Methods

Three models were compared:

1. The EU-Rotate_N model (www.warwick.ac.uk/go/eurotaten) was developed by a consortium of European researchers. It is particularly intended for vegetable production (although arable crops are also included). Modelling of a range of fertility building crops includes aspects such as nitrogen fixation, the effect of mowing, litter loss in long-term leys and establishment of crops by undersowing. It runs on a daily step so can take account of one-off events such as rainstorms. The model in its present form is not user-friendly and is aimed at the researcher rather than the farmer.

2. The NDICEA model (www.ndicea.nl) was developed by the Louis Bolk Institute to enable the assessment of organic fertilisation strategies and crop rotations using easily obtainable input values. The model is run on a weekly step basis. It is a simpler model and includes a user-friendly interface that can quickly generate an output for use by an agronomist or farmer.

3. The Fertility Building Crop (FBC) model was developed by IBERS to predict yields, soil mineral nitrogen and leaching using simple data obtainable by agronomists or farmers. It uses regional weather data for each year and runs using a monthly step. It is relatively simple to use, as it is based on a spreadsheet.

The models were tested using historical datasets taken from nine different cropping sequences grown at HDRA, Ryton Gardens on a sandy loam in the period 1993 – 1999. These comprised a 2 year grass clover ley followed by one of 3 cover crop treatments, then by one of 3 crop sequences (summarised in the Table 8). This data was used because information collected within this project was not yet available.

Table 8. *Summary of cropping used to compare the three computer models.*

Treatment name	**2 year ley**	**Winter cover crop**	**Following crops**
S1 Bare	2 year grass clover ley	Bare	Potatoes, winter wheat, winter oats, broad beans (arable cropping)
S1 Rye		Rye	
S1 Vetch		Vetch	
S2 Bare		Bare	Spinach, winter cabbage, lettuce, broad beans (vegetable crops present all year round)
S2 Rye		Rye	
S2 Vetch		Vetch	
S3 Bare		Bare	Spring cabbage, onion, carrots, peas (vegetable crops, bare over winter)
S3 Rye		Rye	
S3 Vetch		Vetch	

The models were validated by running them using the relevant crop parameters and weather data for the site for each of the nine crop sequences. The output generated by the model was then plotted against the actual measured values and a linear regression carried out to generate an r^2 value for each cropping sequence.

Results - soil mineral nitrogen measurements

None of the models predicted the levels of available nitrogen accurately in the top 60 cm of soil at any one time. EU-Rotate_N and FBC generally underestimated levels of available nitrogen whilst NDICEA overestimated it. All the models predicted a rapid rise in available nitrogen when the grass clover ley was ploughed in, although none of the models predicted the magnitude of this rise accurately. Generally, throughout the cropping sequence, EU-Rotate_N predicted the timing of changes in levels of soil available nitrogen quite well but was poor at predicting the magnitude of changes. The r^2 values for the correlation between modelled and actual measured values of available soil nitrogen are presented in Table 9.

Table 9. *r^2 values for correlation between modelled and actual measured values of soil available nitrogen for the three models. *FBC was unable to run sequence 2 because it included a crop failure.*

Treatment name	NDICEA	EU rotate	FBC
S1 Bare	0.021	0.920	0.753
S1 Rye	0.111	0.420	0.694
S1 Vetch	0.006	0.685	0.524
S2 Bare	0.045	0.845	NA*
S2 Rye	0.035	0.790	NA*
S2 Vetch	0.046	0.694	NA*
S3 Bare	0.002	0.891	0.177
S3 Rye	0.328	0.677	0.182
S3 Vetch	0.099	0.742	0.000

The correlation between modelled values and measured values was good for EU rotate (generally r^2>0.70). However, despite there being a good correlation, the model consistently underestimated available nitrogen by 60 to 70%. The correlation between modelled values and measured values was poor for NDICEA, with r^2 values generally below 0.1. The performance of FBC was variable, showing a good correlation for Sequence 1 (an arable rotation) but a very poor correlation for Sequence 3 (vegetable cropping).

