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Soil grown crops
Projects FV 299 and 299a

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Green manures – species selection

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Green manures, also referred to as fertility building crops, may be broadly defined as crops grown for the benefit of the soil. There is a wide range of species that can be drawn upon, each with their particular qualities and this factsheet aims to help growers select the most appropriate green manures to fit various roles. Two related factsheets address the effects of green manures on soil nutrient management and soil physical and biological properties (24/10) and the economic implications of their use (26/10).

Background

Green manures have been used in traditional agriculture for thousands of years but conventional farming systems largely rejected them as the use of fertilisers and pesticides became more common. They can bring a range of benefits:

- Adding organic matter to the soil
- Increasing biological activity
- Improving soil structure
- Reduction of erosion
- Increasing the supply of nutrients available to plants (particularly by adding nitrogen to the system by fixation)
- Manipulating the availability of soil nutrients
- Reducing leaching losses
- Suppressing weeds
- Reducing pest and disease problems
- Providing supplementary animal forage
- Drying and warming the soil

Despite these effects green manures are still often under utilised by today's growers. There can obviously be problems with their use – there are direct costs of seed and husbandry and they can tie up land that would otherwise be used for cash cropping. They may demand attention at busy times of year and under some circumstances pest, disease and weed problems can be exacerbated. However, recent emphasis on reducing the environmental impact of all farming systems (partly stimulated by new legislation) has led to a growing interest from the conventional sector.

To gain the most from green manure crops it is important that they are carefully integrated into the crop rotation and proper attention paid to their husbandry (Figure 1). A wide range of plant species can be used as green manures and some are more suitable for specific purposes than others.

1 To gain the most out of green manures, proper attention should be paid to their husbandry

Types of green manures

Long term green manures

Leys are usually established for two or three years and form a basic part of many organic field vegetable and arable rotations (Table 1). Where animals are present on the farm the leys would usually be grazed or cut for silage, but in stockless systems they are normally cut several times during the summer period and the mowings allowed to remain on the surface as a mulch. Such leys may be pure clover (when nitrogen fixation is a priority) or a grass/clover mixture (when organic matter build up is also important). Red or white clover and ryegrass are key species.

Table 1 Long term green manures

Common name	Latin name	Nitrogen fixer?	Notes
White clover	*Trifolium repens*	Yes	Many varieties available. Usually mixed with grass for medium to long term leys
Red clover	*Trifolium pratense*	Yes	Many varieties available. Often mixed with grass for short to medium term leys. May also be grown as a summer green manure
Lucerne or alfalfa	*Medicago sativa*	Yes	Deep rooted and persistent. A medium to long term ley – performance improves in successive years
Sainfoin	*Onobrychis viciifolia*	Yes	Drought tolerant medium to long term species suited to thin alkaline soils
Perennial ryegrass	*Lolium perenne*	No	Good persistence, thriving on fertile soils. As a green manure it is usually mixed with clover
Cocksfoot	*Dactylis glomerata*	No	Large root mass contributes to soil organic matter
Timothy	*Phleum pratense*	No	Well adapted to cooler and wetter conditions
Chicory	*Chichorum intybus*	No	Often mixed with grass and clover. Deep roots bring up nutrients from subsoil

Winter green manures

Sown in the autumn and incorporated in the following spring, they provide a way of fitting a fertility building crop into a rotation by utilising land that would otherwise be bare (Table 2). However, it can be difficult to establish them early enough to do any good if harvest of the preceding summer crop is delayed. They can be legumes (e.g. vetch), but a major use for this class of crops is to minimise nitrogen leaching for which non-legumes (e.g. rye) are particularly effective. When used for this purpose they are often called winter cover crops.

Table 2 Winter green manures

Common name	Latin name	Nitrogen fixer?	Notes
Common vetch or tares	*Vicia sativa*	Yes	Probably the best leguminous winter green manure. Can also be sown in spring
Field beans	*Vicia faba*	Yes	Can be established late in the autumn but produces a rather open canopy over the winter
Grazing rye	*Secale cereale*	No	Very effective for preventing nitrate leaching. Adds considerable organic matter to the soil
Brassicas	Various *Brassica* and *Raphanus* species	No	There can be issues with growing Brassicas as green manures in a field vegetable rotation
Ryegrass	*Lolium multiflorum*	No	Westerwolds ryegrass can give very rapid growth. Can also be sown in the spring, often mixed with a clover

Summer green manures

Usually legumes (e.g. fenugreek) that are grown to provide a boost of nitrogen mid rotation (Table 3). They may be grown for a whole season from April to September or for a shorter period between two cash crops. These shorter-term green manures can include non-legumes such as mustard and phacelia.

