Soil Nitrogen Building Crops in Organic Farming.

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Introduction

Organic farming aims to be self-sufficient in nitrogen (N) supply, managing inputs and minimising losses (see Table).

Sources	Losses
Fixation of atmospheric N	Nitrate leaching
Purchased feed stuffs	Ammonia volatilisation
Imported manures/composts	N_2 and (NO_x) emissions
Rainfall	Crop/animal produce
	Exported manures

The effective management of legumes, which capture atmospheric N and convert it to plant-available forms, is absolutely critical to the development of a successful organic rotation.

Fixation is the most important source of N in the rotation.

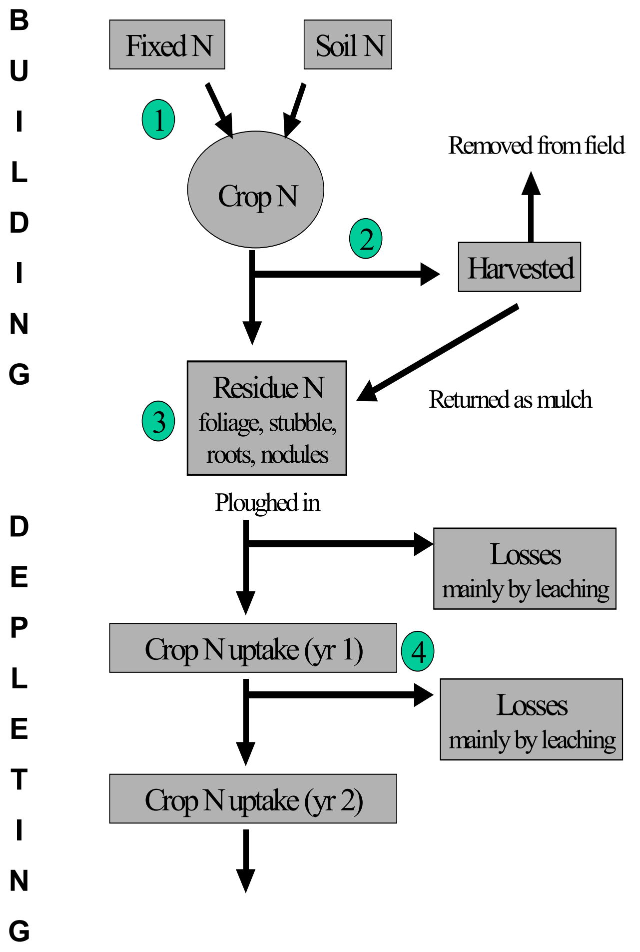
Why manage N? – Too little N in a rotation limits yields and productivity: too much N (or managed badly) can cause environmental damage.

Building and depleting fertility **–** Rotations are usually designed to build up fertility using legumes and then exploit it during a fertility depleting phase (see box).

Think field AND farm **–** Nitrogen can be transferred around the farm, e.g. where forage is harvested from one field, fed to animals and the manure spread on another field.

This booklet aims to provide **practical advice** on making best use of legumes.

Fertility building *vs* fertility depleting



When managing legumes for N supply, we need to consider **'capture'** (fixation) and **'use'** of N: both have to be managed effectively. Many factors can affect N fixation, e.g. levels of N in the soil (1) or cutting and removal versus cutting and mulching (2 and 3). Efficient use of N by the following crops relies on management practices and cropping patterns that make best use of the N released by mineralisation of the residues (4). All of these are covered later in more detail in this booklet.

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Nitrogen accumulation

The fertility building phase of a rotation is used to accumulate N in the soil and in unharvested crop residues. Although recycled plant residues and animal manures help to maintain the overall nutrient balance on the farm, the only true import of N (to compensate for removal in sold products and losses to the atmosphere and in leaching) is from fixation of atmospheric N_2 by legumes.

How does N accumulate?

The amounts of N that can be accumulated will not only depend on how well the legume grows, but also where it gets its N from, since legumes tend to prefer to obtain N from the soil, rather than fix N from the atmosphere.

Nitrogen exists in two main forms: **organic** and **inorganic**. Inorganic N is readily available to plants in the forms in which it commonly occurs (mostly ammonium and nitrate). However, over 90% of the N in most soils is held in organic forms which must first undergo mineralisation, through the action of soil microbes, to release available N. Nitrogen represents about 5% of the dry weight of soil organic matter (**SOM**) and so the content of SOM will largely determine the N supplying capacity of soils.

Microbial activity –Inputs of organic matter and the activity of soil microbes result in a build up of SOM. This can be rapid when soils are converted to pasture after long-term arable (on average between 55-75 kg N/ha accumulates each year during the first 10-50 years), but the rate begins to slow down as the SOM reaches an equilibrium. The time taken to reach this stage differs in different soils, depending on soil texture, climate, management and cropping, but can take from 50 to 200 years. Typical ranges for SOM are from as little as 1.5% (of dry soil weight) in sandy soils under arable cultivation, to as much as 10% in clay soils under permanent pasture. At the upper end of this range, this can amount to between 5 and 15 t organic N/ha in the top 15 cm.

Where is the N?

In cut or grazed swards, large amounts of herbage, stubble and roots are not harvested and return to the soil to be incorporated in the SOM. This can represent more than the amount of organic matter actually consumed by grazing animals. At the end of the fertility building phase, there are also large amounts of N in unharvested plant material and in roots (including nodules on clover roots which can represent over a third of the total root weight) which are returned when the legume-based sward is ploughed in. Figure 1 shows the amounts of N returned in swards from 12 farms in the South West (Nos. 1-6) and in the North East (Nos. 7-12) of England. It can be seen that N accumulation varies widely between the sites (150 - 450 kg N/ha) and that a large proportion of this N was found below ground.

Where SOM has built up, this indicates that the rate of accumulation has exceeded the rate of mineralisation, but even in soils that are accumulating N, a small proportion of the total soil N (usually 1-5%) will be released each year.

