Factsheet 26/10
Soil grown crops
Projects FV 299 and 299a

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Green manures – implications of economic and environmental benefits on rotational management

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Green manures, also referred to as fertility building crops, may broadly be defined as crops grown for the benefit of the soil. This factsheet aims to help growers appreciate the financial implications of their use and the potential for computer models to help integrate them effectively into rotations. It draws on the findings of a number of projects funded by HDC, Defra and the EU. Two related factsheets address the selection of suitable species of green manures (25/10) and the benefits which they can bring (24/10).

Background

The concept of green manures is not new to agriculture or horticulture. The ancient Romans grew lupins to improve the soil. Green manure crops have been used deliberately for at least 300 years, when they were introduced into crop rotations to replace the fallow phase widely used during the Middle Ages. Before the industrial revolution, the first promoters of green manures were gentlemen farmers like Charles Townshend in Britain ('Turnip Townshend', best known for the other crop he added to the rotation) or the Mennonite tenants on large estates. They based this replacement of the fallow, not on their intricate knowledge of the nitrogen fixation mechanisms in legumes, but rather on 'practical intelligence'. This was derived from detailed observation and travel to farms with different soils and climates.

Through the use of fossil fuels in the 20th century, enough energy became available to produce artificial fertilisers. Nitrogen fertiliser replaced green manures in many parts of the developed world, although they continued to be used by organic farmers and in countries without sufficient money to buy the synthetic alternatives.

In recent years annual fossil fuel production has started to decline and the contribution of fossil carbon to climate change has raised a big question mark over the sustainability of the use of artificial fertilisers and those farming systems that rely solely upon them. Increasing oil prices could well be followed by supply shortages sooner than many people anticipate. This scenario puts the use of green manures in a pivotal position for the future of agriculture and horticulture.

The maximum benefit of green manures can only be achieved by considering their strategic place in the rotation strategically using crops either to fix or conserve nitrogen. Making appropriate choices of following crops ensures maximum utilisation of the N fixed or retained.

This factsheet demonstrates the considerations that need to be made to maximise both economic (Figure 1) and environmental benefits.

1 Estimating the economic implications of using green manures

Costs of green manures

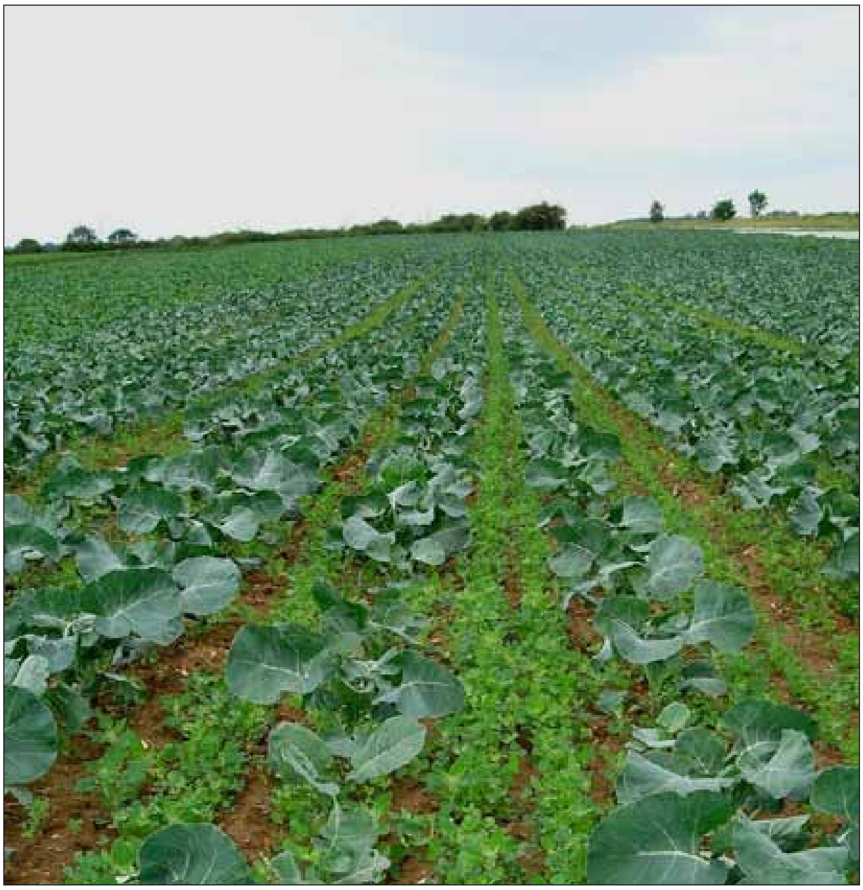
Green manures are generally relatively cheap to grow with low inputs. However they do require attention to management and a reasonable seedbed like a cash crop, otherwise the green manure may fail, wasting the seeds, whilst leached nutrients are also lost.