Table 3 Summer green manures

Common name	Latin name	Nitrogen fixer?	Notes
Crimson clover	*Trifolium incarnatum*	Yes	An annual that dies after setting seed. Can also be sown in autumn to be ready for following spring
Persian clover	*Trifolium resupinatum*	Yes	An annual that responds well to mowing
Fenugreek	*Trigonella foenum-graecum*	Yes	A very quick growing annual, not tolerant of mowing
Lupins	*Lupinus* spp.	Yes	The traditional green manure of temperate climates
Phacelia	*Phacelia tanacetifolia*	No	Often grown to attract beneficial insects
Buckwheat	*Fagopyrum esculentum*	No	Particularly effective at scavenging for phosphorus
White mustard	*Sinapis alba*	No	There can be issues with including mustard as a green manure in a field vegetable rotation with other Brassicas
Sweet clover	*Melilotus* spp.	Yes	A biennial that can grow to 2m tall

Undersown green manures

A good way of establishing many legumes is to sow, by broadcasting in the spring, into an established cereal crop (Table 4 overleaf). This gives the green manure a longer growth period and can help in weed control in organic systems although herbicide use can make this impractical for conventional growers. A similar thing can be done with some horticultural crops (e.g. sweetcorn climbing beans or even tall Brassicas), but care is needed to avoid too much competition. This can be minimised by specialist inter row mowers or even root pruning using tractor-drawn implements. A low growing species such as subterranean clover would be suitable for this. A variety of other intercropping systems (e.g. alternate beds of green manures and cash crops) are possible. Greater crop diversity can have pest control effects (e.g. reducing egg laying by cabbage root fly).

Table 4 Green manures particularly suitable for undersowing

Common name	Latin name	Nitrogen fixer?	Notes
Subterranean clover	*Trifolium subterraneum*	Yes	Low growing so ideal for undersowing
Yellow trefoil or black medick	*Medicago lupulina*	Yes	Sets seed freely. Low growing so ideal for undersowing

Protected cropping systems offer particular challenges and opportunities for green manuring. Because of the warmer temperatures it may be possible to sow 'summer' green manures at any time of year but trial and error would be needed to fit them into the particular cropping plan of an individual grower.

Fertility building in orchards is often difficult because nitrogen must be provided at the right time to ensure good fruit set and quality. Green manures grown as an understory can also play an important role in attracting beneficial insects, but management decisions to achieve these twin goals must be carefully integrated. Similar issues also apply in other long term cropping situations such as asparagus production.

Selection of green manure species

General considerations for selection include:

- the relative cost of seed
- speed of germination and growth
- longevity
- tolerance to mowing or grazing
- suitability for animal forage
- competitiveness with weeds
- ability to grow in a nutrient-poor soil
- nitrogen fixing ability
- pest/disease resistance
- ease of incorporation
- speed of decomposition
- unlikeliness to return as a weed in the next crop

The basic division is into legumes and non-legumes. Many of the crops are known by a range of common names and this can result in considerable confusion. Some species (especially red and white clover) have been highly bred to provide particular characteristics as forage crops and for these there is a wide choice of varieties. In other cases there may be no choice of variety at all. The range of varieties supplied as organic seed is usually even more limited.

Leguminous green manures

These are generally considered to be nitrogen fixing but this will only happen in the presence of correct strains of *Rhizobium* bacteria. For more common legume species these will certainly be present naturally in the soil but some species such as lucerne, fenugreek and sweet clover will usually benefit from inoculating the seed before sowing.

Clovers (*Trifolium* spp.) are the most widely grown crops for fertility building purposes. There are many species with different characteristics. Medics (*Medicago* spp.) are another important genus of legumes. They have trifoliate leaves and so appear superficially similar to clovers but can be distinguished by the midrib which projects beyond the leaf margin. All clover seed is small and should be broadcast or drilled at a shallow depth (not more than a few mm). Sowing too deep will reduce the germination dramatically. The soil should be rolled after sowing to increase soil moisture contact with the seed. Several more distantly related groups of legumes are also effective green manures. The use of lupins for this purpose was mentioned by the Romans. Some species are more commonly used as cash crops including field beans and peas.

It must be remembered that some of these legume plants, if grazed without being diluted with other feed, may cause bloat or reproductive problems in the animals.

White clover (*Trifolium repens*)
Suitable for medium to long term leys, white clover is one of the most tried and tested of all the green manure species (Figure 2). Although it does not establish rapidly, once it gets going it produces respectable amounts of biomass over an extended period. It is well suited to grazing. The less aggressive varieties are also suitable for undersowing in cereal and some vegetable crops.

2 White clover is usually mixed with grass for medium to long term leys

White clover can be sown at rates of about 10 kg/ha in spring (March to May) or in the autumn. It will germinate in the summer, but frequently there is insufficient moisture in the soil to allow this. Mid to late August is the best time for an autumn sowing. Establishment is less likely to be reliable if sowing extends too far into September.

The leaf cover of white clover will die back over the winter, and the plant overwinters as an underground stolon structure which should be tolerant of all but the most severe frosts. There is more choice of variety for white clover than any other green manure. The growth habits of varieties vary considerably, and are grouped into small, medium and large leaved varieties.

- Small leaved varieties are best for hard grazing so are particularly well suited for pastures with sheep and possibly intercropping. Varieties include AberPearl or AberAce.

- Medium leaved varieties are more flexible and could be used by grazing cattle, less intense grazing with sheep or used in a cutting mix. Varieties include AberHerald and AberConcorde.

- Large leaved varieties are suitable for less intense grazing and more suitable for cutting – they are likely to produce the most biomass and fix the most nitrogen under good conditions. Varieties include Alice and Riesling.