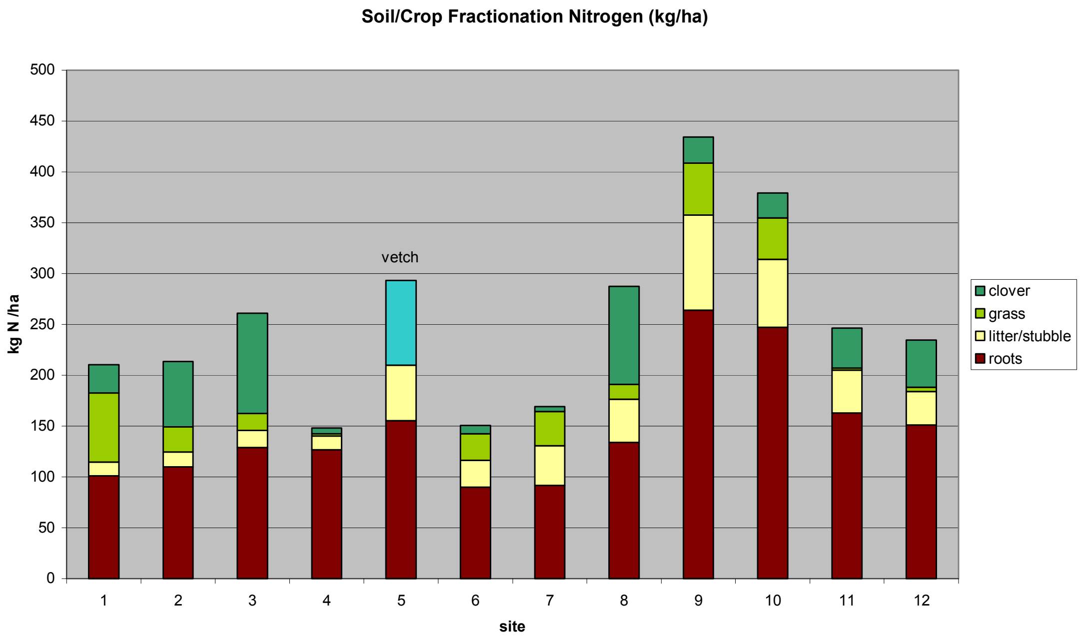

Figure 1. Crop fractionation of N content.

Of course, not all the N contained in the plant residues is immediately available to a following crop, but it is important to retain this N in the upper soil profile so that it is within reach of the next crop.

How much N is fixed?

Nitrogen in legumes comes from the uptake of both soil N and fixation of N from the atmosphere. The amount of N fixed by different legumes is determined by how well the symbiotic association is functioning between the N-fixing bacteria (*Rhizobia*) and the legume host. The efficiency with which N is fixed will depend on the crop's growing conditions (e.g. soil, climate, disease), crop management and length of time for which it is grown. Consequently, the influence of all of these factors means that a wide range of values have been reported. However, for a particular legume species there is usually a close relationship between yield and the quantity of N fixed. Figure 2 indicates the range of fixation estimates quoted for a number of leguminous crops.

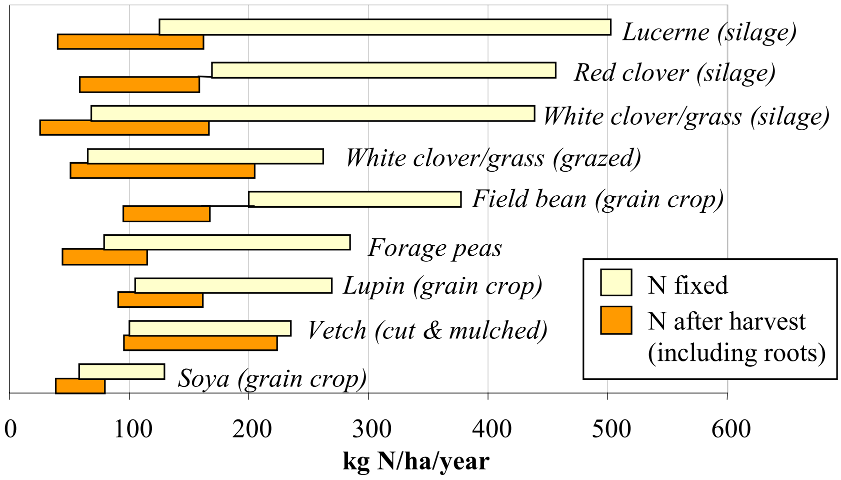

Figure 2. Provisional ranges for quantities of N fixed and remaining after harvest

As well as legume-based leys, organic rotations can also often provide a supplementary boost of N during the fertility-depleting phase by growing a leguminous cash crop, such as field beans or peas. However, harvesting forage or grain will remove much of the fixed N and reduce the benefit to following crops (see Figure 2). The benefit will be further reduced if straw and other crop residues are removed from the field.

Maximising N fixation

Management factors can **influence** N fixation by legumes since:

- The presence of soil mineral N is generally thought to reduce fixation capacity

- Fixation tends to decrease with legume age, mainly because the amount of soil N tends to increase under ley farming

Thus, much of the fixed N can be retained within the farm, if forage and grain are fed to stock on the farm rather than sold.

Factors that **increase** the soil N pool include:

- manure applications
- cutting and mulching
- grazing

Such contradictions, make for difficult management decisions. For example, cutting and mulching is a standard practice in organic rotations, especially in stockless systems, but recent research with red clover/grass swards has shown that this can decrease the amount of N imported into the rotation by limiting fixation from the atmosphere (by up to 50%) and may also lead to a reduction in the clover content.

To **maximise** N fixation, the herbage should be cut for silage and, if possible, on stockless farms it would be better to mulch arable or grass only areas.

Growing the legume in a mixture with a non-fixing plant can increase the proportion of N obtained from the atmosphere. For example, in grass/clover leys, the grass utilises soil N and thus avoids a build-up of soil N that might otherwise inhibit fixation. However, competition from a companion crop also reduces the number of N-fixing plants per unit area by competing for space, light, water and nutrients.

Light: If legumes become heavily shaded by a companion crop, the reduction in photosynthesis will restrict the supply of energy from the plant to the nodules and N-fixation will suffer. Regular defoliation of a mixed white clover is advantageous, but intensive grazing (especially by sheep) can impair the legume's ability to persist in the sward, mainly through reducing the leaf area and number of stolons, but also by removing flower heads, so that seed numbers often become too low for effective regeneration.

Water*:* Legumes are more affected by a lack of water than grasses (apart from Lucerne which is better able to withstand drought conditions), so in dry summers, irrigation would be beneficial to clovers in a mixed sward and the increase in their content and N fixation can be considerable, but depends largely on the amount of stolon material that has survived.

Nutrients*:* Legumes have a higher requirement for some macronutrients, e.g. P (and possibly for K, Ca and S) than grasses, especially in mixed swards. They compete less favourably with grasses which tend to have more finely branched and denser root systems concentrated in the upper soil layer. Legumes also have a greater need for some of the micronutrients involved directly, or indirectly in N-fixation, *viz*. Fe, Cu, Co and Mo and are more sensitive to soil acidity, mainly because of the sensitivity of N-fixation to aluminium toxicity.