The costs include seed purchase and drilling or broadcasting. Better establishment will usually be obtained if the larger seeded species (e.g. rye and vetch) are drilled rather than broadcast, although the latter is cheaper and faster. If drilled, care should be taken that small seeded species (e.g. clovers) are not sown too deep (germination is reduced below 1 cm). Clovers are particularly suitable for undersowing in an establishing cereal crop. They can be broadcast in spring and, if combined with mechanical weed control as is common practice for organic cereals, require no additional machinery passes. Brassicas can also be undersown, although it is important to avoid too much competition (Figure 2).

There are also likely to be some ongoing maintenance costs such as mowing for weed control and to encourage vegetative growth. Irrigation may be needed in some circumstances and fertilisers may need to be applied in exceptional cases. Sometimes a mustard crop grown specifically for biofumigation for pest or disease control, requires a high biomass. Harvesting costs could also be incurred if some of the biomass is removed for livestock feed or biogas production through anaerobic digestion (AD).

Green manures are normally incorporated by rotavating or ploughing (Figure 3). Ideally the plant material should be well mixed with the soil to encourage decomposition rather than being added as a layer. It is best to use a flail mower to chop the foliage; alternatively a herbicide could be used to kill the green manures before incorporation. In many cases, subsequent cultivations would still be needed for establishing the next cash crop.

Typical overall costs (which vary from farm to farm) for drilling, rolling and topping once, would be about £60 per hectare. The additional cost of seed depends on the seed rate and price (Table 1).



2 Clover undersown with a Brassica crop

3 A green manure being incorporated into the soil

Table 1 Typical rates and seed costs (2010 prices) of organic and conventional sourced seed (note some species are not readily available as organic seed).

Species	Seed rate (kg/ha)	Organic (£/ha)	Conventional (£/ha)
Ryegrass and red clover	15 +12	138	99
White clover	15	128	86
Red clover	15	104	77
Trefoil	7	52	52
Lucerne	20	140	112
Mustard	20	74	40
Sainfoin	75	208	172
Vetch	85	208	132
Rye	190	181	131
Phacelia	10	118	70
Buckwheat	63	151	151
Field beans	200	150	109
Lupins	50	80	58
Forage peas	100	75	54
Average		**129**	**96**

Some green manures will benefit from inoculation with the correct rhizobium bacteria. This is particularly the case with legumes other than clover such as lucerne. The inoculation culture will cost about £10/ha.

An additional cost arises when a green manure is grown as a replacement for a cash crop. This does not apply in every case. For instance, winter green manures are grown when the land in vegetable rotations is often otherwise bare. There may, however, be constraints on sowing and incorporation dates. It can be difficult to find the time to sow a winter green manure in the autumn when staff are busy harvesting a cash crop (Figure 4). Early incorporation may also be necessary where stone removal operations are required. This can result in a green manure being destroyed before it has achieved its full potential. Longer term green manures (e.g. clover leys) will occupy the land for a year or more and may be grown as a break crop in a field vegetable rotation in place of cereals. The opportunity cost of this will obviously depend on grain prices and potential use of the green manure as feed for livestock or anaerobic digesters.

4 Staff busy harvesting a cash crop

It should also be recognised that excessively tight rotations can give rise to other problems such as soil-borne diseases. A failed or rejected cash crop that is employed instead of a green manure break crop, can make a much bigger loss than the cost of a green manure. In such cases, a green manure can be seen as a risk minimising strategy.

