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A review of the use of organic manures on lowland grassland pastures in the UK

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A review of the use of organic manures on lowland grassland pastures in the UK

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Glossary of Terms

FYM	Solid manure consisting of animal excreta incorporated with bedding material, usually straw, which has been stored to allow some rotting prior to spreading on land.
Hay meadow	Grassland where grazing animals are excluded for part of the year in order to grow a crop of herbage for hay.
Inorganic	Mineral composition, with no organic content
K or K_2O	Potassium or potash.
Mg or MgO	Magnesium or magnesium oxide.
N	Nitrogen.
P or P_2O_5	Phosphorus or phosphate.
Pasture	Grassland which is grazed by livestock but not "shut up" for part of the year for hay production.
S or SO_3	Sulphur or equivalent amount of sulphur expressed as sulphur trioxide.
Slurry	Semi-fluid mixture of animal faeces and urine deposited in buildings where livestock (principally cattle, pigs and poultry) are housed with little or no bedding material. Slurry is normally stored before field spreading.

Executive Summary

Current guidelines from English Nature recommend the use of farmyard manure (FYM), but not other organic manures, in some semi-natural grasslands, to prevent longer term nutrient depletion and loss in productivity, but only where grass is cut for hay and only where there is a history of FYM use. These restrictions are designed to prevent the risk of undesirable changes in botanical composition and are based upon the assumption that this risk is greater where applied nutrients are recycled through grazing animals. However, some net loss of nutrients might be expected over time through the removal of nutrients via animal production, although such possible effects would vary with livestock enterprise. Nutrient inputs from atmospheric deposition and any supplementary feeding, together with nutrient losses from the soil, will influence nutrient cycling processes and the overall nutrient budget in pasture ecosystems. The current guidelines for pastures require further research and, as a first stage in addressing this issue, English Nature commissioned a review of existing information on organic manure use on lowland pastures in the UK. As such information is limited, the review has also summarised data from studies on more intensive grassland production and considered the relevance of those findings to semi-natural swards.

This review covers a range of topics, including:

- current advice/prescriptions for organic manure use on semi-natural swards;
- current and past manure practices on grassland;
- major nutrient and heavy metal contents of different manure types;
- current legislation and codes of agricultural practice relating to manures;
- nutrient cycling and budgets in pasture systems;
- the impact of manures on pasture species composition and sward structure.

The review also considers the possible interaction between manure use and liming, manuring practice on horse pastures, and the possible effects that the cessation of the traditional practice of folding sheep from chalk grassland onto arable land may have had on nutrient cycling in downland. Predicted effects of organic manure use on species composition in semi-natural pastures are discussed from the findings obtained and recommendations given for future research requirements.

English Nature guidelines in the Lowland Grassland Management Handbook imply that no manures at all should be applied to semi-natural pasture. Prescriptive advice for semi-natural grassland in most of the UK agri-environment schemes is also based on the general premise that organic manures can be used only in some limited circumstances. However, agri-environment scheme advice in England is diverse, particularly for different tiers within ESAs, ranging from total prohibition of manure application to allowing relatively high application rates of both slurries and manures on semi-improved, wet grasslands. Limited information suggests that about a third of existing semi-natural pastures at Sites of Special Scientific Interest have some history of FYM use, principally related to hay cutting practice.

In some areas, there is a trend towards slurry, instead of FYM use, or for manure to be spread straight after winter housing without storage in heaps which allows further rotting before spreading. The limited availability of well rotted FYM, for use on semi-natural grassland, is expected to become an increasing problem. Application rates for FYM on improved grassland are typically around 20 t ha^{-1}, which corresponds to the maximum rate for a single dressing recommended once every three to five years by English Nature for semi-natural grassland, since higher rates can cause sward smothering and prolonged herbage contamination. Mechanical FYM spreaders must chop the manure well and produce a good spread pattern in order to obtain even coverage, less risk of sward smothering and rapid breakdown after spreading. A period of least six to eight weeks should be left between FYM application and subsequent grazing, to allow sufficient time for the manure to break down. Although manures are, to some extent, applied throughout the year on improved agricultural grassland, FYM is usually applied to semi-natural grasslands either in autumn or, more often, in early spring, apart from some northern hay meadows where the tradition is to apply in April-May. The nitrate leaching risk from autumn applied FYM is small, because of the low available N content.

Use of other manure types is generally not permitted on semi-natural grassland, because of their high available nutrient content and likely adverse effect on sward species composition. Poultry manure use on improved grassland is, in any case, very small because of limited supplies and, although sewage sludge recycling to land is increasing, the restrictions imposed by the recently agreed 'UK Safe Sludge Matrix' effectively rule out any potential use of treated sewage sludge bioproducts on semi-natural grassland. However, new developments in application techniques provide scope for more accurate and uniform spreading of slurry at low rates, with reduced ammonia losses compared to conventional broadcasting. These developments could improve the suitability of slurries for use on semi-natural grassland, where appropriate. Cattle slurry application rates of 25-30 m^3 ha^{-1} are generally used for improved grassland under grazing management, where a minimum grazing interval of two to three weeks, and ideally at least six weeks, should be left after slurry application.

Both frequency and individual rates of manure application should be adjusted to take account of the available nutrient content supplied, based on laboratory analysis of representative samples or typical nutrient values. Heavy metal loadings from manure applications to semi-natural grassland are very small and well within acceptable limits for both herbage and livestock production (assuming no direct ingestion by grazing livestock). Manure spreading in accordance with the Codes of Good Agricultural Practice will reduce the risk of nutrient (nitrogen (N) and phosphorus (P)) pollution from losses to air and water, and will also help to minimise any possible risk of pathogen transfer.

Atmospheric deposition supplies some N and sulphur (S) (which also, particularly S, have an acidifying effect on ecosystems), but only small or negligible amounts of other major nutrients (calcium (Ca), magnesium (Mg), P and potassium (K)). Nitrogen deposition, which is on average about 14 kg N ha^{-1} year^{-1} across the UK but can exceed 30 kg N ha^{-1} year^{-1} in some areas, leads to N enrichment which can result in the competitive exclusion of species characteristic of semi-natural grassland, by nitrophilic plants. High levels of N deposition may cause more nitrate leaching in soils which are highly P limited and consequently unable to fully utilise this N source. Sulphur deposition has decreased appreciably since the late 1960s and will continue to decline over the next few years, particularly in lowland areas of the UK. Atmospheric deposition of N and, to a lesser extent, S, contributes to nutrient cycling in semi-natural pastures, but very low deposition rates of P and K are unlikely to be significant. Nutrient losses by gaseous emissions, leaching and/or surface runoff, and also nutrient immobilisation effects, are likely to be very small for semi-natural pastures, compared to more intensively managed grassland.

Nutrient budgeting, based on inputs and outputs at a field scale, may suggest that very gradual nutrient depletion could occur in grazed only semi-natural pastures as a result of nutrient removal in livestock production, although specific data are very limited. Further information is needed but it is tentatively suggested that, in this situation, an application of 20 t ha^{-1} FYM once every five to ten years might be necessary to prevent long term nutrient depletion.

Maximum species diversity in grasslands is theoretically predicted to occur at intermediate levels of both fertility and disturbance. Existing information suggests that, under hay cutting at least, FYM is generally less damaging to botanical diversity than equivalent rates of inorganic fertiliser, though this remains to be confirmed in current work. However, little information is available on the effects of organic manures on the conservation value of pastures managed solely by grazing. Manure application may interact with liming, carried out to reduce soil acidity, to cause undesirable changes in the botanical composition of semi-natural grassland. This subject is under study in current research in hay meadows. Little work has been done on the use of slurry in semi-natural grassland, either under cutting or grazing management. The very limited information available suggests that slurry may be more damaging than FYM at approximately equivalent rates, but no reliable comparisons between slurry and inorganic fertilisers in semi-natural vegetation appear to have been published.

The effects of fertilisers on botanical composition are evident under both grazing and cutting, though the individual species responses are often different between the two types of defoliation management. The usual effect under both management regimes is an increase in the total grass component. When inorganic N is applied, the increase in grasses is usually at the expense of both forbs and legumes with an overall loss in species diversity, but with FYM these effects have been less consistent between studies. The addition of P and K, with little or no N, usually increases the legume content of vegetation and can lead to a build-up of soil fertility, particularly under grazing, due to nutrient recycling. Limited evidence suggests that fertilisers have more effect, per unit of nutrient applied, under grazing management than under hay cutting, presumably due to the recycling of nutrients that occurs with grazing.

Grazing *per se*, compared to cutting only or no defoliation, is favourable for species-richness at low-moderate soil fertility levels but exacerbates the adverse effects of higher fertility levels on sward biodiversity. Grazing by horses and ponies can be consistent with management for wildlife conservation but requires careful management, which often involves the regular removal of dung to avoid the formation of latrine areas. FYM application in these circumstances, and the resulting increase in grass growth, may create further difficulties for grazing management and the maintenance of plant species diversity, by increasing the total area occupied by latrine areas. Sheep folding from chalk downland was traditionally used to raise fertility within a small area of, usually arable, land, through the transfer of nutrients in faeces. However, little information is available on the influence of its cessation on either the botanical composition or soil fertility level of the downland.

More data are needed to test the hypothesis that the use of external nutrient inputs may be less sustainable under grazing than under cutting management, due to the return of nutrients to the soil in largely plant-available form by grazing animals. In the meantime, the more cautious approach of not allowing organic manures to be used in grazed pastures of high conservation value should be continued. FYM use is most likely to be beneficial in sites on light or shallow soils with depleted nutrient and organic matter status. Where these conditions occur in ex-arable situations, the use of FYM may be consistent with the establishment and subsequent maintenance of wildflower seed mixtures.

1. Introduction

English Nature has identified a need for further research to determine whether current precautionary advice, which precludes the use of organic manures on all types of semi-natural pastures, is the correct approach to adopt to avoid any risk of adverse botanical change under grazing management. As a first stage in addressing this issue, English Nature commissioned this review of existing information on organic manure use on lowland pastures in the UK.

The key subject areas addressed by this review are:

- the use and impact of organic manures on all types of lowland grassland managed as pasture, including improved grasslands;
- nutrient removal from pastures through livestock production, management and nutrient cycling, nutrient losses and immobilisation in pastures;
- current advice/prescriptions for organic manure use on semi-natural swards.

Review methodology

An extensive search of published agricultural and ecological literature, scientific papers and reports from the UK and north-west Europe was undertaken, covering the following specific areas:

- current use of organic manure/slurries on pastures (including farmyard manure from cattle housing, pig manure, poultry manure, animal slurry, sewage sludge and horse manure) including typical rates, frequency, timing and methods of application;
- historical context - changes in practice through time;
- the nutrient contents of the different types of manures with particular emphasis on macro-nutrients (N, P, K);
- the impact of different manures (including different rates) on pasture species composition and sward structure;
- nutrient budgets - losses and gains to pasture systems;
- nutrient cycling in pastures including off-take (animal products) and return (dung and urine) of nutrients from livestock rearing on pastures including a contrast with hay meadows;
- the contribution of nutrients from atmospheric deposition and its implications;
- the interaction of organic manure use with liming;
- the traditional practice of folding sheep and its impacts and the effects of cessation;
- manuring practice on horse pastures;

- current advice/prescriptions for organic manure use on semi-natural swards;
- current legislation and codes of agricultural practice covering manure use.

As information on the use and impact of organic manures on semi-natural grazed grassland is limited, the review has also summarised data from studies on more intensive grassland production and considered the relevance of those findings to semi-natural swards. This approach has been backed up by data from studies where nutrient inputs have been compared in both grazed and hayed semi-natural grasslands. Relevant information from studies on upland vegetation management is also included in the review.

From the information which was collected and assessed, the review addresses the following issues:

- predicted effects of the use of organic manures on the species composition of semi-natural grasslands and the scope for modification of existing best management practice;
- the differences between pastures and hay meadows in relation to nutrient dynamics;
- future information and research requirements.

2. Current prescriptive advice for manure use on semi-natural swards

The following sections provide a breakdown of the advice provided to farmers and other land managers by a variety of sources for the use of manures on grassland and, in particular, semi-natural swards. Many of the agri-environment scheme prescriptions do not differentiate between pastures and meadows. For simplicity, therefore, any management advice thought likely to apply to pastures has been included.

2.1 General guidance

2.1.1 *Lowland Grassland Management Handbook* (Crofts & Jefferson 1999)

The 1999 Handbook (2nd edition) updates the advice contained in the 1994 edition and is the principal source of guidance for English Nature and Countryside Council for Wales staff, and others. It recommends that poultry manure and animal slurries are not applied to semi-natural grassland as there is evidence that they would cause a decline in species-richness of the sward. The advice for the use of farmyard manure (FYM) varies according to the type of grassland and the past history of manure use. In general, the use of *well-rotted* (preferably stored for 12 months or more) FYM on semi-natural grasslands is acceptable on:

- Neutral grasslands which are mown for hay (NVC communities MG3, MG5, MG11 and MG13).

- Grassland where the is a history of FYM use and no evidence of damage to the nature conservation value.

For lowland hay meadows, the Handbook recommends that application rates for FYM should not exceed 20 tonnes ha^{-1} every 3-5 years applied in a single dressing.

For MG4 flood meadows, the Handbook recommends that FYM should not be applied unless there is evidence of a deterioration of crop yield as a result of reduced nutrient importation from flooding. It suggests that if hay yields fall below about 2.5 tonnes ha^{-1} $year^{-1}$ the application of well-rotted FYM at about 20 tonnes ha^{-1} every 3-5 years is acceptable but should be reviewed alongside evidence from botanical monitoring and information relating to crop yield and flooding frequency.

FYM is usually applied to fields during the spring. On sites supporting breeding waders and wildfowl, applications should be avoided during the period 15 March to 15 July.

Following the production of the first edition of this handbook in 1994, a questionnaire was sent to local English Nature teams to assess the extent to which they were applying the available guidance on grassland management. The responses relating to the use of FYM on semi-natural pastures indicated that the majority of teams did not permit any application of FYM to pastures, particularly the infertile calcareous and acid grasslands and fen/rush pastures. This falls in line with the recommendations in the Handbook and is based on the principle that there is less off-take of nutrients from pastures, compared to meadows, due to nutrient cycling from dunging and urination. A proportion of teams (around one third) were permitting the use of FYM on neutral, more fertile MG5 and MG8 pastures, often because past use of FYM was appearing to be delivering nature conservation objectives (Jefferson & Robertson 1998).

2.1.2 *Farming and Wildlife Handbook* (Andrews & Rebane 1994)

This handbook is regularly used by farmers and others involved in countryside management decisions. It recommends that no animal slurry is used on unimproved or plant-rich pastures. There is no specific guidance for the use of manure on pastures other than, if the field remains rich in plant species, there should be no reason not to apply FYM at the same rates and frequency as in the past. The use of well-rotted manure is recommended as this will minimise the risk of introducing weed seeds into the sward. The handbook also suggests that the 'richer' nature of 'modern' manure should be taken into account when comparisons with traditional application levels need to be made.

For meadows, the Handbook recommends applying manure 'at the traditional rates where this has been done in the past.' Again, the use of animal slurries in unimproved meadows is not recommended.

On grasslands where the objective is to provide alternative feeding areas for geese or other grazing wildfowl, the use of manures (or artificial fertilisers) can help to create a lush, nutritious sward. However, this should not be done on land which is already of conservation importance in its own right.

2.2 Agri-environment schemes

2.2.1 Countryside Stewardship Scheme (England) (MAFF 1999a)

As a general rule no organic (or inorganic) fertilisers are permitted on pastures under Countryside Stewardship Scheme agreements. In exceptional cases, and with the written agreement of the Project Officer, some sites may be permitted light applications of well rotted FYM (R Gerry, Project Officer, pers. comm.). Light applications of well rotted FYM may also be acceptable on hay meadows where this is deemed compatible with their conservation.

2.2.2 Tir Gofal (Wales) (Countryside Council for Wales 1999)

This is the new all-Wales agri-environment scheme which replaced Tir Cymen (the Welsh equivalent of the Countryside Stewardship Scheme), the Habitat Scheme and the Welsh ESA scheme in the summer of 1999. The management prescriptions in the Tir Gofal handbook provide a basic framework for the management plan that will be tailored to the particular circumstances on the farm.

The management prescriptions prohibit the use of organic fertilisers including FYM except for the following situations:

- Unimproved neutral grassland - FYM may be applied at a rate not exceeding 10 tonnes ha^{-1} every other year.

- Semi-improved grasslands/hay meadows - FYM may be applied at a rate not exceeding 10 tonnes ha^{-1} every other year.

- Coastal grazing marsh and floodplain grassland - Agriculturally improved grassland can be fertilised at no more than 50 kg ha^{-1} $year^{-1}$ of N. Do not use organic fertilisers within 2 m of a river, stream, field boundary ditch or other open water feature. Farmyard manure and slurry must not be applied within 10 m of open water.

In addition to the management prescriptions applying to the individual habitats, there are whole farm management prescriptions, some of which relate to the use of organic manures. For instance, no fertilisers can be used within 1m of field boundaries; no farmyard manure, slurry or other organic manures can be used within 10m of ponds, streams or rivers.

2.2.3 Countryside Premium Scheme (Scotland) (SOAEFD 1999a)

As with Tir Gofal, this scheme includes general environmental conditions that apply to the whole farm. The condition relating to the use of organic manures states that:

> *"You should not apply, ..fertiliser (including farmyard manure and slurry) to rough grazings, unimproved pasture, reverted improved grassland, machair and dune grassland, wetlands, water margins ....."*

The following additional guidance is provided:

> *"Exceptionally, and where there will be no damage to the conservation interest, ... fertiliser including farmyard manure and slurry may be applied to any of the habitats (mentioned above) with the prior written approval of your local SERAD office."*

In addition to the general environmental conditions, there are various individual scheme options including those for grassland management. Those which are applicable to this project include 'Management of species-rich grassland', 'Management of wetland', 'Management of water margins', for all of which the use of manures (and inorganic fertilisers) is prohibited, and 'Management of flood plains', for which no guidance on the use of fertilisers is provided.

2.2.4 Countryside Management Scheme (Northern Ireland) (DANI 1999a)

As for Wales and Scotland, there are 'general environmental requirements' that apply to the whole farm as well as the prescriptions relating to priority habitats. One of the requirements is to follow a nutrient management plan to help maximise the potential nutrient value of the slurry and farmyard manure produced on the farm. It aims to match the input of fertilisers to crop requirements, based on the results of soil analysis. This requirement relates to all types of agricultural land including grassland.

The priority habitats, each with their own management requirements, that relate to lowland semi-natural pastures include: 'Species-rich grassland', 'Wetlands', 'Land adjacent to lakes', 'Parkland', and 'Lapwing breeding sites'. In general, the application of organic (or inorganic) fertilisers to any priority habitat is not permitted. However, there are some variations to this general rule and the specific management requirements relating to the use of organic manures for each lowland grassland priority habitat are presented in Table 1.

Table 1. Manure related management requirements for priority habitats in Northern Ireland's Countryside Management Scheme

Habitat	Management requirements
Species-rich grassland	(Artificial fertiliser), slurry and farmyard manure can only be applied if this has been a traditional practice. However, the total nutrients applied must not exceed 15 kg N, 8 kg P_2O_5 and 8 kg K_2O ha^{-1} $year^{-1}$. For example, a maximum of 5,000 litres of cattle slurry or 8 tonnes of FYM may be applied. Sewage sludge may not be applied.
Wetland	(Artificial fertiliser), slurry and farmyard manure can only be applied to lowland wet grassland if this has been traditional practice. Where this is the case, total application of nutrients must not exceed 25 kg N, 13 kg P_2O_5 and 13 kg K_2O ha^{-1} $year^{-1}$. For example, a maximum of 9,000 litres of cattle slurry or 14 tonnes of FYM may be applied. To protect ground nesting birds the application of fertiliser must not take place between January 1st and June 30th. Sewage sludge may not be applied.
Wetlands - enhanced breeding wader option (for lowland wet pastures)	(Artificial fertiliser), slurry, farmyard manure and sewage sludge may not be applied.
Land adjacent to lakes (including fields next to the lake and all fields adjacent to its in-flowing rivers and streams).	Slurry or other organic fertilisers may not be applied between November 1st and February 28th/29th. At other times of the year, fertilisers (and lime) must be applied in accordance with your farm nutrient management plan. On the 5 m buffer strip (fenced off from the lakeshore), fertilisers, farmyard manure, slurry or sewage sludge must not be applied.
Parkland (including areas of existing grassland containing parkland trees)	No fertilisers, farmyard manure, slurry or sewage sludge may be applied within the area 10 m out from the canopy of a parkland tree. Where there are large numbers of trees the application of fertilisers may not be permitted.
Lapwing breeding sites (fields of improved or semi-improved grassland where lapwing are present between mid-March and early June).	Between March 21st and June 7th (inorganic fertiliser) or farmyard manure must not be applied. Between March 21st and June 30th slurry must not be applied.

2.2.5 Habitat Scheme (England) (MAFF 1994a)

There are three options for land management within the Habitat Scheme (shortly to be subsumed within the Countryside Stewardship Scheme). The Water Fringe Areas option, Former Set-Aside option and Saltmarsh option. Only the Water Fringe Areas option includes the management of semi-natural grassland (fields immediately adjacent to certain waterbodies). Under this option no applications of organic or inorganic fertilisers are permitted.

2.2.6 Habitat Scheme (Wales) (WOAD 1993a)

This scheme, which has now been replaced by Tir Gofal, related to four habitats: water fringe, broad-leaved woodland, species-rich grassland and coastal belt. As a general rule, for existing agreements, no organic fertilisers (including FYM, pig and poultry manure, slurry and sewage sludge) were permitted. However, on species-rich grassland (including pastures and meadows) organic fertilisers could be applied if the Project Officer agreed and gave written approval. Circumstances where the use of organic fertilisers might be acceptable would include, for example, those where sward production had become unacceptably low, and where the use of such fertilisers had been a traditional practice.

2.2.7 Environmentally Sensitive Areas Scheme (England) (MAFF 1996, 1997, 1998a)

The prescriptions for the use of organic fertilisers vary both within and across the English ESAs and it is difficult to generalise. Appendix I provides details of the application rates permitted for the full suite of organic manures within relevant tiers of each of the ESAs in England. In most ESAs there is no differentiation between pastures and meadows. In general, the lower tiers (eg Tier 1 'Permanent Grassland' or 'All Land') which relate to improved grassland (pastures and hay/silage) are more likely to allow the use of fertilisers, including manures, because these tiers are simply trying to maintain the presence of grassland which might otherwise be cultivated. The higher tiers which tend to apply to swards of higher conservation value (both pastures and hay meadows) are more restrictive in terms of fertiliser use, with different application rates permitted in each ESA. The Biodiversity Action Plan grassland types present in each ESA and to which these prescriptions are likely to apply are also identified in Appendix I.

In the Broads, Pennine Dales, South Downs, Suffolk River Valleys and West Penwith ESAs, the prescriptions associated with what are likely to be the highest quality/most sensitive grassland types (including pastures and meadows, unless specified otherwise) prohibit the use of all organic manures. Manure applications of any type are also prohibited within certain 'high level' tiers of other ESAs as follows:

Tier 1	(Heathland - including acid and calcareous heath grassland) and Tier 3 (Water level supplement) grassland in Breckland
Tier 2B	(Marshland) in the Essex Coast
Tier 2	(Wet grassland) in the Upper Thames Tributaries
Tier 1D	(Unimproved pasture and rough land) in the Blackdown Hills

Tier 1D (Unimproved pasture and enclosed rough land) in Dartmoor

Tier 1 Part 3 (Enclosed unimproved permanent grassland) in Exmoor

Tier 1 Part 3 (Downland turf) in the South Wessex Downs

Tier 2A (Herb-rich meadows) and Tier 2B (Herb-rich pastures and allotments) in the Pennine Dales.

The use of pig slurry, cattle slurry and poultry manure is prohibited on 'extensively managed' grassland in the majority of ESAs. In the Somerset Levels and Moors ESA, however, existing levels of pig slurry, cattle slurry or poultry manure can be applied to Tier 1A (Extensive permanent grassland) and Tier 2 (Wet permanent grassland). Existing levels of cattle slurry can also be applied to Tier 1B (i) (Semi-improved permanent grassland) in the North Peak ESA.

Elsewhere, the use of FYM on extensively managed grassland is restricted to existing application levels or lower. There is a fair amount of variation in the application rates permitted in each ESA as outlined in Table 2.

2.2.8 Environmentally Sensitive Areas Scheme (Wales) (WOAD 1993b,c, 1994a,b,c, 1995)

This scheme was replaced by Tir Gofal, the new all-Wales agri-environment scheme in the summer of 1999. For land under existing ESA agreements, the situation appears much more simple than for the ESAs in England. There is just one standard prescription that relates to the use of manures on pastures in all of the ESAs in Wales. This is as follows:

> *"Do not apply any (inorganic or) organic fertiliser, or (except in the case of enclosed partially improved grassland or hay meadows), farmyard manure".*

For the sites where FYM is permitted an application rate of up to 12.5 tonnes ha^{-1} year^{-1} is specified. Partially improved grassland is defined as 'enclosed grassland which has not been regularly ploughed, levelled or reseeded but which has been modified by the application of organic or inorganic fertilisers, lime, herbicides or by drainage'.

2.2.9 Environmentally Sensitive Areas Scheme (Scotland) (SOAEFD 1999b)

For Scotland, Tier 1 (Standard Requirements) is broadly the same for each ESA and generally prohibits the use of any fertilisers on semi-natural grassland, except where it will not result in a deterioration of the sward's diversity. The prescription relating to the use of manures on pastures is as follows:

> *"Do not apply any fertiliser (including FYM and slurry) to rough grazings, unimproved pasture, reverted improved land .... except that:*
>
> *..fertiliser may be applied to unimproved pasture and reverted improved land with the prior written approval of the Secretary of State, provided that the*

level of application does not result in the deterioration or loss of the features of interest."

This scheme will shortly be closing to new applications. Instead, there will be a new Rural Stewardship Scheme.

Table 2. Application rates of FYM permitted on 'extensively managed' lowland grassland in English ESAs

ESA	Tier of agreement	FYM application rate permitted (in all cases this **must not** exceed existing application rates)
Avon and Test Valleys	Tier 1B - Extensive permanent grassland Tier 1C - Wet grassland	Up to 12.5 tonnes ha^{-1} $year^{-1}$
Blackdown Hills	Tier 1C - Low input permanent grassland Tier 2 - Species rich hay meadows	Up to 12.5 tonnes ha^{-1} $year^{-1}$ Up to 20 tonnes ha^{-1} (well rotted) as a single dressing in any 3 year period
Breckland	Tier 3 - River valley grassland	Up to 12.5. tonnes ha^{-1} in any 3 year period
Clun	Tier 1B - Extensive permanent grassland	Up to 12.5 tonnes ha^{-1} in any 3 year period
Cotswold Hills	Tier 1C - Extensive permanent grassland	Up to 12.5. tonnes ha^{-1} in any 3 year period. On hay meadows up to 12.5 tonnes ha^{-1} can be applied each year
Dartmoor	Tier 1C - Low input permanent grassland	Up to 25 tonnes ha^{-1} $year^{-1}$
Essex Coast	Tier 2A - Wet grassland	Up to 12.5 tonnes ha^{-1} $year^{-1}$
Exmoor	Tier 1 Part 2B - Low input permanent grassland	Up to 15 tonnes ha^{-1} $year^{-1}$
North Kent marshes	Tier 1B - Water management tier	Up to 12.5 tonnes ha^{-1} $year^{-1}$
North Peak	Tier 1B (i) - Semi-improved permanent grassland Tier 1B (ii) - Unimproved permanent grassland	Up to existing application rate Up to 8 tonnes ha^{-1} $year^{-1}$ on hay meadows
Shropshire Hills	Tier 1C - Extensive permanent grassland	Up to 7 tonnes ha^{-1} every 2 years on grassland cut for hay
Somerset Levels and Moors	Tier 1A - Extensive permanent grassland Tier 2 - Wet permanent grassland Tier 3 - Permanent grassland raised water level areas	Up to existing application rate Up to existing application rate Up to 25 tonnes ha^{-1} $year^{-1}$
South Wessex Downs	Tier 1 Part 2B - Low input permanent grassland	Up to 12.5 tonnes ha^{-1} $year^{-1}$
South West Peak	Tier 2 Option 1 - Pastures and meadows	Up to 8 tonnes ha^{-1} $year^{-1}$ on meadows only

2.2.10 Environmentally Sensitive Areas Scheme (Northern Ireland) (DANI 1994a,b)

Five ESAs are currently designated in Northern Ireland. These are Mournes and Slieve Croob ESA, Antrim Coast, Glens and Rathlin ESA, West Fermanagh and Erne Lakeland ESA, Sperrins ESA and Slieve Gullion ESA. The Tier 1 (All Farmland) prescriptions state that:

> *"The farmer shall not increase any existing rate of application of organic fertiliser, inorganic fertiliser or any mixture thereof or apply more than 260 kg of such fertiliser per ha in any year."*

For species-rich grassland (covered by Tier 2), a management plan is drawn up for areas of such grassland on the farm. The general prescriptions for Tier 2 are more restrictive than those for Tier 1, although they do not go as far as prohibiting the use of inorganic fertiliser and slurry. They state:

> *"Artificial fertiliser, slurry and farmyard manure applications are restricted to 25 kg N, 13 kg P and 23 kg K per ha."*

2.2.11 Organic Farming Scheme (England) (MAFF1999b)

This scheme has been suspended pending the completion of the Rural Development Regulation. For those land owners with existing agreements, the following prescriptions relate to the use of manures on pastures:

> *"The beneficiary shall not plough, reseed or improve, by use of drainage, manures or liming agents, any heathland, grassland of conservation value, including species-rich grassland, and rough grazing.*
>
> *The beneficiary shall not cultivate, or apply manures within one metre of any boundary features, such as fences, hedges and walls."*

2.2.12 Organic Aid Scheme (Scotland) (SOAEFD 1994)

As with the scheme in England, there is no specific guidance on rates of application for manures on any type of grassland.