Practical approaches to maintaining legumes

1. Correct any nutrient imbalances
2. Maintain soil pH above 6.0
3. Cut mixed swards regularly (6-8 times per year)
4. Graze appropriately: avoid over-grazing in spring and under-grazing in summer
5. Hard grazing in autumn by sheep can help over-winter survival
6. Choose appropriate white clover varieties: small-leaved for continuous grazing; medium for set-stocked and rotational grazing, but include a greater proportion of large-leaved varieties in mixtures with medium-leaved types, the more frequently swards are cut for conservation

Green manure options

This section looks at the Green manure crops that can be grown in the UK.

Green manures are important to add to the diversity of crop types, and are widely used in organic farming systems to reduce soil N losses, help crops out-compete weeds, and to improve soil structure and organic matter levels. Green manures also provide an important ground cover function to prevent soil erosion and minimise nutrient losses, as recognised in cross compliance legislation.

Different rooting characteristics influence soil structure, aeration, mineral availability and mobility, and microbial activity. The deep rooting systems of many green manure crops also have the benefit of drawing up minerals such as potassium and phosphate from deeper in the soil profile and relocating them to the rooting zone of grain crops.

Green manures planted between crops, as over winter covers or as annual covers can be used to fix soil N (build fertility), retain soil N (holding and relocation) and reduce leaching (minimise loss). When these green manures are subsequently incorporated, their decomposition stimulates microbial activity and soil N release, which is available to the following crop. The ratio of the amount of carbon (C) to the amount of N in the green manure crop, or C:N ratio, influences the rate of decomposition of the green manure and nutrient availability. C:N ratios vary depending on the composition of different materials and their growth stages. Young green material with C:N ratios of 15 will break down rapidly and release N. Older more “*woody*” material with a C:N ratio of about 80 will break down more slowly and release N over a longer period. Material with a high C:N ratio has a low percentage of N and conversely a low C:N ratio has a high percentage of N.

Well-mulched young green manure residues decompose slowly in the soil because they are relatively stable, having undergone a significant amount of decomposition already. Residues with a C:N ratio in the mid-20’s will make soil N readily available as they decompose. However mature plant residues with a C:N ratio of over 40 (Table 1) may cause temporary problems in the supply of N to plants as microorganisms immobilize surrounding soil N to aid their growth and reproduction, thus diminishing the amount of nitrate and ammonium available for crop uptake.

Table 1. **Carbon : Nitrogen (C: N) ratios of selected organic materials**

Material	C: N ratio
Soil microorganisms	7
Soil organic matter (SOM)	10 – 12
Clover	13
Compost	15
Grazing Rye	36
Maize stems	60
Wheat straw	80
Fresh sawdust	400

There is potential to use different green manures alone or in combination, which when incorporated decompose at different rates, so as to release soil N at different stages to the growing crop. This can be used to limit the size of the soil “N flush” after leguminous green manures are incorporated and better match the release of soil N to the demand of subsequent cash crops.

When selecting green manures for use in organic systems, in addition to their contribution to N management a range of issues related to their use, management and suitability to the system operated have to be considered.

- Will it be cut and mulched only, or is it required for grazing or forage production ?
- How long is it programmed to remain in place, between summer crops ? Over winter ? As an annual green manure cover ?
- How rapid is the development of the green cover from sowing ?
- Will the cover be frost hardy if used over winter ?
- What form of management will be required, single or multiple cutting and mulching, or grazing ?
- What are the cost implications of establishment and maintenance ?.

Green manure crops should also be selected so as to avoid ‘like’ cash crops in the rotation to minimise pest and disease transfer *i.e.* avoid using brassica green manures when brassicas are grown in the cropping rotation (see section on Pests and Diseases on page 24 for more detail).

Key points

- Select green manure type in relation to other crops in the rotation, weeds, usage, management and length of time in place.
- Avoid green manures of the same family as cash crops in the rotation.
- Match green manure breakdown characteristics to N requirement and time of uptake of subsequent cash crops.

Legume options for the UK

Red and white clovers are the most widely used green manures in UK organic agriculture, but other options are shown in Table 2.

Table 2 : Legumes grown in trials under UK organic farming conditions

Latin names	Common names
Trifolium pratense	Red clover (reference crop)
Trifolium repens	White clover (reference crop)
Lolium perenne	Perennial ryegrass (PRG)(reference crop)
Trifolium subteranneum	Subterranean clover
Trifolium resupinatum	Persian clover
Trifolium alexandrinum	Egyptian clover
Lotus pedunculatus (L. uliginosus)	Large birdsfoot trefoil
Medicago lupulina	Trefoil or “black medick”
Lupinus alba	White-flowering lupin
Lupinus luteus	Yellow-flowering lupin
Lupinus angustifolius	Blue-flowering or ”Narrow-leafed” lupin
Glycine max	Soya beans
Lens culinaris	Lentil
Galega orientalis	Galega or “Goat’s rue”
Melilotus alba	White sweet clover
Cicer arietinum	Chickpea
Trigonella foenum graecum	Fenugreek

Trials of these were grown during the project and their effectiveness at accumulating biomass and ability to fix nitrogen was affected by soil conditions and previous cropping. More work is needed to investigate these alternative crops, but initial comments showing their potential compared with red and white clover are shown in the box below.

Best crops:

- **Potential for N fixation** White sweet clover, trefoil black medic, persian clover
- **Quantity of forage** - white sweet clover or fenugreek
- **Grain monetary value** - lentil (human healthfoods) or lupins
- **Undersowing/bicropping** – subterranean clover appears to produce relatively more N below ground than above ground compared with the other crops, and has good growth close to the ground
- **Competing with weeds -** White sweet clover has rapid growth and out-competes most weeds
- **Ground cover –** Lentils are not a tall as some of the other crops but their ground cover is sufficient to compete with weeds

Nitrogen utilisation

Previous sections have discussed how, and how much, N is built up by fertility building crops. As explained earlier, this is only part of the challenge of good N management (Figure 3): we now have to manage the soil and crop rotation to maximise the efficient use of the N.

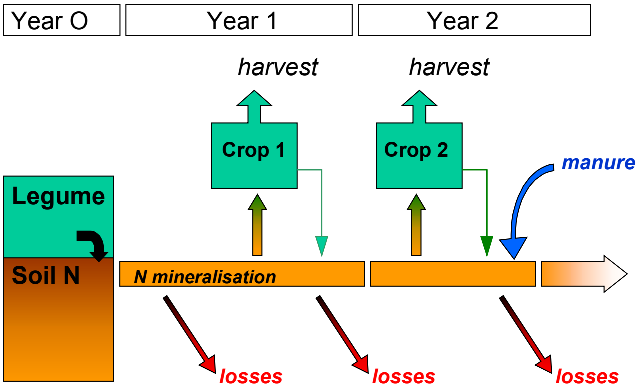

Figure 3 **Nitrogen dynamics for a 3 year rotation.**

How effectively the residue N is used by the subsequent crops in the rotation will depend on many factors, including:

- the rate of release (mineralisation);
- the efficiency of uptake by crops;
- the N removal in harvested products;
- the N return in plant residues; and
- losses of N.