Valuing the benefits of green manures

5 Fertiliser costs are increasing each year

The effect of nitrogen addition from a green manure is the easiest to quantify, specifically the addition to the soil by fixation from the atmosphere by a legume or the conservation of nitrogen where nitrate leaching is minimised.

In conventional production this nitrogen will reduce the need for nitrogen fertilisation of the following crop. This can be related to fertiliser prices, especially as fertiliser costs are increasing each year (Figure 5). For organic systems, nitrogen fixation represents the major source of nitrogen inputs.

There are large seasonal differences, but a leguminous green manure can be expected to add, on average, about 150kg N/ha/year to the soil by fixation. It can be significantly more, particularly in the case of the longer term crops. Lucerne is known to fix 500kg N/ha/year. However, it can be much less if the crop is poor, particularly in a dry year when establishment conditions are difficult.

A vigorous winter green manure crop of rye can prevent the loss of 200kg N/ha. Not all of the nitrogen will be immediately available, as the plant residues must be mineralised by microbial action. However, given growing costs of £100 to £200 per ha, the price of this green manure nitrogen compares favourably with current (2010) nitrogen fertiliser prices. This is even more so in conventional farming, as green manure seed costs are 30 - 50% lower than for organically sourced seed (Table 1 – previous page).

Data from John Nix's Farm Management Pocketbooks indicate that between 2003 and 2009, fertiliser prices increased by 45% each year whilst green manure costs (seed and cultivation) increased by only 7% each year. If this trend continues, then using green manures as a nitrogen source will become even more attractive.

It is much harder to quantify the financial gains to be made from other benefits of green manures, such as improvement to soil structure, water holding capacity, increased availability of nutrients (such as phosphorus) or weed management. These benefits may not be seen after individual green manure crops but only become apparent after several years. Looking at rotational gross margins (over one or two full rotations) may identify them rather than concentrating on individual crops. For example, one 15-year long (Defra funded) study compared the effects of three contrasting fertility building strategies in an organic field vegetable system. In the early years, there was little difference between crops grown with two-year leys or only six-month clover green manures. However, after two cycles of the rotations, there were clear yield benefits from the longer term green manures.

Growing green manures can also help gain points in Environmental Stewardship schemes (e.g. for undersowing spring cereals with a grass and clover mixture).

The role of computer models (or decision support systems) in rotation planning

It can be difficult to predict all the effects of including green manures in a crop rotation. Various species will perform differently due to seasonal effects and soil conditions. The pattern of availability of plant nutrients will also depend on soil microbial activity. The utilisation of these nutrients will depend on the demand of the different cash crops in the rotation.

The interactions between the costs and benefits of green manures are very complex because the rotations occur over several years. One solution is to use rotation modelling to make better or more informed decisions (Figure 6).