Results - nitrogen leaching measurements

Measurements showed that ploughing in the grass clover ley resulted in nitrogen being leached. All the models predicted that this leaching event, although they all underestimated the actual amount lost. NDICEA underestimated the amount leached by a greater degree than the other models. Growing a rye crop after ploughing in the grass clover ley reduced leaching by 85% compared to the soil left bare - vetch also reduced leaching but by a much smaller amount. NDCEA was the only model to predict that growing a cover crop, reduced leaching, although the actual values of leaching were not accurate. All models correctly predicted that the amount of nitrogen leached over the summer was much less than that leached over the winter. The correlation between predicted and measured values was good for the EU-Rotate_N model, with an r^2 value generally greater than 0.75. However, although the correlation was good, the predicted values of leaching were consistently underestimated.

Conclusion

In their current form, none of the models reliably predicted the actual amounts of available nitrogen in the soil or amounts leached. However, they may still prove useful as a planning tool to illustrate what may happen under different cropping scenarios. The EU-Rotate-N model was best at showing the type of effect that might occur under different management practices, although the magnitude of effects were consistently underestimated. As this is a sophisticated model, there is the potential to improve it by using improved crop parameters within the internal workings of the model. Also the interface on this model is difficult to use, and is unlikely to be used by farmers, growers or agronomists. In its current state the NDICEA model was by far the most useable of the models, and could easily be used by agronomists as a planning tool. However its predictions were often poorly correlated with actual measured data. The FBC model was designed as a simple planning tool, but currently is not available for general use.

Objective 5: To interpret the new data within the context of whole farm systems to assess the implications of organic farming on soil fertility.

Uptake by growers

Green manures have used to improve the soil for thousands of years but their use declined after the 1930s owing to the availability of cheap synthetic fertiliser. Many mixed pastures were replaced with monocultures of perennial ryegrass fertilised by synthetic nitrogen fertiliser. However, indications are that over the last 10 years, their use has increased, although the area grown still represents a small proportion of the total land farmed. The areas estimated from seed sales from one distributor of green manures indicate that the sales increased five fold over the period 1993 – 2007.Organic growers are likely to grow green manures for a wide range of reasons including providing a long or short term supply of nitrogen, improving soil structure, pest control, weed control and increasing soil organic matter. In the past, conventional growers were likely to purchase green manure seeds primarily to lower their fertiliser costs and to improve the quality of their seed beds. However, with increased costs of chemical inputs such as herbicides and pesticides, and also regulations restricting their use, conventional growers are more likely to use green manures for a wider range of benefits similar to organic growers.

Choice of species

At present the majority of green manure sown in the UK is red or white clover mixed with perennial ryegrass. The UK lags behind some other countries with respect to the choice of species and varieties available. A visit to an Australian seed supplier's website showed that six varieties of Persian clover were available and many other varieties including some that are very rarely grown (or even heard of) in the UK including strawberry clover *(Trifolium fragiferum),* rose clover *(Trifolium hirtum)* and berseem or Egyptian clover *(Trifolium alexandrinum*). There is obviously the potential to extend the range of species grown and this will almost certainly become a necessity. Firstly in a changing climate, it may be necessary to grow new types to cope with adverse conditions such as drought. Secondly, if more legumes are to be grown, then it is important not to grow the same type too often to prevent the build up of soil borne pests and diseases such as stem nematode (*Ditylenchus spp.* and *Sclerotinia trifoliorum*). This is a common phenomenon (known as 'clover sickness') and was responsible for the failure of many red clover crops in the 1970s and 1980s. Additionally there is the potential for greater use to be made of mixtures in green manure crops. Using species mixtures is not a new concept. Traditional mixes of legumes and grasses such as ryegrass and clover, peas and barley or vetch and oats have been used for years predominantly for grazing or forage mixes to make up a balanced food source for livestock. Using mixes of legumes to build soil fertility in horticultural systems has not been explored to such a great extent in the UK, and there must be the potential to exploit the range of benefits brought about by including a range of species.

Financial implications of growing green manures

The main reasons that green manures are not widely used in conventional systems is because they are costly to grow and over the last 50 years it has been cheaper to apply synthetic nitrogen fertiliser. At the time of writing, costs for growing a green manure were typically £125 - £250 / ha, most of this being seed.