The rate of depletion will be reduced if manure is applied or if the rotation includes further legumes during this phase. This Section therefore considers the factors affecting N release, interaction with crop uptake and loss processes, and methods of predicting N release.

Nitrogen forms

Before the next crop can use the accumulated N, it has to be converted (mineralised) into plant available forms (nitrate and ammonium). Some will already be in this form, but most will need to be mineralised by microbial action after cultivation (see Box). Generally, the organic forms of N associated with the fertility-building crop can be termed ‘residue N’. It should also be noted that not all of the residue N will necessarily be fixed N – some will have derived from uptake of (a) N released from the native soil organic matter and (b) mineral N in the soil at the time of establishment of the fertility-building crop. The proportion of non-fixed N will depend on many factors, as described in the previous Sections.

Pools of N in the soil-crop system at the end of the fertility-building stage			
What	**Available?**	**Comments**	**'Typical' amounts**
Soil mineral N in the soil profile	Yes	Much of this could have derived from mineralisation of organic residues during the fertility-building stage (or from recent manure applications)	Depends on history and management of the fertility-building crop. 50-200 kg N/ha
Soil microbes	No		50-100 kg N/ha
Roots and nodules	No		50-250 kg N/ha
Leaf litter	No	At various stages of decay. Comes from either natural leaf drop or cutting and mulching the fertility-building crop. Could also be straw residues if the crop has been harvested and removed from the field (e.g. peas/beans)	10-50 kg N/ha
Stubble & foliage.	No		50-100 kg N/ha
Manure residues	No	If manure has been applied recently or the crop has been grazed	100-200 kg N/ha
Native soil organic matter	No	Amount depends on long-term inputs and soil texture	2-5 t/ha

Nitrogen release

Nitrogen mineralisation is performed by soil micro-organisms when they use organic N compounds as energy sources.

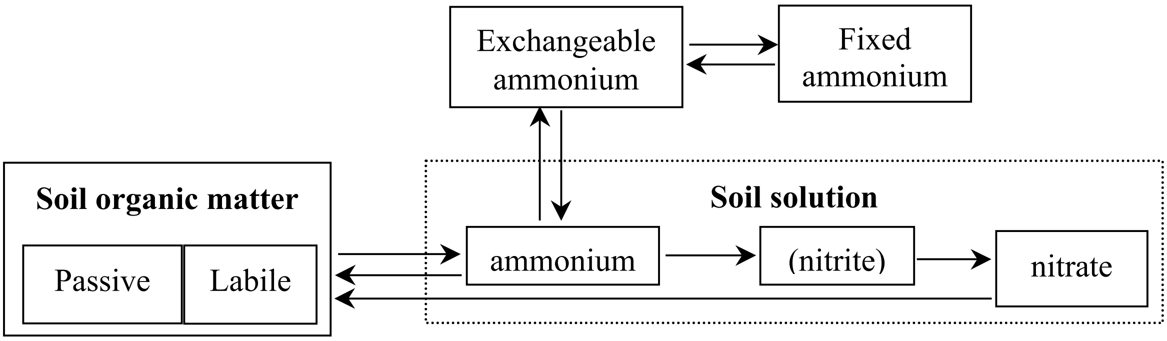

Figure 4 **Transformations between forms of N carried out by soil processes.**

Plant available N is a by-product of microbial degradation (that in the soil solution pool in Figure 4). Many factors affect rate of mineralisation, some of which are controllable by the land manager, but others are not:

Temperature and moisture

The most important environmental factors controlling soil N release, because of their effects on microbial growth and activity.

Biological 'health'

Relatively little work has been done on the effects of soil organisms on the mineralisation of organic matter; intuitively, we might expect that a diverse and active population of soil organisms would be more effective. Earthworm activity increases N release by increasing soil mixing (which increases contact between residues and the soil microbial population). Protozoa and nematodes may also enhance N mineralisation and recycling.

Soil texture

The proportion of physically protected organic matter increases with increasing clay content of the soil, because more is located in small pores and is adsorbed on clay surfaces. This reduces contact between residues and micro-organisms.

Soil physical condition

Good soil structure will allow good soil aeration and minimise water logging, which will benefit microbial activity and N mineralisation.

Soil disturbance

Cultivation practices affect SOM turnover because of the dramatic changes to the physical, chemical and biological interactions within the soil following ploughing. Intensive cultivation increases soil porosity and temperature and decreases the stability of soil aggregates. The physical disruption of SOM by ploughing often enhances net N mineralisation as a result of increasing aerobicity and exposure of organic matter to microbial decay. Together, these result in decreases in SOM content and water holding capacity.

Type of residue

The chemical and physical quality of the returning residue has a large influence on the rate of decomposition. This is discussed in more detail below.

The importance of residue type

Crop residues will break down and release N at different rates; much will depend on the chemical and physical properties of the residue. A key factor is the C:N ratio of the crop residue (see Green Manure section), which influences the rate of decomposition and nutrient availability. In some cases, the C:N ratio might be too simplistic a measure of degradability because it does not always reflect the accessibility of the C and N to the microbial population. For example, residues with a high lignin content will be difficult to break down. Therefore, although native soil organic matter and compost have narrow C:N ratios (and might be expected to 'mineralise'), these materials are well humified and are difficult to break down further.

Predicting N release

There is no simple way to predict N release from fertility building crops. Look-up tables, computer models and soil tests have all been used. Recommendations within this booklet are based on recent experiments, scientific literature and computer models.

Crop uptake

Nitrogen released from the fertility building crops provides N for plant uptake. Whereas fertiliser-N is applied to the soil surface, the supply of N from incorporated residues, etc. is more evenly distributed within the plough layer. Plants for organic systems may therefore require a more extensive rooting system with the ability to take up nutrients at low concentration. Typical values for the amount of N removed from the soil in a range of harvested crops are shown in Table 3. Although they are a guide to the overall N balance of the soil, these values are not a measure of the total N uptake or requirement of the crop.

Table 3 **Typical Nitrogen offtake by common crops.**

Crop	Harvested yield (t/ha)	N content (kg/t)	Crop offtake (kg/ha N)
Rye (grain)	3.8	15	57
Wheat (grain)	4.0	15	60
Winter barley (grain)	4.0	20	80
Spring barley (grain)	3.5	18	63
Oats (grain)	4.1	17	70
Cereal straw	3-4	5	10-20
Field beans	3.2	43	138
Carrots	30	2	60
Potatoes (main crop)	28	4.5	126
Potatoes (early)	15	3	45
Cabbages	30	3.5	105
Grass/clover silage (* dry weights)	10*	25*	250

Temporal patterns of N uptake by the crop may be particularly important in organic systems where N is released gradually by mineralisation of organic matter. For example, maximum potential uptake of N by winter wheat occurs in spring when soils are only beginning to warm and mineralisation is still slow (Figure 5). This is likely to limit the supply of N at a critical time for wheat crops on organic farms. Mycorrhizal fungi have been shown to absorb and translocate both N and P nutrients to the host plant; however, because nitrate is more mobile in the soil than phosphate, this is of less importance for N than for P nutrition.