The Scheme's explanatory leaflet reproduces the guidelines set by the UK Register of Organic Food Standards (UKROFS) to ensure the protection of environmental features and semi-natural habitats. The over-riding theme throughout these guidelines is that there should be concern for the environment such that appropriate conservation bodies are consulted with regard to the management of important habitats. Natural features, including species-rich grassland should be retained as far as possible. Care should be taken with the spreading of manures and slurry to avoid contamination of watercourses.

The UKROFS guidelines are presented in Appendix II.

2.2.13 Organic Farming Scheme (Northern Ireland) (DANI 1999b)

Landowners entering into an agreement under this scheme have to abide by certain environmental management prescriptions. There are two which relate to the use of organic manures on grassland. The first prohibits the use of manures (of any type) on 'grassland of conservation value, including species-rich grassland and rough grazing'. The second prohibits the use of manures within 1m of any boundary features, including fences, ditches, hedges and walls. No specific application rates for organic manures are stated.

2.3 Summary

It is clear, from the above, that advice relating to the use of organic manures on pastures (and other types of semi-natural grassland) is very variable, both in terms of the application rate and type of manure.

Both the Farming and Wildlife Handbook (Andrews & Rebane 1994) and the Lowland Grassland Management Handbook (Crofts & Jefferson 1999) are clear in their advice that no slurries should be applied to semi-natural grassland. They also both suggest that, where there has been a traditional practice of applying small amounts of well rotted farmyard manure with no detrimental impact on the conservation value of the grass, that this practice should be acceptable for hay meadows only in the future (ensuring that application rates do not increase).

The advice provided in the agri-environment schemes relating to semi-natural grassland in England ranges from total prohibition of manure application (eg Countryside Stewardship Scheme, Habitat Scheme, Organic Farming Scheme and certain 'higher' ESA tiers) to allowing relatively high application rates of both slurries and manures on wet grasslands where high water levels encourage greater diversity of breeding and overwintering birds (eg in the Somerset Levels and Moors and North Peak ESAs). The prescriptions for ESAs in England are particularly diverse, when compared with those of the other UK countries, and reference needs to be made to the individual ESA and tier to identify what manure use is permitted.

Elsewhere in the UK, the agri-environment scheme advice is, generally, more straight forward. The new Tir Gofal scheme for Wales, which has replaced the Tir Cymen, ESA and Habitat Schemes, has prescriptions which provide a framework for tailoring management, including manure use, to individual farms. These start with the premise that no organic manures can be used, although exceptions are made for certain types of grassland. In Scotland, the Countryside Premium Scheme and ESA Scheme prohibit the use of organic manures unless prior approval is given by the Project Officer. In Northern Ireland, although the Countryside Management Scheme generally prohibits the use of organic manures, they are allowed in small quantities where this has been a traditional practice. In the Northern Ireland ESAs, fertiliser applications on species-rich grasslands are restricted but still permit the use of slurries. In contrast, no manures of any type are allowed to be applied to grassland of conservation value coming into the Organic Farming Scheme in Northern Ireland.

3. Use of organic manures on lowland pastures

This section provides an overview of the production, utilisation and nutrient value of organic manures in UK agriculture, and considers both the nutrient loading and other implications of manure use on semi-natural grassland.

3.1 Production and recycling of organic manures

Organic manures recycled to agricultural land supply valuable quantities of plant nutrients and organic matter, which contribute to soil fertility and help to supply crop nutrient requirements (Smith & Chambers 1995). At present, around 90 million tonnes of farm manure (fresh weight) are collected annually from farm buildings and yards, requiring handling, storage and subsequent application to agricultural land (Table 3). Of these, approximately 50% are handled as solid manure (mainly cattle, sheep, pig and poultry) and the remainder as liquid slurry (cattle and pig), with little having received any form of treatment before land application. Farm manure applications are made annually to around one third of the agricultural land (c. 3.3 million hectares) in Britain. Additionally, around 60 million tonnes of excreta are deposited directly in the field each year by grazing cattle, sheep and pigs.

Using animal manure for grassland or other crop production is costly relative to the use of mineral fertiliser. Farmer perception of the fertiliser value of manures is poor and manure has largely been considered a waste since mineral fertilisers became widely available. Manure needs should be carefully incorporated into a well-designed farm fertiliser plan. However, Smith & Chambers (1995) adapted statistics on fertiliser use from the annual British Survey of Fertiliser Practice to show that, over a period of 6 years, fertiliser inputs on fields which had received manure application(s) in a given year, were little different from those which had received no manure. It is clear that inappropriate and inefficient use of manure is a major source of nutrient leaching to aquifers and surface waters (Lord, 1996) and of ammonia (NH_3) emission to the atmosphere. Poor manure practice, which does not take proper account of the nutrient content, will also raise the overall soil fertility status.

In addition to animal manures, the amounts of sewage sludge and industrial by-products recycled to agricultural land has increased in recent years. In 1996/97, 520,000 tonnes of sewage sludge dry solids (ds) were applied to 80,000 hectares of agricultural land (c. 0.7% of agricultural land; average application rate 6.5 tds ha^{-1}), which was equivalent to 47% of UK sludge production (Gendebien *et al* 1998).

By the year 2006, sludge production is predicted to double with the estimated quantity recycled to land increasing to 926 000 tds yr^{-1} (DoE, 1993). Currently, also ca. 4.5 million tonnes of industrial “wastes” are applied to land each year, with the majority (1.75 million tonnes) derived from the paper industry. Other sources include the food (600 000 tonnes) and sugar (200,000 tonnes) industries. As with livestock manures, inappropriate use of sewage sludge or industrial “wastes” on natural or semi-improved pasture is likely to lead to increased soil fertility.

Table 3. Amount of livestock manure applied annually to land in the UK (derived from Pain *et al* 1998)

Animal	Manure[1]	Manure applied			
		Amount of manure		N	
		1000 Tonnes	%	Tonnes	%
Cattle	Slurry	34033.2	36.4	153150	25.3
Pig	Slurry	3916.2	4.2	27413	4.5
Sheep	Slurry	-	-	-	-
Poultry	Slurry	-	-	-	-
Other	Slurry	-	-	-	-
Cattle	Solid manure	40831.6	43.9	244990	41.1
Pig	Solid manure	7979.1	8.6	55853	9.4
Sheep [2]	Solid manure	1805.3	1.9	10832	1.8
Poultry	Solid manure[3]	4499.6	4.8	103567	17.4
Other [4]	Solid manure	13.9	0.015	111	0.019
Total		93078.9	100	595916	100

Notes:
1. Slurry estimated on the basis of "standard" excretal output (Smith & Frost 2000; Smith, Charles & Moorhouse 2000) for stock, assuming no dilution. Solid manure includes deep litter, farmyard manure and is estimated from excretal output adjusted for typical bedding litter additions.
2. Sheep include goats. Manure estimated for lowland flocks, assuming one month housing period during lambing, on straw bedding.
3. Approximately 22% of broiler litter output burnt for power generation has been taken into account.
4. Farmed deer.

From the 471 responding dairy farms in recent studies of manure management practice in the different livestock sectors (Smith *et al* in press(a)), overall, 98% of farms produce both slurry and FYM; including the straw bedding inputs, 34% of manure is produced as FYM and 66% as slurry (based on an estimated 242,000 tonnes FYM and 463,000 tonnes of slurry within the survey). From the 515 responding beef producers, 345 farms (67%) produce slurry and 440 (85%) FYM, with a large proportion producing both slurry and FYM. On beef units, however, FYM production is predominant, with the balance estimated at 82% FYM and 18% slurry (based on 385,000 tonnes FYM and 85,000 tonnes of slurry within the survey sample). These estimates compare well with recent estimates for stored dairy cattle manure and beef manure derived by expert review (Table 4), though these latter estimates did not include slurry and manure stored within livestock buildings (Nicholson & Brewer 1997).

Table 4. Estimates of the relative proportion of slurry and FYM in dairy and beef production

	Smith *et al* survey		Nicholson & Brewer 1997	
	FYM	Slurry	FYM	Slurry
Dairy manure	34	66	30	70
Beef manure	82	18	75	25

Within the pig sector, despite the predominance of FYM-based production systems, estimates of annual, total slurry and FYM production based on pig numbers within the equivalent manure practice study (Smith *et al* in press(b)) suggested (within the responding group) a total of 486,700 tonnes of raw, undiluted slurry and 646,360 tonnes of FYM; that is about 43% slurry and 57% FYM. These estimates compare closely with other recent estimates of 44% slurry and 56% FYM for stored pig manure (Nicholson & Brewer 1997). Estimates of 35% slurry and 65% FYM, based on consultant experience and expert opinion, are currently applied for pigs in UK inventories of gaseous emissions (eg Pain *et al* 1998). Horse manure production is covered in Section 3.4.1.

The estimates of manure production show that cattle FYM or slurry are much more likely to be available for use on pastures than other forms of manure. Applications of poultry manures or sludge bioproducts would provide external inputs of nutrients to semi-natural pasture ecosystems, whereas FYM produced from overwinter housing of the livestock grazing such pastures can be used to recycle nutrients within the system.

3.2 Past and present manure practice on lowland pastures

Recommended practices for utilising manures on grassland are outlined by Chambers *et al* (1999a).

3.2.1 Manure use on grassland

Information on organic manure use has been collected for many years in the British Survey of Fertiliser Practice (BSFP), which initially covered England and Wales and was subsequently extended to Scotland in 1983 (Chalmers *et al* 1999). Data for England and Wales since 1975 show that the proportion of grassland spread with some form of organic manure has increased over the last twenty-five years, largely as a result of more intensive livestock production on agriculturally improved grassland (Figure 1). Both total grassland and permanent grassland (defined in the survey as at least seven years old, until 1991, and subsequently as at least five years old) show the same trend, while the small difference in percentage treated area between the two categories reflects greater use of manures on younger swards used for silage production. Corresponding data for Scotland show a similar pattern. However, no reliable data are available from this survey on fertilised rough grazing or other types of semi-natural grassland.

The recent BSFP data show that manures are applied annually to about 43% of grassland in England and Wales, compared to 15% of tilled land (Chalmers *et al* 1999). Nearly all grassland is grazed to some extent during the season, but manure is applied to only one third of grassland which is solely grazed, compared to two thirds of grassland which is both grazed and cut for hay or silage. For grassland cut at least once during the season, manure is applied to two thirds of the grassland area cut for silage and to about half of the area cut for hay. These survey estimates are based on agriculturally improved grassland, rather than semi-natural grassland for which very few data are available. However, a recent survey of liming practice on grassland at Sites of Special Scientific Interest (SSSIs) and within agri-environment schemes found that about a third of the 74 sites recorded had received FYM (Tallowin 1998).

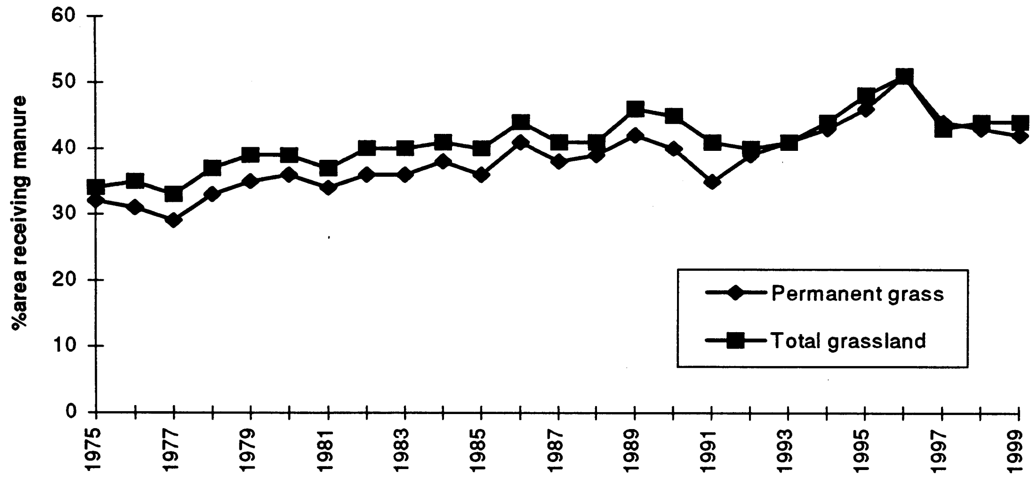

Figure 1. **Proportion (%area) of total and permanent[a] grassland treated with some form of organic manure in England and Wales, 1975-99**

[a] at least 7 (up to 1991) or 5 years old
(Source: British Survey of Fertiliser Practice)

For agricultural grassland, FYM and sewage sludge bioproducts are the most and least frequently used forms respectively (Table 5). Use of both sewage sludge and poultry manure is very limited, at only 2 to 3% respectively of the manure-treated grassland area. Smith. & Chambers (1995) estimated averages of 170 kg ha^{-1} N, 69 kg ha^{-1} P_2O_5 and 108 kg ha^{-1} K_2O for annual total nutrient loadings to soils receiving manure applications in England and Wales.

Table 5. **Proportion (%) of the total manure-treated area of grassland receiving different types of organic manure, England and Wales 1992-95**

FYM	Slurry	Poultry manure	Sewage Sludge
76	39	3	2

(Source: British Survey of Fertiliser Practice)

3.2.2 Manure rates

Manure application rates on improved grassland depend largely on manure type and sward usage. A typical application rate for FYM is around 20 t ha^{-1}, as higher rates tend to increase the risk of sward smothering and prolonged herbage contamination. Annual high rates (>30 t ha^{-1}) of FYM cause scorching and bare patches to reseeded grassland. Simpson & Jefferson (1996) concluded that annual or even less frequent applications at these rates to semi-natural pastures would be very damaging, reducing species richness and diversity. For cattle slurry, 25-30 m^3 ha^{-1} is a general application rate, which is often increased to 30-40 m^3 ha^{-1} on silage ground (J Laws pers. comm.). In comparison, however, higher slurry rates (typically 60-80 m^3 ha^{-1}) are generally used on arable and maize land.

3.2.3 Manure timing

British Survey of Fertiliser Practice data show that manure applications are made throughout the year on agricultural land in England and Wales, depending on soil type, soil conditions, cropping and manure storage capacity (Chalmers *et al* 1999) (Figure 2). The majority of organic manures are applied during the winter and spring period, although about 25% and 40% of manure applications were made during autumn on grassland and tillage crops respectively. A comparison of manure timings over 1988 to 1991 and 1992 to 1995 suggested a small shift towards more spring applications both on tillage crops and, though less so, on grassland.

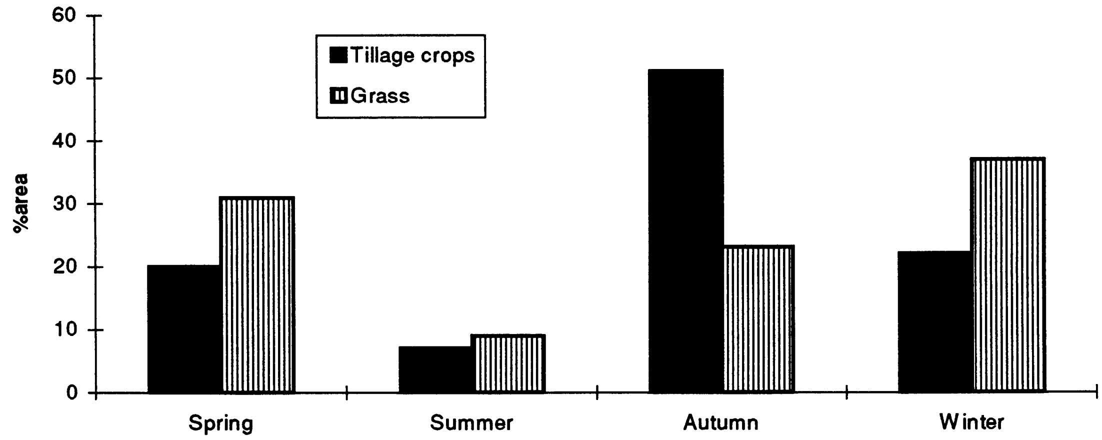

Figure 2. Timing (as % of total treated area) of organic manure applications on tillage crops and on grassland, England and Wales 1992-95
(Source: British Survey of Fertiliser Practice)

Detailed information collected from within the recent studies of manure management practice in the beef, dairy, pig and poultry sectors (Smith *et al* in press a,b,c), allowed estimates to be made of the proportion of these manures which are applied to grassland or to arable land and also of the distribution of manures through the year, on a quarterly basis, to grazing land or grass for silage (Table 6). The spreading of pig slurry and poultry manures appears to be fairly evenly distributed throughout the year on grassland (mostly intensively managed), but lower proportions of beef and dairy manure and slurry are spread during the summer period. The results showed, in line with BSFP findings, that about one fifth to a quarter of total manure (as slurry, FYM or poultry manure) applications on grassland are made during the August to October period, which poses the greatest risk of subsequent nitrate leaching loss (Smith & Chambers 1998).

Table 6. Farmer estimates of proportion of manures applied to arable or grassland and application time (Smith *et al* in press a,b,c)

Manure type	% applied to[1]:		Estimated application time on grass (%):				
	Arable[2]	Grassland	G/S[3]	Feb-Apr	May-July	Aug-Oct	Nov-Jan
Dairy FYM	40	60	G	26	8	29	36
			S	30	6	28	36
Dairy slurry	24	76	G	29	10	21	40
			S	34	16	18	32
Beef FYM	34	66	G	35	12	25	28
			S	36	10	22	32
Beef slurry	12	88	G	37	12	21	30
			S	40	17	15	27
Pig FYM	78	22	G	31	17	26	26
			S	33	10	18	39
Pig slurry	54	46	G	26	26	24	23
			S	32	30	17	21
Poultry manure	53	47	G	28	26	26	20
			S	39	16	23	21

Notes:
[1] estimates based on numbers of respondents applying to the different crops
[2] arable crops includes forage maize
[3] G/S – grazing land (G) or grass for silage (S)

On grassland swards, the timing of manure dressings depends on the cutting and grazing management system, on the form of manure (liquid or solid) applied, and the related risk of smothering or scorch. For grazed grassland, the time interval required between application and subsequent grazing, to avoid tainting or contamination of the herbage, is largely weather-dependent. For FYM, an interval of at least six weeks may be needed to allow sufficient time for breakdown of the manure. For slurry, a general guideline is to leave an interval of at least two to three weeks; Smith *et al* (1995), for example, noted that high application rates should be avoided after early March on early grazed swards. However, Laws & Pain (2000) showed that beef cattle had a preference for untreated swards until six weeks after spreading in spring, but that both timing and method of application were influential. In spring, cattle were less averse to swards treated with slurry by surface placement (using a 'trailing shoe' applicator), compared to broadcasting or shallow injection, but where slurry was applied after a silage cut, cattle showed a greater aversion to slurry which was broadcast rather than applied by either of the other methods. Both surface placement and injection were no less acceptable than untreated swards when grazing started thirty two, rather than ten days after slurry spreading.

Information on the traditional timing of FYM application to semi-natural grasslands was reviewed by Simpson & Jefferson (1996). This information suggested that FYM was normally applied either in autumn or in late winter-early spring, with a slight emphasis towards the latter. Traditional practice would therefore seem to differ little, in general, from the timings quoted for beef FYM in Table 6. However, in hay meadows in areas such as the Pennine Dales, where growth starts comparatively late in the spring and fields are shut up for hay in mid May for cutting in July, the traditional practice is to apply FYM in April-early May (Smith & Rushton 1994; Smith 1997).

Where slurry is applied for first cut silage, late winter spreading is typical. This allows at least ten weeks between application and cutting to avoid any risk of sward contamination which could reduce silage fermentation and acceptability (Boxem & Remmelink 1987). However, the effect of timing on the extent of contamination is uncertain. A recent study using slurry with low (3%) dry matter content, showed that decreasing the time between application and ensilage from ten to six or two weeks for first cut, and from six to two weeks for second cut, had no effect on silage intake (Allison *et al* 2000). However, some negative effects would be anticipated if higher dry matter slurries were applied only a few weeks before grass ensilage, since these would be expected to remain for longer on standing herbage.

3.3 Spreading systems for manure applications

Current spreading systems for solid manures and slurries, and their use, are outlined by Chambers *et al* (1999b). Surface spreading of manures can cause sward damage, principally due to smothering and scorching effects (Prins & Snijders 1987).

3.3.1 Solid manures

Simpson & Jefferson (1996) also summarised the types of solid manure spreaders which are available and their spreading characteristics. Solid manures are predominantly applied to arable land, mostly in the autumn period; some attempt is made to incorporate manures within a day of application (>10%), with 50-60% incorporation within a week of application (see Table 7). On grassland, FYM needs to be well chopped by the spreader to obtain even coverage, reduced risk of sward smothering, and to encourage more rapid breakdown after spreading.

Machine spreading of manures should be avoided in wet soil conditions, as it will inevitably lead to wheeling damage, compaction and impeded surface drainage problems.

Accurate spreading, both in application rate and uniformity of spread pattern, is an important aspect of manure and slurry utilisation (Smith & Baldwin 1998). Recent studies have examined the effect of manure spreading imprecision on crop yield (Smith 1999a) and also the potential for improving the utilisation of solid and liquid manures, through greater accuracy of application (Smith 1999b).

Table 7. Solid manure application

Manure	Applied to: grassland %	arable %	Incorporation < 1 day %	Incorporation < 1 week %	Comments
Cattle FYM	20-40	60-80	10	50	25% applied by rear-discharge machine; 75% side-discharge
Pig FYM	7	93	23	54	80% applied with rear-discharge machine; 20% side-discharge
Poultry	20	80	10	60	60% applied by rear-discharge machine; 40% side-discharge

(Source: Smith *et al* in press a,b,c)

3.3.2 Slurries

Based on estimates of excretal outputs, slurry contributes about 40% of the total amount of land spread manure (Table 3). The great majority of slurry is surface applied, mostly by tankers equipped with splash plates, and only a small amount (1-10%) is injected (see Table 8). However, as well as being slower and more expensive than broadcasting, injection can damage grassland swards, particularly under dry conditions (Chambers *et al* 1999b). In contrast, Long & Gracey (1990) concluded that mid-season injection of slurry can be an effective means of utilising slurry-N in terms of herbage DM production and consequent N use. A significant proportion of pig slurry, being dilute, is applied via irrigation systems. Some shallow injection equipment is now in use, but the recently developed surface placement equipment, eg trailing hoses, is only just being considered by the industry. There are only a few of these machines in the UK, mostly owned by contractors. Application by these methods is likely to increase in the future, due to the need to reduce ammonia volatilisation and improve distribution of manure, thereby also increasing N-efficiency of the applied manures.

Slurries, from whatever source, as well as pig and poultry manures, are considered unsuitable for use on grasslands of high nature conservation value, mainly because of their high available N content which gives competitive grasses an advantage over herb species (Crofts & Jefferson 1999). This effect will ultimately cause a decrease in species-richness in semi-natural grasslands as a result of competitive exclusion (see Section 6.5). In contrast, light dressings of cattle FYM give a more gradual and prolonged release of N and other nutrients through mineralisation of the organic matter content (Simpson & Jefferson 1996). However, current machinery developments to improve both the accuracy and range of application rate, and also spreading uniformity, may make it feasible to use low rates of slurry to supply any nutrient requirements of grazed pastures. FYM tends to be a more variable material and more difficult to spread evenly than slurry, which leaves less solids 'trash' in the sward after spreading.

Table 8. Slurry application techniques

Animal	Broadcast spreading %	Trail-hose application %	Injection %	Irrigation %
Cattle [1]	95	-	1	4
Pig [2]	66	-	11	23

Notes:
1. cattle slurry 6-8% of arable applications incorporated <1 day; 20-40% <1 week
2. pig slurry 15% arable applications incorporated <1 day; 27% <1 week
(Source: Smith *et al* in press a,b)

3.4 Nutrient and potentially toxic element (PTE) content of manures and bio-solids

3.4.1 Major nutrients

Assessment of total and available nutrient content. Where manures are applied to improved grassland, it is essential to know their nutrient content so that fertiliser inputs can be adjusted accordingly. In the case of some semi-natural grasslands where fertilisers are not normally applied, the information is needed so that nutrient budgets can be estimated. The recent manure surveys (Smith *et al* in press a,b,c) indicated that about a quarter (pigs/poultry) to half (beef/dairy cows) of livestock farmers used some means to estimate the NPK content of manures. Most farmers, particularly on beef and dairy units, claimed to make some adjustment in fertiliser NPK inputs to allow for the nutrient content of applied manures. Fertiliser PK inputs on improved grassland should also take account of the soil nutrient status and these surveys reported that two thirds or, on dairy farms, three quarters of livestock farmers said they used soil PK analysis, on average every 3 - 4 years.

Laboratory analysis. As the nutrient content of manures can be variable, representative samples should be taken at the time of field application and analysed for total and available nutrient contents. The analyses should include: dry matter, total N, P, K, S and Mg, and ammonium-N. Additionally, for straw based FYM samples, nitrate-N should be measured, and for poultry manures, uric-acid N. Guidance on obtaining representative manure samples for analysis is provided by Chambers *et al* (1999b).

On-farm analysis methods. For slurries, laboratory results can be supplemented by on-farm N meter measurements of ammonium (readily plant available) N (Figure 3). A slurry hydrometer can also be used to measure dry matter (DM) content and to provide an estimate of total N and P contents. Suppliers of these instruments are listed in the recently published booklet on livestock manure use on grassland (Chambers *et al* 1999a).

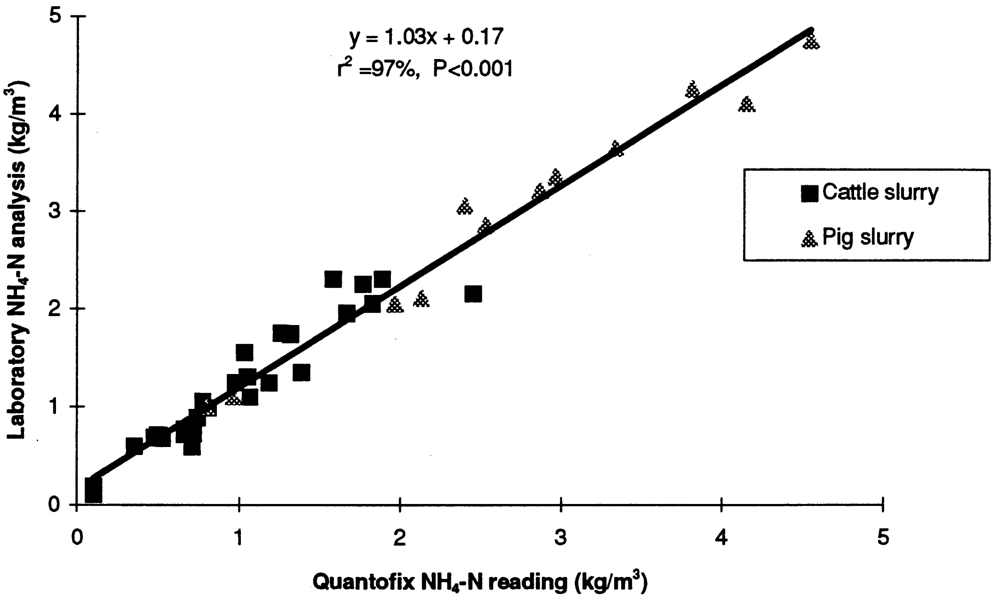

Figure 3. Relationship between laboratory NH_4-N analysis and Quantofix nitrogen meter readings

Typical values. General guidance on the nutrient content of animal manures, based on the analysis of large numbers of samples, is provided in Table 9 for total contents, and in Tables 10 and 11 for typical N, P and K availabilities. These figures should be used in the absence of laboratory or on-farm analysis data.

Horse manure. Data on the total nutrient content of horse manure are very limited, compared to other organic manures. Analysis results for stable manure indicate typical contents of 32% dry matter and, on a fresh weight basis, 0.7% N, 0.5% P_2O_5 and 0.6% K_2O (MAFF 1976). Values for horse manure without bedding are 30% dry matter and 0.59% N, 0.32% P_2O_5 and 0.59% K_2O (fresh weight basis; ASAE 1993). Manure output (excluding bedding) has been estimated at 23 kg day^{-1} per horse (at 450 kg body weight), giving an annual production of 9.1 tonnes which is equivalent to about 52 kg N year^{-1} per horse (R Phillips pers. comm.). In addition, use of straw bedding is estimated at 13 kg day^{-1} per horse.

