Factsheet 24/10
Soil grown crops
Projects FV 299 and 299a

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Green manures – effects on soil nutrient management and soil physical and biological properties

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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 understand the range of effects that they can have, drawing on the findings of a number of projects funded by HDC and Defra. Two related factsheets address the selection of suitable species of green manures (25/10) and the economic implications of their use (26/10).

Background

Both organic and conventional growers can gain many benefits from increased use of green manures. A wide range of plant species can be grown as green manures as different ones can bring a variety of benefits. Leguminous plants will fix nitrogen from the air whilst non-legumes will conserve nitrogen by preventing nitrate leaching. Green manures add organic matter to the soil, improving its physical and biological properties and they can assist with pest, disease and weed management. Some of the effects on soil physical properties may only become significant after several green manure crops have been grown over a period of perhaps five to ten years. Green manures are often categorised according to the time of year they are grown.

Winter green manures or cover crops are usually sown in the autumn and incorporated in the following spring and may be legumes (e.g. vetch) or non-legumes (e.g. rye).

Summer green manures are usually annual legumes (e.g. crimson clover, Figure 1) which are grown to provide a short term boost for fertility. However, they could also be non-legumes (e.g. mustard).

Longer term green manures are usually pure clover or grass/clover leys grown for two or three years. They are common in organic stockless rotations where they form the main source of nitrogen. However, in conventional farming these rotations would be harder to justify unless there were animals to graze them.

Green manures may also be used in intercropping systems, although

1 Crimson clover is a short term annual green manure

in vegetable cropping it is important to avoid too much competition with the cash crop. Protected cropping systems offer particular challenges and opportunities for green manuring whilst fertility building in orchards can be difficult as nitrogen must be provided at the right time to ensure good fruit set and crop quality. Green manures grown as an understory can also attract beneficial insects.

Nitrogen fixation

Green manures are often grown to add nitrogen to the soil. In organic systems this represents the main source of nitrogen, whilst for conventional growers, it can be a way of minimising fertiliser inputs. Almost all legumes use Rhizobia bacteria (Figure 2, Figure 4) to fix nitrogen from the atmosphere. Unfortunately finding out how much nitrogen is actually fixed is not easy and depends on many factors.
Firstly, the correct strain of bacteria must be present. Different bacterial species interact with different groups of legumes (clovers, lucerne and trefoils, lupins, beans etc.). If the same types of plants are regularly grown then sufficient bacteria will usually be present to establish sufficient nodules. Sometimes it is worth inoculating the seeds with the correct type of bacteria. There are several types available commercially, at a modest cost.

2 The root nodules turn pink when nitrogen fixation is occurring

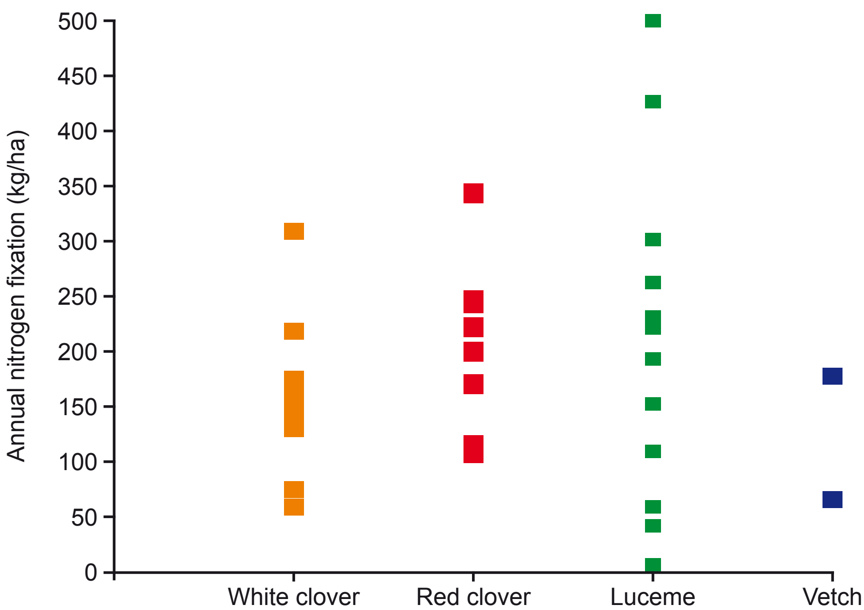
Sometimes the nitrogen fixation still does not occur, even if the roots form a symbiosis with the bacteria. Some strains will infect the plant but not be very effective. They can even drain the plant of resources.