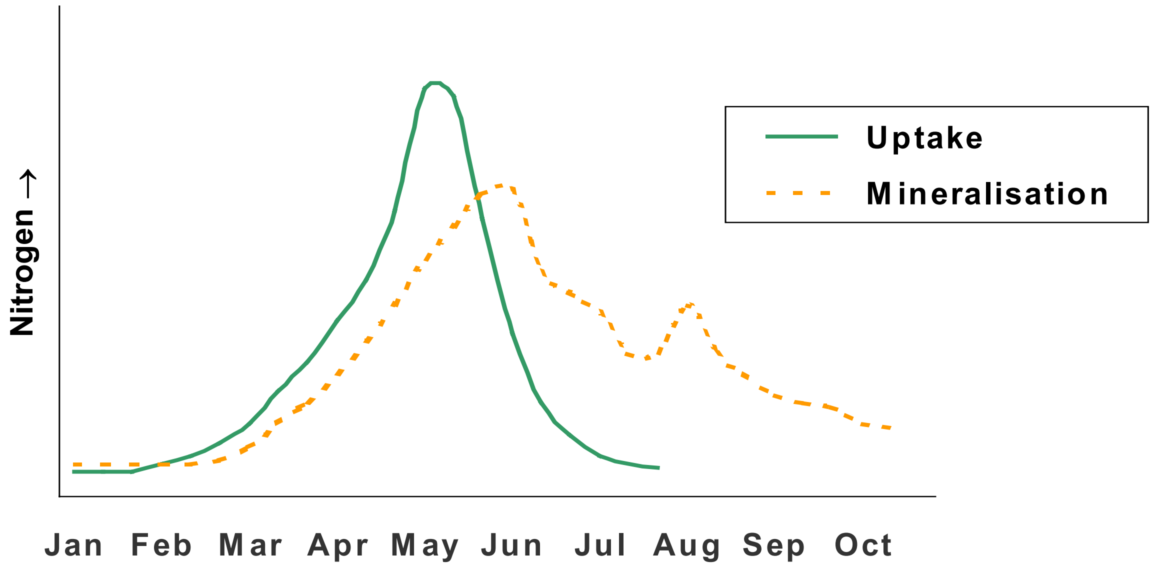

Figure 5 **The timing of N release by mineralisation and uptake by a winter wheat crop.**

Nitrogen loss

Once mineralised, N is also susceptible to loss from the soil and it is important that as much as possible is retained for use by the crop. Losses occur mainly through nitrate leaching and, sometimes by ammonia volatilisation and denitrification.

- Losses of N as ammonia can be large following manure application (but can be controlled by rapid incorporation of the manure) or during deposition of excreta during grazing. These losses represent a loss from the farming system and from the soil fertility-building crop either indirectly (if loss is from manure produced by feeding the crop as fodder) or directly (if grazing the fertility-building crop).
- Denitrification losses can also be large, particularly in warm moist soils following incorporation of N-rich residues or manure.
- Nitrate leaching occurs predominantly during the autumn/winter. Nitrate losses can therefore be large if the fertility-building crop is ploughed in the autumn. Autumn manure applications (particularly those with a high mineral N content) also risk substantial loss after an autumn application.

Practical approaches to conserving N for crops

Look upon the N captured during the fertility building phase as a valuable resource. Manage rotations to maximise use of this N. Some factors to consider include:

- Timing of cultivation of ley – spring *vs* autumn breaking of ley though this can have practical applications.
- Cropping patterns to make best use of N – match crops with a high N demand with positions in the rotation that supply N; green cover; use of fertility boosting crops.
- Maintaining good soil structure and pH.
- Manure use – consider if it is being supplied at the right point in the rotation, *e.g.* not at a point with an already large N supply (unless P & K required – then use low N manure).

Other management factors

In this section we will take a brief look at the other agronomic factors such as acidity, and other nutrient and weed/pest/disease problems that can affect growth of nitrogen fertility builders and the following crops.

Soil pH

Not only will the yields of most cash crops and fertility building legumes be reduced by soil acidity but N-fixation is also impaired if legumes are not grown at the correct pH. Generally, rhizobial growth/activity appears to be more sensitive to low soil pH than that of the host plant. However, some legumes, notably various Lupin species, prefer a lower pH (<pH 6) especially in heavy soils.

Phosphate and Potash

Where the growth of legumes is affected by nutrient deficiency (or acidity) the potential for soil N build up is reduced. Thus, it is necessary to supply adequate phosphate and potash to ensure satisfactory growth of legumes, particularly where the offtake of soil nutrients is large, as in harvested silage crops, root crops or intensive field scale vegetable production (Table 4).

Example

Winter wheat yields 5 t/ha of grain. The straw is baled and removed from the field.

Phosphate offtake = 5 x 8.6 = 43 kg/ha P_2O_5

Potash offtake = 5 x 11.8 = 59 kg/ha K_2O

Table 4 Phosphate and Potash in Crop Products

Crop	Harvested product	Phosphate (P_2O_5)	Potash (K_2O)
		kg/t of fresh material	
Cereals	Grain only (all cereals)	7.8	5.6
	Grain and straw		
	- winter wheat/barley *	8.6	11.8
	- spring wheat/barley *	8.8	13.7
	- winter/spring oats *	8.8	17.3
Peas	Dried	8.8	10.0
	Vining	1.7	3.2
Field beans		11.0	12.0
Potatoes		1.0	5.8
Grass	Fresh grass (15-20% DM)	1.4	4.8
	Silage (25% DM)	1.7	6.0
	Silage (30% DM)	2.1	7.2
	Hay (86% DM)	5.9	18.0
Kale		1.2	5.0
Maize	Silage (30% DM)	1.4	4.4
Swedes	Roots only	0.7	2.4
Broad beans		1.6	3.6
French beans		1.0	2.4
Beetroot		1.0	4.5
Cabbage		0.9	3.6
Carrots		0.7	3.0
Cauliflowers		1.4	4.8
Onions	Bulbs only	0.7	1.8
Sprouts	Buttons	2.6	6.3
	Stems	2.1	7.2

(* Offtake values are per tonne of grain or seed removed but include nutrients in straw.)