The financial benefits of growing green manures are not always straight forward to quantify. The two most common methods are either to consider how much nitrogen they supply, or the resulting yield increase in the following crop. The first approach provides a comparison with using synthetic nitrogen fertiliser, but it does have its problems. Conventional growers often ask 'how many kg of N does a green manure fix?' but this is not a straight forward question to answer. Estimates range from 150 kg/ha to 450 kg/ha for red clover. Prices for nitrogen fertiliser have increased over the last few years from 43 p /kgN in 2006 to £1.10 / kgN in 2008. It is almost certain to continue rising in line with the cost of oil, and there will come a point, when growing a green manure is a much more cost effective option than using synthetic nitrogen fertiliser.

The approach of quantifying the yield increases in subsequent crops resulting from growing green manures has the advantage of encompassing the wider range of benefits, rather than just fixing nitrogen. In the work in this project, growing a green manure resulted in an increase of 0.8 t/ha of grain. At a price of £210 /t for organic barley, this result in an increase £168 /ha. For more valuable crops, this can have a more significant impact. In trials elsewhere on potatoes, yield increases were 7.7 t/ha. At a price of £180 /t, this would equate to positive increased income of £1386 per ha (HDC project FV299).

Use of green manures to reduce nitrate leaching

Agriculture remains a major source of diffuse pollution, with 55% of nitrate in water estimated to come from agricultural land. Nitrate vulnerable zones (NVZs) were introduced in an attempt to regulate this source of pollution by regulating the timing and amounts of manures and fertiliser applications and encouraging best practice. From 1 January 2009, a total of 70% of England was designated an NVZ, a substantial increase from the 55% in 2002. The revised regulations implemented in 2009 were originally scheduled to include the compulsory growing of cover crops over winter but this was excluded from the final legislation after pressure from farming lobby groups. The current environmental stewardship schemes have recognised the benefits of growing green manures and rewards farmers for using them.

Even if green manures do not form part of water framework directive legislation growers are more likely to want to reduce losses of an increasingly expensive resource of nitrogen in the soil. There is no doubt that a well managed winter cover crop can result in massive reductions in nitrate leaching over winter. This was clearly demonstrated by work carried out by HDRA. which showed that growing a green manure of grazing rye reduced over winter leaching by 89%. However, it is essential that the green manure establishes well enough to take up nitrogen that may be leached. Cultivating the soil to form a seed bed and establish a green manure results in the mineralisation of nitrogen. If the green manure does not then grow well, the end result can be more leaching than if the soil was left undisturbed.

Farming schemes and legislation

The environmental stewardship schemes were introduced in 2005, with the intention of subsidy payments reflecting farmers' contribution to managing the countryside as well as food production. The benefits of growing green manures has been recognised by these schemes, and components of the Entry Level Scheme (ELS), the Organic Entry Level Scheme (OELS) and the Higher Level Scheme (HLS) all contain components related to green manures and cover crops. In the OELS, and the ELS, growing winter cover crops, contributes 65 points per ha and undersowing spring cereals, 200 points. Both of these are enough points to qualify for the ELS or OELS payments. The HLS has various features under the 'options to protect soil and water'. At the time of writing, growing winter cover crops attracts £65/ ha. Options of permanent grassland with low inputs or very low inputs attract £85/ha or £150/ha respectively. Grass and clover mixes are an attractive option for low input pasture, as they have less need for applying nitrogen fertiliser. Under sowing spring cereals also qualifies for £200/ha under the 'options to encourage a range of crops' in the HLS.

Benefits for pest control

It is well established that plants growing against a green background suffer far less pest infestation than those growing against bare soil. Green manures can play a key role in this, with cabbages transplanted into a bed of clover typically showing a 50 – 70 % reduction in egg laying from the cabbage root fly compared to those growing in bare soil. However, there is a fine balance between achieving sufficient ground cover of the green manure to reduce pest infestation whilst ensuring that it does not compete against the crop, reducing its yield. Yield reductions of at least 30% are typical when transplanting cabbages into a bed of clover, but this is dependent on conditions, and in some cases the green manure crop can completely over run the main crop.