White clover is slower to establish than some green manures and will benefit from early topping to control weeds. However, biomass production becomes more prolific later in the season and in subsequent years, offers good weed control. The larger leaved varieties are more competitive with weeds than the smaller leaved.

The crop will reach a height of 20–30cm, depending on leaf size. The clover should be mown regularly whenever it attains a height of 30cm. The first cut may be made before this if there is a severe weed problem. The frequency of mowing will vary widely between sites. On a dry sandy soil, it may only need cutting twice in the season. Conversely, on a fertile soil in a warm wet summer, it may need cutting as frequently as once every ten days. Allowing the crop to produce too much plant material runs the risk of smothering the foliage if cut and mulched.

Overall biomass production is usually slightly less than red clover but it persists for a greater number of years – it can remain for 7 to 8 years in pastures. It proliferates through an underground stolon structure, so even if one part becomes damaged, the crop can still regenerate. White clover is shallow rooted and makes little growth in dry conditions. Estimates for nitrogen fixing potential of white clover vary very widely from 50 to 300kg N/ha annually. A typical figure is 150 kg/ha if cut and mulched. Continued defoliation stimulates root growth and N fixation.

A lot of breeding effort has gone into the different varieties of white clover, and as such, many have good tolerance to the common pests and diseases such as clover rot (*Sclerotinia trifoliorum*) and stem nematodes. As new varieties with different resistance are still being developed it is worth referring to the most up to date NIAB guide for forage crops.

Red clover (*Trifolium pratense*)

Suitable for short to medium term leys, red clover is one of the most commonly grown leguminous green manures (Figure 3). It is especially popular with organic growers in intensive horticultural systems. It is capable of relatively rapid growth and establishment and shows reasonably good persistence for up to two years.

Red clover can be sown at a rate of 15 kg/ha in the spring or the autumn. There has been considerable breeding work. Milvus is still one of the most commonly grown varieties, however, there are others that have been developed more recently. Merviot produces large amounts of biomass and has shown some resistance to *Sclerotinia* rots. AberRuby is also very productive. Late flowering varieties (e.g. Britta) have greater persistance and are more suited to medium term leys.

Red clover generally competes well against weeds. It also grows back rapidly after topping, which is important in out competing the weeds. Red clover will reach a height of at least 50cm if left unchecked, although it should generally be mowed before this, to prevent it from turning woody. Red clover should be mown regularly whenever it attains a height of 30cm. The first cut may be before this if there is a severe weed problem. The frequency of mowing will vary widely between sites – it will need to be done between two and ten times in a year. Allowing the crop to produce too much plant material runs the risk of smothering the remaining foliage if cut and mulched. This crop is one of the most productive, typically producing an annual dry matter yield in the order of 13 t/ha. Its deep taproot makes it more drought resistant than white clover. Estimates of N fixed show a wide variation from 100 to 400kg N fixed annually; 150 kg/ha per year is a typical figure for a ley that is cut and mulched, but this

3 Red clover can be used as a short to medium term ley or as a summer green manure

could be considerably more if the material is removed for silage. The red clover plant is a perennial and survives over winter as a crown. The crowns gradually deteriorate over time, becoming diseased, damaged by cutting, trafficking or trampled by animals. The crop is frost tolerant and should persist for two years – the population tends to decline if left longer.

Red clover is more susceptible than other species to the soil borne disease *Sclerotinia trifoliorum* and the stem nematode, *Ditylenchus dipsaci*. They were responsible for 'clover sickness' observed in many red clover crops in the 1970s and 1980s until there was a concerted effort to breed more resistant varieties. For this reason, there should be a four-year gap between red clover crops. As these disorders are reasonably specific to red clover, other fertility building crops can be used as an alternative.

Crimson clover or Italian clover (*Trifolium incarnatum*)

An annual crop, suitable as a short term nitrogen fixer that is commonly used as a break in intensive horticultural systems. Crimson clover produces a spectacular display of flowers (Figure 4).

Crimson clover is normally sown in spring at 15 kg/ha. The crop dies soon after flowering and so it is short lived. It usually sets its seed by July or August. It can also be sown in the autumn – possibly a little later than other clovers. In this case it will survive as small plants through frosts over the winter – growth begins in earnest the following spring. Contea is a commonly used variety. Crimson clover initially produces a canopy that provides effective weed control. This often becomes more sparse at the onset of flowering allowing some weed growth to establish and then rapidly senesces once flowering is finished. Crimson clover can reach a height of 70cm if not cut; once flowering has begun it does not take kindly to topping and this may limit the options for weed control. The crop will produce less total annual biomass than red clover but occupies the ground for less time. There is little information concerning nitrogen fixation, one study estimated it to be 100kg N/ha annually.

The information on pest and disease tolerance in crimson clover is also limited. Its tolerance to sitona weevil and downy mildew are similar to red clover. However, it is not attacked by the same types of stem nematode as red clover, so can form an alternative crop in the rotation to prevent the build up of this soil pest.