Table 9. Typical total nutrient content of livestock manure (fresh weight basis)

Manure Type	Dry matter (%)	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Sulphur (SO_3)	Magnesium (MgO)
Solid manures:			kg t^{-1}			
Cattle farmyard manure(1)	25	6.0	3.5	8.0	1.8	0.7
Pig farmyard manure (1)	25	7.0	7.0	5.0	1.8	0.7
Poultry layer manure	30	16	13	9	3.8	2.2
Poultry broiler litter	60	30	25	18	8.3	4.2
Slurries/liquids:			kg m^{-3}			
Dairy(2)	6.0	3.0	1.2	3.5	0.8	0.8
Beef(2)	6.0	2.3	1.2	2.7	0.8	0.8
Pig(2)	4.0	4.0	2.0	2.5	0.7	0.8
Dirty water	<1.0	0.25	Trace	0.3	ND	ND
Separated cattle slurries (liquid portion) :			kg m^{-3}			
Strainer box	1.5	1.5	0.25	2.2	ND	ND
Weeping wall	3.0	2.0	0.5	3.0	ND	ND
Mechanical separator	4.0	3.0	1.2	3.5	ND	ND

Notes:
(1) Values for solid manure are as removed from housing. Values of N and K_2O will be lower for FYM stored for long periods in the open.
(2) Values for diluted slurries. A rough, pro-rata adjustment to the nutrient content of dilute slurries can be made if dry matter content is known or can be estimated.
ND. No data
(Source: Chambers *et al* 1999c)

Sewage sludge bioproducts are a potential source of N, P and also S, but contain very little K. Typical values for both total and available N and P contents in digested (*ie* treated) sludges are shown in Table 12.

Chemical analysis gives the total nutrient content of manures but the effectiveness or "availability" of nutrients in terms of short term crop response (ie over the following season) is usually lower.

Nitrogen For N, the ammonium-N content is a good indication of potential availability. The exception is poultry manures where available N is a combination of ammonium-N and uric acid-N (UAN). In all cases, availability will be affected by N losses following manure application to land (mostly as ammonia gas or nitrate leaching - see Section 5.3). The available N supplied by manures is affected by manure type, slurry DM content, application time and soil type (Table 11). Slurry thickness (ie DM content) has two important effects:

- total nutrient content increases with increasing DM;

- slurry N availability decreases with increasing DM (less ammonia is lost from dilute slurries).

Table 10. Typical available nutrient content of livestock manures.

	DM	Available nutrients[3]		
	%	N	P_2O_5	K_2O
Solid manures			**% of total nutrients**	
Cattle FYM[1]	25	See Table 11	60	60
Pig FYM[1]	25		60	60
Layer manure	30	See Table 11	60	75
Poultry litter	60		60	75
Slurries/liquids				
Dairy[2]	6	See Table 11	50	90
Beef[2]	6		50	90
Pig[2]	4		50	90
Dirty water	<1		50	90
Separated cattle slurries (liquid portion)				
Strainer box	1.5	See Table 11	50	90
Weeping wall	3.0		50	90
Mechanical	4.0		50	90

Notes:
(1) Values of N and K_2O will be lower for FYM stored for long periods in the open.
(2) Values for typical diluted slurries; pro-rata adjustment for nutrient content can be made based on slurry DM.
(3) Nutrients available for utilisation by the next crop.

Table 11 summarises N availability for the main types of farm manures and accounts for the effect of application timing on nitrate leaching losses, which are greatest following autumn application of manures containing a high proportion of readily available N (MAFF 1994b). More detailed guidance on the availability of manure N is provided by the ADAS "MANNER" computer program (Chambers *et al* 1999d).

Table 11. Percentage of total nitrogen available to the next crop following surface applications of livestock manures (% of total N)

Timing		Autumn (1) (Aug-Oct)		Winter (1) (Nov-Jan)		Spring (Feb-Apr)	Summer (May-July)
Soil type	**DM %**	**Sandy/ shallow**	**Other mineral**	**Sandy/ shallow**	**Other mineral**	**All Soils**	**All soils**
Fresh FYM(2)	25	5	5	10	15	20	n/a(3)
Poultry manures	30-60	10	15	15	25	35	n/a(3)
Cattle slurry	10	5	5	5	10	15	5
Cattle slurry	6	5	10	10	20	30	20
Cattle slurry	2	5	10	15	30	50	35
Pig slurry	6	5	10	10	25	35	20
Pig slurry	4	5	10	10	30	45	30
Pig slurry	2	5	10	15	35	60	40
Separated slurries (cattle)	1-4	5	10	15	30	50	35
Dirty water	<1	0	10	10	40	80	50

Notes :
(1) Assume drainage of 250mm for autumn application; 150mm for winter application.
(2) Values calculated assuming fresh FYM, with about 25% ammonium-N content; for FYM stored in the open and for long periods (>6 months), values should be reduced by half.
(3) n/a - application of solid manures to grassland during the summer months is best avoided.

Phosphorus and potassium. Manure P availability is dependent upon climatic and soil conditions, but the intrinsic characteristics of the residue (a function of the waste treatment or the animal nutrition for instance) are also important. In nutrient balances, total P content is taken into account, but only a part of it is initially available for the crop. Agronomic experiments have shown that, in the long term, the total P value of manure can be regarded as equivalent to inorganic fertiliser P.

Due to its high water solubility, the availability of manure K is generally high, commonly 60-90%, depending on manure type. Recent evidence, however, has suggested that the mean efficiency of manure K is even higher than currently advised, and was about 90% (range 72-116%) in experiments with cattle and pig FYM, broiler litter and cattle slurry on sugar beet (Chambers 1998).

Table 12. Typical total and available nutrient contents of digested sludges

	DM	Total		Available	
	%	N	P_2O_5	N	P_2O_5
Liquid digested (kg m^{-3})	4	2.0	1.5	1.2	0.8
Digested cake (kg t^{-1})	25	7.5	9.0	1.1	4.5

(Source: MAFF 1994b)

Sulphur. Sulphur is required by crops in similar amounts to P and, with inputs from the atmosphere continuing to decline due to reducing levels of airborne pollution (sulphur dioxide), crop responses to added S are increasingly common. Grass cut for silage is particularly responsive and organic manures, especially solid livestock manures and sewage sludges, contain useful amounts of S (McGrath, Zhao & Withers 1996).

About 50% of the S in cattle slurry is available for crop uptake (Lloyd 1994), however some leaching of S can occur during the winter months, so it is best not to rely totally on S from autumn applications of slurry. Yield responses to S in intensively cut silage and some arable crops are particularly common, on freely drained soils following wet winters. The utilisation of manure S has been little researched and clearly, should be considered in the future, in view of the increasing importance of S and the need to encourage better manure recycling. However, for extensive grassland management, especially grazed swards, there is a much smaller risk of S deficiency.

Magnesium. Inputs from manures should largely be regarded as contributing to the maintenance of soil reserves.

3.4.2 Heavy metals

Heavy metals can be either phytotoxic or affect animal and human health, if applied in excess (Smith, 1996). The elements which can cause phytotoxicity or reduce crop yield, if present at high concentrations, include zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), chromium (Cr) and arsenic (As) (MAFF, 1998b). Heavy metals which may be particularly harmful to animals or, via the food chain, to humans are lead (Pb), mercury (Hg), As and Cu, while Cr is less likely to be harmful. For grazing animals, the effect may be due to direct toxicity as a result of ingesting contaminated soil and/or herbage, or due to an induced trace element deficiency caused by heavy metal antagonism. Crop damage from metal toxicity, such as reduced herbage yield in grassland, is much more likely to occur in acid soils. In instances where large amounts of metal have accumulated in agricultural soils, it may be necessary to maintain soil pH at 7.0 or above to reduce metal uptake by crops.

Both livestock manures and sewage sludges contain heavy metals in varying amounts. However, at normal agronomic application rates, the heavy metal loadings are well within acceptable limits for both herbage and livestock production (assuming no direct ingestion by grazing livestock). In a recent study, 183 livestock feeds and 85 animal manure samples were collected from commercial farms in England and Wales and analysed to determine their heavy metal contents (Nicholson *et al* 1999). Zinc and copper concentrations ranged from 150 - 2920 mg Zn kg^{-1} dry matter (DM) and 18 - 217 mg Cu kg^{-1} DM in pig feeds, depending on the age of the pigs. In poultry feeds, concentrations ranged from 28 - 4030 mg Zn kg^{-1} DM and 5 - 234 mg Cu kg^{-1} DM, with laying hen feeds generally having higher heavy metal contents than broiler feeds. Concentrations of Zn and Cu in dairy and beef cattle feeds were much lower than in pig and poultry feeds. Pig manures typically contained *c*.500 mg Zn kg^{-1} DM and *c*.360 mg Cu kg^{-1} DM, reflecting metal concentrations in the feeds (Table 13). Typical concentrations in poultry manures were *c*.400 mg Zn kg^{-1} DM and *c*.80 mg Cu kg^{-1} DM, and in cattle manures *c*.180 mg Zn kg^{-1} DM and *c*.50 mg Cu kg^{-1} DM. The dry matter content of cattle and pig slurries was a useful indicator of heavy metal concentrations on a fresh weight basis.

Table 13. Dry matter and heavy metal contents of animal manures

Manure Type (No. of samples)		Dry matter (%)	Zn	Cu	Ni	Pb	Cd	As	Cr
			mg kg^{-1} DM						
Dairy cattle FYM	Mean	18.4	153	37.5	3.7	3.61	0.38	1.63	5.32
(6)	Range	14.9 - 30.1	99 - 238	26.2 - 55.8	1.7 - 9.1	<1.00 - 9.18	<0.10 - 0.53	0.57 - 4.83	0.77 - 21.40
Dairy cattle slurry	Mean	7.6	209	62.3	5.4	5.87	0.33	1.44	5.64
(20)	Range	0.2 - 16.1	<5 - 727	<1.0 - 352	0.1 - 11.4	<1.00 - 16.9	<0.10 - 1.74	<0.10 - 4.48	<0.20 - 12.9
Beef cattle FYM	Mean	21	81	16.4	2	1.95	0.13	0.79	1.41
(12)	Range	16.4 - 24.2	41 - 274	10.5 - 27.9	0.2 - 3.1	<1.00 - 6.40	<0.10 - 0.24	0.39 - 1.53	0.79 - 2.05
Beef cattle slurry	Mean	12	133	33.2	6.4	7.07	0.26	2.60	4.69
(8)	Range	2.2 - 21.0	68 - 235	17.5 - 48.7	1.9 - 20.4	1.07 - 18.0	0.11 - 0.53	0.43 - 10.8	1.13 - 15.7
Pig FYM	Mean	21.7	431	374	7.5	2.94	0.37	0.86	1.98
(7)	Range	14.4 - 32.6	206 - 716	160 - 780	3.0 - 24.3	1.01 - 4.65	0.19 - 0.53	0.52 - 1.34	0.67 - 3.42
Pig slurry	Mean	4.4	575	351	10.4	2.48	0.3	1.68	2.82
(12)	Range	0.5 - 21.6	<5 - 2500	<1.0 - 807	<0.1 - 49.8	<1.00 - 9.74	<0.10 - 0.84	<0.10 - 6.7	<0.20 - 6.81
Broiler/turkey	Mean	59.3	378	96.8	5.4	3.62	0.42	9.01	17.17
litter (12)	Range	46.0 - 78.0	208 - 473	45.7 - 173	2.2 - 12.3	<1.00 - 9.28	0.20 - 1.16	<0.10 - 41.1	3.57 - 79.8
Layer manure	Mean	40.7	459	64.8	7.1	8.37	1.06	0.46	4.57
(8)	Range	23.0 - 67.1	350 - 632	49.4 - 74.8	4.5 - 11.4	3.36 - 14.80	0.44 - 2.04	0.15 - 0.82	2.14 - 7.06

Note : Where samples were below the limit of detection (LOD), a value of 0.5 *x* LOD was used to calculate means
(Source: Nicholson *et al* 1999)

There have been reductions in the concentrations of heavy metals in sewage sludges over the last two decades, which has helped to reduce soil heavy metal loadings (Gendebien *et al* 1999) (Table 14). Maximum limits for total soil metal concentrations where sludge is recycled to agricultural land are summarised in Table 15 (DoE 1996).

Table 14. Typical heavy metal concentrations (mg kg^{-1} dry solids) in sludge used on agricultural land in 1982/83 and 1996/97

Element	1982/83	1996/97	% change 1982/83 to 1996/97
		(mg kg^{-1} dry solids)	
Zinc	1205	792	-34%
Copper	625	568	- 9%
Nickel	59	57	- 2%
Cadmium	9	3.3	-63%
Lead	418	221	-47%
Mercury	3	2.4	-20%
Chromium	124	157	+27%

Where organic manures, which are also sources of increased metal additions, are applied to land the routine soil sampling requirements of The Sludge (Use in Agriculture) Regulations (SI, 1989) provide farmers with a soil metal baseline, which can be used to assess the rate at which metals are accumulating in soils.

Table 15. Maximum advisory total heavy metal concentrations in soils and maximum annual metal application rates

	Maximum permitted concentrations in agricultural soils (mg kg^{-1})				Maximum average annual rate of addition over a 10 year period (kg ha^{-1} per annum)**
	pH 5.0<5.5	pH 5.5<6.0	pH 6.0<7.0	pH* >7.0	
Zinc (Zn)	200	200	200	300	15
Copper (Cu)	80	100	135	200	7.5
Nickel (Ni)	50	60	75	110	3
		For pH 5.0 and above			
Cadmium (Cd)		3			0.15
Lead (Pb)		300			15
Mercury (Hg)		1			0.1
Chromium (Cr)		400			15***

* The increased concentration limits in soils >pH 7.0 only apply to soils containing more than 5% $CaCO_3$

** Sludge applications must match crop N and P requirements (DoE 1996)

*** Provisional

3.5 Manures and bio-solids and the risks of pathogen transfer

The number of reported cases of food-borne illness has risen significantly over recent years. For example, there has been a six-fold increase in the collective number of gastro-enteritis and food poisonings in the UK, between 1982 and 1998 (Jones 1999). The main causative organisms are bacteria, particularly *Salmonella*, *Campylobacter*, *Listeria* and verocytotoxic *E. coli* (VTECs) and viruses. In addition, significant levels of human illness are caused by the parasitic protozoans *Cryptosporidia* and *Giardia*. It is possible that in many cases transmission to man is via food contaminated with pathogenic organisms.

The application of animal manures to agricultural land is one route by which zoonotic pathogens may be introduced into the human food chain at the primary food production stage. All the bacterial and protozoan pathogens listed above may be present in animal manures and although human viruses are unlikely to be found in animal manures, this latter risk is clearly present with the recycling of human sewage. Of course, animal pathogens also cause concern, as well as other organisms unfavourable to silage fermentation, eg *Bacillus* and *Clostridium* spores (Rammer *et al* 1997). *Cryptosporidia* contamination of potable water supply sources is also a potential source of infection and new drinking water regulations require the water companies to undertake risk assessments. This could have implications for animal grazing and manure spreading in surface water catchment areas in particular.

3.5.1 Minimising risk from bio-solids

In the UK, the recent health scares over salmonella, listeria, BSE and *E. coli* O157, and the pathogens potentially present in untreated sewage sludge, led the supermarkets to question the long-term sustainability of sourcing food supplies from land receiving sewage sludge. At the same time the Water Industry had to implement the EU Urban Waste Water Treatment Directive (EC 1994), which was forecast to increase the amount of sewage sludge recycled to agricultural land. Current legal requirements under the UK "Safe Sludge Matrix" are outlined in Section 4.

The surface spreading of treated sludge on grazed grassland was banned from 31 December 1998 and treated sludge can now only be applied to these areas by deep injection. This form of application will therefore normally preclude the use of sewage sludges in semi-natural grassland.

3.5.2 Minimising risk from farm manures

The number of organisms present in animal manures will depend upon the source of the manure, health of the livestock and management practices between production and spreading. To date, legislation and Codes of Practice in the UK covering the management of farm manures, have largely concentrated on the prevention of environmental pollution (water and air) and transmission of animal diseases.

Salmonella spp. have long been recognised as an important cause of food poisoning. In a study of manure samples taken from different livestock types, *Salmonella* (predominantly *S. dublin*) was isolated from 11% of cattle slurry samples, 22% of pig slurry and 42% of poultry manure samples (Jones & Matthews 1975). Researchers in Britain and North America have generally concluded that it is safe for cattle to graze pastures where slurry or sewage sludge has been applied after an interval of 2-3 weeks. However, a more precautionary approach has been recommended whereby the land spreading of slurry and sludge is confined to arable land or land used for silage (RCEP 1979; Davies 1997).

The main reservoir for *E. coli* O157 in livestock is thought to be in the intestinal tract of cattle and sheep. A recent study on samples of rectal faeces taken from one abattoir (cattle, sheep and pigs) and a poultry processing plant over a one year period, showed carriage rates of 15.7% from the 4800 cattle analysed, 2.2% from 1000 sheep, 0.4% from 1000 pigs and nil from 1000 chickens (Chapman *et al* 1997). There is evidence that *E. coli* O157 can remain viable in soil for at least four months and the pathogen appears to be highly resilient, possessing the capability to adapt easily to environmental stresses (Jones 1999). However, Jones (1999) also reported that the behaviour of the pathogen in different soil types and the influence of environmental conditions and management strategies on the pathogen remains largely unknown. Pathogens are better adapted for survival in aquatic environments than in soils or crops (Thomas *et al* 1999), and will therefore survive for longer in water courses. Current MAFF guidelines suggest safe 'no spread' times (eg not before or during heavy rain) and areas (eg not near to surface waters or boreholes), aimed at preventing pathogens entering water courses (MAFF 1998c). The use of grass buffer strips may also reduce pathogen levels in runoff.

MAFF codes recommend that, wherever possible, slurry application should be by band spreader or injector, in order to reduce odours and ammonia loss. Manure spreading systems which minimise the production of dust or aerosols are also recommended. In addition, farmers are advised to spread manures at times when complaints and nuisance to local residents can be avoided. Surface applications of slurry and manure to cultivated land should be incorporated as soon as possible to provide protection against pathogen inhalation, although adjacent crops, grazing land and waterways could still become contaminated. Use of band spreaders may encourage pathogen survival on the soil surface compared to broadcast spread slurries. Pathogens in injected or incorporated manures are likely to survive longer than those from surface applications, although they will be removed from contact with growing crops or grazing livestock.

To minimise the risks of animal disease transmission, it is recommended that manures are not applied to grassland during the grazing season. If this is unavoidable, farmers should store manures for as long as possible (at least one month) before spreading. Ideally, pastures should not then be grazed for at least one month (preferably 8 weeks), or until all visual signs of manure solids have disappeared (see also Section 3.2.3). These time intervals are probably sufficient to eliminate most pathogens by the time grazing resumes and to minimise the transmission risks.

3.6 Manures and liming

On agricultural grassland, lime should be applied periodically to non-calcareous soils to maintain the soil pH at an optimum level of 6.0 or 5.3 for mineral or peat soils respectively (MAFF 1981). Soil acidity increases as a result of Ca leaching losses, which subsequently causes a gradual reduction in both the yield and quality of herbage production. The rate of Ca loss depends on a number of factors including soil chemical and physical characteristics, rainfall and fertiliser inputs (Gasser 1973). Nutrient additions from organic manure applications also have a potential acidifying effect, particularly as a result of N mineralisation processes, but this effect is largely counterbalanced by the Ca content of manures. Gardner & Garner (1953) for example found that repeated application s of FYM, containing 612 kg CaO per 10 tonnes, could significantly increase exchangeable Ca content and reduce soil acidity. Cattle FYM has an alkaline pH, which can range from 7.7 to 9.5 (Simpson & Jefferson 1996). Normal agricultural rates of FYM (and slurries) consequently have very little, if any, effect on soil acidity (MAFF 1981).

The use and effects of lime application on semi-natural grasslands in Britain, and existing guidelines, were reviewed by Tallowin (1998). The review endorsed the policy of not allowing lime to be applied to semi-natural acidic grasslands, although the possibility of future derogations for developing more mesotrophic grassland communities was identified. The findings of the review were also in accord with the liming recommendations for semi-natural neutral grasslands in the first (1994) edition of the *Lowland Grassland Management Handbook*, which specified a 5 to 10 year liming frequency and that any single application should not exceed 3 tonnes CaO (or equivalent) ha^{-1}. A survey of liming practice on 74 grassland SSSI sites, carried out as part of the Tallowin (1998) review, found that a greater percentage of sites with a history of liming had also received FYM and/or inorganic fertiliser compared to the unlimed sites. These differences were thought to suggest that liming was considered an integral part of agricultural management practice for the majority of semi-natural grassland in the past. On neutral grasslands where liming material had been applied as basic slag, which also acted as a source of fertiliser P, there was evidence of long term effects, including loss of some key semi-natural mesotrophic grassland species (Tallowin 1998).

Liming can increase soil nutrient availability and the utilisation of nutrient inputs from fertiliser or manure applications (MAFF 1981). For example, Johnston & Whinham (1980) found that, for cereal and potato crops, the loss in yield from omitting P fertiliser decreased with increasing soil pH. Tallowin (1998) identified a need for research into the long term effects of inorganic P input, with or without lime application, against equivalent inputs of P applied as FYM on semi-natural grasslands, to better understand the influence of soil P availability (and its interaction with pH) on community structure in grasslands. Tallowin (1998) tentatively predicted that the combined effects of reduced soil acidity as a result of liming, and increased soil nutrient status from FYM additions, could cause undesirable changes in botanical composition towards NVC type MG6 grasslands (Rodwell 1992). A new study, which started in 1999, is currently investigating some of these potential interactive effects, but no definitive results are yet available at this early stage.

British Survey of Fertiliser Practice data suggets that the proportion of agricultural grassland which is limed in any one year has increased in Britain since 1983 (Chalmers *et al* 1999). No data, however, are available from this survey for semi-natural grassland.

3.7 Summary

About 90 million tonnes of farm manure (fresh weight) are collected annually from farm buildings and yards and subsequently applied to agricultural land. Around 60 million tonnes of excreta are also deposited directly in the field each year by grazing cattle, sheep and pigs. Approximately 50% of manure collected from housing is handled as solid manure (mainly cattle, sheep, pig and poultry) and the remainder as liquid slurry (cattle and pig). The dominant forms of manure are slurry on dairy farms and FYM on beef and pig units. Farm manures are applied to around one third of the agricultural land (c. 3.3 million hectares), including 44% of grassland, in Britain each year. About 80% and 40% of manure-treated agricultural grassland receives FYM (cattle and pig) and slurry (cattle and pig) respectively, but the proportion receiving poultry manure and sewage sludge is very limited (2 - 3%). Manures are applied to one third, a half or two thirds respectively of agricultural grassland which is grazed only, cut for silage or cut for hay. Limited survey data suggest that about a third of semi-natural pastures in SSSIs and agri-environment schemes have received FYM at some stage.

Manure application rates on improved grassland depend largely on manure type and sward usage. A typical application rate for FYM is around 20 t ha^{-1}, as higher rates tend to increase the risk of sward smothering and prolonged herbage contamination. Application rates for cattle slurry are generally 25-30 m^3 ha^{-1}, often increasing to 30-40 m^3 ha^{-1} on silage ground. Manures are applied throughout the year on agricultural grassland, depending on soil type and conditions, sward management and manure storage capacity . The majority of organic manures are applied during the winter and spring period, although about a quarter of applications on agriculturally improved grassland are made during the autumn period, when the risk of nitrate leaching is greatest. Where used on semi-natural grasslands, FYM is applied either in autumn or early spring, although in some northern hay meadows the tradition is to apply in April-May. At least six to eight weeks should be left between FYM application and subsequent grazing, to allow sufficient time for the manure to break down. For slurry, a minimum interval of at least two to three weeks, and preferably up to six or more weeks, should be left between a broadcast application and subsequent grazing.

When spread on grassland, FYM needs to be well chopped by the spreader to obtain even coverage, reduced risk of sward smothering and to encourage more rapid breakdown after spreading. Most slurry is currently broadcast as a surface application on improved grassland, as injection can damage the sward, particularly under dry conditions, as well as being slower and more expensive than broadcasting. The use of recently developed surface placement techniques may, however increase in the future, in order to reduce ammonia volatilisation losses and obtain more uniform slurry distribution, even at low application rates.

The nutrient (N, P, K, Mg and S) value of applied manures can be estimated from typical values. However, as nutrient content can be very variable, laboratory analysis or rapid on-farm testing (for N and P) of representative manure samples is preferable. Nitrogen availability depends on manure type, application timing and soil type and, for slurries, DM content. The available N supply from FYM, although small at moderate rates of manure application, would cause some increase in herbage production if used on semi-natural pastures, which could require a higher stocking density for part of the grazing season to manage the extra vegetative growth. Although repeated FYM applications can increase soil organic matter content, which improves the biological, chemical and physical (eg water holding capacity) properties of the topsoil, such effects are likely to be very small with very infrequent, moderate rates of application.

Both livestock manures and sewage sludges contain heavy metals in varying amounts but, at normal agronomic rates of application, the heavy metal loadings from these forms of manure are well within acceptable limits for both herbage and livestock production (assuming no direct ingestion by grazing livestock).

The application of animal manures to agricultural land is one route by which zoonotic pathogens might be introduced into the human food chain at the primary food production stage. Similarly, the recycling of human sewage to land could pose a potential risk with respect to human viruses. Adherence to the Codes of Good Agricultural Practice when spreading animal manures on agricultural land will help to minimise any possible risk of pathogen transfer. The UK "Safe Sludge Matrix" has been set as the minimum standard for recycling sewage sludge bioproducts to agricultural land, because of public perception and concerns about possible food safety.

The amounts of sewage sludge and industrial by-products recycled to agricultural land has increased in recent years. In 1996/97, 520,000 tonnes of sewage sludge dry solids (ds) were applied to 80,000 hectares of agricultural land, which was equivalent to 47% of UK sludge production. Sludge recycling to land is expected to increase to 926 000 tds/yr by 2006. However, sewage sludge is only recycled on a very small percentage of improved grasland and the 'Safe Sludge Mix' requirements effectively rule out the use of treated sludges on semi-natural grassland. Currently, also *c.* 4.5 million tonnes of industrial 'wastes' are applied to land each year, with the majority (1.75 million tonnes) derived from the paper industry. Other sources include the food (600 000 tonnes) and sugar (200,000 tonnes) industries.

Liming can increase soil nutrient availability and plant utilisation of nutrient inputs from fertiliser or manure applications. A reduction in soil acidity, as a result of liming, may cause ecologically undesirable changes in the botanical composition of some types of semi-natural pastures, which could be further exacerbated where soil nutrient status (particularly N and P) is increased by manure applications.

4. Current Legislation and Codes of Practice on Manure Use

Statutory controls in England and Wales currently tend to be fewer than in many other European countries, as the intensity of livestock production per unit of land area is lower, and Government policy has been to obtain voluntary compliance wherever practical.

4.1 Codes of Good Agricultural Practice

The Ministry of Agriculture Fisheries and Food and Welsh Office Agriculture Department (MAFF/WOAD) publish three separate Codes of Good Agricultural Practice (COGAPs) for the Protection of Water, Air and Soil which give guidance on best practice for avoiding pollution (MAFF 1998b; 1998c; 1998d). These Codes were first published in 1991-93 and were revised in 1998 to take account of new practices, research results and changes in legislation. Similar codes have been produced for Scotland.

4.2 Regulations

The siting, sizing, and minimum structural requirements for all new or substantially altered slurry stores are laid down in the Control of Pollution Regulations. The recycling of livestock manures is excluded from regulations on the use of 'waste materials' spread to land. A voluntary guideline of a maximum of 250 kg ha^{-1} yr^{-1} total N from applied organic materials is given in the COGAP for The Protection of Water (MAFF 1998c). Under the EC Nitrate Directive, 68 Nitrate Vulnerable Zones (NVZ's) in England and Wales have been designated where there are compulsory limits on amounts of total N applied by returning animal manures to land by spreading or grazing (MAFF 1998e). Estimates of animal numbers per hectare to comply with maximum N loadings from manure spreading to land are given in Appendix III. Within these NVZs, which cover around 600,000 ha of agricultural land, there are also closed periods (in autumn) for spreading high available N manures on sandy and shallow soils.

EC Directive 85/337/EEC (CEC 1985) sets down a framework which requires member states to request an environmental assessment covering all likely environmental effects before consent is given for certain major projects to be undertaken. In England, a full environmental assessment is required for new systems to house over 100,000 broilers or 50,000 layers or over 400 sows or 5000 finishing pigs (DoE 1988).

There are currently no controls directly relating to ammonia emissions from buildings, nor any requirement to cover slurry stores to reduce the loss of ammonia. The future implementation of the EC Directive on Integrated Pollution Prevention and Control (IPPC) will however require certain measures to be taken to control of emissions from larger pig or poultry units and the spreading of slurry and manure from these units (MAFF 1997b). Such units will need a permit.

Present legislation and recommendations are summarised in Table 16. Future controls are likely to focus more on diffuse water pollution and air pollution from ammonia and greenhouse gases.