There are ways of preventing excess competition from the green manure crop. One method that has been tried is root pruning in order to reduce the vigour the of the green manure crop. An alternative method is to sow the green manure into the module itself. Although this method can be effective in some instances, further work is still needed to establish the most appropriate species of companion plant for the right situation.

Energy use

The synthesis of nitrogen fertiliser is a highly energy intensive process and can typically contribute 30% of the energy needs of growing a conventional wheat crop. The carbon dioxide emissions resulting from the energy needed to apply 200 kg N / ha of urea or ammonium nitrate fertiliser are 0.83 t/ha. Growing a typical fertility building crop only results in 0.29 t/ha equivalent value. This 65% reduction has a significant reduction in the overall energy use of growing a crop. Even when the lower crop yields and the land taken out of production for fertility building are considered, this is a substantial reduction in CO_2 emissions.

Conclusions

Green manures can serve many functions, and after decades of neglect are likely to become an integral component of agricultural systems once more. The most likely considerations for uptake by most growers is cost, and their use is likely to become a more favourable alternative to nitrogen fertiliser as energy rise. The various environmental stewardship schemes also provide some financial reward for growing these crops, and this will make a contribution towards the cost of growing these crops. There are also many other wider benefits to growing these crops such as improving soil structure, preventing nutrient leaching and pest control that are perhaps more difficult to quantify but should be considered when using green manures.

Objective 6: To disseminate the findings of the project through a number of channels.

Three events were held during the course of the project at different experimental sites; they were aimed principally at farmers and advisors. These were advertised via the horticultural press, specialist organic publications, through various websites and by direct mailing of farmers and growers in the appropriate areas of the country. Between 40 and 50 people attended each event:
Managing soil fertility in organic systems held on 18/10/08 at Warwick HRI, Wellesbourne. A series of talks placed the project in the context of other related studies both in Britain and in Sweden and a visit was made to the Hunts Mill field to view the experimental work.
Improving soil nutrient management through the use of green manures held on 11/6/08 at G's Marketing Ltd near Ely, Cambridgeshire. This event focussed on nutrient budgeting and the use of computer models as a management tool with a visit to the green manure species trial nearby.
Managing the future of your soil – the role of green manures held on 5/8/09 at Duchy College near Camborne, Cornwall. This event covered the breeding of new varieties of green manures and financial implications of their use. A visit was made to see nearby trial plots from the Defra legume LINK project.

Papers have been presented at the following conferences:

Vegetable Consultants Association Conference, 2nd December 2008
Organic Producer Conference at Harper Adams, 6-7th January 2009
Integrated agricultural systems – methodologies, modelling and measuring, 2-4th June 2009 (published in *Aspects of Applied Biology*, 93)
Organic Producer Conference at Harper Adams, 7-8th January 2010.

Articles related to the project have appeared in *The Vegetable Farmer, Farmer Weekly, Farmer's Guardian, HDC News, The Organic Way* and *The Organic Grower*. Peer reviewed publications are in preparation.

Information from previous Defra projects, led by ADAS, concerning green manures and fertility management in organic systems (OF0316, OF0164) has been made available on http://www.gardenorganic.org.uk/organicveg together with case studies describing the on farm trials, details of the work at Hunts Mill and a practical guide to the selection and use of green manures in field vegetable and arable systems.

4. POSSIBLE FUTURE WORK

- Continued monitoring of the Hunts Mill site to evaluate further long term implications of the various rotations. This could include more dedicated trials to manage problems such as perennial weeds.

- Further evaluation of the performance of green manures under various climatic and soil conditions. This should include mixtures and different varieties of key species.

- Exploration of the degree to which pests and diseases limit fertility building crop growth such as stem nematodes and sclerotinia.

- Development of computer models to manage nitrogen in organic and low input systems. Parameters for a wider range of fertility building crops need to be developed and tested against measured values.

- Optimising the use of nitrogen in fertility building crops by using anaerobic digestion to process material cut and removed from longer term leys in stockless systems; this would encourage greater nitrogen fixation, generate energy and provide digestate which would be targeted at crops at a particularly nutrient demanding stage.

- Design of intercropping systems suitable for field vegetable production. More work is needed to assess the potential of different approaches (strip cropping, permanent clover beds etc) to supply nitrogen and offer good control of weeds, pests and diseases.

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.

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