Persian clover (*Trifolium resupinatum*)

Suitable as a short term nitrogen fixer, Persian clover is an annual capable of rapid growth and is ideal where there is a window of five months to one year (Figure 5). It is a relatively novel crop in the UK; although it originates from areas such as Turkey, Afghanistan and Greece, it is grown successfully in other countries such as New Zealand which has a similar climate to ours.

Persian clover should be sown at a rate of 10 kg/ha, ideally in March to May. An autumn sowing could be tried but Persian clover will not establish at low temperatures and is unlikely to be successful if sowing extends too far into September. The leaf cover of Persian clover will be knocked back by frost, but will recover to provide a reliable crop. There is currently very little choice of variety; Laser is commonly available.

On emergence this plant produces very small leaves but, after the seedling stage, leaf expansion is rapid, producing a thick canopy cover that is extremely competitive. Persian clover will reach a height of at least 60 to 70cm if left unchecked, although it should generally be mowed before this (whenever it reaches about 30cm). Although the plant is an annual, it shows greater persistence than other annuals such as crimson clover. It will start to die off by October from a spring sowing in April. This crop produces large amounts of biomass very quickly. The stem material has

4 Crimson cover is an annual crop that dies after setting seed

5 Persian clover is an annual crop that responds well to mowing

less tendency to turn woody than many other green manures making it easy to incorporate. There is little information on the nitrogen fixing potential of this crop, with only one value in the literature of 100kg N/ha fixed annually.

The pest and disease problems of this species are not well documented in the UK. As stem nematode races are very species specific, it is unlikely to suffer from the same nematode problems as red clover. Therefore, alternating this crop with red clover may reduce the chances of stem nematode populations building up in the soil. Anecdotal observations suggest that this crop is slightly more susceptible than red clover to damage from the sitona weevil although this is most significant only in the early stages of growth.

Subterranean clover (*Trifolium subterraneum*)
A low growing plant suitable as a short term nitrogen fixer. This is an annual plant with a low dense growth habit and long branched creeping stems. The flowers (self pollinated) are pushed into the soil; the plant then dies off but regenerates the following year possibly causing a weed problem. Because it never grows taller than about 20cm, it may be particularly interesting for intercropping in a vegetable system. It is frost tolerant but will not put on much growth overwinter from an autumn sowing.

Other Clovers
Many other true clover (*Trifolium*) species could be grown. Some of these may offer particular advantages in some circumstances. For example Alsike clover (*T. hybridum*) is well adapted to wet acid soils whilst strawberry clover (*T. fragiferum*) is tolerant of wet and salty soils. Caucasian clover (*T. ambigum*) also tolerates waterlogged conditions with low pH and phosphate level. Berseem or Egyptian clover (*T. alexandrinum*) requires warmer temperatures than those of the UK although it may give reasonable yields during the summer months and yellow suckling clover (*T. dubium*) is a common contaminant of white clover seed. Rose clover (*T. hirtum*) may be useful in conditions of low fertility and rainfall.

Lucerne or Alfalfa (*Medicago satvia*)
Suitable for medium to long term leys (Figure 6), particularly if these can be cut for silage or hay. It is not the best choice for a green manure of less than two years duration, but its deep roots make it tolerant of drought conditions. It favours alkaline soils.

Lucerne seeds are slightly larger than clover so they can be sown a little deeper; 0.5cm is ideal at a sowing rate of 20 kg/ha. It can be sown in the spring or, if moist enough, in August. September sowings are less likely to establish well as the soil temperature is cooler. Varieties have been trialled by NIAB, and reference should be made to the most recent book on livestock crops. Currently, the most commonly used varieties are Mercedes and Vela although other less established varieties such as Daisy, Diane, Marshal and Pondus also produce good yields.

Foliage of lucerne dies off over the winter but the plant survives as a tap root which resumes growth in the spring. Lucerne is slow to establish initially, but, once it gets going, shows good competition against weeds. Early topping in the first year is usually necessary for weed control and it should be sown into a warm soil to prevent weeds gaining an advantage. The crop will attain a height of at least 1m if not mown. However it should be cut before this to avoid an abundance of woody stem material. The plants need topping two to three times per season. The frequency depends very much on season and soil type but careful management is essential to prevent the canopy becoming too thin. Excessive competition must be avoided particularly when young. Lucerne shows good persistence and can be grown for longer than the normal two to three years. Its persistence depends on factors affecting survival of the tap roots. It is not favoured by waterlogged soils and poaching or driving will also shorten its longevity. Lucerne becomes much more productive in the second and third years, typically yielding 15 t/ha dry matter annually. There are a wide range of values of estimates for N fixation in lucerne ranging from 125 to 500kg N/ha annually. A typical figure might be 150kg N/ha.

Lucerne appears to be slightly more susceptible to downy mildew and attack from sitona weevil than red clover. It also suffers from the same soil borne pests and diseases as red clover including stem nematode and Verticillium wilt. There should therefore be a four-year break between lucerne crops. Some varieties such as Vela have been shown to have good resistance to both of these disorders.

6 Lucerne is suitable for medium to long term leys

Yellow trefoil or Black medik (*Medicago lupulina*)
Suitable as a short term nitrogen fixer this plant can be annual or biennial. Its low growing habit makes it a common choice for undersowing in cereals and it may be suitable for intercropping with vegetables.