Table 16. Present UK legislation and recommendations regarding the use of animal manures

Legislation or recommendations	Summary
Control of Pollution Regulations 1991/1997	• Items related to NH_3 emissions. • Relate to new storage structures for slurry, silage effluent and fuel. Requirements for impermeability, structural stability and siting in relation to watercourses. • Minimum 4 months storage. • No requirement to cover stores.
Nitrate Vulnerable Zone Regulations (EC Nitrate Directive)	68 zones defined. Rules relate to: • Closed periods for organic manures on shallow or sandy soils. • N limits from organic manures of 250kg ha^{-1} on grassland and 210kg ha^{-1} on arable. • Sufficient storage to cover closed periods. • Keeping of records.
MAFF/WOAD Water Code 1998	Recommendations regarding all aspects of avoiding water pollution from the storage and spreading of manures , including preparation of a Farm Waste Management Plan specific to the farm showing risks of run-off and where, when and how much manure can be spread. There is a voluntary guideline of a maximum of 250 kg ha^{-1} yr^{-1} total N from applied organic materials.
MAFF/WOAD Air Code 1998	Recommendations regarding all aspects of avoiding air pollution from livestock housing, the storage and spreading of manures, including odours, ammonia and greenhouse gas emissions. These recommendations generally involve current good hygiene and husbandry practices, but also suggest that slurry injection or band application, and rapid incorporation of solid manures may be used to reduce ammonia emissions from land spreading.
PROPOSED Integrated Pollution Prevention and Control (IPPC) Regulations. (EC Directive 96/1)	This will shortly be implemented in the UK. It will apply to installations for the intensive rearing of poultry or pigs with more than 40,000 poultry, 2000 places for production pigs (over 30 kg) or 750 places for sows. Various measures to reduce ammonia emissions from animal housing, manure storage and spreading are under discussion and may include covering of stores, subsurface application of slurries and incorporation of manures. The details of the Consultation Document being prepared by the Environment Agency were due to be available in September 1999.

4.3 UK "Safe Sludge Matrix"

Recent negotiations between the UK Water Industry, the British Retail Consortium (BRC, representing the major retailers), and ADAS, were aimed at securing a sustainable route for recycling sludge to agricultural land that would be acceptable to the Food Industry, Water Industry, regulators, and farmers and growers. The "Safe Sludge Matrix" agreement, commonly known as the ADAS Matrix, has been accepted as the minimum standard for sustainable sludge recycling to agricultural land. The Matrix consists of a table of crop types together with clear guidance on the minimum acceptable level of treatment for any sludge based product (biosolids) which may be applied to that crop or rotation. All UK outdoor crops are covered from grass for grazing and silage making, maize for silage, combinable crops and animal feed crops, through to horticultural crops, vegetables, salads and fruit. Outline details of the Matrix are shown in Table 17.

Table 17. The "Safe Sludge Matrix"

		Untreated sludges	Treated sludges	Advanced treated sludges (5)
Fruit		X	X	✔ (6)
Salad		X	X (1)	✔ (6)
Vegetables		X	X (1)	✔ (6)
Horticulture		X	X	✔ (6)
Combinable & animal feed crops		Target end date 31.12.1999 (2)	✔ (3)	✔
Grass	Silage	X	✔ (3)	✔
	Grazing	X	X (3)(4)	✔
Maize	Silage	X	✔ (3)	✔

✔ = All applications must comply with the DoE Code of Practice and certain additional crop and harvest restrictions.
X = Applications not allowed (except where stated conditions apply).
( ) numbers in parenthesis refer to further detailed guidance notes on timing, harvest interval, or treatment (see below).

Guidance notes referred to in Table 17:

(1) Field Vegetables

Field vegetables may form part of an arable rotation to which treated sludge is applied subject to:

- A period of 12 months must elapse between the application of treated sludge for the arable crop and harvest of the following field vegetable crop.
  Where the field vegetable crop may be eaten raw (for example a ready to eat crop) application must be made at least 30 months before harvest.

(2) Combinable & Animal Feed Crops

The application of untreated sludge to combinable and animal feed crops will cease with effect from 31.12.1999, although untreated sludge can still be applied to agricultural land growing industrial crops under contract until 31 December 2001. Where a field is returning to a rotation which may include field vegetables, the periods specified in (1) above shall apply.

(3) Treated Sludge

The application of treated sludge to these crops will be permitted and the water industry has put in train a research programme to provide the necessary assurances that food safety is not compromised.

(4) Grazing

The surface spreading of treated sludge onto grassland used for grazing shall cease with effect from 31.12.98. However, treated sludge may continue to be deep injected into grassland used for grazing subject to (3) above.

(5) Advanced - Treated
To include heat treated and other methods of treatment as agreed by the Steering Group.
(6) Regulations & Code Of Practice
All applications must be in accordance with the Regulations (SI 1989, No 1263) which implement EU Directive (86/278/EEC) and the DoE Code of Practice for the Agricultural Use of Sewage Sludge (DoE 1996). Where the Matrix allows for the continued use of sewage sludge, including advanced - treated, all applications shall be carried out in accordance with the Regulations and the 1996 DoE Code of Practice for the Agricultural Use of Sewage Sludge.

Since 31 December 1999, untreated sludge should no longer be applied to land, although under the agreement, certain combinable crops that are further processed by heat may continue to receive untreated sludges until the end of December 2001. The surface spreading of treated sludge on grazed grassland was banned from 31 December 1998. Treated (liquid) sludge can only be applied to grazed grassland if it is deep injected, which could damage sward composition. Although advanced treated (eg thermally dried) sludge can be surface applied to grazed, as well as silage grassland, the high total N and P contents of these bioproducts would give very high nutrient loadings even at low sludge application rates. More stringent treatment processes are required where sludge is applied to land growing vegetable crops and in particular those crops that may be eaten raw (eg salad crops). Treated sludge can be applied to agricultural land which is used to grow vegetables provided that at least 12 months has elapsed between application and harvest of the following field vegetable crop. Where the crop is a salad, which might be eaten raw, the harvest interval must be at least 30 months.

4.4 Summary

Voluntary Codes of Good Agricultural Practice have been published which provide guidance on best practice for minimising risk of water and air pollution from manure storage and spreading on agricultural land. Such practices also result in more efficient utilisation of the nutrient content in manures for grassland or other crop production. Current legislation on manures is limited, but future implementation of the EC Directive on Integrated Pollution Prevention and Control (IPPC) will however require certain measures to be taken to control emissions from larger pig or poultry units and from the spreading of slurry and manure from these units.

There are existing regulations relating to new storage structures for slurry. As a result of the EC Nitrate Directive, there are mandatory rules in the Nitrate Vulnerable Zones which specify closed periods for organic manure applications on shallow or sandy soils; a total annual manure-N limit of 250kg ha^{-1} on grassland (210kg ha^{-1} on arable land); sufficient manure storage to cover closed periods; and the keeping of field records on manure and N fertiliser use.

Regulations and Codes of Practice on sewage sludge applications to agricultural land control heavy metal inputs to soils, to protect plant growth and crop quality. The recently agreed 'Safe Sludge Matrix' sets the minimum standard for sludge recycling to agricultural land. The Matrix provides a sustainable strategy for recycling sludge to land, meeting the needs of retailers, legislators and the farming industry as a whole. In practical terms, the Matrix means that only advanced treated sludges would be potentially suitable for application to semi-natural pastures, as treated sludges would have to be deep injected. However, thermal drying, as a form of advanced treatment, will produce sludge products with high N and P contents.

5. Nutrient Cycling in Pastures

5.1 Atmospheric deposition of nutrients

The principal nutrients deposited from the atmosphere over the UK are N (as gaseous nitrogen dioxide, nitric acid and ammonia, and nitrate and ammonium in rain water) and S (as gaseous sulphur dioxide and sulphate in rain water). The base cations of Ca, Mg and K are also deposited, although to a lesser extent (DETR 1997). There is also some atmospheric deposition of trace elements and heavy metals (Anon 1998).

The ecological effects of atmospheric deposition of nutrients were first observed during the 19th Century when declines in lichen populations around Manchester were attributed to smoke pollution (Lee 1998). By the 20th Century emissions of S had increased dramatically in this country due to smelting activities and the burning of fossil fuels. In the 1950's severe air pollution incidents, such as the smogs in London, resulted in the passing of various Clean Air Acts to reduce their impact on public health. Although these Acts were successful in reducing air pollution in cities by raising chimney heights and relocating power stations in less populated areas, the potential for long-range transport of air pollutants, including plant nutrients, was increased (DETR 1997).

The environmental impact of transboundary pollution was highlighted by Sweden during the early 1970's following research which identified large areas of southern Scandinavia where freshwater had become acidified as a result of S deposition from emissions from the industrial areas of Europe (DETR 1997). Since then, the extent of acid deposition and its impact on the environment have become more clearly understood and further international agreements have been made to introduce control measures such that emissions are reduced. The most recent measures include the Protocol concerning the Control of Emissions of Nitrogen Oxides or Their Transboundary Fluxes (adopted in 1988), the Second Protocol on the Further Reduction of Sulphur Emissions (adopted in Oslo in 1994) and the EC Directive on Integrated Pollution Prevention and Control (adopted in 1996).

The sources of nutrients in the atmosphere, quantities deposited and impacts on semi-natural grassland are discussed in the following paragraphs.

5.1.1 Nitrogen

The principal sources of atmospheric N are fossil fuel combustion and vehicle emissions (both producing NO_x species), and livestock wastes (producing NH_x species). Atmospheric N is deposited in both wet and dry forms. Overall, the total annual input is around 454 kt (INDITE 1994) and the average rate of deposition of atmospheric N throughout the UK is about 14 kg N ha^{-1} $year^{-1}$.

Wet deposition occurs as nitrate (NO_3^-) and ammonium (NH_4^+) ions in rain or cloud water. Wet deposition of NO_3^-- and NH_4^+-N on the land is greatest in areas of high rainfall or extensive cloud cover, which means that wet deposition of N is of particular significance in upland areas and in the north west of the UK. In these areas an average of 30 kg N ha^{-1} (as NO_3^-- and NH_4^+) is deposited each year (INDITE 1994).

Dry deposition of atmospheric N occurs principally as nitrogen dioxide (NO_2) and ammonia (NH_3). NO_2 deposition is greatest in the Midlands and south east of England and is closely associated with polluted urban areas since its principal sources are road vehicles and power stations. The N as NO_2^+ deposited to individual 20 x 20 km grid squares in England ranges from 0.5 kg N ha^{-1} $year^{-1}$ in western Wales and the Scottish borders to 10-15 kg N ha^{-1} $year^{-1}$ in London and other large cities in the Midlands and the south east of England (INDITE 1994; CLAG 1997).

Dry deposition of NH_3 is a complex process because it can be emitted by or deposited on leaves, depending on the NH_3 'compensation point'[1]. The compensation point probably varies with plant nutrition (ie intensity of agricultural management), physiological activity and environmental conditions such as temperature, solar radiation, etc.. Another complication is that NH_3 is very soluble and often deposits rapidly to leaf cuticles resulting in a competition between cuticular and stomatal exchange processes. In general, semi-natural communities (unfertilised grasslands, heathland, forests, etc.) act as a sink for NH_3. Over fertilised grassland and arable crops, however, the exchange of NH_3 is very much bi-directional. Emissions tend to occur during dry, warm conditions, whereas deposition of NH_3 occurs when the intensively managed grassland or crop is wet with rain (Sutton *et al* 1997).

There is no single simple map of NH_3 deposition for the country because the deposition rates are so closely connected with differences in the community type and management. There is only limited information on the rates of NH_3 deposition to unfertilised grassland and the estimates for moorland have sometimes been applied as a best estimate. However, such estimates must be regarded as uncertain (CLAG 1997). The map showing the mean annual dry deposition of NH_3 to moorlands in the UK (1992-1994), at a scale of 20 km x 20 km, indicates a range of <5 kg N ha^{-1} $year^{-1}$ around the south coast, to more than 25 kg N ha^{-1} $year^{-1}$ in parts of the south west, Welsh borders and East Anglia (CLAG 1997).

Differences in land use close to point sources of ammonia (eg an intensive livestock unit or field in which slurry has been spread) result in very localised differences in deposition rates. Where intensively managed agricultural land is down wind of a source of NH_3, recapture may be small due to the large NH_3 compensation point of the associated vegetation. On the other hand, if semi-natural land (such as unfertilised grassland) or forest is down wind of the source then recapture of NH_3 may be more significant. In an experiment to measure the dispersion and deposition of NH_3 downwind of slurry spreading, it was found that about 20% of NH_3 would be recaptured within 2 km if the land cover was short semi-natural vegetation, but a smaller fraction would be recovered by intensively managed grassland or crops (Sutton *et al* 1997).

The fact that atmospheric N deposition varies so much at a local scale has important implications for estimating the ecological impacts of NH_3 when using national-scale model estimates, even at a resolution of 5 km. In the majority of the UK, particularly in lowland areas, intensively managed agricultural land can be in close proximity to semi-natural areas. This will lead to high spatial variability in NH_3 deposition with semi-natural land near the margins of agricultural land (eg within about 200m) receiving much more NH_3 through dry

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[1] This is the concentration of NH_3 occurring in equilibrium with plant tissues within the plant stomata. When the concentration of NH_3 in the air is less than that in the plant tissues emission from the leaves occurs. Deposition onto the leaves occurs when the concentration of NH_3 in the air is greater than that in the plant tissues.

deposition than semi-natural land further away (eg > 1 km from the source) (Sutton *et al* 1997) or land upwind of the source.

Impacts. Nitrogen is often the limiting nutrient in semi-natural ecosystems (although the availability of P may also very low in chalk grasslands (Wilson, Wells & Sparks 1995) and grasslands on peat (Kirkham, Mountford & Wilkins 1996)) and these systems are generally adapted to grow under conditions of low N availability. If the availability of N is increased, whether from atmospheric deposition, manure or fertiliser application, it can result in:

a. short term effects to individual plant species;

b. soil-mediated effects of acidification, including losses of buffer capacity, lower pH, increased leaching of base cations;

c. increased susceptibility to secondary stress factors (eg drought, frost, pest damage);

d. accumulation of N compounds leading to changes in competitive relationships between species (Bobbink & Roelofs 1994; Bobbink, Hornung & Roelofs 1998).

Nitrate leaching can also occur where the rate of N accumulation has an impact on nutrient cycling within the ecosystem.

Different ecosystems vary in their sensitivity to increased inputs of N. Unfertilised grasslands and other ecosystems poor in N are those most likely to change as a result of N deposition because species adapted to low levels of N will be out competed by species with a higher demand for N. Over 50% of the native species of central Europe are indicators of N deficiency (Ellenberg 1988) and able to withstand competition only at conditions of low N nutrition. Many of the threatened species in central Europe are most abundant in semi-natural ecosystems, including species-rich grasslands. These grasslands rely on management, ie grazing or cutting, to remove nutrients and maintain their species diversity (Fangmeier *et al* 1994).

Atmospheric N deposition is likely to have more impact on ecosystems where N is the limiting element as opposed to other macronutrients such as P (Kooijman *et al* 1998). However, in addition to effects attributable to increases in productivity following nutrient addition, any change in the balance of nutrients may affect vegetation composition, since plant species appear to show individual preferences for particular resource ratios (Tilman 1982). Foliar N:P ratio is a useful indicator of which of the two resources is limiting at the plant community level in semi-natural vegetation (Koerselmann & Meuleman 1996). Interpretations of data using this criterion have indicated situations where atmospheric N deposition has caused a change from P limitation to N limitation within the ecosystem (Kooijman *et al* 1998; Kirkham, unpublished).

The amount of a pollutant below which significant harmful effects to the ecosystem does not occur is known as the 'critical load'. The critical loads for N are those below which changes in species composition, increased sensitivity to environmental stresses and/or increased nitrate leaching are all avoided (Hornung *et al* 1997).

The critical loads for certain communities have been estimated through the collection of experimental data, data from field observations and dynamic ecosystem models. Table 18 shows the current critical loads that have been estimated for lowland grassland communities.

Using national deposition and critical load maps, areas of critical loads exceedence for each type of ecosystem can be highlighted. However, as stressed earlier, local variability will still result in major uncertainties about whether particular communities are subject to deposition rates in excess of critical loads. Brown & Farmer (1996) examined the geographical distribution of critical loads exceedence for natural ecosystems, resulting from current and future N (and S) deposition. They concluded that exceedence of critical loads for N was a severe problem for many upland and lowland natural areas in England.

Table 18. Summary of empirical critical loads for nitrogen deposition (kg N ha^{-1} $year^{-1}$) to lowland grassland (from Bobbink, Hornung & Roelofs 1996)

Ecosystem type	Critical load (kg N ha^{-1} $year^{-1}$)	Reliability rating	Indication of exceedence
Calcareous grassland*	15-35	#	Increased mineralisation, N accumulation and leaching. Increase in tall grass; change in diversity.
Neutral-acid grassland	20-30	#	Increase in tall grass; change in diversity

* use low end of the range for N limited, high end of the range for P limited calcareous ecosystems
# quite reliable: when the results of some studies are comparable

Calcareous grasslands. There has been great interest in studies of calcareous grassland carried out in the Netherlands (Bobbink 1991) where tor grass (*Brachypodium pinnatum*) has increased in dominance over the last 50 years. The same changes were obtained in fertilisation experiments using N and it has been suggested that recent increases in the deposition of atmospheric N are responsible. However, Wilson, Wells & Sparks (1995) argue that much of the increase in tor grass in the Netherlands can be attributed to a decline in grazing pressure since the 2nd World War. Baxter & Farmer (1994) reported that even very aggressive tor grass could be controlled by correct management under UK conditions and that there was no evidence that N deposition levels were causing degradation of correctly managed chalk grassland sites.

In the UK, tor grass is a relatively widespread species but any problems of dominance seem to be more marked in certain areas eg Kent and East Yorkshire (R Jefferson pers. comm.). This may be partly because tor grass is absent from many chalk grasslands in the UK, but also because current N inputs in the UK are much lower than in the Netherlands (Wilson, Wells & Sparks 1995). In Derbyshire, for instance, deposition to calcareous grassland has been measured as 19 kg N ha^{-1} $year^{-1}$ (Morecroft, Sellers & Lee 1994) whereas inputs above 80 kg N ha^{-1} $year^{-1}$ occur in some regions of the Netherlands (van Dam 1990). Also important is the management of the grassland. In the Netherlands many grasslands have been either unmanaged or periodically mown since the 2nd World War, whereas in the UK many chalk grasslands are still traditionally grazed.

In an experiment to simulate N deposition on chalk grasslands at a frequency and concentration comparable with ambient rainfall, Wilson, Wells & Sparks (1995) found that there was no loss of species diversity even at N inputs as high as 80 kg ha^{-1} $year^{-1}$. Management, and other factors that limit N assimilation (such as the soil P status), appear to be more important in retaining the structure and diversity of the sward. Wilson, Wells & Sparks (1995) found that even species with low Ellenberg N values tended to flourish under increased inputs of atmospheric N, suggesting that the index is not a reliable measure of a species' ability to compete under high N supply. Managing the sward by grazing (or cutting to simulate grazing) had a more pronounced effect on the sward and prevented the spread of tor grass.

Although, in the study by Wilson, Wells & Sparks (1995), inputs of N increased growth and N yield of the sward compared to untreated plots, the uptake of N by vegetation was small and did not increase with N dose. This was thought to have been as a result of the low availability of P which is typically very low in calcareous grasslands. In another experiment, Morecroft, Sellers & Lee (1994) applied N to a grazed *Festuca-Avenula* calcareous grassland (NVC class CG2d - Rodwell 1992) at rates as high as 140 kg ha^{-1} $year^{-1}$. After three years of treatment there was no significant effect on the growth of any of the species or the species composition when N was applied alone. However, the sward did increase in height when both P and N were applied. In the same experiment, after 6 years, there was a tendency for a decrease in higher plant cover (particularly *Thymus praecox* and *Hieracium pilosella*) with increased N deposition. It is thought likely that further changes in the plant community through N deposition may take much longer to occur, eg tens of years and that different types of calcareous grassland in different locations appear to respond at different rates (Morecroft, Sellers & Lee 1994).

The critical load for calcareous grassland is at the high end of the scale, in the UK, because of its low P status. Hornung *et al* (1997) have compared the current estimated deposition of atmospheric N with the distribution of calcareous grasslands across the UK and found that there was no exceedance of the critical loads for this type of habitat. There are concerns, however, that because the vegetation cannot utilise additional N inputs (due to limited P availability), 'excess' deposited N will be leached as nitrate from such grasslands and potentially cause adverse impacts on associated aquatic ecosystems, surface and groundwater quality.

It is essential, therefore, when trying to predict the impact of atmospheric N on calcareous grasslands (or other habitats) that the past and current management practices (grazing/cutting regime and fertiliser inputs) and soil nutrient status is known. The work by Wilson, Wells & Sparks (1995) and Morecroft, Sellers & Lee (1994) suggested that, in calcareous grassland, grazing can prevent grasses from becoming dominant irrespective of N deposition. However, this is certainly not the conclusion to be drawn from fertiliser experiments in a wider range of grasslands (see Sections 6 and 7). Moreover, Wilson, Wells & Sparks (1995) did record differential responses to N between species, although tor grass did not show the expected increase. The vulnerability of a grassland to deposition of atmospheric N may depend on P availability. Critical loads for total N will be at the higher end of the scale for grasslands that are being managed by grazing and/or cutting and with limited availability of P. It is also important to take account of the long time-scale over which changes in sward composition are likely to occur - Wilson, Wells & Sparks(1995) studied the response to N applied over two years only.

Neutral-acid species rich grassland. The critical loads for this type of grassland are lower than those for calcareous grassland so it is not surprising that, when the deposition map for atmospheric N is compared with the area occupied by this habitat, a large proportion (53%) shows critical load exceedance (Hornung *et al* 1997). There are small areas of exceedance by NH_3 deposition alone in the Midlands and west of England and the Welsh Borders. However, when total N deposition is assessed, critical loads for this type of grassland are exceeded across virtually the whole of the west of England, the Midlands and Yorkshire. The largest exceedance of critical loads for N tends to occur in agricultural regions with large NH_3 emissions, although significant exceedance occurs all over the UK in all but the most remote upland areas (Hornung *et al* 1997).

This finding appears to concur with the results of an analysis of data from the Countryside Surveys of 1978 and 1990 (Barr *et al* 1993). An analysis of Ellenberg scores (Ellenberg 1988) allocated to plant species within plots in the two Countryside Surveys indicated that infertile (and fertile) grassland had higher scores in 1990 than in 1978. This suggests that there is a trend towards more eutrophic grassland species assemblages. This trend is more pronounced in areas receiving high inputs of atmospheric N, eg close to intensive livestock units. However, other factors, such as differences in fertiliser use, grazing and/or cutting regimes could also be linked to these findings (Hornung *et al* 1997).

In their experiment to investigate the effects of atmospheric N deposition on *Festuca-Agrostis-Galium* grassland (NVC class U4e - Rodwell 1992), Morecroft, Sellers & Lee (1994) applied different amounts of N in solution as ammonium nitrate or ammonium sulphate. There was no change in the relative abundance of vascular plants after three years, even at an application rate of 140 kg N ha^{-1} $year^{-1}$, a level much larger than normal deposition rates (and much greater than the critical load for N for this type of grassland). Phosphorus was thought to be a limiting factor, although no change in the sward height had occurred even when P was applied with N. However, mosses were sensitive to N application, and cover of *Rhytidiadelphus squarrosus* declined on the plots receiving ammonium sulphate, even at the lowest application rate (35 kg N ha^{-1} $year^{-1}$). This was thought to be due to acidification of the plots and a decrease in nitrate reductase activity. Nitrate reductase activity in *Rhytidiadelphus squarrosus* also decreased in plots treated with ammonium nitrate. It was predicted that the moss would die out after a longer period of exposure and that this might have secondary effects on the sward as a result of the creation of gaps (allowing the colonisation of other plants), changes in the microclimate and the percolation of rain water and its constituent solutes to the soil. After a further three years of treatment, the cover of higher plants was also significantly reduced (particularly *Agrostis capillaris*) when N was applied at the highest rates (140 kg N ha^{-1} $year^{-1}$). Except for the cover of bryophytes, the rate of change in the composition of acid grassland, as for calcareous grassland, appears to be slow, as might be expected in communities composed of long-lived perennials where P is also a limiting factor (Lee & Caporn 1998). Morecroft, Sellers & Lee (1994) suggested that the proportion of species upon which high N supply is toxic, such as mosses, could be a useful index of grassland sensitivity to N deposition.

5.1.2 Other nutrients

Sulphur. Sulphur is an essential nutrient for all plants (and animals) although it is more important to some crops such as legumes, brassicae, cereals and cut grass (Courtney & Trudgill 1981). Experiments on intensively managed grassland have shown that applications of about 10 kg S ha^{-1} per silage cut are sufficient to maintain its yield in areas of low S deposition (McGrath, Zhao & Withers 1996). However, when S is deposited from the atmosphere as sulphate in 'acid rain' it is renowned for having a detrimental impact on semi-natural ecosystems, particularly in upland areas (especially those close to emission sources) where the soils are poorly buffered.

Emissions of sulphur dioxide (SO_2) from burning S-containing fossil fuels and smelting sulphide-containing ores are the main source of S deposited from the atmosphere (DETR 1997). During the 19th Century the large emissions of SO_2 from industrial cities in northern England caused the disappearance of *Sphagnum* moss species from blanket bogs in the Pennines (Lee 1998). The majority of mosses have leaves which are just one cell thick and lacking in a cuticle. Their photosynthetic cells are, therefore, directly and continuously exposed to atmospheric deposits, which, in SO_2 polluted districts, may be phytotoxic (Lee 1998). The lack of *Sphagnum* species from the blanket peats of the Pennines is still the only large-scale vegetation effect in Britain for which experimental and observational evidence can be combined to demonstrate the effects of S pollutants (Lee 1998).

Concerns about the effects of acid rain on natural ecosystems resulted in steps being taken in Europe and other parts of the world (Protocol on the Reduction of Sulphur Emissions or Their Transboundary Fluxes adopted in 1985) to reduce emissions of SO_2, thus reducing S deposition. In the UK, changes in legislation, fuel use and combustion technology have resulted in much lower concentrations of SO_2 in formerly polluted areas. Since 1970, SO_2 emissions have decreased by 50% from 3 Mtonnes S $year^{-1}$ to 1.3 Mtonnes $year^{-1}$ in 1994 (DETR 1997). This has resulted in a decrease in non-seasalt S deposition across the country. Now, about 350 ktonnes of non-seasalt S is deposited in the UK each year (1992-1994 figures) of which about 60% is wet deposited and 40% dry deposited (DETR 1997). The Pennine hills are subjected to the highest inputs of about 35 kg S ha^{-1} with the lowest values of 3-8 kg S ha^{-1} in the drier parts of northern Scotland. Across the country as a whole an average of 13 kg S is deposited on each hectare of land. These inputs represent just 22% of the annual emissions of S from this country. The remainder is 'exported' out of the country by the wind (DETR 1997). Ironically, these reduced deposition rates have resulted in certain crops becoming S deficient in many parts of the UK, such that S containing fertilisers are required to maintain crop quality and yield (McGrath, Zhao & Withers 1996). Even so, Brown & Farmer (1996) concluded that S deposition was causing a number of natural areas in England, especially in the uplands, to be at high risk from exceedence of S critical loads, although this problem was expected to decrease considerably in the future.

High level emissions of SO_2 from power stations and the increased dispersion of SO_2 have now become more important than those from vehicles and other low level sources (Lee 1998). It is possible that the acidification of soils and freshwaters of areas quite remote from such power stations has been accelerated by the increased dispersion and deposition of acidic pollutants, such as sulphate (SO_4^{2-}). However, the responses of semi-natural terrestrial ecosystems to low concentrations of these pollutants are difficult to quantify and distinguish from natural acidification processes, so they may be having a more widespread effect than currently realised (Lee 1998). Moreover, as noted in Section 3, organic manures contain significant amounts of S, and there may be interactions between atmospheric S deposition and the effect of these manures on the productivity and composition of semi-natural vegetation.

Calcium, magnesium and potassium. The base cations Ca^{2+}, Mg^{2+} and K^+ are also deposited on land in the UK, although K^+ deposition is negligible (DETR 1997). The main impact of base cation deposition is the influence they have on the critical loads for acid deposition to soils, helping to counteract some of the detrimental impacts of acidic pollutants. It is estimated that base cation deposition, on average, balances about 20% of the acidifying deposition of S and N (CLAG 1997).

Wet deposition of Ca^{2+} amounts to about 121 ktonnes each year (of which 72% is non-seasalt and comes from industrial processes and the re-suspension of soil particles). A further 16 ktonnes of Ca^{2+} is dry deposited each year, mainly from non-seasalt sources. Deposition of non-seasalt Ca^{2+} tends to be concentrated between the Mersey and Humber estuaries in which Ca^{2+} deposition exceeds 8 kg Ca ha^{-1} $year^{-1}$. Other areas of high Ca^{2+} deposition include Cumbria, parts of Galloway and the west central Highlands. The areas where the smallest amounts of Ca^{2+} are deposited have an input of about 1 kg Ca ha^{-1} $year^{-1}$ (DETR 1997).

Virtually all the Mg^{2+} that is wet deposited in the UK (about 125 ktonnes each year) comes from seasalt with only 15% from non-seasalt sources. A further 12 ktonnes of Mg^{2+} is dry deposited each year, mostly from seasalt. Areas with the highest rainfall have the highest inputs of non-seasalt Mg^{2+} with annual inputs of up to 3 kg Mg ha^{-1} $year^{-1}$. In low rainfall areas the Mg^{2+} inputs can be as low as 0.2 kg Mg ha^{-1} $year^{-1}$ (DETR 1997).