For effective fixation, a minimum soil temperature of about 7°C is needed and the plants need to have adequate nutrients available to them. Active nodules have a pinkish colour when broken open (Figure 2). The amount of nitrogen fixed varies between different species (Graph 1). In broad terms it is related to total biomass production and so is affected by speed of establishment and growing conditions (for example water availability and weed competition).

If there are high levels of available nitrogen in the soil from fertilisers or as a result of the decomposition of crop residues plants will not fix much nitrogen.

The cutting regime has a big

3 Clover being mown



Graph 1 Nitrogen fixation by different leguminous green manures showing the range of measurements that have been made (data from Defra Project OF0316)

effect on nitrogen fixation (Figure 3). Removal of plant material, for example in silage, will encourage further fixation, as long as levels of potassium are maintained, whilst returning the mowings as a mulch can inhibit the process.

Some growers have experimented with making compost from green manure crops or using the mowings as a mulch in other fields but there can be logistical difficulties and costs associated with doing this.

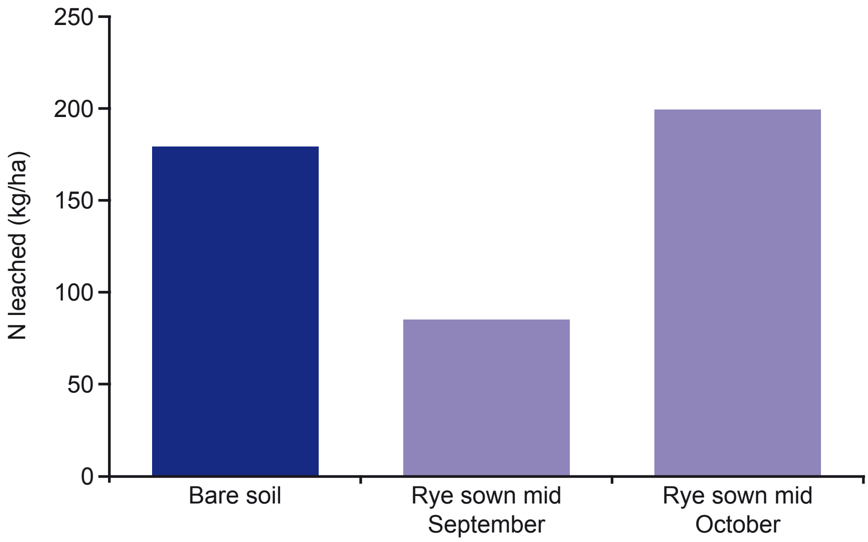
Nitrogen conservation

Large quantities of nitrate can be lost from soil when it is left bare overwinter. Unlike other nutrient ions, nitrate is not strongly attracted to soil particles, so any nitrogen that is in solution in the autumn will be washed away as water moves down through the soil with the onset of heavy winter rains (Graph 2). This is bad for the environment because nitrates can contribute to the formation of algal blooms in watercourses and are arguably bad for human health, when contaminated water is drunk.

The Nitrate Vulnerable Zones regulations were introduced to address this problem. For farmers, leaching also represents the loss of a valuable resource – this is particularly serious for organic farmers because it is much harder for them to replace the lost nitrogen. It is widely recognised that one of the best ways of preventing nitrate leaching is to maintain a crop cover over the winter period.

Winter green manures can be very effective crops for ‘mopping up’ excess nitrate in the soil in the autumn. Different species vary in their ability to reduce leaching. Grazing rye is particularly effective – in one set of trials, leaching was reduced by an average of 95% whilst vetch reduced losses by 45% and field beans had scarcely any impact at all.