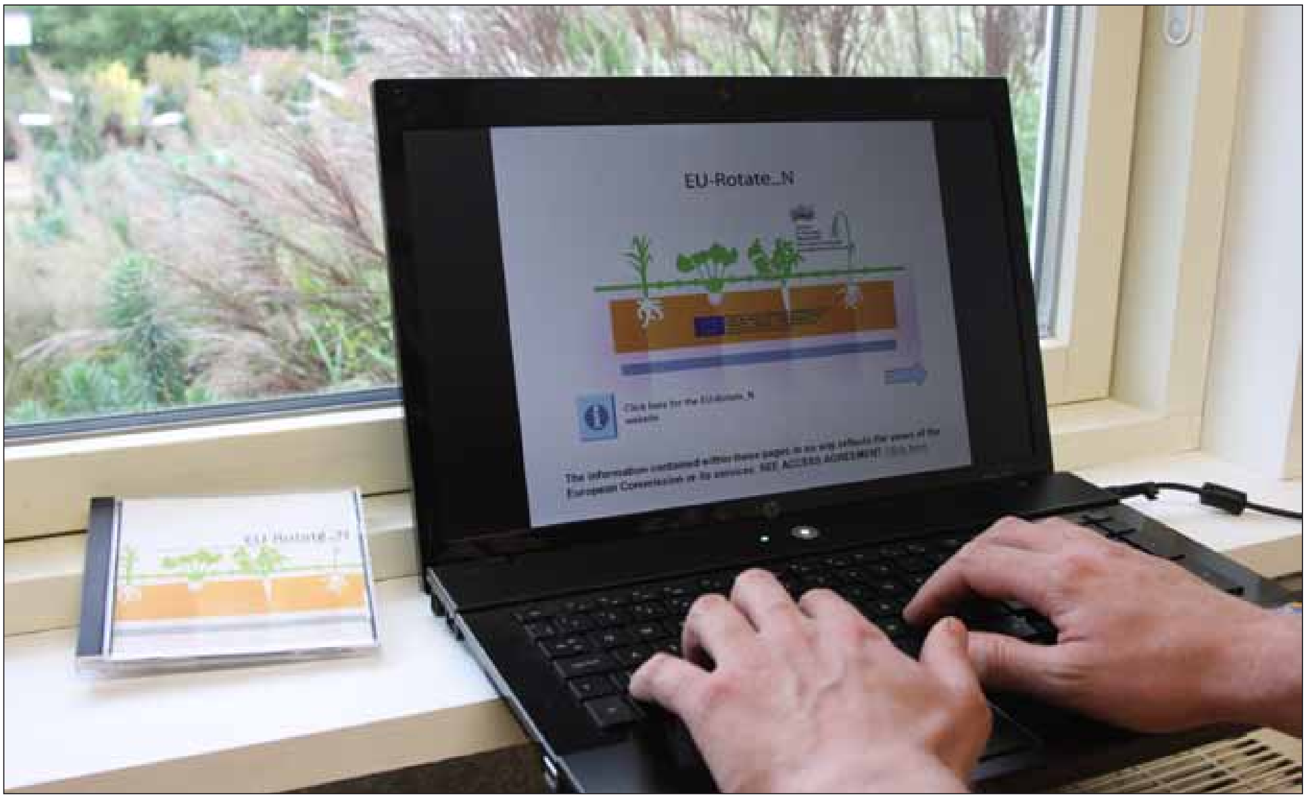
Typical questions that computer models can help answer include:

- How much nitrogen is needed by a particular sequence of cash crops (provided either by fertilisers or by legume fixation)?
- How much time in a rotation should be dedicated to growing green manures in order to supply sufficient nitrogen to subsequent crops?
- What are the cost implications of differing green manure strategies?
- How much nitrogen can be expected to be conserved by a winter cover crop?
- How much of it is available to further crops in the rotation in subsequent years?
- Would a different sequence of crops use the available nitrogen more effectively?
- Which green manures are most suitable at different points in the rotation?
- Can the vegetable crop planting density be manipulated to optimise utilisation of soil mineral nitrogen from the green manure residues?

Many models have been developed to help with the management of fertility for grass, arable or horticultural crops. Relatively few deal adequately with green manures in a rotational situation. Three that do are 'The Fertility Building Crop Model' (created by Steve Cuttle of IBERS, as part of the Defra Project OF0316), the 'NDICEA' model developed by the Louis Bolk Institute in the Netherlands and the 'EU-Rotate_N model' (the output of an EU project led by Clive Rahn, The University of Warwick).

The EU-Rotate_N model is unusual in that it produces both agronomic and financial outputs for crop sequences spanning many years. Specific farm information about prices of crops obtained through various market channels can be used.

It is normal to run models with historical weather data for a particular site. It is also possible to run simulations with more extreme weather to see the impact that climate change or particularly wet or dry years will have on nutrient availability and crop performance.