On organic farms, these nutrients are most likely to be supplied as animal manures (Table 5). As these materials also contain N, their use may cause short-term inhibition of N–fixation in any legume and in the longer term reduce clover contents in mixed swards. These effects will be less with FYM and composts than with slurry and poultry manure which generally contain a higher proportion of readily-available N

Table 5 **Typical total phosphate and potash contents of livestock manures on organic farms (fresh weight basis).**

Manure type	Dry matter (%)	Total phosphate	Total potash
		kg/t	**kg/t**
Cattle FYM	25	3.1	6.6
Pig FYM	25	6.1	6.5
		kg/m^3	**kg/m^3**
Cattle slurry	6	0.8	2.3

(Values of potash may be lower for FYM stored for long periods in the open)
(To convert kg/t to units/ton, multiply by 2. To convert kg/m^3 to units/1000 galls, multiply by 9)

Key points

- Balance P and K-offtakes and get most benefit from the manure N content by applying livestock manures to non-legume crops in the rotation.
- Clover competes poorly with grass for soil nutrients and therefore needs a plentiful supply of nutrients other than N when grown in a mixed swards.

Pests and Diseases

Fertility building crops are subject to pest and diseases, which can reduce their effectiveness at increasing soil N supply, there is also a risk of carry-over into the following cash crop, so rotations need to be planned carefully. Consider cropping history and previous pest and disease problems before selecting fertility building crops. For example soil-borne pest and disease risk is increased by selecting fertility building crops of the same ‘type’ as arable or vegetable cash crops. *i.e.* cruciferous, brassica or legume families (Susceptible crops grown in fields where there are already soil-borne disease problems). It is also wise to think about the crops being grown in neighbouring fields and farms. Maintaining a green cover in the autumn (either through early drilling or use of cover crops) to minimise leaching losses increases the risk of some pests and diseases that spread to nearby crops.. Good soil management and drainage are important factors in reducing threat from soil-borne diseases and cultivation techniques can minimise the impact of some soil pests such a slugs, leatherjackets and wireworms. Bi-cropping or companion cropping can reduce pest and disease severity through physical presence and possibly also alleopathic effects.

Key pest issues

- Mixed grass clover swards are prone to damage by slugs, leatherjackets and wireworms, and to a lesser extent by frit fly
- Clover can be affected by stem nematodes, slugs and weevils.
- Peas and beans can be affected by stem nematodes, weevils, cyst nematodes (peas only) and aphids.
- Slug, leatherjacket and wireworm problems will carry-over into most cash crops.

Key disease issues

- Where possible maintain a five year gap between similar crops to prevent build up of soil borne diseases such as legume foot rots (*Fusarium* spp., *Pythium* spp., and *Phoma medicaginis) and club root in crucifers*
- Don't use cover crops in the rotation which are of the same type as cash crops.
- Good soil conditions can reduce the impact of soil borne diseases
- A high soil pH can reduce to impact of club root in brassicas
- Soil incorporation of green manures may have a suppressive or antagonistic effect on soil- or air-borne pathogens

Weeds

Weed populations vary with soil type and are affected by the crops in the rotation. Perennial weeds (*e.g.* grass and creeping thistle) can cause trouble in stockless organic systems and charlock, docks and cleavers are often reported as significant problems. There can also be difficulties with self sown fertility builders, for example, vetch flowers early in Cornwall so must be incorporated earlier than in the north, to prevent seeding and volunteer growth. Weed control in organic farming has recently been reviewed in a Defra funded project

(OF0315) which has its own website for information:
(http://www.gardenorganic.org.uk/organicweeds/index.php).

Key weed issues

- Plan rotations to include a mix of annual and perennial crops and also autumn and spring germinating crops.
- Dense crops shade out weeds; good seedbed conditions and soil structure encourage crop development, also try longer strawed varieties of cereals.
- Use mulches to inhibit germination of annual weeds.
- Use stale seedbeds or open crops like maize as an opportunity to encourage weed germination and then kill them by cultivation.

Estimating the amount of nitrogen available during the rotation

The previous sections indicate the many factors that have to be considered when planning a cropping rotation to make the most efficient use of the N that is available. In this planning, it is usually necessary to look at the whole rotation because the available N in one year will be largely determined by what happened in the previous years.

Handling this level of complexity and the need to calculate N flows over a number of years is something that is particularly well-suited to computer models (decision support systems). A number of models of N accumulation and N release are under development: however, none is fully tested or widely available. In the absence of a suitable model, this booklet summarises its advice in a number of look-up tables (Tables 6 - 9) and a simple flow diagram (Figure 6) to guide the user through the calculation steps necessary to estimate:

- the amount of N accumulated during the ley phase of the rotation
- the N available to following crops and the likely yields under this level of N supply.

This form of presentation has to adopt a simplified approach, and we only include a restricted range of cropping options.

How to use the tables

The calculations are performed by following the steps in the flow chart shown in Figure 6. This assumes that the rotation starts with a ley phase, which is followed by up to four years of arable cropping. Year 1 is the first year of arable cropping. The calculation process may appear complicated, but this reflects the complexity of N cycling through the rotation. We have tried to make it as simple as possible and include instructions and a worked example. It is intended that Table 10 should be photocopied and the copy used for entering the results of each stage of the calculation and for calculating the final results. As a guide, Table 10 also includes a worked example for the first year of the rotation described in the “Example Box .”

The starting point is an estimate of the amount of N released from the ley in the first year after cultivation. Typical amounts are shown in Table 6. Starting at the top of Figure 6 and working through each step in turn, the various stages are as follows:

Step 1. Select the appropriate type and age of ley in Table 6 and look up the soil N (SN) supplied by the ley in Year 1. Enter this as S1 in the second row of Table 10. In Year 1, there is no N from the previous year, so there is a zero value for “Y” in the first row of the table.

Step 2. Is manure applied? If 'yes', refer to Table 7 to find the amount of N supplied per tonne of manure and multiply by the weight applied. Enter this as "M." Alternatively, the computer model MANNER could be used to provide a more accurate estimate of "M." The next stage of SN supply, "B," is equal to A + M. If no manure is applied, B = A.

Step 3. Refer to Table 3 to find the total N uptake ("U") for the crop at the maximum expected yield and compare this with the soil N that is available ("B"). If "U" is greater than "B," there is not enough soil N available to support this level of growth and it will be necessary to increase the amount of manure applied or to return to Table 8 and select a lower yield at which "U" is less than "B." Use this yield to select the correct column in Table 8 to look up the amount of N obtained by biological fixation. This will be zero for non-legumes. In the same column, look up the N removed in the crop at harvest ("H"), selecting the appropriate row for whether or not straw is removed from the field. The Year 1 Soil N balance is calculated as B + F - H.