The amounts of Ca^{2+} and Mg^{2+} deposited annually are probably balanced by losses, particularly in upland areas, through leaching. In studies by Adams & Evans (1989), it was found that soil under semi-natural upland grassland in west Wales lost about 15 kg Ca ha^{-1} $year^{-1}$. When lime is applied to grassland for agricultural purposes it is applied at a rate of about 3 tonnes ha^{-1} (Tallowin 1998), ie 375 times the highest annual deposition rate of Ca^{2+} in the UK. This would suggest that the impact of the atmospheric deposition of Ca^{2+} and Mg^{2+} on semi-natural grasslands in lowland England is likely to be negligible.

Phosphorus. Atmospheric deposition of P via rainfall is very low, compared to other nutrients, generally ranging from about 0.2 to 0.5 kg P ha^{-1} $year^{-1}$ according to location (Gibson, Wu & Pinkerton 1995; Withers *et al* 1999). In NE Scotland, however, atmospheric inputs of P are even lower, around 0.1 kg P ha^{-1} $year^{-1}$ (Haygarth *et al* 1998). The majority of P input in rainfall tends to be in particulate form, rather than as dissolved P.

5.2 Nutrient Losses

Nutrient losses from grassland may depend on a range of factors, including:

- the type and intensity of livestock production system;
- sward composition and age;
- soil type and background fertility status;
- form, rate and timing of fertiliser and manure inputs, where used;
- seasonal weather pattern.

The major nutrient loss processes in grazed systems are volatilisation and leaching (Scholefield & Fisher 2000). Nitrogen is lost by both pathways, through ammonia volatilisation and nitrate leaching. Ammonia losses principally occur from urine and dung patches left by grazing livestock and from manure applications, particularly slurry (Whitehead 1995). Denitrification processes also cause some gaseous losses of N, mostly as nitrous oxide (Oenema *et al* 1997). Phosphorus, S and K are lost by leaching, although P leaching losses are usually very small unless past fertiliser and manure applications have built up a high soil P status. Sakadevan *et al* (1993) showed that urine patches deposited by sheep increased the leaching losses of native soil Ca and Mg.

Organic manure applications to land can, if not carefully managed, be a major potential source of point or diffuse pollution of water and of air as a result of nutrients losses (Pain *et al* 1998; Smith *et al* 1998a; Chadwick *et al* 1999; Costigan, 1999). The following sections consider the main pathways of nutrient losses from grazed swards, including the potential effects of applying organic manures, and ways in which potential losses can be reduced.

5.2.1 Nitrogen

Apart from uptake by plants and removal in animal products, N is lost from the nutrient cycle as nitrate in drainage water (leaching) and as gaseous losses (ammonia, nitrogen (N_2), nitrous and nitric oxide). Losses from intensively managed grassland by leaching and gaseous emissions are commonly equivalent to 50-100% of N applied as inorganic fertiliser (Dampney & Unwin 1993). In contrast, nitrate leaching losses from unfertilised, ungrazed grassland are minimal (Archer, Johnson & Lord 1998). The environmental implications of nitrate leaching are well documented (Costigan 1999). In grassland management systems, nitrate losses are associated with grazing via dung and urine patches and inappropriate application of N as either inorganic fertiliser or manures (Jarvis 1999a), although the amount of N leached depends on a combination of factors (Scholefield & Fisher 2000). Izaurralde *et al* (1995) reported that nitrate losses were related to fertiliser N and mineralization of soil organic matter and proposed that increased efforts should be directed towards a better synchronization of N release from, or addition to, soils with plant N uptake. Cuttle (1995) also identified matching mineralised N release as a complication when trying to adjust fertiliser inputs in relation to manure use. In some conditions, N and other nutrient losses may be caused by direct runoff of manures into water courses or down cracks into field drains.

On agriculturally improved grassland, a change to less intensive systems will result in a reduction in nitrate leaching per unit of production, since a greater land area will be required to achieve the same agricultural output (Cuttle & Scholefield 1995). In this situation, the economic penalties associated with reductions in output can be partly offset by greater reliance on symbiotic N fixation and the use of clover-based swards in place of inorganic N fertilisers. Scholefield, Garwood & Titchen (1988) outlined a number of other practices which could potentially be used to reduce leaching and other forms of N losses from grazed pastures. Measurements of nitrate leaching in the Pilot Nitrate Sensitive Areas Scheme (NSAs) showed very low losses in fields after conversion from arable land to Premium scheme grass, which received little or no N fertiliser (Archer, Johnson & Lord 1998).

Nitrate leaching from organic manures. Studies following the application of animal manures to free draining soils in lowland England have shown that manures high in soluble N (eg slurries and poultry manures) represent a high nitrate leaching risk, particularly following applications in September-November (Figure 4; Smith & Chambers 1998). Considerably lower N losses were recorded following farm yard manure (FYM) applications. Similar results were obtained on both arable and grassland soils. Autumn manure applications to a drained clay soil resulted in considerable N (and also P) losses in drainage water, particularly in the case of pig slurry (N and P) and poultry manure (N), as a result of rapid by-pass flow to the drainage system (Smith *et al* 1998a). This effect has important implications for manure spreading on under-drained heavy textured soils.

Recent surveys on the production and disposal of livestock manures in the beef, dairy, pigs and poultry sectors (see Section 3) showed that, although manures are spread onto agricultural land throughout the year, approximately a quarter of the applications are made during the August to October period (Smith *et al* in press a,b,c). Application at this time of year presents the greatest risk of subsequent nitrate leaching loss and also less efficient utilisation of manure N.

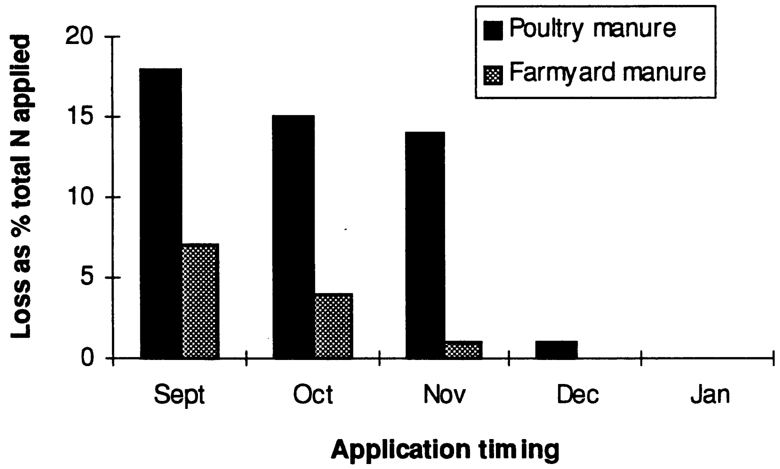
A range of practical on-farm measures in terms of manure rate, timing and application method, can be implemented to reduce the risk of manure-N losses by nitrate leaching and ammonia volatilisation (Smith & Chambers 1993; Carton 1995). Within the designated nitrate vulnerable zones (NVZ's) there are mandatory limitations on N loadings from manures, and timing restrictions on some soil types for spreading manures with high available N content (MAFF 1998e). These measures also emphasise the utilisation of animal manures as valuable sources of nutrients, which should be accounted for as precisely as possible when assessing fertiliser requirements (Prins & Wadman 1990). In the UK computer packages are available to assist farmers to achieve this objective (Chambers *et al* 1999d).

Direct runoff from manures. Heathwaite (1995) found that, in SW England, grazing intensity determined whether N from manures was lost as runoff, subsurface flow or preferential flow. Ammonium-N transport, primarily in surface runoff, was correlated with sediment transport. Buffer strips can be used to reduce runoff (Griffiths, Heathwaite & Parkinson 1995; Heathwaite, Griffiths & Parkinson 1998). Losses are higher when manures are spread when the soil is at field capacity and rainfall follows soon after application (Misselbrook *et al* 1995; Smith, Jackson & Pepper in press). McLeod & Hegg (1984) found that concentrations of N (and other nutrients) in runoff were more dependant on the number of rainfall events than on quantity of rainfall.

Ammonia loss. Losses from grazing stock depend on fertiliser N input and related herbage N intake, soil pH, temperature and moisture conditions (Hatch, Jarvis & Dollard 1990) and can range from 1 kg ha^{-1} for sheep on grass/clover swards to 41 kg ha^{-1} for dairy cows on intensively fertilised grass (Jarvis, Scholefield & Pain 1995). Only small losses from livestock grazing would therefore be anticipated for unfertilised semi-natural pastures.

Land spreading of manures accounts for almost a third of the ammonia emissions from UK agriculture, with slurry making a greater contribution than FYM to the total ammonia volatilisation losses from manure applications (Pain *et al* 1998). Ammonia losses following broadcast slurry applications can be 31-84% of the ammonium-N content in the slurry (Pain *et al* 1990). More recent research has shown that, under experimental conditions, injection of slurry or restricted surface placement, can considerably reduce ammonia emissions following land spreading (Smith *et al* submitted). In plot experiments, bandspread, 'trailing shoe' and shallow injection techniques gave overall reductions in ammonia emissions over 5-6 days following slurry application of 39%, 43% and 57% respectively, relative to a conventional surface broadcast application. The risk of ammonia losses is, however, lower from broadcast applications of FYM than slurry, due to the lower ammonium content of the solid manure.

(a) poultry manure to arable soil (ADAS Gleadthorpe, 1989/90 to 1992/93)



(b) Slurry application to grassland sites (1990/91 to 1993/94)

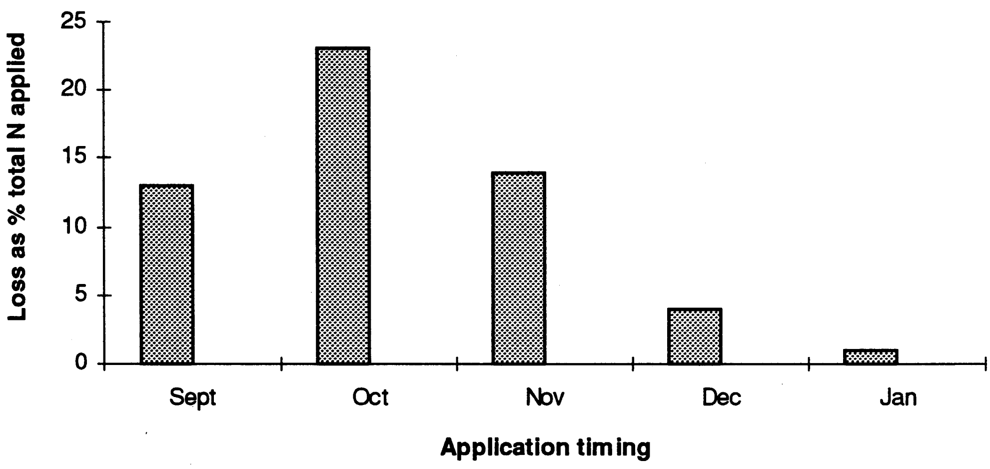


Figure 4. **Nitrate leaching losses following manure applications to free draining agricultural land**

Other gaseous N emissions. Nitrogen losses as N_2 gas and nitrous oxide (one of the greenhouse gases associated with climate change effects) occur as a result of denitrification and also, for nitrous oxide, nitrification processes in the soil (Oenema *et al* 1997). Denitrification losses from grazed pastures can be considerable in some situations (Scholefield & Fisher 2000). Nitrous oxide emissions from agriculture have major environmental implications and emissions from farmed livestock have been estimated by Chadwick *et al* (1999). Grazing derived nitrous oxide emissions, expressed as a percentage of the amount of N excreted by grazing animals in dung and urine, range from 0.2 to 9.9%, with an overall mean of 2% (Oenema *et al* 1997). Denitrification occurs under warm, anoxic conditions with high levels of carbon substrate and nitrate present. Smith *et al* (1998b) found a very strong relationship between N_2O emission and soil nitrate content for cut, ungrazed grassland in SE Scotland, provided the water-filled pore space was > 70%.

5.2.2 Phosphorus

Johnes & Hodgkinson (1998) summarised the processes and pathways of P loss from agricultural soils. Soils with high P status may increase P losses to the aquatic environment, through a combination of leaching, surface runoff and eroded soil material. A major concern is that such losses may promote eutrophication of surface waters. Similarly, surface runoff from recently applied manures or P fertiliser can also result in increased P losses (Smith, Jackson & Withers in press).

Increased P leaching losses have been measured on soils with a history of manure treatment, but only where considerable enrichment in topsoil P status, to extractable P levels > 70 mg l^{-1}, had occurred (Smith *et al* 1998a). There have been few long-term studies of P leaching from pastures. Hooda *et al* (1999) reported annual losses of molybdate-reactive P of 1.7 and 3.5 kg ha^{-1} P from grazed grass receiving no P fertiliser and P fertilised grass/white clover, respectively. However the main loss of P from soil is as a result of surface runoff (Heathwaite 1995). Indeed, on grassland soils P transfer is not solely related to soil P status (Heathwaite *et al* 1997). Soluble (<0.45 micro m) inorganic forms of P dominate P loss from grassland, but organic and particulate forms are also significant, especially in subsurface hydrological pathways. Preferential flow paths can be established in the saturated zone (Stamm *et al* 1998). Where manures are applied, subsequent rainfall events can lead to runoff, thus risk is higher in winter (Kolenbrander 1977). This can be reduced by the use of buffer strips (Griffiths, Heathwaite & Parkinson 1995; Heathwaite, Griffiths & Parkinson 1998).

5.2.3 Leaching losses of other nutrients

Scholefield & Fisher (2000) summarised limited results from UK studies which had shown K and S leaching losses from grassland ranging from 4-37 kg ha^{-1} and 19-29 kg ha^{-1} respectively. For both nutrients, losses tended to be correlated to N input. Lysimeter studies by Hogg (1981) in New Zealand showed very small leaching losses of K from sheep dung and urine, but appreciable losses of Mg and S from the urine.

5.3 Nutrient inputs, offtakes and budgets for lowland pastures

Nutrient budgets have been used for some time, but have only recently been constructed for complete, managed grassland systems (Frissel 1997). Balances can be constructed in several ways, depending on the approach, scale and data needs. Jarvis (1999b) outlined the following types which have been used for grassland systems:

Farm gate balance or surplus. This method, which has been widely used in policy analysis, requires records of N and P (or other nutrient) inputs and outputs entering and leaving the farm gate. The difference between total input and total output is a measure of the depletion (including losses) or enrichment of the system. Neither uncontrollable inputs, eg from atmospheric deposition or biological N fixation, nor losses are usually included in the balance calculations.

Surface balance. This determines nutrient fluxes across the soil surface, so that the difference between total inputs and removal in crop uptake provides a measure of soil nutrient depletion or gain. This balance also includes uncontrollable inputs but does not usually indicate the fate or origin of surplus nutrients. This approach is a useful tool for predicting field scale changes in soil nutrient levels and is commonly used for determining crop nutrient requirements.

Systems balance. This provides detailed information on inputs, outputs and losses and internal recycling, usually for different components of the system, eg soil, crop, livestock, manures and, if more detail is required, can be further subdivided into different pools. Systems balances are more complex and are commonly used for research, eg in dairy systems (Aarts, Biewinga & Van Keulen 1992) and to assess effects of changes in N management (Jarvis, Wilkins & Pain 1996), but can also be used for planning purposes.

Systems and farm gate balances are useful policy tools and, by determining trends in nutrient use, can be used to assess the potential for increasing efficiency and decreasing pollution in more intensive grassland management systems. With appropriate modelling, they can also be used at a regional or national scale to predict the effects of changes in specific management practices. At farm scale level, these balances enable farmers to assess nutrient use efficiency, and hence optimise the utilisation of nutrients for required production levels (Jarvis 1999b).

The following sections consider nutrient budgets for lowland pastures, as determined by nutrient inputs and offtakes at farm or field scale. The implications are assessed for grazed semi-natural pastures which are managed according to prescriptive advice on the use or otherwise of inorganic fertilisers and/or organic manures within SSSIs and agri-environment schemes. Some farmers are concerned that nutrient removal in livestock production from grazed semi-natural pastures may, in the longer term, lead to a decline in soil fertility, especially P status.

5.3.1 Nutrient inputs

The main forms of nutrient input at the farm gate level are: fertilisers; purchased feed; bought-in bedding; new/replacement livestock; atmospheric deposition (mainly for N; see Section 5.1); and, for N, biological fixation (Watson & Stockdale 1999). Nutrient inputs from fertilisers and concentrate feed imported onto the farm are high, particularly for N and P, in more intensively managed dairy and beef systems (Oyanarte *et al* 1996; Jarvis 1999b; Watson & Stockdale 1999). For extensively managed semi-natural pastures, however, there is usually little or no nutrient input from these sources.

Nutrient returns at grazing. The excretal return of nutrients to grass via dung and urine is spatially and temporally very heterogeneous and this can have dramatic localised impacts on soil microbes and fauna, and can damage vegetation (Schechtner *et al* 1980) and affect grazing patterns (Kimura & Kurashima 1991). These aspects are also discussed, with particular reference to semi-natural pastures, in Sections 7 and 9. One extreme effect may be the disproportionate redistribution of nutrients contained in herbage grazed on hillsides, to the flatter 'campsite' areas (Scholefield & Fisher 2000). Brasher & Perkins (1978), for example, noted that sheep on upland pasture distributed excreta unevenly as a result of both selective grazing and night camping habits.

Oomen (1995) reported that ruminants excrete most of the N intake in urine and this N is at risk of gaseous or leaching loss. The proportion of excreta produced as faeces or urine is reported as 1.1 to 2.4 for dairy cows, 0.6-1.7 for ewes and 0.35-0.6 for lambs (Smith & Frost 2000). For cattle the ratio is affected by weather (Morse *et al* 1994), lactation stage (Tietjen 1966), diet (Metcalf 1995) and grazing regime (Smith & Frost 2000). The nutrient content of sheep faeces was reported by MAFF (1976) as 0.8% N, 0.45% P_2O_5, 0.3% K_2O and sheep urine by Givens (pers. comm.) as 0.46%N and by Loehr (1974) as 0.02% P_2O_5, 0.25% K_2O. For cattle equivalent figures are given in MAFF (1976) as 0.4% N, 0.2% P_2O_5, 0.32 K_2O in faeces and 0.79% N, 0.002% P_2O_5, 1.6 K_2O in fresh urine. The corresponding nutrient contents of slurries and manures produced by housed livestock, where dung and urine are mixed together, are presented in Section 3. These data for dung, urine and stored manures relate, however, to livestock production on more intensively managed grassland. Nutrient contents are likely to be lower for livestock grazing semi-natural pastures. A survey by Shepherd *et al* (1999) found that, despite wide variations in nutrient contents due to management factors, organic livestock farming systems produced manures with NPK contents which were generally *c.* 20-40% less than published values for 'conventionally' produced manures.

The K and Mg returns from dung and urine affect the balance of K:Mg in soil and herbage, with dung increasing soil and herbage Mg levels, whilst urine increases soil exchangeable K (Hogg 1981). Dung and urine patches can also act as a source of S for pastures (Kennedy & Till 1981). Although most of the nutrients contained in dung and urine are of potential use to plants, net N losses are incurred through volatilisation and leaching and the pattern of excretal distribution is one of the most important factors in determining initial nutrient availability (Brasher & Perkins 1978).

5.3.2 Nutrient offtakes

The main forms of nutrient output, excluding any leaching, runoff and gaseous losses (see Section 5.2), at the farm gate level are the nutrient removals in animal (*eg* milk, meat or wool) and crop production (Watson & Stockdale 1999). At field level, nutrient offtakes in pastures depend on the grazing or cutting management system used. The amounts of nutrients applied as inorganic fertiliser and/or organic manure may also have some influence on subsequent nutrient offtakes, because of their effect on both herbage nutrient concentrations and herbage dry matter production (Scholefield & Fisher 2000).

Grass grazed *in situ*. When grass is grazed *in situ*, there is a direct return of nutrients removed in the ingested grass through dung and urine, with net offtake being represented by the animal products being sold off the farm. Ruminants are inefficient at incorporating the nutrients obtained from herbage into milk or meat (Scholefield & Fisher 2000). About 10 to 20%, depending on N concentration, of dietary N is retained by grazing beef animals. Haynes & Williams (1993) found that 25, 35 and 12% of the N, P and K respectively ingested by dairy cows was incorporated into milk. Aarts, Beiwinga & Van Keulen (1992) estimated average offtake in milk of 63 kg ha^{-1} N, 11 kg ha^{-1} P and 18 kg ha^{-1} K, for intensive dairy production.

Data for sheep used in the Farming and Wildlife Advisory Group (FWAG) nutrient budget approach (Knight 1999) indicate that 122 kg N, 0.11 kg P and 1.1 kg K are removed in every tonne of wool, and 0.96 kg N, 0.28 kg P and 0.06 kg K in a typical fat lamb (38 kg liveweight). Nutrient budgets calculated by Perkins (1978) for an upland grassland site with sheep grazing, showed a loss of nutrients as a result of both sheep production, with removal during and at the end of the grazing season, and also transfer in dung and urine, 25% of which was deposited on night camping sites. Nutrient input in rainfall was considered to largely compensate for N and P, but not K losses. Loss of K was mainly caused by the high transference to night camping sites. The overall nutrient budget suggested that P was finely balanced and may limit primary production, and Brasher & Perkins (1978) concluded that uneven dung distribution by sheep has a strong influence on spatial variation in the productivity of this ecosystem.

For beef cattle (500 kg liveweight) the FWAG figures are 12.65 kg N, 3.7 kg P and 0.85 kg K. These offtake data for beef cattle indicate a removal ratio for N:P:K of 13:4:1, while the N:P:K nutrient content ratio in cattle FYM is 6:4:8. Periodic light dressings of FYM, if applied to grazed cattle pasture to avoid long term nutrient depletion, would therefore need to be based on P (and K) content. For beef and sheep, total nutrient removal in meat (and/or wool for sheep) will depend on stocking density. No data on liveweight NPK content were found for horses, however they would tend to be kept on the same land for a number of years and so net nutrient removal would be small.

Guidelines on stocking rates for semi-natural pastures are given in the Lowland Grassland Management Handbook (Crofts & Jefferson 1999). Tallowin (1997), in reviewing the agricultural productivity of lowland semi-natural grassland, reported that dry matter yields from a sample of such grasslands were 40-80% of those that might be expected from intensively managed, agriculturally improved grassland. However, there was very little information on the performance and output from livestock systems based either partly or fully on semi-natural grasslands. Available information indicated that winter grazing is often only marginally suitable for maintenance of livestock, unless supplementary feeding is carried out, while during the summer most semi-natural pastures are able to sustain either maintenance requirements or modest growth of livestock.

Grass Removed. Grass can be removed as hay or silage, with crops of the latter often being taken more than once during the season in intensive production systems. Fields are often grazed after cutting and sometimes in early spring prior to shutting up for a silage or hay crop. Hopkins *et al* (1985) reported that in South West England, most fields were both cut and grazed. Calculation of offtakes in these fields is complicated by the problems of grazing identified above. Typical nutrient offtake from intensively managed, first cut silage may be estimated as 104 kg ha^{-1} N, 15 kg ha^{-1} P and 100 kg ha^{-1} K and hay as 57 kg ha^{-1} N, 13 kg ha^{-1} P and 75 kg ha^{-1} K. Potassium offtakes in cut grass can be much higher, because of 'luxury uptake' where soil K levels increase as a combined result of K fertiliser inputs and K returns in dung and urine when the sward is grazed (Jourdan 1987).

Most nutrients ingested by grazing animals are returned directly in excreted dung and urine to grazed pastures. However, nutrients removed in hay or silage from cut swards are only returned indirectly if manures (FYM or slurry), produced overwinter by housed livestock fed on that forage, are subsequently spread on the same swards. In practice, FYM is often applied to semi-natural hay meadows to avoid nutrient depletion, which would otherwise occur as a result of crop removal, and hence prevent any reduction in potential hay yield (Simpson & Jefferson 1996). Jefferson & Robertson (1998) recommend that well rotted cattle FYM can be applied to hay meadows as a single dressing of up to 20 t ha^{-1} every three to five years, but note that more frequent (eg annual) applications to upland meadows might be compatible with the maintenance of nature conservation value. No specific data on nutrient offtakes in hay produced from semi-natural meadow grassland were quoted by Simpson & Jefferson (1996) in their review of this topic, but offtakes, particularly of P and K, can be expected to be lower than those for conventionally fertilised hay production (as shown above). For example, in unfertilised species-rich hay meadows on the Somerset Levels, offtakes of 70.1 and 51.7 kg N ha^{-1} were recorded in hay at cutting and baling respectively, and 5.5 and 39.4 kg ha^{-1} of P and K respectively at cutting (amounts of P and K were not measured in baled hay) (Kirkham & Wilkins 1994a).

Historically the application of FYM was observed to provide additional benefits compared with inorganic fertiliser, as reported for example by Kneale and Johnson (1972) for trials where permanent upland meadow was cut annually for hay over an 18-year period. In Poland (Jankowska-Huflejt, Niczyporuk & Zastawny. 1996) found benefits in terms of less soil acidity and increased Mg and Ca contents when permanent meadow was treated annually (over a 12 year period) with manure compared with conventional fertiliser. In France, Fleury, Jeannin & Dorioz (1987) found that in mountain hay meadows heavy manuring produced increased yields which required mowing earlier to obtain the same degree of digestibility. Effects of manure (FYM and slurry) applications on the ecology of lowland pastures are discussed in Chapter 6.

5.3.3 Nutrient balance

A nutrient budget or whole farm balance has been recommended for a number of years and by many workers, as a convenient tool for determining nutrient shortages or surpluses at farm level, and for fertiliser planning at field level (eg O'Callaghan, Dodd & Pollock 1973, Knight 1999). For the livestock farmer this may mean using stored manures more efficiently when recycled to land and adjusting application rates of fertiliser, where used. It may also mean adjusting dietary concentrates (Kirby *et al* 1997). Specific information on nutrient budgets for semi-natural pastures is very limited, although Green (1972) had suggested that a greater knowledge of nutrient budgets was fundamental to the scientific management of certain plant communities such as chalk grassland.

Conventional dairy farms in the UK have large N and P surpluses, on average 111 and 32 kg ha^{-1} respectively (Jarvis 1999b), which are very similar values to mean data for European dairy farms where surpluses in 1990/91 ranged widely from 40-337 and 10-50 kg ha^{-1} respectively (Brouwer *et al* 1995). In comparison, Shepherd *et al* (1999) calculated an N surplus (excluding losses) of 125 kg ha^{-1} for a typical organic dairy farm. However, both N and P surpluses can be much lower in other types of organic or extensively managed livestock systems. For example, Shepherd *et al* (1999) estimated an N surplus (excluding losses) of 23 kg ha^{-1} for an organic upland/hill farm with beef and sheep, while Haygarth *et al* (1998) estimated a typical P balance (excluding losses of 0.4 kg ha^{-1}) of just 0.6 kg ha^{-1} for an upland farm

Specific data on K balances for livestock farming systems are limited, as this nutrient is not considered to pose any risk of environmental pollution. High soil K levels in the soil should, however, be avoided, because of their antagonistic effect on herbage Mg uptake and associated risk of hypomagnesemia in grazing livestock, especially in early spring. A number of factors affect the relationship between K balance and exchangeable and non-exchangeable soil K levels (Johnston 1988).

The dangers of not identifying balances between inputs and offtakes in upland grass was identified by Johnson (pers. comm.) with respect to the manure policy in ESAs. The maximum inputs of fertiliser and manure were found to be inadequate to replace offtakes in cut hay. In Ireland, Humphreys *et al* (1997) reported that application of cattle FYM and slurry maintained soil P, K and Mg concentrations in line with the requirements for optimum production from grass/white clover swards.

Nutrient budgets affect soil nutrient status and changes in nutrient levels over time. Data from the Representative Soil Sampling Scheme indicate that soil P and K levels both declined under managed grassland between 1969 and 1993, although K levels rose initially before falling (Skinner & Todd 1998). Data on the nutrient status of semi-natural grasslands are limited. However, analysis of a large number of soil samples taken from grassland sites in 14 ESAs throughout England, to evaluate relationships between soil pH/nutrient status and botanical composition, showed that the soils had a wider range of pH values, lower P levels and higher organic matter contents than agriculturally improved grasslands (Chambers *et al* 1999e).

5.4 Summary

The impact of atmospheric N deposition on semi-natural grasslands is influenced by the amount and duration of the deposition, the buffering capacity and nutrient status of the soil and the management regime. Different types of grassland therefore differ in their sensitivity to atmospheric N with those on acidic soils being more vulnerable than those on more highly buffered calcareous soils. Most research suggests that N deposition leads to the competitive exclusion of species characteristic of semi-natural grassland, which are replaced by nitrophilic plants. Where soils are highly P limited, increased N mineralisation and leaching to the groundwater can occur. It is also evident that long-term studies, over tens of years are required, to gain a better understanding of the impact of increasing rates of atmospheric N deposition.

Modelling studies suggest that implementation of the 2nd Sulphur Protocol will result in greatly reduced S deposition (already reduced by about 25% from the late 1960s amounts) over the next few years, particularly in the lowlands, where dry deposition predominates. This means that the importance of N deposition will continue to increase, pending any reduced emissions following the implementation of IPPC. Atmospheric deposition of Ca, Mg, P and K should not, however, have any significant impacts on semi-natural grasslands.