Both rapid early growth and the development of an effective root system are essential. Once leaching has begun, the plants have very little time to take up the nitrogen before it is all washed away. If the crop cannot be established in good time, it may be counter productive to sow a green manure because the cultivations used to establish the seedbed may stimulate the mineralisation of nitrogen that then cannot be captured by a green manure struggling to germinate and grow under ever colder conditions.



Graph 2 An example of the amount of nitrate leached overwinter, between September and April. This experiment followed an autumn ploughed grass/clover ley on a sandy loam soil

Making nitrogen available

Large amounts of nitrogen are added to the soil by a successful green manure. How soon this becomes available will depend on several factors. Bacteria and fungi carry out a process called mineralisation where complex molecules are converted to ammonium and nitrate ions.

Mineralisation proceeds fastest when the soil is warm and moist.

The quantity of nitrogen released is also dependent on the total amount actually added to the soil and the chemical composition of the incorporated material.

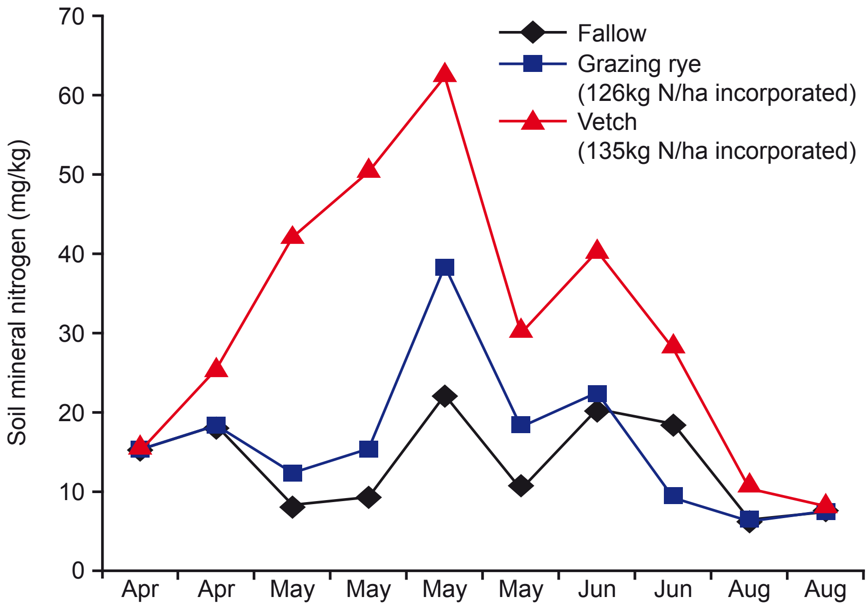
4 Electron micrograph of *Rhizobium leguminosarum* bacteroides in a pea root nodule

It is not just the C:N ratio which is important. The carbon can be in different forms. For example lignin is more resistant to decomposition than cellulose and some plants contain chemicals (e.g. polyphenols) which can inhibit microbial action.

Vetch, which is a legume, is a plant which has a high nitrogen content throughout its life (3 to 4% of its dry weight) and is consequently readily mineralised. It grows rapidly in the spring. In one trial it had accumulated 98kg N/ha in late March, 132 kg/ha in mid April and 206 kg/ha by early May.

Non-legumes (e.g. grazing rye or mustard) can add as much total nitrogen to the soil as legumes. However, the nitrate availability is slower. This is because they have a lower percentage nitrogen content (1 to 2%) and thus a higher C:N ratio.

Furthermore, the nitrogen concentration in many non-legumes usually decreases even further as the plants age and prepare to set seed so the date of incorporation is crucial; rye incorporated at the end of April will release nitrogen, although not as much as vetch. If left until May, the decomposing organisms will actually have to compete with plants for soil nitrate in order to break down the residues. This is sometimes called 'nitrogen robbery'.