6 Computer models help growers to make more informed decisions on the financial benefits of green manures

Example: Selected model outputs of the EU-Rotate_N model

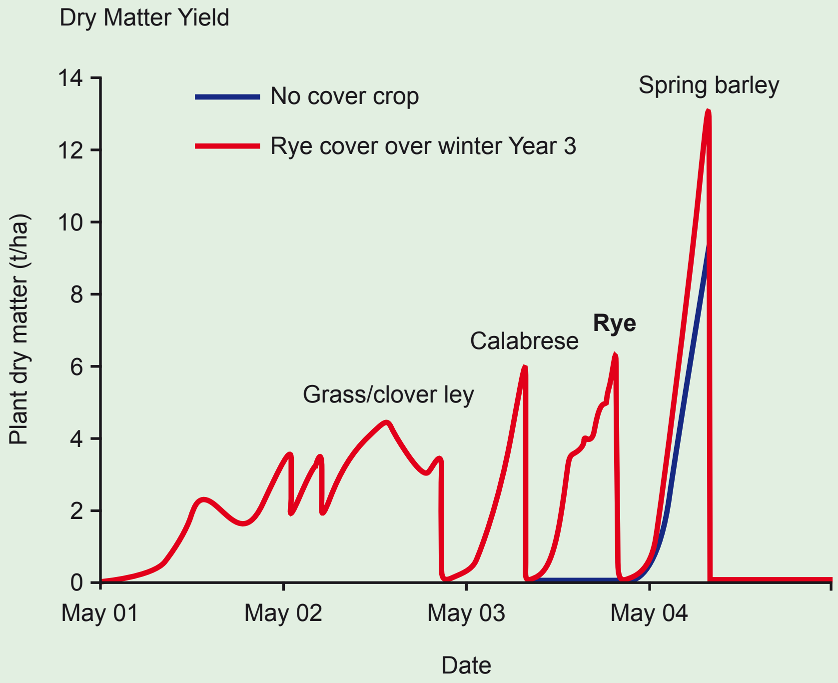
Figure 7 shows a simulation of an organic rotation without any external nitrogen inputs from mineral fertilisers or manures.

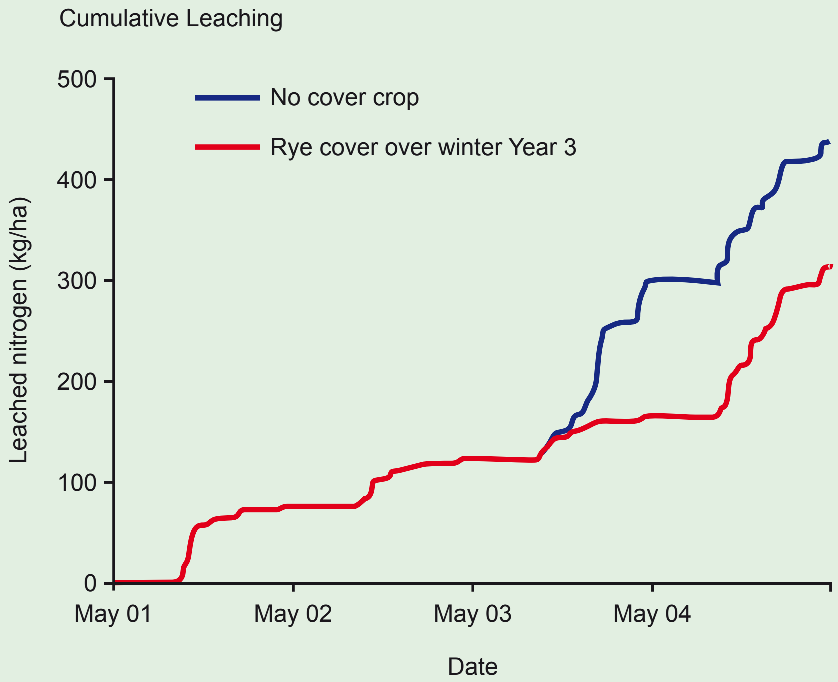
A two-year grass-clover ley is followed by a nitrogen hungry calabrese crop and then by a spring cereal. The nitrogen fixed by the grass/clover (mulched once in its first year and twice in its second year) is sufficient to sustain good yields in the calabrese and spring barley crops.