Trefoil should be sown at 8 kg/ha in March/May or mid to late August. From the later sowing the plants will overwinter, flower the following year and then die off. However it sets large quantities of viable seed very

rapidly which can lead to it becoming effectively perennial and there can be a weed problem in the next crop. There is little information concerning varieties but Virgo is commonly grown.

Yellow trefoil (Figure 7) shows reasonable competition against weeds. It is not the most rapid growing of species but its low growing growth habit is good for covering the ground and smothering weeds. It can also be relatively productive early in the season. It will reach a height of about 30cm if not mown - it should be mown regularly whenever it attains a height of 20cm. The first cut may be before this if there is a severe weed problem. Mowing is important to maintain the viability of a yellow trefoil crop and to prevent it running to seed too soon. Information on pest and disease tolerance is very limited.

Several other Medicago species may be used as green manures but few have been evaluated under UK conditions. One of the most interesting is snail medick (*Medicago scutellata*) which produces characteristically snail shell shaped seed pods which may persist in the soil and cause a weed problem. The seeds are relatively large and the plants become established rapidly from either spring or autumn sowings.

Trefoils (*Lotus* spp.)

Mainly adapted to cool climates and fairly acid, damp soils. They have a more open growth than many other legumes which minimises competition and interest in them has focussed on their use as an intercrop to help with the control of Brassica pests - they can be sown into the transplant module.

There are three main species that have potential as green manures. Birdsfoot trefoil (*L. corniculatus*) has a distinct crown with several stems but no stolons: it is used for forage in a similar manner to lucerne but it must not be cut too close as regrowth emanates from lateral buds well above the soil. It is suitable for soils too poor for red clover or lucerne. Greater birdsfoot trefoil, marsh birdsfoot trefoil or lotus (*L. pedunculatus/L. uliginosus/L. major*) are similar to the above but produce spreading shoots. They are more suited to wet soils but establishment is slow. Slender or narrow leaf trefoil (*L. tenuis*) can stand greater soil salinity than almost any other legume.

7 Yellow trefoil is suitable as a short term nitrogen fixer

Sweet clover or Melilot (*Melilotus* spp.)

Suitable as a short to medium term nitrogen fixer. It is a large biennial plant – both white and yellow flowered forms occur. It is unsuitable for feeding to animals because of toxicity problems.

Sow at 15 kg/ha, ideally between March and May. There is limited information on differences between varieties. Sweet clover (Figure 8) has an erect growth habit, resulting in an open canopy structure that is less suited to competing on soils with high weed burdens. It also does not like being cut too low to the ground; this restricts the options for early weed control. Sweet clover will survive over winter as a tap root – this root also makes it drought resistant. The crop can grow to a height of over 2m if left uncontrolled, although by this stage the stems will have become very woody and would be a problem to incorporate. Sweet clover does not take kindly to hard topping, so should be topped no closer than 10cm above the ground. If this crop establishes well, it is one of the most prolific for producing biomass rapidly. There is limited information about the nitrogen fixing potential of this crop, with one estimate of 110 kg/ha annually. As this is a biennial, it will die off after flowering. It can set seed and come back in subsequent crops.

Although the plants are very conspicuous, they tend to be in relatively small numbers. The seeds can cause tainting of cereal products. The information on pest and disease tolerance in sweet clover is limited. Observations suggest that it is considerably more susceptible to sitona weevil and downy mildew than red or white clover.

8 Sweet clover is a biennial that can grow to 2m tall

Fenugreek
(*Trigonella foenum-graecum*)
Suitable as a short term nitrogen fixer. It is one of the most rapid green manures to establish and produces a quick boost to soil fertility in just a few months. It is not commonly grown but has potential for use to fill in short breaks in an intensive horticultural system.

Seed of fenugreek (Figure 9) is rather larger than clover seed so can be sown a little deeper (0.5cm is ideal, at 25 kg/ha). It is generally sown in the spring, ideally from March to May.

It will germinate in the summer, but frequently there is insufficient moisture in the soil to allow this. Despite being a Mediterranean crop, fenugreek will show a surprising resilience to hard frosts. Fenugreek grows extremely rapidly, so will compete well against weeds. It does have quite an erect growth habit, so may need sowing at higher rates on weedier sites to provide adequate ground cover.

Fenugreek will grow to a height of around 1m. It is best not to top fenugreek at all as in most cases this will kill it. Its growth is vigorous enough to compete against weeds without the need for cutting. This annual crop will start to flower and set seed after a few months.

There is very limited information on nitrogen fixation with just one published figure of 30kg N/ha annually. It should be noted that this crop has an extremely short life cycle, so the figure for annual nitrogen fixation should be expected to be lower than that for perennial crop. Fenugreek has few known pest or disease problems and is not closely related to many of the more common green manures.