Nitrogen losses can occur as a result of both nitrate leaching in drainage water and gaseous emissions due to ammonia volatilisation and denitrification processes. Leaching is also the main pathway of loss for the other major nutrients apart from P, which is mostly lost by surface runoff rather than leaching, unless soil P levels are very high due to past fertiliser and manure inputs. Nutrient losses will be much smaller from semi-natural pastures than from more intensively managed grassland. Where manures are applied, appropriate management practices in relation to rate, timing and application method can be used to reduce the risk of subsequent nutrient losses.

Models for single nutrient cycling can be developed which enable advantageous (either environmentally or economically) changes in management practices to be identified. It is, however, necessary to take into account the impact on other nutrient flows. Whole farm nutrient budgets can identify overall surpluses or deficits but are not necessarily helpful at a field scale. There is a risk that prescriptive restrictions on nutrient inputs, which do not make allowance of variable offtakes, will create nutrient imbalances. Nutrient returns, in periodic dressings of FYM at low application rates, may be necessary for semi-natural hay meadows in order to avoid gradual soil nutrient depletion and associated reductions in potential hay yield. Few studies have estimated nutrient budgets for semi-natural pastures but, in this situation, a very slow nutrient depletion might occur as a result of nutrient offtake in animal production. If so, an occasional application of 20 t ha^{-1} FYM may be needed once every five to ten or more years, depending on 'surface balance' nutrient budget calculations. Where FYM is used on semi-natural grassland, adequate field records should be kept (including rate, timing and periodicity of manure applications and stocking/cutting management), so that field scale nutrient balances can be monitored and nutrient inputs adjusted if/as necessary. Typical values for nutrient content of FYM should be used if it is impractical to determine the nutrient composition by laboratory analysis of representative samples. Slurries are not considered a suitable source of plant nutrients for either grazed semi-natural pastures or traditional hay meadows, because of the potential adverse effects of their high available N content on sward biodiversity in sensitive ecosystems. However, slurry may be a more viable option if it can be applied at low rates.

6. The effects of organic manures and fertilisers on the ecology of lowland pastures

6.1 Background

The use of organic manures, particularly farmyard manure (FYM), is traditional in hay meadows and the application of moderate dressings of FYM is considered to be consistent with conservation interest in most such meadows (Crofts & Jefferson 1999), although some questions remain to be answered (Simpson & Jefferson 1996). Harvesting hay from the field removes a large amount of nutrients, and under traditional practice the aim is to balance this removal by the application of the FYM produced by stock feeding on the hay over winter. Any additional N in the FYM resulting from supplementary protein feeds given to stock might be expected to be balanced by losses during housing, storage of the FYM and by leaching in the field. However, in grazed pastures the situation is different because a very high proportion of the nutrients consumed by grazing animals is returned in the form of faeces and urine (reviewed in detail in Section 5 of this report). When nutrients are continually added to grazed pastures in excess of the amounts being removed in animal products (wool, meat and milk) or lost by leaching or volatilisation, a build-up of fertility can be expected. However, the influence of grazing on the botanical composition of pastures is by no means simply a function of the amount of nutrients returned in excreta. Changes in soil fertility resulting from adoption, cessation or modification in the use of inorganic or organic manures will almost invariably be accompanied by concomitant changes in stocking density. It is primarily the interacting effects of changes in soil fertility with those of grazing *per se* which determine the ecological outcome, although the amount of information available which might allow this outcome to be predicted in a given situation is very limited.

Little research has been carried out into the ecological effects of organic manures in semi-natural pastures managed solely by grazing, and such information as is available is reviewed below. There is a little more information on the use of these manures under hay cutting, from long-term experiments at Rothamsted (Lawes & Gilbert 1859a,b; Lawes, Gilbert & Masters 1882; Brenchley 1924; Williams 1978), at the Royal Agricultural College, Cirencester (Kinch & Stapledon 1911,1912) and at Cockle Park (Arnold, Hunter & Gonzalez Fernandez 1976; Hopkins & Shiel 1996). The use of farmyard manure (FYM) in hay meadows was reviewed in detail by Simpson & Jefferson (1996), who concluded that more research was needed on FYM rates, periodicity of application and the influence of storage time. This has resulted in a six-year project funded by MAFF, EN, CCW, WOAD and DANI to investigate the use of FYM (and lime) in semi-natural hay meadows, in comparison with equivalent rates of inorganic fertilisers. No results are yet available from this project, which was started in 1999.

In view of the paucity of information directly related to the use of organic manures in grazed pastures, compared to hay meadows for example, much of this and the following section of the report focuses on the ecological effects on mixed species vegetation of nutrient inputs *per se*, the effect of grazing in comparison with cutting management, and the interacting effects of nutrient inputs and grazing. Comparisons are made between the effects of inorganic and organic fertilisers where possible. The main emphasis is on the effects on botanical composition, but the effects of organic manures on soil fauna and above ground invertebrates are referred to briefly. The information reviewed is used to infer the likely effects of organic manures under grazing conditions and to support such direct information as is available on these effects. The findings are first put into context by a brief outline of the theoretical considerations surrounding grazing and its interaction with soil fertility.

6.2 Soil fertility and disturbance interactions

Fertiliser treatments, particularly those including N, frequently lead both to an increase in biomass and to a reduction in plant species richness (Lawes, Gilbert & Masters 1882; Brenchley 1924; Willems 1980; Elberse, Van Den Bergh & Dirven 1983). This can lead to the assumption that the second of these factors is a direct consequence of the first, and that loss of species richness can be averted or minimised by preventing the accumulation of biomass by frequent defoliation or grazing (Marrs, 1993). In reality the interactions between soil fertility, species density, defoliation and biomass accumulation are fairly complex. This is important in the context of grazed pastures receiving nutrient inputs, because there is a limit in the extent to which the effects of increased fertility can be mitigated by increased grazing pressure. In fact, there is a point along a scale of increasing soil fertility beyond which increased grazing intensity begins to exacerbate, rather than mitigate, the harmful effects of soil fertility, although there appears to be no general rule as to where that point might lie in a given situation.

Maximal plant species richness generally occurs in moderately resource-poor habitats (Grime 1979; Tilman 1982,1997; Marrs 1993). However, there are few examples of an increased nutrient input leading to an increase in species richness. In Milton's experiments in the Welsh uplands (Milton 1938,1940; Milton & Davies 1947), a number of species invaded the plots receiving fertiliser and lime, but only where controlled grazing was also introduced. The ingress of new species was negligible where sheep grazing remained lax, or where plots were cut for hay, although fertilisers did bring about a change in the balance of existing species on these plots. However, the pastures were initially very species-poor and dominated by *Agrostis spp., Festuca ovina* and *Molinia caerulea*, their composition reflecting both the nutrient-poor, acid soil conditions and the previous low grazing intensity. The results support another general rule that, other resources being equal, maximal species richness occurs at moderate to intermediate levels of disturbance (Grime 1979; Huston 1979); this level of disturbance helps to contain the growth of 'competitive' species (*sensu* Grime 1977), at the same time providing some spatial heterogeneity in the habitat without imposing undue stress on the vegetation (Grime, 1973a,b, 1979; Crawley, 1997; Marrs, 1993). The significance of spatial heterogeneity in relation to species-richness is discussed in Section 7.

6.3 Fertilisers and botanical composition

A large number of experiments have investigated the effects of fertilisers, particularly in inorganic form, on the botanical composition of species-rich and moderately species-rich temperate vegetation and many of these have been reviewed previously (eg de Vries & Krujne 1960; Rorison 1971; Rabotnov 1977; Snaydon 1987a; Marrs 1993). In more recent research in wet meadows on a peat moor, repeated applications of rates as low as 25 kg N ha^{-1} year^{-1}, with amounts of P and K sufficient to replace those removed in hay, led to a reduction in plant species diversity and dominance of grasses such as *Lolium perenne* and *Holcus lanatus* (Mountford *et al* 1993, 1994; Kirkham, Mountford & Wilkins 1996). The vast majority of past experiments have been carried out under cutting management, mostly hay making, with or without grazing outside the period when hay was grown.

Pigott (1982) noted that in the Park Grass Experiment at Rothamsted (Williams 1978), different treatments had produced distinct and recognisable vegetation types. Dodd *et al* (1994) later matched the plant communities occurring under different treatments over time with those of the National Vegetation Classification (NVC) (Rodwell 1992). Stapledon (1914) used the results of several fertiliser experiments current at the time, including those at Rothamsted (Lawes, Gilbert & Masters 1882), Cockle Park (Gilchrist 1906) and Cirencester (Kinch & Stapledon 1911,1912), to develop a fairly rudimentary classification of grassland 'types' according to their species composition in relation to fertiliser use.

It is clear from a wide range of information available that the exact nature of the plant communities developing under particular fertiliser treatments varies in different situations, eg according to soil type, moisture regime and cutting/grazing management (Rodwell 1992). A general finding, however, is that fertilisers, particularly those containing substantial amounts of N, increase the proportion of grasses in the vegetation at the expense of legumes and other dicotyledonous species (forbs), whilst P and K applied alone often increase the legume content. The superior response to N inputs of grasses compared to forbs and legumes is attributable to a number of characteristics, including their more rapid accumulation of biomass in spring (Grime 1980), more efficient N metabolism, a larger proportion of roots in the upper soil layer, better water economy (which is improved by N application, Garwood 1988), and tall growth giving more efficient light interception (Rabotnov 1966,1977). Legumes are favoured by the application of P and K without N, since their ability to fix N compensates for a less ramified root system and a poorer root cation exchange ability compared with grasses (Gray, Drake & Colthy 1953; Mouat & Walker 1959; Kydd 1965; Jackman & Mouat 1972). Application of P and K to a peat soil containing high levels of organic N, but where P was limiting, increased N uptake in the vegetation with a concomitant increase in the proportion of grasses at the expense of forbs (Kirkham, Mountford & Wilkins 1996; Tallowin *et al* 1990).

In addition to low N availability, low soil P is a characteristic feature of semi-natural grasslands and is associated with high species-richness (Kirkham, Mountford & Wilkins. 1996; Jannsens *et al* 1997, 1998 - but see also Smith 1987, referred to below). Applications of P, particularly in inorganic form, as opposed to in the form of bonemeal, significantly reduced flowering populations of green-winged orchids (*Orchis morio*) in an old meadow (Silvertown *et al* 1994). The results suggested that application rates of inorganic P equivalent to ten times the amount removed in hay were toxic to the orchid or to it's mycorrhizal symbiont.

The potential of atmospheric N deposition to alter the balance between N and P availability in semi-natural ecosystems has already been discussed in Section 5 of this report. It is possible that the response of vegetation to the same rates of N, P and K applied in different locations may be influenced by the large geographical differences in N deposition (ie of <25 kg N ha^{-1} per year) which currently exist in the UK (Pitcairn, Fowler & Grace 1995; RGAR 1997). However, such effects would not be easy to identify accurately using existing data from fertiliser experiments, both due to temporal changes in N deposition and also because no attempt is made in such experiments to prevent atmospheric N deposition on 'control' areas.

6.4 Long-term experiments

In experiments where FYM has been compared with inorganic fertilisers (under cutting management), the effects of FYM have been less marked than those of inorganic fertilisers, but the overall effect has been an increase in the proportion of grasses (Lawes, Gilbert &

Masters 1882; Kinch & Stapledon 1911,1912). Treatments in these older experiments were largely unreplicated, and in plots over limestone at Cirencester, variations in soil depth, which affected both the soil water capacity and the Ca content of the soil, had a greater effect on botanical composition than the treatments themselves (Kinch & Stapledon 1912). *Bromus erectus* dominated shallower soils where it was more than three times as abundant than on deeper soils. Vegetation on deeper soils was dominated by a more even mixture of *B. erectus*, *Festuca longifolia* (erroneously named *F. duriscula* - Hubbard 1984), *Dactylis glomerata*, *L. perenne* and *Trisetum flavescens*. This difference was less marked with FYM application, where, in contrast to all other plots, *F. longifolia* was the most common grass. *Alopecurus pratensis* accounted for 10% of the herbage on these plots, but did not exceed 2% elsewhere (Kinch & Stapledon 1912). With the exception of P applied alone, all fertiliser treatments, including FYM, increased the total grass content and reduced legumes compared to the unfertilised plot, but the only notable effect on other broad-leaved species ('weeds') was an apparent increase with P application. As with most early experiments, the rates of fertilisers applied were not high, particularly for N (53 kg N ha^{-1} as ammonium sulphate, or 62 kg N ha^{-1} as sodium nitrate, per year). P and K were applied annually at 72 and 63 kg ha^{-1} respectively, and FYM at 30 t ha^{-1} every second year. All combinations of the three elements were tested in mineral form. Hay yields appeared to be unaffected by soil depth with FYM application, in contrast to unfertilised plots and those receiving inorganic fertilisers, reflecting a higher moisture retention in soils receiving FYM (Hunter 1931).

In the Park Grass Experiment (Lawes, Gilbert & Masters 1882; Williams 1978), FYM was applied at 35 t ha^{-1} every fourth year for the first eight years (1856-63), after which it was discontinued (plot 2). *Poa trivialis* and *Bromus mollis* became co-dominant initially with FYM application to plot 2, but subsequently declined after application was discontinued, mainly in favour of *Agrostis capillaris*, *Festuca rubra*, *Helictotrichon pubescens* and *H. lanatus* (Lawes, Gilbert & Masters 1882; Williams 1978). Four years after cessation of FYM application, the vegetation consisted of 85% by weight of grasses, 1.6% legumes and 14% 'others'. These proportions were very similar to those on the plot receiving N, P and K annually at 48, 35 and 225 kg ha^{-1} respectively, and markedly different from the vegetation on unfertilised plots (62% grasses, 8.1% legumes and 30% 'others', averaged over two plots). Total species numbers differed too, at 47, 39 and 34 species per plot for unfertilised, FYM and NPK treatments respectively (note that NPK plot was twice the area of control plots and FYM plots). Legumes also increased after FYM application ceased, returning to levels approaching those on unfertilised plots by 1877. The number of 'other' (broad-leaved) species increased progressively over the same period, although the proportion by weight of this group changed little. Both the number and proportion of the group declined after aftermath grazing was replaced by a second cut on all plots from 1877 onwards.

From 1905 onwards, FYM was applied to plot 19, which had previously received N, P and K since 1872 (N48,P35,K225). This change was made nine years before the first full botanical assessment since aftermath grazing ceased, and it is not easy to interpret the cause of subsequent changes in botanical composition. By 1877 the grass content on this plot exceeded that on unfertilised plots by about 12%, although differences were comparatively small for individual species. From 1914 onwards, the main difference between this plot compared to both unfertilised plots was in the increased abundance of *A. pratensis*.

Trends in species number per plot in the Park Grass Experiment, presented by Smith (1987), showed that whilst the greatest number were almost always on the unfertilised plot (data for only one unfertilised plot were presented), the difference between this and plots receiving either FYM (plot 19) or P and K without N were small compared with treatments receiving N, P and K in inorganic form. When data were expressed using the Shannon-Wiener diversity index, which takes into account the evenness of abundance amongst the species as well as the total number present (Kent & Coker 1992), differences within the first group were less marked and became smaller with time (Smith 1987). Smith (1987) interpreted this as indicating that high species diversity was associated with moderate fertility and noted that some input of P was beneficial. The data presented by Smith showed no advantage of either P and K or FYM application over the unfertilised plot in terms of species richness or diversity, but there were distinct advantages in terms of maintenance of hay productivity (Brenchley 1924). Hay yields on unfertilised plots declined markedly on unfertilised plots after the cessation of aftermath grazing in 1877 (Brenchley 1924), almost certainly due to reduced nutrient cycling and an increase in the amount of nutrients removed from the plots attributable to the second cut each year.

The results of the Park Grass Experiment are complicated to some extent by the fact that N was applied either as ammonium sulphate, which has an acidifying effect, or as sodium nitrate which does not (Williams 1978). The results for the NPK treatment, quoted by Smith (1987) and referred to above, related to N applied in sulphate form. As Smith (1987) points out, the results of the experiment as a whole confirm that at least moderate soil pH is important in maintaining species-richness (Grime 1979). The negative effect of N on forb content was clear at the lowest N rate (48 kg N ha^{-1}) when applied as ammonium sulphate, but only at higher rates when applied as sodium nitrate (Williams 1978). By contrast, on acid-neutral peat soils on the Somerset Levels (Mountford *et al* 1993,1994), the negative influence on forbs and the positive effect on grasses of N applied as ammonium nitrate (which is not particularly acidifying) was very evident even at low rates of N (25-50 kg ha^{-1}). In the latter situation the amount of available soil N was relatively high during the growing season (Kirkham & Wilkins 1993) and P was the main element limiting productivity and influencing botanical composition (Kirkham & Wilkins 1994a; Kirkham, Mountford & Wilkins 1996).

In the Palace Leas experiment at Cockle Park, species-richness increased on control plots (ie those receiving no nutrient addition) between the beginning of the study in 1897 and 1985 (Smith 1987), in contrast to the Park Grass Experiment. Smith (1987) attributed this difference to the continued grazing outside the period when hay is grown on the Palace Leas plots, demonstrating the positive benefits for species-richness and diversity of aftermath grazing of hay meadows. The highest number of species in 1984 was recorded on the plot receiving inorganic P alone (18 species m^{-2}), followed by P and K and N, P and K (both 17 species m^{-2}), compared to 13 species m^{-2} on the control plot and 11 species m^{-2} with annual FYM application (20 t ha^{-1}). Arnold, Hunter & Gonzalez Fernandez (1976) noted that the soil on the Palace Leas plots was deficient in P, despite the fact that this field had received better treatment in the form of dung applications than the remaining grassland (Pawson 1960). Analysis of data presented by Arnold, Hunter & Gonzalez Fernandez (1976) shows a very strong linear relationship between hay yields averaged over the years 1897-1975 and soil mineral P content in 1973 (correlation r=0.97, P<0.001). Comparison of these data with species per m^2 data for 1984 presented by Smith (1987) show that maximum species-richness occurred on plots previously showing intermediate levels of both mean hay yield and soil mineral P, ie those receiving the P alone treatment. This result concords both with theoretical predictions (Grime 1979) and, in terms of trends in species-richness against hay yield, with data from a fairly wide range of hay meadows in the Netherlands (Oomes 1992). However, the actual inorganic P concentrations quoted by Arnold, Hunter & Gonzalez Fernandez (1976) appear to have been miscalculated, possibly by a constant factor of 10. Pawson (1960) quotes values from an earlier analysis of the same soils as, for example, 0.005% and 0.008% P_2O_5 for the unfertilised plot and the plot receiving N and K only for 76 years (NK) respectively, equivalent to 2.2 and 3.5 mg P $100g^{-1}$ (22 and 35 mg P g^{-1}) respectively. These compare with values of 227 and 224 mg P μg^{-1} quoted by Arnold, Hunter & Gonzalez Fernandez (1976) for the same plots in 1973. The value of 227 mg P μg^{-1} (22.7 mg P $100g^{-1}$) is approaching the maximum P level of 35 mg $100g^{-1}$ recorded in 281 grassland sites across Britain and the mainland of Europe (Jannsens *et al* 1997,1998). The latter authors quote a value of 5 mg P $100g^{-1}$ as that above which potential species-richness is severely reduced, and their data suggest an optimum of about 3 mg P $100g^{-1}$ for potential maximum species-richness. Adjusting down figures quoted by Arnold, Hunter & Gonzalez Fernandez (1976) by a factor of ten gives 4.84 mg P $100g^{-1}$ (quoted as 484 μg g^{-1}) as the P concentration on the plot achieving the greatest species-richness by 1984 (ie the P alone treatment). This value accords fairly well with the data of Jannsens *et al* (1997,1998). It also corresponds almost exactly with the value quoted by Pawson (1960) for an earlier analysis of the same plot (0.011% P_2O_5 $\equiv$ 4.80 mg P $100g^{-1}$).

The Palace Leas plots were not particularly species-rich when the experiment started in 1897. Grasses represented between 69% and 91% of the vegetation (about 63% contributed by *Agrostis* species) with legumes 3-11% and 'weeds' 4-22% (Gilchrist 1906). The overall proportion of grasses changed little under all treatments between 1897 and 1905, although the contribution of *H. lanatus* and *F. rubra* was increased by FYM. The main effect during this period was the increase in legumes with P and K application, even where N was also applied, although inclusion of N reduced the effect compared to P and K applied without N (16% compared to 27%). By 1973, legumes had all but disappeared from most plots, notable exception beings that receiving inorganic N, P and K (25% of the vegetation) and, to a much lesser extent, plots receiving N and K (5%) or K alone (7%) (Arnold, Hunter & Gonzalez Fernandez 1976). The superior abundance of legumes (mainly *Trifolium pratense*) on the plot receiving N, P and K appears contrary to the results of most of the work referred to above. However, the rates applied (36, 26 and 56 kg ha^{-1} N, P and K respectively), were not high, particularly with respect to N. In work in meadows on the Somerset Levels, P and K applied at rates sufficient to replace amounts removed in hay, either without N or with N at 25 kg ha^{-1} $year^{-1}$, increased legumes (mainly *T. pratense*), whilst higher N rates (>50 kg ha^{-1}) reduced legume abundance (Mountford, Lakhani & Kirkham 1993; Kirkham, Mountford & Wilkins 1996).

Botanical data for the Palace Leas plots in 1973, quoted by Arnold, Hunter & Gonzalez Fernandez (1976), do not indicate the general trend of increased grass content and reduced abundance of forbs which is the typical response to fertiliser application (eg Kinch & Stapledon, 1912; Williams 1978; Mountford *et al* 1994). However, Arnold, Hunter & Gonzalez Fernandez. (1976) noted a clear break in the dominant species between the unfertilised and the FYM plots on the one hand and those receiving inorganic fertilisers on the other. The former were dominated by *A. pratensis*, *D. glomerata* and *L. perenne* and, in the case of the FYM plots, *P. trivialis* and *Anthriscus sylvestris* also, whereas *Anthoxanthum odoratum*, *F. rubra* and *A. canina* were common on the remaining plots, except for those receiving N, P and K, where *D. glomerata*, *Plantago lanceolata* and *T. pratense* were dominant. *P. lanceolata* appeared to have been increased markedly on plots receiving inorganic N, either alone or with P and/or K, in marked contrast to other work (Williams 1978; Kirkham, Mountford & Wilkins 1996).

In trials on a *Festuca valesiaca* grassland in Romania in 1987-94, 10-30 t ha^{-1} of sheep manure were applied with or without different rates of P and K fertilisers (Vintu 1996). Sheep manure increased the legume content by 3-5% and grasses by 3-12% at the expense of forbs. Use of manure + 33 or 66 kg N + 8-16 kg P ha^{-1} did not radically alter the botanical composition of the sward; *F. valesiaca* and *F. pseudovina* remained dominant, but *Arrhenatherum elatius* and *Poa pratensis* increased by 1-8 and 2-6%, respectively.

6.5 Slurry effects on semi-natural vegetation

A search of published literature has confirmed the view of Crofts & Jefferson (1999) that very little work appears to have been done on the use of slurry in semi-natural grassland. Its use in this type of grassland is not recommended, due to the ready availability of the nutrients it contains compared to FYM (Crofts & Jefferson 1999). Where it has been used in meadows in the French Alps, it has promoted nitrophilic species (Ellenberg 1988) such as *Anthriscus sylvestris*, *P. trivialis*, and *Rumex obtusifolius*, as well as *Ranunculus repens*, *R. acris* and *Taraxacum officinale*, 'to the detriment of good forage grasses such as *Dactylis glomerata*, *Festuca pratensis* and *Trisetum flavescens*' (Dorioz, Fleury & Jeannin 1987). However, these effects were most noticeable at the sites cut latest in the season, and the authors note that cutting date was more influential than fertiliser treatment in determining botanical composition.

6.6 Effects of organic manures on soil micro-organisms and above- and below-ground fauna

Earthworm populations are increased by the addition of organic matter to the soil, and populations are further increased if the amendments include manure (Hughes, Bull & Doube 1994). Similar effects have been shown by microarthropods, enchytraeids and nematodes in agricultural cropping systems (Andren & Lagerlof 1983). Large volumes of liquid manure applied to grassland were shown to increase populations of nematodes greatly, but populations were taxonomically poor, consisting largely of saprobiotic *Rhabditis* species (Koslowska 1986). Edwards & Lofty (1982) showed increases in earthworm populations in grassland receiving both organic and inorganic N, though the response was less than in arable soils where there was a very strong positive correlation with the amount of inorganic N applied. They also showed some evidence of a negative effect when liquid manure was applied as a large single dose. Scullion & Ramshaw (1987) showed an increase in earthworms burrowing to the soil surface with poultry manure application, but a reduction with inorganic NPK application.

Applications of FYM to grasslands appear to encourage development of soil fungal populations, in particular vesicular-arbuscular mycorrhizae (VAM) (Bardgett 1996), whereas inorganic fertilisers reduce fungal populations in favour of soil bacteria (Sparling & Tinker 1978; Bardgett *et al* 1997). VAM play a role in the promotion of seedling establishment and the maintenance of species diversity in grasslands (Grime *et al* 1987; van der Heijden *et al* 1998).

Studies on the soils of the Palace Leas plots at Cockle Park showed large differences in microbial biomass and activity between plots receiving ammonium sulphate and the remainder, due to differences in acidity (Hopkins & Shiel 1996). However, amongst the less acid soils, FYM increased microbial biomass, except where inorganic NPK was also applied.

Lepidoptera numbers and diversity have been shown to be related to variations in management practice (mowing, cattle grazing and application of liquid manure) in floodplain grasslands in Slovakia (Kulfan, Degma & Kalivoda 1995). A community from an undisturbed late-successional grassland habitat showed the highest diversity, whilst cut wet meadows to which liquid manure was applied showed the lowest diversity and evenness of populations.

6.7 Summary

Theoretical considerations predict that maximum species diversity in grasslands will occur at intermediate levels of both fertility and disturbance. There is little information is available on the effects of organic manures on the conservation value of pastures managed solely by grazing, or on the relative effects of organic and inorganic fertilisers in these situations. The balance of evidence suggests that, under hay cutting at least, FYM is less damaging to botanical diversity than equivalent rates of inorganic fertiliser, though this remains to be confirmed. When inorganic fertilisers are applied, particularly those including N, grasses usually increase at the expense of both forbs and legumes, but with FYM these effects have been less consistent between studies. Addition of inorganic P and K with little or no N usually increases the legume content of vegetation and can increase N availability from soil organic matter where P and/or K are limiting. This leads to a build-up of fertility, particularly under grazing due to the recycling of nutrients (see Sections 5 and 7). FYM is beneficial to ground dwelling invertebrates compared to inorganic fertilisers, and increases microbial biomass and activity, including beneficial mycorrhizae. Little work has been done on the use of slurry in semi-natural pastures, either under cutting or grazing management. Very limited information suggests that slurry may be more damaging than FYM at approximately equivalent rates, but no reliable comparisons between slurry and inorganic fertilisers in semi-natural vegetation appear to have been published.

7. The influence of grazing on botanical composition and interactions between grazing and nutrient inputs

7.1 Positive and negative influences of grazing

Grazing tends to favour small, slow-growing, or prostrate plants by controlling the growth of faster-growing, taller species (Grime 1979; Wells 1980). It also leads to spatial heterogeneity in the habitat, both through uneven nutrient return (Petersen, Lucas & Woodhouse 1956; Richards & Wolton 1976; Tallowin & Brookman 1988) and through gap creation (Gross & Werner 1982; Watt & Gibson 1988; Peart 1989; Silvertown & Smith 1989; Bullock *et al* 1994). Such heterogeneity is important in providing regeneration niches and refuges from which species can disperse to other parts of the habitat where, in competitive equilibrium, they would be excluded (Grubb 1977; Crawley 1997). Watt (1947) attributed the patchy distribution of mature species within grassland largely to seedling establishment within gaps.

For these reasons, grazing is often associated with high species richness (Grubb 1976; Bakker *et al* 1983; Willems 1983). The survival of many short-lived forbs in chalk grassland is dependent upon establishment from seed which is in turn enhanced by the short turf and gaps produced by regular grazing (Shenkevald & Verkaar 1984). On the other hand, grazing often reduces flowering and seed production in pastures, particularly in contrast to hay meadows (Rabotnov 1969; Korte and Harris 1987). For example, Zelenchuk (cited in Rabotnov 1969) noted that 31% of the species in a lowland, extensively grazed meadow in the USSR did not produce any seed, whereas only 17% failed to do so in hay meadows. However, such comparisons are influenced by stocking rate on the one hand and time of cutting on the other. In a permanent pasture grazed by sheep and cattle in Wales, the number of flowering plants of *Ranunculus spp.* which set seed in lightly grazed sites was more than three times that in intensely grazed areas, with an 11-fold difference in the number of seeds set per flowering plant (Sarukhan 1974). These differences were attributable not only to defoliation, but also to physical damage to flowering parts by trampling in intensely grazed areas.

In hay meadows, only the smallest and most prostrate plants escape defoliation at the time of cutting, so that the opportunity for a plant to disperse ripe seed is very dependant upon time of cutting in relation to its flowering phenology (Smith & Jones 1991; Kirkham & Tallowin 1995; Kirkham 1997). By contrast, in grazed pastures, the opportunity for plants to set seed is more dependent upon their ability to escape grazing. Rosette-forming species such as *Hypochaeris radicata, Taraxacum spp, Bellis perennis, Leontodon hispidus* and *Plantago lanceolata* are common in species-rich grazed pastures (Elberse, Van den Bergh & Dirven 1983; Bakker, 1989). Their prostrate growth habit allows them to escape the inhibitory effects on reproductive development of defoliation (Korte & Harris 1987) and to retain sufficient leaf material to generate flower heads and produce seed (Stewart & Thompson 1982). The possession of a robust, wiry flower stem in some of these species also allows seed heads to ripen undamaged (Grime, Hodgson & Hunt 1988). Grazing animals themselves, particularly sheep, can act as vehicles for the transfer and spread of seed (Fischer, Poschlod & Beinlich 1996).