Graph 3 An example of pattern of soil mineral nitrogen (0-15cm) after incorporation in mid April of two contrasting winter green manures compared to a fallow control

In the longer term, the nitrogen conserved by cover crops, especially the slower mineralising non-legumes, is prone to leaching in the first winter after incorporation if the land remains uncropped; rotation design should take account of this.

Green manures have their biggest effect on soil mineral nitrogen within the first year after incorporation and so this is the crucial period when the cropping regimes need to be planned to make effective use of it. Ideally green manures are selected and managed to match the pattern of their mineralisation with crop demand (Graph 3).

The potential risks of mis-managing green manure nitrogen are greater with ley crops grown for one or more years. Classical ley/arable rotations, as practiced by many organic farmers, have a potential leaky point just after the ley is incorporated.

Effects on other soil nutrients

Soil should be sampled to measure mineral levels (Figure 5). Potassium can be lost through leaching and measurements range from virtually nothing to over 40 kg/ha/year. Losses of phosphorus are normally thought to be mainly by surface run off and erosion, but studies have shown that losses by leaching can sometimes be significant.

Relatively little attention has been paid to the effects of green manures on phosphorus and potassium losses. Any effect is likely to be more marked under conditions of high soil fertility. The uptake of potassium, and to a lesser extent phosphorus, can be substantial over a period of 1 to 3 years. Chicory in particular is deep rooting (Figure 6) and in one three-

5 Soil sampling to measure mineral levels

year trial was found to take up an average of 95 kg/ha of potassium annually; this was 50% more than shallower rooting ryegrass. In grass clover leys, the grass component takes up more potassium than the clover; this is probably related to the more extensive rooting system of the grass.

Some plants, particularly lupins and buckwheat, can increase phosphate mobility in the soil by the exudation of organic acids from the roots – in one study the uptake of phosphorus by lupins was ten times greater than that of wheat. This phosphorus will then be more readily available to subsequent crops after incorporation.

There is also work to suggest that elements such as sulphur may be leached out of sandy soils and thus eventually becoming deficient in low input systems. Cruciferous crops such as winter rape or fodder radish can be particularly effective at preventing sulphur being leached into lower soil horizons. Other green manures (for example chicory, with its deep tap root) have been reported to accumulate large amounts of sulphur, boron, manganese, molybdenum and zinc. This 'mining' effect is particularly useful if the subsoil is rich in nutrient elements but the topsoil is relatively poor.

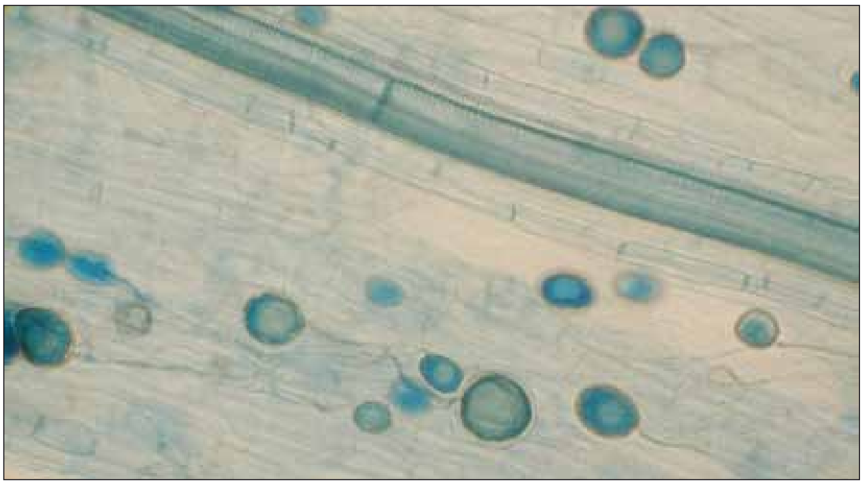
6 Chicory has a very deep tap root

Effects on soil structure and properties

Legumes usually decay rapidly and so have relatively little effect on long term soil organic matter. However, they do stimulate microbial activity in the first few months after incorporation. In contrast non-legumes generally break down relatively slowly with their residues providing a physical effect for some time.