Example Box

First year after cultivating the ley

Sandy soil. Annual rainfall 680 mm

Ley: 3-year white clover/grass ley, grazed, medium clover content

Manure: old FYM, 5 t/ha applied in August

Crop: winter wheat (expected yield 4.5 t/ha)

Straw removed after harvest

Step 4. Refer to Table 9 to calculate the N leached from the soil. This requires separate calculations of that leaching from soil N and that from crop residue N sources. Together, these are equal to the potential N leaching ("L"). If there is no crop in the ground over winter, the actual loss will be equal to "L." If there is a winter crop or catch crop sown before late September, this will take up some of the N and reduce the amount leached. In this case, assume that the leaching loss is L - 25, where "L" is the loss as calculated above. If "L" is less than 25, so that L-25 is negative, enter the leaching loss as zero. Subtract the amount leached from "B" to obtain the soil N supply at the end of winter ("C").

Step 5. Continue the calculations for Year 2. In Table 10, copy the value of "C" to the first box in the column for Year 2. Add the amount of N released from the ley residues in the second year after cultivation (S2 from Table 6) to obtain soil N supply "A." From here, repeat the stages for manure and crop uptake as described for the first year to obtain the Soil N balance ("Y") after harvest in Year 2.

Step 6. From this point, return to Step 4 to calculate the leaching loss and the end of winter soil N ("C") for Year 2. In Table 10, copy this value to the first box in the next column and repeat the calculations for Year 3, adding the amount of N supplied by the ley in Year 3 (Table 6). Similarly, repeat the steps for Year 4.

Figure 6 **Flow diagram showing the stages in calculating the N available to crops in the first and second years after cultivating the ley.**

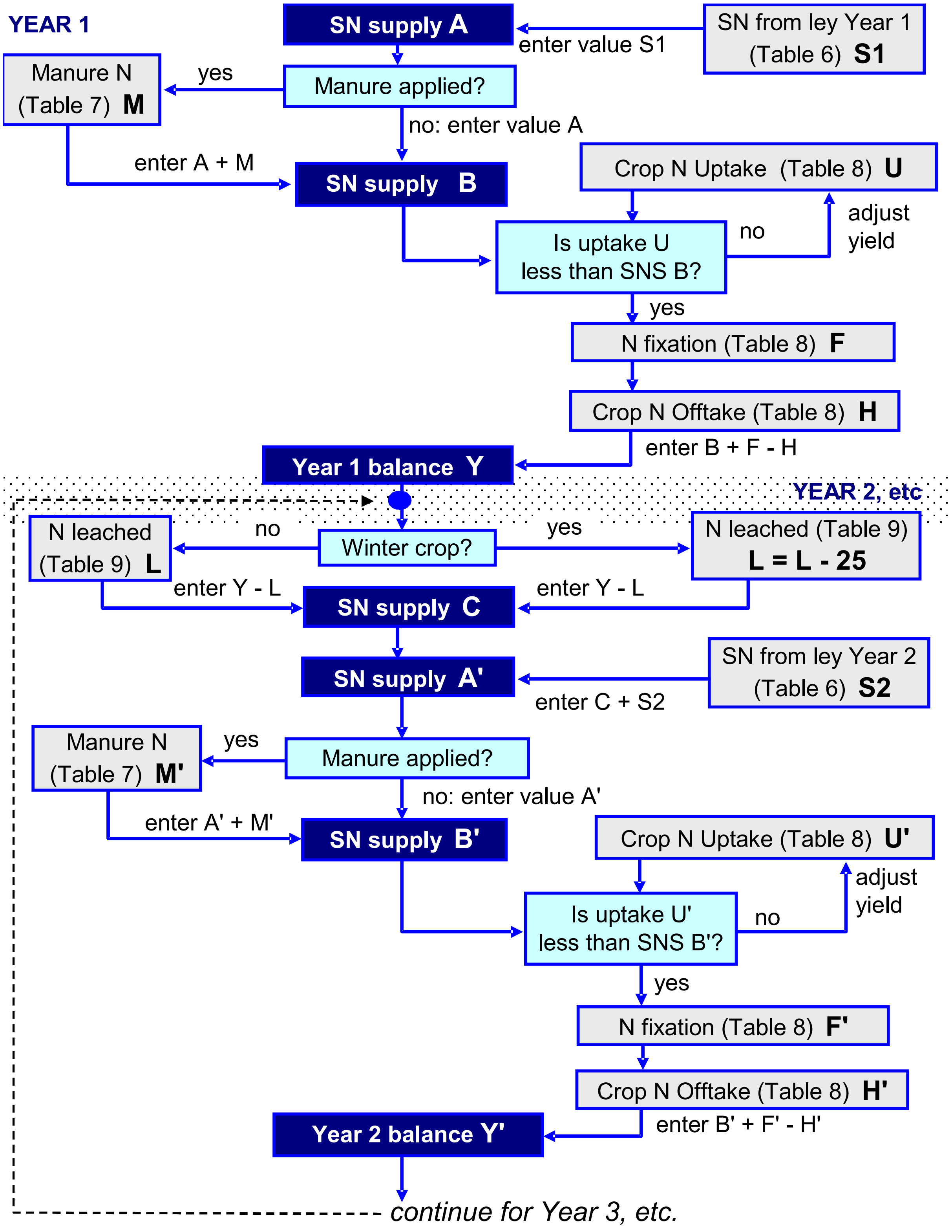
YEAR 1
SN supply A
SN from ley Year 1 (Table 6) S1
enter value S1
Manure N (Table 7) M
yes
Manure applied?
no: enter value A
enter A + M
SN supply B
Crop N Uptake (Table 8) U
Is uptake U less than SNS B?
no
adjust yield
yes
N fixation (Table 8) F
Crop N Offtake (Table 8) H
enter B + F - H
Year 1 balance Y
YEAR 2, etc
N leached (Table 9) L
no
Winter crop?
yes
N leached (Table 9) L = L - 25
enter Y - L
SN supply C
enter Y - L
SN supply A'
SN from ley Year 2 (Table 6) S2
enter C + S2
Manure N (Table 7) M'
yes
Manure applied?
no: enter value A'
enter A' + M'
SN supply B'
Crop N Uptake (Table 8) U'
adjust yield
Is uptake U' less than SNS B'?
no
yes
N fixation (Table 8) F'
Crop N Offtake (Table 8) H'
Year 2 balance Y'
enter B' + F' - H'
continue for Year 3, etc.

Table 6 **Nitrogen released from different leys in Years 1 - 4 after cultivating the ley (kg N/ha/year)**.