Many low-growing species such as those mentioned in the previous paragraph are physiologically adapted to coping with infertile soil conditions, an advantage which is lost when fertility is raised (Grime 1979). Moreover, whilst several of the factors associated with grazing contribute to heterogeneity in composition and structure of grazed swards, these effects are countered by those resulting from the higher stocking levels associated with increased soil fertility. At low-moderate stocking levels, animals tend to graze selectively, both between species and between different parts of the plant (Watkin & Clements 1978), but this behaviour is much less evident at higher stocking rates (Watkin & Clements 1978; Korte & Harris 1987). Grasses are, in general, better able to withstand both defoliation and treading than broad-leaved species, due to their more rapid leaf turnover (Sears 1956; Edmond 1966; Grime 1979), whilst grass species themselves differ markedly in their tolerance of treading (Edmond 1966). As grazing intensity increases, therefore, fewer species are able to tolerate the increasing frequency of defoliation and treading damage, contributing to the decline in species-richness associated with high levels of disturbance (Grime 1979).

7.2 Evidence for the effects of grazing on pasture composition

The influence of grazing in increasing the diversity of species-poor vegetation in the Welsh uplands has already been noted above (Milton 1938,1940; Milton & Davies 1947). Similarly, when cattle grazing was introduced to a neglected *Cirsio-Molinetum* fen meadow in Devon, the dominance of *Molinia caerulea* was greatly reduced, with a concomitant increase in species richness (Tallowin & Smith 1996). Most of the species emerging in the vegetation were typical fen meadow species which had previously been recorded only in the seed bank. Other evidence of recognisable plant communities developing under grazing compared with cutting or no defoliation has been provided by work in sand dunes (De Bonte *et al* 1999), in species-rich pastures on acid clay soil (Elberse, Van den Bergh & Dirven 1983), and in grazed and mown species-rich alluvial meadows and pastures (Baker 1937). Elberse, Van den Bergh & Dirven (1983) noted good agreement in their results with the findings of a large-scale survey of temperate pastures in the Netherlands by de Vries, reviewed by Krujne, De Vries & Mooi (1967). This, and other surveys reviewed by Snaydon (1987b), showed differences in botanical composition in grassland to be largely associated with differences in soil conditions and grazing/cutting management. Blackstock, Stevens & Yeo (1997) identified low fertility and grazing by cattle or horses as the most important features in the conservation of *Molinia / Juncus* pastures in Wales. Hay cutting and aftermath grazing of this vegetation type, as often practised on the Iberian peninsular, produces recognisably different variants on these communities, although these are normally no less species-rich.

The beneficial role of grazing in hay meadows, either in the spring or in the autumn or both, has been demonstrated by work in Norway (Losvik 1988), the Pennine Dales (Smith & Rushton 1994), Welsh lowlands (Jones & Hayes 1997) and the Somerset Levels (Kirkham, Mountford & Wilkins 1996). A decline in species-richness occurred on control plots in the Park Grass Experiment after aftermath grazing was replaced by cutting from 1877 onwards (Lawes, Gilbert & Masters 1882; Brenchley 1924; Williams 1978). However, this has not always been appreciated in the past (eg Marrs & Gough 1989; Marrs 1993) because Williams (1978) presented data only for species which had contributed at least 0.5% to the harvested vegetation on at least one occasion. Many of the species contributing to temporal trends in species numbers before and after cessation of grazing were excluded by this criterion, emphasising the value of grazing in helping to maintain a dynamic population of species at low abundance.

7.3 Horse grazing

Most animals tend to create latrine areas - zones in the field where a high proportion of dung is deposited. These areas remain ungrazed by horses and other livestock and are usually species-poor (Putman, Fowler & Touts 1991). This behaviour is particularly common with horses, unless particular care is taken to prevent overgrazing (Dirven & de Vries 1973; Gibson 1996,1997; Anon 1997). However, horses are not as deterred by dung of other grazing animals and will graze close to cattle dung pats (Frape 1986). Gibson (1996,1997) showed that good quality MG5 grasslands (Rodwell 1992) could be maintained by light to moderate grazing with horses, and that grazing management was more important than species of grazing animal. The very richest MG5 communities were those grazed by cattle, but caution is required in interpreting this aspect since the sample size was small. Other work has shown that horse grazing can maintain botanical diversity and the abundance of ancient grassland indicators in chalk grassland (Bioscan 1995). Low soil fertility is considered particularly important in maintaining the wildlife conservation value of horse pastures and the manual removal of dung is recommended (Anon 1997). This is also good practice for the containment of parasites (McCarthy 1987). The effects of horse grazing and manuring practice are covered in more detail in Section 9 of this report.

7.4 The significance of nutrient returns in animal excreta during grazing

Plant species differ not only in their preference for, and response to, different levels of fertility (Ellenberg 1988; Frame 1991), but also in their preference for particular nutrient supply ratios (Tilman 1982). Dung is rich in P with appreciable amounts of N, Ca, and Mg, whereas urine is rich in N and K but contains little P (Sears 1956; During & McNaught 1961; During, Weeda & Dorofaeff 1973 - see also Section 5). Whilst both forms of excreta are returned unevenly to the sward, this is more marked in the case of dung (Herriott & Wells 1963), partly because, being largely solid, dung is deposited in more discrete portions. The botanical composition of pastures can be influenced locally by urine scorch (Skrijka 1987). However, whereas stock urinate regularly throughout the day during grazing, they tend to dung more often in specific latrine areas, as noted above. The same latrine areas are used by different cattle in successive years (Tallowin & Kirkham, personal observations), presumably resulting in long-term patterns of coarse-scale heterogeneity in soil fertility. Norman & Green (1958) showed that grazing animals reject herbage growing around dung patches for periods of up to 18 months, whilst urine patches were rejected initially but grazed preferentially later. Growth around dung pats and in latrine areas therefore becomes rank and dominated by a few tall-growing grasses, unless very tight grazing is imposed (Korte & Harris 1987; Tallowin *et al* 1990). The area occupied by these areas is positively related to the number of stock present and therefore to the level of nutrients applied to the sward, and this contributes to the changes in species composition that occur when fertility levels are increased in grazed pastures (Tallowin *et al* 1990).

Thus, although at low levels of fertility the heterogeneity in nutrient supply might be expected to have a positive role in promoting species co-existence and sustaining species-richness, at higher fertility levels the influence of nutrient return is negative. Moreover, the form in which nutrients are excreted allows them to be taken up rapidly by the sward (Sears 1956; Herriott & Wells 1963; Skrijka 1987). This contributes significantly to pasture growth and productivity compared to cut swards (Frame & Hunt 1971) or grazed swards where excretal returns are prevented artificially (Sears 1956; Herriott & Wells 1963).

Low soil fertility is a particular feature of ancient, sheep-grazed chalk downland (Rorison 1990). Low fertility was perpetuated in the past by the traditional practice of removing sheep from the downland and 'folding' them on arable land at night, resulting in a continual net transfer of nutrients away from the downland (Gibson 1995). There is very limited information on the implications for the ecology of chalk downland of ceasing this practice, which is discussed in more detail in Section 8.

Wells & Cox (1993) showed the effects of returning nutrients to the sward in the form of cut vegetation, compared to removal of cuttings. Plots to which cuttings were returned consistently outyielded plots from which cut material was removed after the treatments had been imposed for 14 years. Cut plots, either with cuttings returned or removed, were significantly more species-rich than plots left uncut, but there was no difference in species-richness after 22 years attributable to return or removal of cuttings. However, there were differences in the relative abundance of species between these treatments, with nine species more abundant in plots where cuttings had been returned, and seven species where cuttings were removed. Soil K levels were higher where cuttings were returned, whilst soils were higher in Na, Mg and Mn where cuttings were removed, with no difference in N, P, pH or organic matter content. Earlier work at the same site had shown similar results, except that removal of cuttings had led to a significant reduction in extractable soil P after 10 year (Wells 1980). The lack of any effect of return or removal of nutrients in these experiments contrasts with results of Green (1972) who found that return of cuttings led to eutrophication and loss of species. However, Greens's results were from a site where the cut material was a 2m high stand of gorse (*Ulex europaeus*), an N fixing plant. Soils beneath areas to which cut material was returned showed increases of about 700 kg N ha^{-1}, and this resulted in a significant increase in the abundance of nitrophilous species.

7.5 The effect of inorganic fertilisers on botanical composition in grazed pastures

Several experiments have shown significant fertiliser-induced botanical changes under continuous or rotational grazing (Kydd, 1965; Elliott *et al* 1974; Elberse, Van den Bergh & Dirven. 1983; Williams, 1985; Tallowin *et al* 1990). Some of these studies have compared cutting and grazing managements in terms of the response to fertilisers, and these are reported below in Section 7.7.

Early studies by Armstrong (1907) showed that the most fertile and productive grazed permanent pastures were those dominated by *L. perenne* and *T. repens*, whilst poorer pastures usually contained a high proportion of *Agrostis* spp. and a wider variety of forbs. In an experiment on an agriculturally 'poor', grazed pasture at Cockle Park (the Tree Field Experiment), started at the same time as the Palace Leas experiment, phosphatic fertilisers in the form of either basic slag of superphosphate, increased the legume content and reduced the forb content ('weeds') of the sward compared to unfertilised plots (Gilchrist 1906). The overall proportion of grasses showed no marked effect, although the proportions of individual grasses did so. *Agrostis* species tended to be reduced by P, particularly when applied with lime, whereas the proportions of *D. glomerata* and *Cynosurus cristatus*, and of *Bromus mollis* and *H. lanatus* (the latter two species were reported as an amalgam), were increased by P treatments, particularly when a small amount of N was included (19 kg ha^{-1}). *L. perenne* was present in only trace amounts on some plots initially, and was increased slightly by some of the treatments which included P. A very similar experiment was established in 1900 in another 'poor' pasture over chalk on the South Downs and was reported by Somerville (1911). Somerville's report gave little botanical information, but noted that P, particularly in the form of basic slag, dramatically increased productivity in terms of mutton, and the author attributed this to a marked increase in fertility due to a greatly increased clover content. He also noted that a large, one-off application of basic slag was at least as effective as repeated lower doses in terms of productivity and clover content and attributes this to the continued recirculation of P via the grazing animals.

Middleton (1905) reviewed the results of six experiments on infertile grazed pastures on clay or 'strong loam' soils which had been taken out of arable production 8-40 years previously. These showed a large response to P in terms of productivity during the first three years, some response to K but little response to N. The legume content of the swards was increased greatly by P during this period but declined subsequently in favour of grasses as fertility built up. The response to K and lime increased notably from the fourth year onwards on plots receiving P and/or N.

Kydd (1965) tested various combinations of N, P and K in chalk downland pastures grazed by cattle. All plots received K at 62 kg ha^{-1}, and P was the element limiting production. Grasses were increased by P application (at 20 kg ha^{-1}), with little additional effect of applying N (60 kg ha^{-1}) with P. Legumes were increased by P application, but legumes and herbs were reduced when N was applied with or without P. The grasses which increased most were *D. glomerata* and *H. lanatus* (with NPK) and *P. trivialis* (PK) with little effect on *L. perenne* or *F. rubra,* whilst *Agrostis stolonifera* was increased by NK and reduced by NPK compared to K alone. The most susceptible forb species were *Leontodon autumnalis*, *P. lanceolata*, *Leucanthemum vulgare* (all reduced by PK and NPK compared to K alone) and *Leontodon hispidus* (NPK only).

Williams (1985) showed significant differences between fertilised (N, P and K) and unfertilised paddocks in the composition of both the above ground vegetation and the soil seed bank of a grazed pasture where fertiliser treatments had been imposed for a total of 19 years. For the first 11 years, treatments were applied under both hay cutting (plus aftermath grazing) and rotational grazing management (Elliott *et al* 1974), but all paddocks were grazed rotationally in the remaining years. There were differences in vegetation composition due to both fertiliser treatment and defoliation regime during the initial phase (see below), but three years after the change to grazing on all paddocks, only one species showed any significant effect of previous defoliation management (*Luzula campestris*, hay>grazing) (Williams 1985). Total grass cover was significantly increased (by about 20%) in fertilised swards compared to unfertilised by the end of the experiment, whilst total forb cover was reduced more than 11-fold. *A. capillaris* and *F. rubra* were exceptional among the grasses in that they were significantly reduced in the vegetation by fertiliser treatment, whereas *Poa* species, *H. lanatus, A. pratensis* and particularly *L. perenne* were all increased significantly. *D. glomerata* was significantly increased by fertilisers at an assessment in 1979, but was significantly reduced by the last assessment in 1984. Differences between fertilised and unfertilised swards in the total grass component of the seed bank increased between these two assessments, with that beneath fertilised swards almost double that of unfertilised paddocks by 1984. This difference was largely attributable to *Poa trivialis* and *P. annua*, which together showed a 23-fold difference, whereas the seed bank of *A. capillaris* was more than four times smaller beneath fertilised than unfertilised vegetation. Despite the very large differences in the forb content of above ground vegetation, the total forb content of the soil seed bank did not differ between fertilised and unfertilised swards. This reflects the greater seed bank persistence of forb species in general compared to grasses (Grime, Hodgson & Hunt 1988) and agrees with other work showing a greater correlation between above ground vegetation and seed bank composition for grasses compared to forbs, and for short-term persistent (type III *sensu* Thompson & Grime 1979) species compared to long-term persistent (type IV) species (Kirkham & Kent 1997).

Tallowin *et al* (1990) showed a very rapid increase in the *L. perenne* content of a semi-improved sward with N application under continuous grazing, mainly at the expense of *P. trivialis*. However, *L. perenne* cover was about 25% at the outset and the effects were shown at high rates of applied N (200-400 kg N ha^{-1} $year^{-1}$). In pastures where *L. perenne* was absent or at very low levels initially, and N was applied at 170 kg ha^{-1}, the increase in *L. perenne* was very slow, reaching 9% cover after 14 years and 16% after a further five years (Williams 1985). Increases in *Poa* species were far more rapid from similar initial levels, reflecting the probable abundance of these species in the seed bank compared to *L. perenne* which does not form a persistent seed bank (Williams 1985; Grime, Hodgson & Hunt 1988).

7.6 Organic manures in grazed pastures

As noted above, data on the use of organic manures in grazed semi-natural pastures are very sparse. Early researchers appear to have considered the comparison between inorganic fertilisers and FYM to be appropriate only under hay cutting, since FYM treatments were not included in grazed-only trials run contemporaneously or in parallel with hay plot trials (eg Middleton 1905; Gilchrist 1906; Somerville 1911). However, the interest of these early experiments was almost entirely agronomic. Much more recently, Jones & Haggar (1997) compared organic manures (FYM and slurry) with inorganic fertilisers for their impact on wild flower and grass species in field margin strips and hedge bottoms, in a five-year experiment in sheep grazed pastures. Forbs were drastically reduced by the high N treatment (300 kg N ha^{-1}), whereas FYM showed signs of developing species-rich communities, at the same time providing a relatively high yielding and nutrient-rich sward of high mineral content. Effects with rain-diluted slurry treatments, providing 27-72 kg N ha^{-1}, were less promising than FYM treatments (which provided 30-42 kg available N ha^{-1}), though less damaging than inorganic fertilisers. However, in common with most experiments comparing FYM with inorganic fertilisers, the rates of available nutrients supplied in each case differed between the three forms. Both FYM and slurry have been shown to reduce the *T. repens* content of swards, due to detrimental effects on stolon development (Humphreys *et al* 1997). Spring applied slurry allowed greater stolon survival overwinter and greater persistency of clover compared to other manure treatments.

7.7 Interaction between grazing and nutrient inputs on botanical composition - experimental evidence

In experiments where grazing was compared with hay making, fertiliser application has caused botanical changes of apparently similar overall magnitude under each defoliation regime, although the responses of individual species differed significantly between cutting and grazing (Elliott *et al* 1974; Elberse, Van den Bergh & Dirven 1983). Elberse, Van den Bergh & Dirven (1983) applied N, P, K and lime (CaO) treatments as inorganic fertiliser both to grazed paddocks and to those cut twice a year for hay, with unfertilised plots in each case. Both managements represented a change from the previous management of cutting and grazing in alternate years. The vegetation was species-rich with 109 species recorded *in toto* during the 20 years of the trial. The rates of fertiliser differed between grazed and hay cut paddocks, with rates of 100, 52 and 332 ha^{-1} $year^{-1}$ of N, P and K respectively on hay plots and 60, 18 and 50 ha^{-1} $year^{-1}$ respectively on grazed paddocks, in the following combinations: nil, P, K, PK and NPK in hay plots; and nil, PK and NPK in grazed paddocks. Lime was applied at 1000 kg CaO ha^{-1} $year^{-1}$ in both cases. Despite the differences between hay plots and grazed paddocks in the rates of fertiliser applied, the effect of each treatment was equally marked under each management regime, and the rate of loss of species per year did not differ greatly between grazing and cutting under corresponding fertiliser treatments. However, when the effects on botanical composition are viewed in relation to the amount of each nutrient applied under grazing compared to cutting, it is clear that, per kg applied, fertilisers had more effect under grazing. Moreover, the response of individual species to fertiliser treatment, and the resulting plant communities, differed markedly between managements, leading the authors to conclude that management regime was more important in influencing botanical composition than fertiliser treatment. Species which increased markedly with fertilisers were *L. perenne*, *P. trivialis* and *T. repens* under grazing, and *Arrenatherum elatius* and *D. glomerata* under hay cutting. *A. pratensis* increased under both regimes.

Elliott *et al* (1974) measured the effects of fertiliser application in low-lying pasture in the Thames valley under either rotational grazing or hay cutting followed by aftermath grazing. A compound NPK fertiliser was used and botanical composition was recorded over a six-year period. Fertiliser application increased total grass cover at the expense of forbs and legumes under both defoliation regimes. *F. rubra* showed little response to either fertiliser or defoliation regime. Amongst the grasses, *P. trivialis* showed the greatest response to fertiliser, reaching a higher abundance level on hay-cut plots than under rotational grazing. *D. glomerata* was increased by fertiliser under both defoliation regimes, but particularly under rotational grazing. *Agrostis* species declined markedly with fertiliser application under both regimes. Amongst the forbs, *Rumex acetosa* declined with fertiliser in grazed plots but not under hay cutting, whilst *P. lanceolata* declined to a similar extent under both rotational grazing and hay cutting. *L. perenne* was absent initially. Small amounts appeared on all plots in subsequent years, with a small positive influence of fertiliser application detectable under both defoliation managements.

High rates of inorganic N (200-400 kg N ha^{-1}), applied to a grass-dominated semi-improved pasture in Devon under continuous grazing, caused *L. perenne* to increase from about 25% cover to over 60% cover during the course of the first season, mainly at the expense of *P. trivialis* (Tallowin *et al* 1990). When the same treatments were applied to plots cut six times during the growing season instead of grazed, the effects were equally marked in terms of the increase in *L. perenne* content, but increases were at the expense of several grasses, particularly *A. stolonifera* (F. Kirkham, unpublished data). When a range of organic and inorganic fertiliser treatments were applied to a species-poor pasture in Germany under either hay cutting or grazing management, organic treatments led to a spread of grasses and *Trifolium repens* under grazing and a spread of herbs (mainly *Taraxacum officinale* and *Plantago lanceolata*) under cutting (Elsasser & Kunz 1988).

7.8 Summary

Grazing produces recognisable differences in vegetation composition compared to cutting management. Whilst the effects of fertilisers on botanical composition are evident under both grazing and cutting, the individual species responses are often different between defoliation managements. Moreover, whilst grazing *per se*, compared to cutting only or no defoliation, is favourable for species-richness at low-moderate fertility levels, it can exacerbate the effects of higher fertility levels. Limited evidence suggests that fertilisers have more effect, per unit of nutrient applied, under grazing management than under hay cutting, due to the recycling of nutrients that occurs with grazing. Available evidence therefore provides justification for the cautious approach, as adopted within several ESAs and other agri-environment schemes (see Section 2), and also by English Nature (Crofts & Jefferson 1999), of precluding the use of organic manures in grazed pastures.

8. Effects of traditional sheep folding practices on semi-natural grassland

8.1 The history and practice of sheep folding

The practice of sheep folding can be traced back to 1570, when sheep were run in large flocks on the chalk downlands of England (Smith 1980). The practice was to graze sheep on the downland during the day and fold them (ie contain them at high density) on arable land at night, particularly on root crops. A similar practice was used in north-west Europe, except that sheep were confined within sheds at night and the dung subsequently transferred to arable crops (Willems 1980). The most common breeds of sheep used in Britain were the Western, the Old Wiltshire or the Old Hampshire. A larger breed such as these was favoured 'for its folding quality, for its propensity to leave its droppings on the arable at night, and for its ability as a walking dung-cart, robbing the downs for the sake of the tillage, but maintaining the down pastures by feeding them closely' (Kerridge 1972). Farmers ploughed the downs to grow corn when it was economically expedient to do so. Root crops were sometimes alternated with grain and sheep were sometimes folded onto these root crops.

By the latter half of the seventeenth century, folded sheep were beginning to be offered new crops such as dwarf rape (*Brassica napus)* and Cotswold sainfoin (*Onobrychis viciifolia).* Pure stands of red and white clovers were also introduced into arable rotation. Thus the arable soils of the lower slopes were steadily improved by the combined effects of sown grasses and legumes, and by the dunging of sheep (Smith 1980).

The Great Depression of the 1800's saw the demise of sheep folding. Such labour-intensive methods of farming were replaced by low-cost systems which led to the grassing-down of much arable land, either deliberately or through natural succession from tumble-down fallows. The number of sheep in the country fell from 28 to 26 million, but the very marked the decline of sheep occurring on the chalk were masked to some extent by the substitution of 'grass sheep' and increases in sheep in the uplands. Much of the marginal land on the chalk went out of agricultural production altogether and was abandoned to rabbits (Smith 1980).

8.2 The effect of sheep folding on pasture composition

The practice of folding sheep on arable crops relied on the fact that sheep void a high proportion of their faeces at night. It is assumed that the continuance of this practice over very long time periods will have had the effect of maintaining low soil fertility on the downs (Gibson 1995). However, there appears to be no information on the amount of nutrients removed from downland in this way. These amounts could be estimated, given data such as the downland stocking rate, the relative proportions of excreta voided on downland and arable land, the chemical composition of these faeces, and the contribution of the crops upon which sheep were folded to the volume and composition of the excreta voided. Such detailed information appears to be lacking, nor are there empirical data available on the effect of cessation of sheep folding on the botanical composition of the downland pastures.

There have been some studies abroad, although not all relating to lowland pastures, which give information on nutrients applied to pastures by sheep folded onto them after grazing elsewhere. In 1977, Loiseau, Lambert &Merle (1980) conducted trials where sheep were folded for one to three nights at 1.0 animal per m^2 on rough pasture at 800 metres altitude in the Auvergne mountains. The effect on dry matter (DM) yield, botanical composition and nutrient status of the pasture of folding alone or in conjunction with weed removal and over-sowing was assessed and compared with that of an equivalent application of N P K fertiliser. The optimal treatment for rapid agricultural improvement of neglected grasslands was folding for two nights with over-sowing of a desirable species such as ryegrass at the beginning of grazing, with or without removal of weeds, depending on the stage of vegetation at sowing.

Further studies (Loiseau 1983) investigated the effect of sheep folding over a five-year period (1976-80) at a stocking rate of 1.0 - 5.0 ewe-night per m^2 (en m^{-2}) each year on pastures dominated by *Nardus stricta* (moor mat grass) and *Calluna vulgaris* (common heather). Pastures were located at 1,000 metres altitude in the volcanic region of Monts Domes. The supply of elements to the pasture was 195 kg N, 19 kg P, 114 kg K, 28 kg Ca and 10 kg Mg per ha at 1.0 en m^{-2} each year and rates of appearance of these nutrients in the grass yield were 55, 64, 86, 70 and 65%, respectively. Pasture dominated by *N. stricta* giving annual DM yields of 2.4 tonnes ha^{-1} was transformed after 12-15 years to pasture dominated by white clover (*Trifolium repens*) with DM yields of 3.8-7.1 tonnes ha^{-1}, although these changes were achieved on only 15% of the total area.

Fillat, Garcia & Garcia (1984) studied the effect of folding sheep on three different types of upland pasture in the Pyrenees (recently abandoned cereal fields, meadow and pasture land) in terms of changes in floristic composition and quality of the pasture. The quantities of dung deposited were not large but the high levels of K provided by the urine determined floristic evolution. Digestibility was enhanced where sheep had been enclosed. The technique tended to increase floral diversity, and the extent of the enhancement was influenced by the timing of the enclosure, animal behaviour, the depth of soil, and rainfall.

8.3 Summary

Sheep folding is the traditional practice of confining sheep which have been grazing a large area of grassland by day within a small area of, usually arable, land at night. The objective is to raise fertility in the second area by making use of the fact that sheep void a high proportion of their faeces at night. This practice was largely discontinued in Britain during the 19th century, but little information is available on the influence of this cessation on the botanical composition, or soil fertility level, of downland. In parts of France and Spain, folding sheep onto areas of grassland has been tested successfully as a means of improving the agricultural productivity of these areas. Increases in floristic diversity have been achieved in this way where diversity was initially low, although in some such situations the result has been a sward dominated by white clover (*Trifolium repens*).

9. Manuring practices on horse pastures

9.1 Introduction

A significant proportion of semi-natural grassland is grazed by equids (horses, ponies or donkeys) and in a survey of habitats managed for conservation, 16% were grazed by this class of animal, mostly ponies (Small *et al* 1999). Grassland management for horses and ponies presents a number of problems which are different to those encountered in conventional agriculture. For example, the nutritional requirements of equids differ from those of cattle and sheep and, in particular, a lower protein content (and therefore a lower clover content) is usually desirable (Archer 1973; Oates 1994). A further major requirement is to provide a safe and well managed turnout area on which the horse can exercise.

9.2 Key features of horse grazing

Horses and ponies are selective grazers and have distinct dietary preferences for different varieties of grass (Houpt 1983; Small *et al* 1999). However, Collins & Brooks (1984) and Putman *et al* (1987) found that whilst horses are highly selective, they utilise a wider array of plants than other livestock species. Surveys carried out under the Grazing Animals Project (GAP - Small *et al* 1999) have shown that different breeds of pony differ markedly in their dietary preferences. For example, 13 plant species and species groups were listed as being 'liked' by Exmoor ponies, whilst Dartmoor and Shetland ponies apparently 'liked' only one group, the Graminae. Fell, Konik, New Forest and Welsh Section A ponies all 'liked' an intermediate number (4-9) of plant species/groups.

Free ranging horses devote only 20-30% of their time to resting, 50-70% to eating and are otherwise active and alert for the remainder of the time (Mayes & Duncan 1986). Horses and ponies often graze to a more distinct spatial pattern than other stock. They tend to mark the excreta of other horses with their own urine or faeces and this causes an accumulation of excreta in 'latrine areas'. The presence of faeces discourages horses from grazing close by. Odberg & Francis-Smith (1977) demonstrated this by presenting grass cut from both grazed and latrine areas in separate trays. The horses readily ate from both sets of trays, but refused both when a faecal bolus was present. The vegetation in latrine areas becomes tall, rank and species-poor and these areas often cover more than half of the total surface of the field (Dirven & de Vries 1973; Frape 1986). Horses will, however, graze close to horse urine, and will graze right up to cattle dung pats (Frape 1986).

Horses' demand for grass is relatively constant throughout the year. A common dilemma in grassland management for horses is therefore to balance the demands of the animal with the growth pattern of the grass (ADAS 1994). Hay therefore forms an important part of a horse's diet, and is more suitable for horses than silage (Gibson 1996).

Horses and ponies are prone to a condition called laminitis, an inflammation of the sensitive laminae of the foot. In the UK this condition is often associated with over fat ponies and horses kept at grass, especially when grass is legume-rich or when growth is lush in the spring (Dorn *et al* 1975; Pilliner 1992). Equids that have had laminitis are prone to further attacks and appropriate management and body weight control are important (Pilliner 1992).

9.3 Recommended management practices for horse paddocks

The prevention and treatment of intestinal parasites can be a burden to the horse owner. Regular treatment with anthelmintics (wormers) can overcome this problem, but paddock management is also important. For horses at grass, the best method is to collect all droppings, twice a day. Less frequent collection may be more convenient, but is considerably less effective, as some worm larvae will migrate from the dung within a few hours of it being passed (McCarthy 1987). In many cases, this technique is not practicable as it is extremely labour intensive. However, regular dung removal is good practice not only for parasite control (ADAS 1994), but also to contain the development of latrine areas in pastures of conservation value (Anon 1997).