The outputs for the crop rotation show the effects of including rye as a winter green manure cover crop in Year Three. This is grown after the Brassica crop to help reduce the nitrogen leaching from this crop and its residues. The rye cover crop has grown well and produced considerable plant dry matter (6 tonnes/ha). With the nitrogen made available in the soil (and not lost by leaching), the spring barley achieved a higher dry matter and yield then without cover crop. Another simulation (not shown) used clover rather than rye – this was not so effective at preventing leeching (375kg per ha lost overall) and brought less benefit to the following cereal, showing that over the winter period nitrogen conservation is more important than growing a crop with potential for nitrogen fixation.

Another winter green manure after the spring barley would help reduce overall nitrogen leaching losses in this rotation even further. Undersowing the cereal with a green manure ley would be another option. In this example the use of a green manure crop has prevented the loss of more than 100kg N/ha over one winter. This nitrogen was available for the barley (if conventional the fertiliser for this crop could have been reduced).

The modelled data for this example shows a 7% higher gross margin for the whole rotation and a 28% reduction in leaching.





Model outputs ----------------- Model run	Additional Cost (£/ha)	Cumulative gross margin (4 years) (£/ha)	Cumulative N leaching (4 years) (kg N/ha)
No cover crop	0	4610	435
Rye cover crop	150	4950	312

7 Selected outputs (dry matter yield, nitrate leaching and economic performance) from an example simulation of the EU_Rotate-N model

Further outputs of the model (not shown) include soil mineral nitrogen at various depths, gross margin information for specific crops in the sequence and details of soil microbial biomass that are of more interest to the researcher than the grower.

Action points for growers

- Compare the financial value of nitrogen added to the soil by a green manure (fixation or conservation) with the cost of the equivalent fertiliser.
- Do not underestimate the other benefits which are harder to quantify such as improvements to soil structure.
- Growing green manures demands management time and has direct costs for establishment, maintenance and incorporation. Care is needed to get the best result from this investment.
- Computer models can be used to help plan rotations that include green manures so that different options can be tested and the beneficial effects of green manures can be maximised.

Further information

Sources of advice and information

Organic Eprints
An international open access archive for papers related to research in organic agriculture including information on rotations and fertility building crops (www.orgprints.org)

Garden Organic
(formerly known as HDRA)
Research on sustainable horticulture, including the use of green manures in a range of cropping systems (www.gardenorganic.org.uk/organicveg)

Abacus Organic Associates
Advice on the use of fertility building crops in organic systems (www.abacusorganic.co.uk)

Vegetable Consultancy Services Ltd
Agronomic advice, particularly concerning conventional production (www.vcsagronomy.com)

Scottish Agricultural College (SAC)
Research in sustainable land management (www.sac.ac.uk)

The Organic Research Centre – Elm Farm
Research and support for sustainable land use, including the use of green manures (www.efrc.com)

National Institute of Agricultural Botany (NIAB)
Variety research and publishers of information e.g. NIAB Livestock Crops Pocketbook (www.niab.com)

Institute of Biological Environmental and Rural Sciences (IBERS)
Research and information concerning green manures (www.aber.ac.uk/en/ibers)

Natural England
Information about agri-environment schemes, including the possible roles of green manures to maintain soil quality (www.naturalengland.org.uk)

Useful publications

Garden Organic
Garden organic have a number of reports available from a range of projects (mainly funded by Defra) including a comprehensive literature review which formed part of an ADAS led project 'The development of improved guidance on the use of fertility building crops in organic farming' (www.gardenorganic.org.uk/organicveg/stay_organic/fbc/show_fbc.php?id=3)

The EU_Rotate-N model
A model to help plan field vegetable rotations which includes both agronomic and economic outputs (www2.warwick.ac.uk/fac/sci/lifesci/acrc/research/nutrition/eurotaten/)

The NDICEA model
A Dutch model to help plan rotations, specifically for organic farmers (www.ndicea.nl/indexen.php)

Specialist companies supplying green manure products and support services

Cotswold Seeds Ltd
Seed supplier, specialising in a wide range of green manure and grassland seeds (www.cotswoldseeds.com)

Plant Solutions Ltd
Seed supplier, specialising in biofumigant Brassica green manures (www.plantsolutionsltd.com)

Legume Technology Ltd
Supplier of Rhizobium inoculants for legume seeds (www.legumetechnology.co.uk)

Acknowledgements

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Additional Information

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