Age of ley and clover content of grass/clover leys	**Herbage cut and removed**				**Grazed**				**Mulched**			
	Year 1 S1	Year 2 S2	Year 3 S3	Year 4 S4	Year 1 S1	Year 2 S2	Year 3 S3	Year 4 S4	Year 1 S1	Year 2 S2	Year 3 S3	Year 4 S4
2-year ley												
- low clover	72	58	46	41	104	64	48	42	127	71	52	44
- medium clover	105	66	49	43	140	73	52	44	161	79	55	46
- high clover	124	67	50	43	150	71	52	44	171	79	55	46
- pure clover	114	60	47	41	123	61	47	41	152	71	51	44
3-year ley												
- low clover	89	63	49	42	134	73	52	44	155	80	55	46
- medium clover	127	73	52	44	171	81	56	46	191	87	59	48
- high clover	142	73	52	44	180	79	55	46	199	86	59	48
- pure clover	124	63	48	42	140	65	49	42	168	75	53	45
4-year ley												
- low clover	105	69	51	44	153	79	55	46	179	87	59	48
- medium clover	132	74	53	45	179	83	57	47	206	92	61	49
- high clover	148	74	53	45	187	81	56	46	215	91	61	49
- pure clover	126	64	48	42	144	66	49	43	176	77	54	45

Low clover: average of less than 20% clover in the sward over the season (by visual assessment)

Medium clover: average of 20 - 50% clover in the sward over the season

High clover: average of more than 50% clover in the sward over the season

Table 7 Quantities of N supplied to the following crop from different types of manure.

Manure type	Dry matter %	N available to next crop (kg/t)				
		Autumn (Aug-Oct)		Winter (Nov-Jan)		Spring (Feb-Apr)
		Sandy /shallow	Other mineral	Sandy /shallow	Other mineral	All soils
Surface application (not incorporated)						
FYM - fresh	25	0.3	0.6	0.6	0.9	1.2
FYM - old or Compost	25	0.3	0.6	0.6	0.6	0.9
Cattle slurry	6	0.1	0.3	0.4	0.6	0.7
Poultry manure	30	1.6	3.2	2.4	4.4	5.2
Incorporated within 24 hours after application						
FYM - fresh	25	0.3	0.6	0.9	1.2	1.5
FYM - old or Compost	25	0.3	0.6	0.6	0.9	1.2
Cattle slurry	6	0.1	0.3	0.4	0.7	0.9
Poultry manure	30	1.6	4.0	3.2	6.4	7.6

Available N (kg/ha), M = available N (kg/t) from table x application rate (t/ha)

Table 8 **Nitrogen uptake and N removed at harvest for different crop yields, and the amount of N fixed by bean crops (all in kg N/ha).**

Winter wheat									
Yield (t/ha)	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0
N uptake (G)	53	66	79	93	106	119	132	159	185
N offtake (H)									
- grain only	35	44	53	62	70	79	88	106	123
- grain + straw	41	51	62	72	82	92	103	123	144
Spring barley									
Yield (t/ha)	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0
N Uptake (G)	40	54	67	81	94	108	121	135	162
N offtake (H)									
- grain only	26	34	43	51	60	68	77	85	102
- grain + straw	29	38	48	58	67	77	87	96	115
Triticale									
Yield (t/ha)	2.0	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0
N Uptake (G)	66	100	116	133	149	166	183	199	232
N offtake (H)									
- grain only	40	60	70	80	91	101	111	121	141
- grain + straw	48	73	85	97	109	121	133	145	170
Potatoes (maincrop)									
Yield (t/ha)	20	25	30	35	40	45	50	55	60
N Uptake (G)	84	104	125	146	167	188	209	230	251
N offtake (H)	67	84	101	118	134	151	168	185	202
Onions (maincrop)									
Yield (t/ha)	10	15	20	25	30	35	40	45	50
N Uptake (G)	33	50	67	84	100	117	134	151	167
N offtake (H)	19	28	38	47	57	66	76	85	95
Winter beans									
Yield (t/ha)	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0
N Uptake (G)	37	49	61	74	86	98	110	123	147
N fixation (F)	72	96	120	144	168	193	217	241	289
N offtake (H)									
- grain only	54	73	91	109	127	145	163	181	218
- grain + straw	85	113	142	170	198	227	255	283	340

Table 9 **Calculation of the amount of soil N and N from crop residues available for leaching during the winter (kg N/ha).**

Soil type	Annual rainfall (mm)		
	Low (<600 mm)	Moderate (600-700 mm)	High (>700 mm)
Proportion of soil N leached, *p1*			
sandy/shallow soils	0.60	0.75	0.75
medium soils	0.15	0.40	0.55
clay soils	0.05	0.25	0.40
Proportion of N leached from crop residue, *p2*			
Cereal residues			
sandy/shallow soils	0.12	0.15	0.15
medium soils	0.03	0.08	0.11
clay soils	0.01	0.05	0.08
Potato and onion residues			
sandy/shallow soils	0.23	0.29	0.29
medium soils	0.06	0.16	0.21
clay soils	0.02	0.10	0.16
Bean residues			
sandy/shallow soils	0.22	0.27	0.27
medium soils	0.05	0.14	0.20
clay soils	0.02	0.09	0.14

N leached from soil N	L1 = soil N x *p1* = (B – U) x *p1*
N leached from residue	L2 = residue N x *p2* = (U + F – H) x *p2*
Potential N leached	L = L1 + L2

Table 10 Calculation stages for estimating the N available (kg N/ha) during the arable phase of an organic farming rotation

Calculation stages	**Formula**	**Example (see Box 1)**	**Year after cultivation of ley**			
			Year 1	**Year 2**	**Year 3**	**Year 4**
N from previous year	Y	0	▨			
N from ley (Table 6)	S	###				
Soil N supply	A = Y + S	###				
Manure N (Table 7)	M	###				
Soil N supply	B = A + M	###				
Crop N uptake (Table 8)	U	###				
N fixation (Table 8)	F	###				
N removed in crop (Table 8)[1]	H	###				
Year balance	Y = B + F - H	###				
N leaching, L1 (Table 9)	L1 = (B – U) x *p1*	###				
N leaching, L2 (Table 9)	L2 = (U + F – H) x *p2*	###				
Potential leaching	L = L1 + L2	###				
Actual N leached[2]	L or (L - 25)	###				
End of winter Soil N	C = Y - N leached	###				

[1] Select value from the appropriate column in Table 3 depending on whether or not straw is removed from the field. [2] If no winter crop or poorly developed crop over-winter, N leached = L. If crop or catch-crop sown in autumn, N leached = L - 25 (NB If L - 25 is less than zero, set N leached as 0)

CAUTION: Because of the much-simplified method of calculation, which cannot take account of all the factors influencing N accumulation and release, these estimates should only be used as a very approximate guide to the amount of N that is likely to be available to crops.