Green manures can improve soil structure in a number of ways:

- Extensive fine roots enmesh the soil, helping to stabilise aggregates and increase pore size.
- Some species (e.g. lucerne, chicory and red clover) produce deep tap roots which help break up compacted soil.
- Root exudates provide food for micro-organisms, which in turn produce polysaccharide gums, that 'glue' soil aggregates together.
- Green manures can maintain the population of soil mycorrhiza (Figure 7) between cash crops; these fungi, as well as being important in phosphorus nutrition, help to maintain soil structure by enmeshing soil aggregates. Brassicas and lupins however are non-mycorrhizal.
- The root system has a binding effect on the soil, so water erosion is substantially reduced.
- A green manure increases surface roughness, lessening the wind speed close to the soil and helping to minimise wind erosion.
- Actively growing green manures can dry out the soil in the spring. This can allow it to warm up more quickly and may aid cultivations, although it may also hinder the germination of a subsequent crop.
- Increased soil organic matter can help to improve water holding capacity.



7 Spores of *Glomus manihotis* mycorrhizal fungus in an onion root

Effects on weeds

One of the major benefits of green manures is their ability to suppress weeds. Growing a green manure adds diversity to the rotation and reduces the opportunities for weeds to become adapted to a particular cropping pattern. Management practices associated with growing a green manure (e.g. mowing and grazing) can also suppress weeds. The lack of soil disturbance during the long growing period of a ley can also reduce viable seed numbers. Green manures will compete with weeds for light, water and nutrients. Rapidly growing crops such as mustard are the most effective at doing this.

Some green manures also secrete specific chemicals into the soil (both during their life and after incorporation) that inhibit weed seed germination. This 'allelopathic effect' is demonstrated by many clovers but also non-legumes including rye. This can be used to advantage although there is also a danger of inhibition of the subsequent crop; transplants will generally not be affected but drilling of direct sown crops (especially those with small seeds) should be delayed as the germination suppressive effect can last for several weeks.

Care should be taken that green manures do not serve to increase weed infestation in a rotation by becoming weeds themselves. For example, phacelia has the ability to self seed prolifically and may become a weed in subsequent crops.

Effects on pests

Green manures can act as habitats for general predators. These can be especially important to provide cover overwinter whilst summer flowering plants will encourage good populations of hoverflies, lacewings and parasitic wasps.

Cabbage root fly and various other Brassica pests can be disrupted by greater diversity in the field (Figure 8). There may be opportunities for using green manures to achieve this by intercropping (Figure 9), either as an understory or in strips (e.g. growing them in alternate beds). This approach needs some experimentation to adapt the ideas to a particular system but does offer good opportunities for pest control.

8 Cabbage root fly can be disrupted by a greater crop diversity

9 Cabbage intercropped with clover

Long grass clover leys tend to harbour populations of some soil pests. Management can ameliorate this effect. For example autumn ploughing and disking can reduce numbers of wireworms, whilst close mowing between July and September can reduce the chances of egg laying by crane flies (the adults of leatherjackets). There is some evidence that a quick mustard crop (if using a high glucosinolate variety), can offer effective control of soil pests, but this depends on achieving a large biomass and a rapid incorporation into sufficiently damp soil.

The ploughing in of leafy crop residues can provide a favourable environment for egg laying by bean seed fly, an insect than can damage emerging seedlings of many crops.

Growers are often concerned that green manures will encourage slugs but in practice this is not often seen. Trials have shown differences between species. Ryegrass or lucerne seem particularly unlikely to cause problems.

Effects on diseases

The glucosinolates in Brassica green manures have also been used in disease control (e.g. against Verticillium wilt of strawberries and Rhizoctonia of various vegetables). Many green manures will support microbial communities of non-pathogenic bacteria and fungi which will antagonise pathogenic organisms. However, as with pest effects, there is the danger of maintaining a green bridge that increases some disease risks (e.g. clubroot).

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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