Safoin or Cockshead
(*Onobrychis viciifolia*)
Suitable for nitrogen fixing in the medium term. It is a perennial with an erect growth habit, producing characteristic pink flowers. It is extremely palatable to animals and has a very good nutritional balance. It can be grazed, or fed as hay or silage. It is drought tolerant and thrives particularly on thin alkaline soils. Sainfoin seed is large and should be drilled to a depth of 1 to 2cm at a rate of 70 kg/ha. It is traditionally sown as a spring crop (March to May). Adequate moisture is essential for good establishment, so sowing later in summer may be less reliable. It can be slow to start with, but produces enough ground cover to compete against weeds once it is well established. Sainfoin (Figure 10) is extremely tolerant of frosts and has the potential to persist for 3 to 4 years. Often it does not achieve this as the tap roots are easily damaged. It is best to avoid heavy grazing and poaching which can reduce the population of viable tap roots. Sainfoin will generally need topping 2 to 3 times a season, although this will vary considerably with season and soil type. There is very little information on the nitrogen fixing potential of sainfoin, although there are some suggestions that it fixes slightly less than red clover. Sainfoin can be susceptible to crown rot, which can reduce the persistence of the stand.

9 Fenugreek is a very fast growing annual that is not tolerant of mowing

10 Sainfoin is a drought tolerant species suited to thin alkaline soils

Common vetch or Tares (*Vicia sativa*)

Useful as a short term nitrogen fixer suitable for either spring or autumn sowings. *Vicia villosa* (hairy vetch) is very similar. Vetch is probably the best leguminous winter green manure (Figure 11).

Vetch seeds are relatively large and should be sown about 1cm deep at a rate of 85kg/ha. March to May is the ideal time for sowing in the spring. It will germinate in the summer, but frequently there is insufficient moisture in the soil to allow this. August to mid September is the best time for an autumn sowing. Establishment is less likely to be reliable if sowing is too late although it can be sown later than many other legumes. There is limited comparative information on varieties. Early English is commonly grown.

Vetch has good frost tolerance and will maintain a canopy over the winter. The crop rapidly produces large amounts of biomass for example, an average of 3 t/ha above ground dry matter, containing 70kg N/ha, developed overwinter in one series of experiments. Estimates of annual nitrogen fixation range from 100 – 250kg N/ha. A typical figure is 150kg N/ha. Vetch will grow to a height of around 50cm, or taller if grown in conjunction with a cereal (e.g. grazing rye or oats) to provide support. Vetch is extremely competitive against weeds, forming an aggressive canopy. It is best not to top vetch at all, as it does not recover well. Its growth is vigorous enough to compete against weeds without the need for cutting. This crop dies after seed pods have developed. It has often flowered then senesced by August but ideally should be incorporated before this. When incorporated, the residues also have an allelopathic effect, inhibiting germination of new seeds. This effect persists for around six weeks, and an adequate interval should be left if drilling direct sown crops after incorporating vetch.

Pest damage (insects and birds) may be devastating in some places. Sitona weevil can attack it during early stages, but this generally has little effect on the subsequent success of the crop. Pigeons can sometimes set back the development of the crop, if there is little else for them to eat. There is limited work to suggest that growing vetch results in fewer slugs in the subsequent crop than clover crops.

11 Vetch is suitable as a short term nitrogen fixer

12 Lupins are the most traditional green manure of temperate climates

White lupin (*Lupinus albus*), bitter blue lupin (*Lupinus angustifoilus*) and yellow lupin (*Lupinus luteus*)

Suitable as short summer green manures. These were the traditional green manures of temperate climates (Figure 12). Flower colour is not necessarily related to the name of the species. They are well adapted to sandy soils and acid conditions. Wild lupins contain toxic alkaloids in their foliage and seeds but modern breeding has developed varieties which may be grazed. The plants have deep penetrating taproots and the stems are erect yet easily crushed and readily decomposed. They have poor frost tolerance and are very susceptible to slug damage.

Field beans (*Vicia faba*)
These can make a good leguminous winter green manure as they will establish late in the autumn. However, the canopy is quite open leaving much of the soil exposed and large seeds necessitate a high, and expensive, seed rate. Peas are an alternative but are not so frost hardy. For a short summer green manure more exotic species such as lentils may also be a possibility.

Non-leguminous green manures

These will not fix nitrogen but can be very effective at preventing nitrate leaching, adding organic matter to the soil and smothering weeds. Most suitable plants are cereals or grasses (often grown mixed with legumes) but there are also a range of Brassicas and occasional other species with particular characteristics.

Grazing rye (*Secale cereale*)
Suitable as an overwinter cover crop (Figure 13). This species is one of the most effective crops for reducing nitrogen leaching over the winter and adding organic matter to the soil in the spring.

Rye is usually sown in the autumn in order to establish overwinter cover. It has an advantage over the legumes in that it can be sown later and will still grow successfully if sown in September or October. It should be sown at a rate of 180 kg/ha at a depth of 1 to 2cm. This is a high rate, making it an expensive crop to establish, so particular care should be taken to ensure that sowing conditions are optimal. Grazing rye is extremely tolerant to frost and after a rapid establishment continues to grow in cool weather overwinter. Because of this it is able to utilise soil mineral nitrogen that would otherwise be washed out in winter rains (up to 95% reductions in leaching losses have been measured compared to bare soil).

Varieties bred specifically for winter grazing (sometimes called Hungarian grazing rye) are generally considered to be better cover crops than grain varieties since they produce more leafy growth.

This is an annual crop – it is best incorporated in mid April – any earlier and it may regrow and if left later it will produce vast amounts of dry matter that may lock up available nitrogen. By this time it will have attained a height of about 1m. Grazing rye can be lightly topped to delay its flowering and prevent it from becoming stemmy.

Grazing rye establishes very quickly and competes against weeds effectively. The residues, when dug in, have an allelopathic effect against germination of seed. This should be taken into consideration when sowing direct drilled crops after grazing rye; an interval of six weeks should be left. Rust and mildew will affect rye but this usually has negligible effect on performance.

Other cereals such as oats (*Avena sativa*) or barley (*Hordeum vulgare*)
These may be grown as alternatives to rye (as seed is often available on farms without buying it in specially), although they are much less effective at preventing leaching. Oats appear to be particularly suitable when sown thinly as a nurse crop for establishing legumes.

13 Grazing rye is suitable as an overwinter crop

Grasses

Grasses add organic matter to the soil, help suppress weeds and can encourage nitrogen fixation of a companion legume crop by utilising any nitrogen that is mineralised in the period of green manure growth. They can also improve the digestability of leys that are to be used for animal forage. Grasses can be sown a little deeper than most legumes. A suitable rate would be 20 to 30 kg/ha on their own or about 10 kg/ha in a mixture.

14 Ryegrass establishes rapidly and will survive for three to four years

Perennial ryegrass (*Lolium perenne*)
This is the most widely sown grass in the UK and shows good persistence (up to four years) in leys. Perennial ryegrass (Figure 14) establishes rapidly and will survive for three to four years. It will thrive on fertile soil, establishing deep and dense fibrous root systems but on poor or drought prone soil, other grasses, such as cocksfoot may be more suitable. Typical annual dry matter production is 15 t/ha. Ryegrass is most commonly used in a mixture with various clover species – it may be established by being undersown in a cereal crop. Its high sugar content and digestibility make it particularly suitable for silage production.
There are many varieties of ryegrasses which are divided into early, intermediate and late groups. Early varieties such as AberTorch, Donard and Moy will provide good early growth and head in mid May. Intermediate varieties include AberDart and AberGold and later varieties such as AberCraigs will head in mid June.

Italian ryegrass (*Lolium multiflorum*)
Used for short term leys of up to three years. It produces more early season growth than perennial ryegrass but midseason growth tends to be stemmy. Frost tolerance is not as good as perennial ryegrass and is also susceptible to drought. Diploid varieties such as Adin and Alamo are more suited to wet environments and under these conditions will outyield tetraploid varieties in the second year. Tetraploid varieties such as Danergo and Fabio will produce higher yields in the first year than diploid varieties. Their drought tolerance and cold tolerance is better than diploid varieties.

Westerwolds ryegrass (*Lolium multiflorum*)
A group of annual ryegrass varieties that are capable of very rapid growth. When sown in the summer or spring they will flower in the same season and not persist over winter. Plants are winter hardy and can be sown in autumn to provide early spring growth. Varieties include Lifloria and Mendoza.

Hybrid ryegrass
This hybrid is a cross between perennial and Italian ryegrass, and has both high yield and reasonable persistency. Varieties include AberExcel.

Cocksfoot or Orchard grass (*Dactylis glomerata*)
Slower growing in the first year of sowing than perennial ryegrass but more tolerant of heat and drought and suitable for growing in drier areas with free draining soils. Cocksfoot has a reputation for producing a large amount of root mass which is beneficial for soil organic matter content and soil structure. Cocksfoot may use water more efficiently than perennial ryegrass. Cocksfoot is much less commonly grown than perennial ryegrass, especially in systems that are grazed, due to its poor palatability. It often forms clumps within the field especially if establishment is poor. Common varieties of cocksfoot include Prairial and AberTop.

Timothy (*Phleum pratense*)
Well adapted to cooler wetter areas and has good winter hardiness. It is slow to establish but can produce yields similar to perennial ryegrass in the second year. When sown on its own, it has a tendency to become thin and for this reason it is normally sown with other grasses such as perennial ryegrass. Varieties include Motim, Erecta, Pomesse and Comer.

Brassicas

Suitable as short term summer green manures or as winter cover crops. They are probably best avoided in many horticultural rotations because they suffer from the same diseases as the brassica vegetable crops.

White mustard (*Sinapis alba*)
One of the most widely grown green manures, largely as a result of the cheapness of the seed. It should be sown at 20 kg/ha. It is not completely frost hardy but survives in some winters; frost kill need not be a

disaster for a winter green manure, providing that it occurs late in the season and there has been time for significant nitrogen conservation to have occurred. Mustard (Figure 15) is more usually used as a quick summer break between cash crops – as well as adding bulky organic matter to the soil (it grows over 1m tall) it suppresses weeds. All mustards can have a suppressive effect on soil pests such as wireworm. However, much interest has been recently shown in **Caliente mustard**. This is a mixture of varieties (including some Indian mustard, *Brassica juncea*). These have been bred for their high dry matter accumulation and high glucosinolate content that, under the right conditions, can have biocidal properties against pests, weeds and diseases. For this to be effective it is essential that the crop is rapidly chopped and incorporated into a warm moist soil – ideally being sealed in with a plastic mulch. It can sometimes be difficult to establish mustard crops due to poor soil moisture levels and attacks from birds and flea beetles.

Stubble turnips (*Brassica rapa*), Forage rape (*Brassica napus*) or Fodder raddish (*Raphanus sativus*)
These are also used, but their main role is as a source of winter grazing (usually for sheep) with green manuring effects after incorporation of secondary importance.

Phacelia (*Phacelia tanacetifolia*)
Most suitable as a short term summer green manure (Figure 16). This grows rapidly from either autumn or spring sowings (10 kg/ha). Although not completely frost hardy it will survive in mild winters. It produces striking blue flowers and is sometimes planted solely to attract beneficial insects but by this stage (at a height of 60cm) the plants will have become very stemmy and slow to decompose. It also has a strong tendency to become a weed in subsequent crops. One advantage is that it is completely unrelated to any cash crops and so forms a good pest and disease break.

Buckwheat (*Fagopyrum esculentum*)
Suitable as a short summer green manure. This is a broad leaved annual that requires only a short growing season (2 or 3 months). It should be sown at 70 kg/ha when there is no risk of frost. Buckwheat (Figure 17) has an indeterminate growth habit (growing up to 90cm tall) so it will continue producing leaves and flowers throughout the summer until it is killed off by the first winter frosts. It may self seed to produce a second crop – this may cause a weed problem. It will tolerate infertile soils but performs badly on heavy soils. It is believed to be particularly effective at scavenging the soil for phosphorus which is then made more readily available to following crops. The crop may be grown as an attractant for beneficial insects. In Europe the seeds are harvested for flour.

15 Mustard is one of the most widely grown green manures

16 Phacelia is most suitable as a short term summer green manure

17 Buckwheat is particularly effective at scavenging for phosphorus

Chicory (*Chichorum intybus*)
Suitable as a short to medium term green manure, either alone or in combination with grasses and clovers. Chicory (Figure 18) can be sown in autumn or spring. It is important that reproductive growth is cut to prevent an abundance of unpalatable woody material forming. The crop has good frost tolerance and can last for up to four years. The long taproot can break up soil pans and bring up micronutrients from deep in the soil. It is good for grazing and may reduce parasite problems in sheep. Puna is a common variety.

18 Chicory, growing here with clover, has a deep tap root that brings up nutrients from the soil

Mixtures

It is often desirable to sow a mixture of species so as to combine the benefits of each (Table 5). There is also an element of 'hedging your bets' in case one of the components does not do well in a particular season. Although short duration green manures may be sown as mixtures the practice is much more common when establishing leys to last a year or more. Sometimes one of the species is not intended to be persistent in the longer term but to provide good ground cover in the early stages (a thin sowing of mustard often fulfils this role).

Commercially available green manure mixtures can be quite complex containing several different varieties of several species of grasses and clovers. This is particularly the case when the mixture is aimed at the organic farmer. The organic standards stipulate a maximum proportion of seeds that can be derived from conventional production. Because not all the varieties are available as organic seed (and because these seeds are more expensive), different varieties are combined to produce a mixture that complies with the regulations. However, it is not a bad thing to have a range of varieties as different ones are likely to do well under different conditions.

Table 5 Characteristics of some commonly used green manure mixtures

Red clover/ryegrass	This is potentially the most productive mix in terms of both dry matter production and nitrogen fixation. The ryegrass is often either Italian or a vigorous perennial variety – such rapidly growing varieties contribute significantly to dry matter production. Both this and the following mix can be undersown into a preceding crop. The legume normally accounts for approximately one quarter of the weight of seed sown.
White clover/ryegrass	This is typically a longer-term green manure than the other mixtures. It can be used for a period of 2-5 years depending on the persistence of the varieties in the mixture. The clover will fix nitrogen for the duration of the ley while the ryegrass provides a balance. The mixture is able to utilise nutrients and water more effectively and the ley can be grazed to give some income through the fertility-building period.
Oats/peas/vetch	This is another dual purpose mixture in that it can be taken as whole crop silage or incorporated into the soil as a green manure. It is a relatively expensive choice for a short term green manure. If it is cut for feed then there should be a payback in manure from the livestock operation.
Rye/vetch	As an overwintered green manure this can result in effective nitrogen conservation and fixation with large amounts being made available to the following crop. However, there is a danger of the rye swamping the vetch; careful tailoring of the seed rates may be necessary to achieve a good balance of each plant.

Action points for growers

- Several different types of green manures (fertility building crops) are available including winter green manures, short term summer green manures or longer term leys. Green manures can also form part of intercropping systems with either cereals or vegetables and can maintain soil cover in perennial cropping situations such as orchards.
- There are many different species to choose from which are used singly or in mixtures. It is important that the right one is chosen in each situation in order to maximise its effectiveness (e.g. to fix or conserve nitrogen, to minimise erosion, to maintain and improve soil quality or to manage weeds, pests and diseases).
- The final decision will depend on factors such as soil type, climatic considerations, cash cropping, cost, disease pressures, availability of labour and presence/absence of grazing animals.

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)

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Additional Information

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