Well-rotted FYM is sometimes recommended to maintain productivity in horse pastures and can be applied in winter if the soil is dry enough (McCarthy 1987). The British Horse Society advise that only very well rotted manure should be spread on a pasture because high temperatures are required to kill parasites (Anon 1988). However, it is recognised that even extremely well-rotted manure may contain encysted eggs or larvae (McCarthy 1987). Manure may help to encourage more even grazing by disguising the tainting effect caused by the horses' own dung and urine (ADAS 1994), but may make the pasture unpalatable if horses are turned out while the manure is still fresh (Anon 1988). It is advisable to store manure for at least six months and grazing should not take place for a further six weeks after spreading. Cattle manure is preferable to pig and poultry manure which may contain high levels of copper (McCarthy 1987; ADAS 1994). Similarly, (McCarthy 1987) recommended that human sewage should never be used as it can introduce heavy metals to the soil, causing long term soil contamination and, at if present at high concentrations, damage to soil micro-organisms.

Inorganic N is advised only with caution, since grass with a high N content can cause digestive upsets and laminitis if horses are turned onto it too suddenly (Brown & Powell-Smith 1984). The presence of clover will reduce the amount of artificial N required but high populations of clover are undesirable as they may lead to digestive upsets and nutritional imbalances , particularly for breeding stock (ADAS 1994).

Advice for the effective management of horse paddocks can be summarised as:

- pick up horse droppings daily;
- do not spread horse manure onto paddocks;
- use FYM in preference to inorganic fertilisers and use cattle FYM in preference to pig and poultry manure;
- apply FYM in the autumn and allow it to rot down before returning horses to the pasture;
- avoid the use of human sewage on horse paddocks;
- use inorganic N sparingly;
- some clover may be valuable but high populations are undesirable.

9.4 The effects of horse grazing on plant species diversity in lowland grassland

Horses have generally been looked upon as detrimental to grassland composition, largely because horse pastures, particularly those around the urban fringe, are often poorly managed. Gibson (1996, 1997) showed that the species of grazing animal has a minor effect compared to grazing intensity. He confirmed the damage commonly associated with horse grazing, but showed it to be restricted to heavily grazed sites, and heavy grazing by cattle could be equally damaging. Observations over a period of six years on chalk grasslands of varying history in Berkshire showed that overall plant species diversity and the presence of ancient grassland indicator species were maintained or increased under equid grazing (Bioscan 1995).

Nevertheless, Putman, Fowler & Tout (1991) found clear differences in vegetation characteristics under horse grazing, not only between areas receiving different intensities of grazing, but also between areas receiving different amounts of dung. Latrine areas contained few plant species, due to raised fertility (see earlier sections). Because of the horse's marked propensity for developing latrine areas, and the large proportion of a field that these areas can occupy, careful management is needed if a species-rich pasture is to be maintained. Consequently, English Nature and the British Horse society jointly recommend the daily, or, at a minimum, twice weekly removal of dung in the summer and once a week in the winter (Anon 1997).

The management practices recommended for the maintenance or enhancement of biodiversity in horse paddocks are listed as follows (Anon 1997):

- control grazing levels and avoid overgrazing;
- avoid supplementary feeding in the field;
- remove animals when the ground is wet;
- avoid the use of artificial fertilisers and do not reseed;
- pick up dung regularly;
- cut and remove tall ungrazed grass where latrines are forming;
- mix or alternate grazing with other livestock;
- restrict weed control to mechanical methods or spot treatment with herbicide;
- chain harrow outside bird nesting season and flowering time of plants.

It is clear that many of the practices advisable from the point of view of animal health and maintenance are consistent with the requirements of nature conservation listed above.

9.5 Summary and implications for manure use in semi-natural grassland grazed by horses and ponies

Grazing by horses and ponies can be consistent with management for wildlife conservation, but careful management is required. This will often involve the regular removal of dung to avoid the formation of latrine areas. This problem will become more acute as stocking rate increases. Whilst application of FYM may sometimes encourage more even grazing by disguising the tainting effect caused by the horses' own dung and urine, it will necessitate removal of animals while FYM is breaking down. Moreover, since the purpose of FYM application will normally be to increase grass growth, the resultant increase in faecal deposition may enhance the problem of latrine area formation and will increase the need for dung removal. It is conceivable that FYM application may not be detrimental to plant species diversity in areas of inherently very low soil fertility, although this will depend upon rate and periodicity of application. If dung is removed regularly in such cases, this may be equivalent, at least in part, to the removal of nutrients in a hay crop. It will, of course, have no effect on the return of the high proportion of excretal N and K contained in urine (see Section 5). However, under most circumstances, the introduction of nutrients from external sources is undesirable, whether it be in the form of FYM, inorganic fertilisers or supplementary feed. This conclusion is similar to that reached in relation to grazing by livestock in general (see earlier sections). However, the case is even stronger with horse grazing because of the horse's more marked habit of forming latrine areas, and because of the consequent difficulties for management and maintenance of plant species diversity posed by these areas in particular.

10. Conclusions

The main points identified in this review on manure use and nutrient value, in relation to nutrient cycling in semi-natural pastures, were:

- Advice relating to the use of organic manures on pastures (and other types of semi-natural grassland) varies, both in terms of the application rate and type of manure -

    - ❑ The Lowland Grassland Management Handbook specifies that slurries, poultry litter/manures and sewage sludge bioproducts should not be used on semi-natural grassland (whether hay meadow or grazed pasture), as evidence from the effects of inorganic fertiliser use suggests that the high available nutrient content in these manures will reduce the species-richness of such swards. Periodical application of small amounts of well rotted farmyard manure are considered acceptable in hay meadows where this has been a traditional practice and has not been detrimental to the conservation value of the meadow, but not in semi-natural pastures. The Farming and Wildlife Handbook gives similar, but less comprehensive advice.

    - ❑ In contrast, prescriptive advice provided for semi-natural grassland in the agri-environment schemes in England is more diverse, particularly for ESAs, ranging from total prohibition of manure application to allowing relatively high application rates of both slurries and manures on wet grasslands, where high water levels are intended to encourage greater diversity of breeding and overwintering birds. In general though, agri-environment scheme advice is based upon the general premise that organic manures can be used only in some limited circumstances.

- Organic manures are mostly applied as FYM and slurry on agriculturally improved grassland, with little use of poultry manure or sewage sludge bioproducts. Survey data suggest that about a third of grassland SSSIs have some history of FYM use, principally related to hay cutting practice, but there is a lack of information on manure use on semi-natural grassland in general.

- Well-rotted FYM is preferable to fresh manure, but the availability of well rotted FYM will become increasingly limited without greater support for traditional cattle housing with straw bedding.

- Supplies of poultry manures are likely to be very limited for spreading on semi-natural grassland, even if such use of this manure were considered acceptable.

- Although sludge recycling to land is increasing, the restrictions on use of treated sludges within the recently agreed 'UK Safe Sludge Matrix', effectively rule out any potential use of sewage sludge bioproducts on semi-natural grassland.

- Individual application rates for FYM on improved grassland are typically around 20 t ha^{-1}, the same as the maximum rate for a single dressing, once every 3-5 years, recommended by English Nature for semi-natural grassland; higher rates increase the risk of sward smothering and prolonged herbage contamination.

- Manures are applied throughout the year on agricultural grassland, depending on soil type and conditions, sward management and manure storage capacity, although the majority of spreading occurs during the winter and spring period. In semi-natural grasslands, FYM is applied either in autumn or, more often, in early spring, although in some northern hay meadows the tradition is to apply in April-May. The nitrate leaching risk from autumn applied FYM is small, because of the low available N content.

- At least six to eight weeks should be left between FYM application and grazing, to allow sufficient time for the manure to break down.

  Application rates for cattle slurry on improved grassland are generally 25-30 m^3 ha^{-1}. Where subsequent grazing is intended a minimum interval of at least two to three weeks, and preferably up to six or more weeks, should be left between broadcasting slurry and subsequent grazing.

- Slurry is considered unsuitable for use on semi-natural grassland because of its rapid nutrient release, in contrast to FYM. New machinery developments, however, giving more accurate and uniform spreading of slurry at low rates, could improve the acceptability of slurry use on such grassland.

- Manure application rates should be adjusted to take account of their available nutrient content, based on laboratory analysis of representative samples or typical nutrient values.

- Heavy metal loadings from manure applications to semi-natural grassland are very small and well within acceptable limits for both herbage and livestock production (assuming no direct ingestion by grazing livestock).

- Adherence to the voluntary Codes of Good Agricultural Practice when spreading animal manures on agricultural land will reduce the risk of nutrient pollution to the environment, and hence increase nutrient availability, and will also help to minimise any possible risk of pathogen transfer.

- Manure application could interact with lime application to cause undesirable changes in the botanical composition of semi-natural pastures; this subject is currently under study in hay meadows.

- Atmospheric N deposition will continue to increase, pending any reduced emissions following the implementation of IPPC, and can lead to the competitive exclusion of species characteristic of semi-natural grassland by nitrophilic plants.

- Increased N deposition may cause more nitrate leaching in soils which are highly P limited and unable to fully utilise this source of N supply.

- The decline in atmospheric S deposition over recent decades will continue, particularly in the lowlands where dry deposition predominates, which might have implications for the botanical composition of semi-natural grasslands, because of reduced effect on soil acidification and lower S supply. FYM, which contains appreciable amounts of S, may have a buffering effect on these changes.

- The return of nutrients via periodic dressings of FYM at low application rates, may be required on semi-natural hay meadows to avoid gradual soil nutrient depletion and potential loss in hay yield. Although nutrient losses (by gaseous emissions, leaching and/or surface runoff) are likely to be very small from semi-natural pastures, nutrient budgeting at field level may suggest that nutrient depletion could also occur, but more gradually, in grazed only semi-natural pastures as a result of nutrient removal in livestock production. If so, an occasional application of 20 t ha^{-1} FYM once every five to ten or more years may, depending on nutrient budget calculations, be necessary to prevent long term nutrient depletion.

The review has highlighted the following points in relation to species composition of semi-natural grassland:

- Theoretical considerations predict that maximum species diversity in grasslands will occur at intermediate levels of both fertility and disturbance.

- The balance of evidence suggests that, under hay cutting at least, FYM is less damaging to botanical diversity than equivalent rates of inorganic fertiliser, though this remains to be confirmed in current work.

- Little information is available on the effects of organic manures on the conservation value of pastures managed solely by grazing.

- The effects of fertilisers on botanical composition are evident under both grazing and cutting, though the individual species responses are often different between the two types of defoliation management.

- Under both forms of management, the usual effect is an increase in the total grass component. When inorganic N is applied, the increase in grasses is usually at the expense of both forbs and legumes, but with FYM these effects have been less consistent between studies.

- Addition of P and K with little or no N usually increases the legume content of vegetation. This leads to a build-up of fertility, particularly under grazing due to the recycling of nutrients.

- Grazing *per se*, compared to cutting only or no defoliation, is favourable for species-richness at low-moderate fertility levels but exacerbates the effects of higher fertility levels.

- Limited evidence suggests that fertilisers have more effect, per unit of nutrient applied, under grazing management than under hay cutting, presumably due to the recycling of nutrients that occurs with grazing.

- Sheep folding from chalk downland was traditionally used to raise fertility within a small area of, usually arable, land, through the transfer of nutrients in faeces.

However, little information is available on the influence of its cessation on either the botanical composition or soil fertility level of the downland.

- Grazing by horses and ponies can be consistent with management for wildlife conservation but requires careful management, which often involves the regular removal of dung to avoid the formation of latrine areas. FYM application in these circumstances, and the resulting increase in grass growth, may create further difficulties for grazing management and the maintenance of plant species diversity, because of the formation of more latrine areas.

- FYM is beneficial to ground dwelling invertebrates compared to inorganic fertilisers, and increases microbial biomass and activity, including beneficial mycorrhizae.

- Little work has been done on the use of slurry in semi-natural pastures, either under cutting or grazing management. Very limited information suggests that slurry may be more damaging than FYM at approximately equivalent rates, but no reliable comparisons between slurry and inorganic fertilisers in semi-natural vegetation appear to have been published.

The limited amount of data available suggest that external nutrient inputs may be less sustainable under grazing than under cutting management, because grazing animals return recycle applied nutrients to the soil in largely plant-available forms. More data are required to test this hypothesis. English Nature do not recommend the use of FYM in grazed pastures of high conservation value (Crofts & Jefferson 1999), and organic manures are not allowed in pastures within the water fringe option of the Habitat Scheme (now to be subsumed into the Countryside Stewardship Scheme), nor within the Countryside Stewardship Scheme itself save in exceptional circumstances. Although ESA prescriptions covering the use of organic manures in semi-natural pastures vary considerably, most of these prescriptions distinguish between grazed pastures and hay meadows, with organic manures (usually only FYM) more often allowed, or allowed at higher rates, in the latter. Manures are also allowed on semi-improved pastures in the lower tiers of some ESAs. The more cautious approach of not allowing organic manures to be used in grazed pastures of high conservation value seems justified until better information is available.

11. Recommendations for research

Comparison of slurry with FYM and inorganic fertilisers

FYM availability is declining in many areas where its use has been traditional, whereas more dairy farms now produce organic manure in the form of slurry than in the past. Research is needed to resolve the question of how the three forms of nutrient fertiliser - FYM, slurry and inorganic - differ in their effects on semi-natural vegetation at equivalent rates of nutrient input. This question is most appropriate in the context of hay meadows. It is not essential to carry out the same comparison in grazed pastures, particularly if the research recommended below were also to be carried out. A simple comparison of each form at, say, two rates (plus untreated controls) would be adequate, since the main comparison would be between forms of nutrient input rather than dose response. Adequate replication of treatments will be more important than the inclusion of a large number of treatments. Measurements would include botanical composition and yield assessments (the latter primarily to assess nutrient uptake and offtake) and soil analyses for C, total N, P and K.

Comparison of FYM with inorganic fertilisers under grazing

There has probably been sufficient research carried out on the response of species-rich or moderately species-rich vegetation to inorganic fertilisers under grazing, but little research has been done using FYM in these situations. Experiments comparing the effects of FYM with equivalent rates of nutrient applied in inorganic form in contrasting grazed pastures would be valuable. At least four sites would be needed to cover a range of soils and vegetation types, from calcareous soil (possibly arable reversion sites within the South Downs ESA), through acid-neutral species-rich lowland grassland to more acid purple moor-grass and rush pastures. Sites should be representative of situations where a case for the need to raise productivity to a moderate extent might be made on agronomic grounds. As with the study outlined above, the emphasis would be on a comparison of the two forms of nutrient input and on the use of FYM specifically under grazing, so that a wide range of treatment rates would be unnecessary. Measurement would include botanical composition, assessments of nutrient availability in the herbage on offer to grazing animals, assessment of nutrient uptake and offtake under cutting (in areas protected from grazing on a rotational basis), and soil analyses for C, total N, P and K in each case.

Other areas for research

Nutrient budgets in semi-natural grassland. Published information on nutrient cycling and farm- or field-scale nutrient budgets for semi-natural pastures and hay meadows is very limited. A detailed desk study of all forms and amounts of nutrient inputs and outputs is needed for the main systems of livestock production in contrasting semi-natural ecosystems, to more fully evaluate the extent, and longer term implications, of potential nutrient depletion in both hay meadows and pastures. Guidelines on nutrient budgeting could then be developed for farmer use, enabling field-specific monitoring of nutrient balances and more accurate estimation of any additional nutrient requirements in the form of applied FYM. This approach would minimise the risk of FYM use causing an increase in soil fertility and long term damage to sward biodiversity.

The significance of sulphur in semi-natural ecosystems. Atmospheric S deposition has been declining in recent decades after a long period of increase over a century or more (RGAR 1997; Lee 1998). Attention on S deposition in semi-natural ecosystems has largely focused on its acid properties and comparatively little on nutritional aspects. As noted in Section 3 of this report, awareness is increasing of the agronomic implications of these trends, but as also noted, the utilisation of manure S has been little researched, even in agronomic circles. It is possible that the application of FYM in areas where S deposition was formerly highest may have had an important buffering effect against the decline in S deposition. Research is needed on the effects of S application to semi-natural plant communities, particularly under hay cutting management, both in order to help identify trends in vegetation composition which may be explained by temporal changes in S deposition and to assess the significance of liming and FYM application in relation to these trends.

Foliar nutrient concentration ratios as indicators of nutrient limitation. The effect of atmospheric pollutants on vegetation are often identified in terms of 'critical loads' - the level above which ecosystem damage begins to occur. However, it is recognised that this is a very broad-brush approach and must encompass a high degree of local variation (see Section 5). Similarly, the effects of particular nutrient inputs on semi-natural vegetation are assumed to be influenced by the 'background' availability of nutrients and the ratio between them, although this is seldom taken into account in any detail. The foliar content of macronutrients and the total amounts taken up by plants are usually better indicators of the availability of these nutrients than soil analysis, since they represent an integration of availability over time (ie during the growth of the plant). Some progress has been made in identifying 'threshold' levels of foliar N:P ratio to indicate which of these elements is limiting in an ecosystem. There is much potential for developing this approach, both in terms of N:P ratios and in terms of identifying critical ratios between other elements (eg N:K, N:S, P:S) to help assess the significance of atmospheric and other inputs of these nutrients to semi-natural ecosystems.

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Appendix I. Prescriptive advice for manure use on semi-natural swards

Current Advice for Environmentally Sensitive Areas

For most ESAs, the lowest tiers (Tier 1 or Tier 1A) generally relate to permanent grassland that has been improved through intensive agricultural management. Prescriptions **only** applying to improved permanent grassland or arable leys have **not** been included in the table. This table therefore only relates to prescriptions that **could** apply to extensively managed semi-natural swards (both pastures and meadows unless otherwise specified). (NB The most recent prescriptions for some ESAs were in draft form at the time of this review. These are identified in the table).

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
Breckland	Tier 1 (Heathland)	Lowland acid grassland	None permitted	None permitted	None permitted	None permitted	N/A
	Tier 3 (River Valley Grassland)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	Do not apply more than the existing rate. Do not apply more than 12.5 ha^{-1} (5 tons $acre^{-1}$ in any 3-year period.	No guidance
	Water Level Supplement (available on Tier 3 land)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	None permitted	N/A
Broads	Tier 1 (Permanent grassland)	Coastal and floodplain grazing marsh Lowland hay meadow	None permitted	No more than 30 m^3 ha^{-1} (2,600 gallons $acre^{-1}$) at 10% dry matter in any year or the equivalent if dry matter is $<10\%$.	None permitted	Do not exceed existing rates. Do not apply more than 30 tonnes ha^{-1} $year^{-1}$ (12 tons $acre^{-1}$ $year^{-1}$).	No guidance
	Tier 2 (Extensive grassland)	Coastal and floodplain grazing marsh Lowland hay meadow	None permitted	None permitted	None permitted	None permitted	N/A
	Tier 3 (Wet grassland)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	None permitted	N/A

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
Essex Coast (draft)	Tier 1 (Permanent grassland)	Coastal and floodplain grazing marsh Lowland hay meadow	None permitted	None permitted	None permitted	Do not increase your existing application rates and, in any event, do not apply more than 30 tonnes ha^{-1} $year^{-1}$. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of any watercourse.	
	Tier 2A (Wet grassland)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	Do not increase your existing application rates and, in any event, do not apply more than 12.5 tonnes ha^{-1} $year^{-1}$	Do not apply FYM during the period 1 April to 30 June and, outside this period, apply it only in a single dressing.
	Tier 2B (Marshland)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	None permitted	
Suffolk River Valleys	Tier 1 (Grassland)	Coastal and floodplain grazing marsh Lowland acid grassland Lowland hay meadow	Do not increase existing application rates.	Do not increase existing application rates.	Do not increase existing application rates.	Do not increase existing application rates.	No guidance
	Tier 2 (Low-input grassland)	Coastal and floodplain grazing marsh Lowland acid grassland Lowland hay meadow	None permitted	None permitted	None permitted	None permitted	N/A
	Tier 2A (Marshland)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	None permitted	N/A

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
Avon Valley	Tier 1 B (Extensive permanent grassland)	Coastal and floodplain grazing marsh Lowland acid grassland Lowland hay meadow	None permitted	None permitted	None permitted	Do not apply more that the existing rate. Do not apply more than 12.5 tonnes ha^{-1} $year^{-1}$ (5 tons $acre^{-1}$ $year^{-1}$)	Do not apply from 1 April to 31 May. Outside this period apply it only in a single dressing.
	Tier 1 C (Wet grassland)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	Do not apply more that the existing rate. Do not apply more than 12.5 tonnes ha^{-1} $year^{-1}$ (5 tons $acre^{-1}$ $year^{-1}$)	Do not apply from 1 April to 31 May. Outside this period apply it only in a single dressing.
North Kent Marshes	Tier 1 A	Coastal and floodplain grazing marsh Lowland hay meadow	None permitted	None permitted	None permitted	Do not apply more than your existing rate. Do not apply more than 12.5 tonnes ha^{-1} $year^{-1}$ (5 tons $acre^{-1}$ $year^{-1}$)	Do not apply FYM during the period 1 April to 31 May. Outside this period apply it only in a single dressing.
	Tier 1 B (Water Management tier)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	Do not apply more than your existing rate. Do not apply more than 12.5 tonnes ha^{-1} $year^{-1}$ (5 tons $acre^{-1}$ $year^{-1}$).	Do not apply FYM during the period 1 April to 31 May. Outside this period apply it only in a single dressing.
South Downs	Tier 1 (Permanent grassland on the chalk)	Lowland calcareous grassland Lowland hay meadow	None permitted	None permitted	None permitted	None permitted	
	Tier 2 (Permanent grassland in the river valleys)	Coastal and floodplain grazing marsh Lowland hay meadow	None permitted	None permitted	None permitted	None permitted	

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
Test Valley	Tier 1 B (Extensive permanent grassland)	Coastal and floodplain grazing marsh Lowland calcareous grassland Lowland hay meadow	None permitted	None permitted	None permitted	Do not apply more that the existing rate. Do not apply more than 12.5 tonnes ha^{-1} $year^{-1}$ (5 tons $acre^{-1}$ $year^{-1}$)	Do not apply from 1 April to 31 May. Outside this period apply it only in a single dressing.
	Tier 1 C (Wet grassland)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	Do not apply more than the existing rate. Do not apply more than 12.5 tonnes ha^{-1} $year^{-1}$ (5 tons $acre^{-1}$ $year^{-1}$)	Do not apply from 1 April to 31 May. Outside this period apply it only in a single dressing.
Upper Thames Tributaries (Draft)	Tier 1 A (Permanent Grassland)	Coastal and floodplain grazing marsh Lowland calcareous grassland Lowland hay meadow	Do not increase your existing rates of organic fertiliser. For a supplementary payment you may agree not to apply fertiliser on land within 6 m of any field boundary	Do not increase your existing rates of organic fertiliser. For a supplementary payment you may agree not to apply fertiliser on land within 6 m of any field boundary	Do not increase your existing rates of organic fertiliser. For a supplementary payment you may agree not to apply fertiliser on land within 6 m of any field boundary	Do not increase your existing rates of organic fertiliser. For a supplementary payment you may agree not to apply fertiliser on land within 6 m of any field boundary	No guidance.
	Tier 1 B (Extensive Permanent Grassland)	Coastal and floodplain grazing marsh Lowland calcareous grassland Lowland hay meadow	None permitted	None permitted	None permitted	Do not exceed your existing application rates. Do not apply more than 20 tonnes ha^{-1} in any 3-year period.	Do not apply FYM during the period 1 April to 31 May. Outside this period apply it only in a single dressing.
	Tier 2 (Wet Grassland)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	None permitted	N/A

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
Blackdown Hills (draft)	Tier 1 A (All land)	Lowland hay meadow Lowland dry acid grassland Coastal and floodplain grazing marsh Purple moor grass and rush pasture	Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of any watercourse.	Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of any watercourse.	Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of any watercourse.	Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of any watercourse.	
	Tier 1C (Low input permanent grassland)	Lowland hay meadow Lowland dry acid grassland Coastal and floodplain grazing marsh Purple moor grass and rush pasture	None permitted	None permitted	None permitted	Do not exceed your existing application rates and, in any event, do not exceed 12.5 tonnes ha^{-1} $year^{-1}$ (5 tons $acre^{-1}$ $year^{-1}$).	
	Tier 1D (Unimproved pasture and rough land)	Lowland hay meadow Lowland dry acid grassland Coastal and floodplain grazing marsh Purple moor grass and rush pasture	None permitted	None permitted	None permitted	None permitted	
	Tier 2 (Species rich hay meadows)	Lowland hay meadow	None permitted	None permitted	None permitted	Only *well-rotted* FYM permitted. Do not exceed your existing application rates of FYM and, in any event, do not apply more than 20 tonnes ha^{-1} $year^{-1}$ in any 3-year period.	Apply FYM once only in a single dressing.

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
Cotswold Hills (draft)	Tier 1A (All land)	Lowland calcareous grassland Lowland hay meadow Coastal and floodplain grazing marsh	Do not increase existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of any watercourse.	Do not increase existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of any watercourse.	Do not increase existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of any watercourse.	Do not increase existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of any watercourse.	
	Tier 1C (Extensive permanent grassland)	Lowland calcareous grassland Lowland hay meadow Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	Do not exceed your existing application rates and, in any event, do not apply more than 12.5 tonnes ha^{-1} in any three year period except applications on hay meadows where it can be 12.5 tonnes ha^{-1} $year^{-1}$.	Apply FYM only in a single dressing.
Dartmoor (draft)	Tier 1A (All land)	Purple moor-grass and rush pastures Lowland dry acid grassland Lowland hay meadow	Do not increase your existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse.	Do not increase your existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse.	Do not increase your existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse.	Do not increase your existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse.	
	Tier 1C (Low-input permanent grassland)	Purple moor-grass and rush pastures Lowland dry acid grassland Lowland hay meadow	None permitted	None permitted	None permitted	Do not exceed your existing application rates and, in any event, do not exceed 25 tonnes ha^{-1} $year^{-1}$	

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
	Tier 1D (Unimproved pasture and enclosed rough land)	Purple moor-grass and rush pastures Lowland dry acid grassland	None permitted	None permitted	None permitted	None permitted	
Exmoor	Tier 1 Part 2B (Low input permanent grassland)	Purple moor-grass and rush pastures Lowland dry acid grassland Lowland hay meadow	None permitted	None permitted	None permitted	Do not exceed your existing level of home produced FYM and in any event do not exceed 15 tonnes ha^{-1} $year^{-1}$.	
	Tier 1 Part 3 (Enclosed unimproved permanent grassland)	Purple moor-grass and rush pastures Lowland dry acid grassland Lowland hay meadow	None permitted	None permitted	None permitted	None permitted	
Somerset Levels and Moors	Tier 1 (Permanent Grassland)	Coastal and floodplain grazing marsh Lowland hay meadow	Do not exceed your existing level of home produced organic fertiliser	Do not exceed your existing level of home produced organic fertiliser	Do not exceed your existing level of home produced organic fertiliser	Do not exceed your existing level of home produced organic fertiliser	No guidance
	Tier 1 A (Extensive Permanent Grassland)	Coastal and floodplain grazing marsh Lowland hay meadow	Do not exceed your existing level of home produced organic fertiliser	Do not exceed your existing level of home produced organic fertiliser	Do not exceed your existing level of home produced organic fertiliser	Do not exceed your existing level of home produced organic fertiliser	No guidance
	Tier 2 (Wet Permanent Grassland)	Coastal and floodplain grazing marsh	Do not exceed your existing level of home produced organic fertiliser	Do not exceed your existing level of home produced organic fertiliser	Do not exceed your existing level of home produced organic fertiliser	Do not exceed your existing level of home produced organic fertiliser	No guidance
	Tier 3 (Permanent Grassland raised water level areas)	Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	Do not exceed 25 tonnes ha^{-1} $year^{-1}$ (10 tons $acre^{-1}$ $year^{-1}$).	No mechanical operations between 31 March and 1 July.

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
South Wessex Downs	Tier 1 Part 2B (Low input permanent grassland)	Coastal and floodplain grazing marsh Lowland hay meadow Lowland calcareous grassland	? Not mentioned - assume none permitted	? Not mentioned - assume none permitted	? Not mentioned - assume none permitted	Do not exceed existing application rates of well rotted home produced organic fertiliser and in any case do not exceed 12.5 tonnes ha^{-1} $year^{-1}$.	
	Tier 1 Part 3 (Downland turf)	Lowland calcareous grassland	None permitted	None permitted	None permitted	None permitted	
West Penwith	Tier 1 (All land - additional prescriptions for rough land including semi-natural grassland)	Lowland dry acid grassland Purple moor grass and rush pasture	None permitted	None permitted	None permitted	None permitted	
Clun	Tier 1A (All land)	Lowland dry acid grassland Lowland hay meadow Coastal and floodplain grazing marsh	Do not increase your existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse. Only apply slurry produced on the farm.	Do not increase your existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse. Only apply slurry produced on the farm.	Do not increase your existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse. Only apply manure produced on the farm.	Do not increase your existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse. Only apply manure produced on the farm.	

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
	Tier 1B (Extensive permanent grassland and rough grazing)	Lowland dry acid grassland Lowland hay meadow Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	Do not exceed your existing level of application on any fields. In any case do not use more than 12.5 tonnes ha^{-1} in one application in any three year period.	Do not apply during the period 1 April to 31 May. FYM produced off the farm may only be used with the prior written approval of the Project Officer and must be well rotted.
North Peak	Tier 1A (All farmland and moorland)	Lowland hay meadow	None permitted	Do not exceed your existing levels. Do not apply within 50m of a spring, well or borehole used for domestic consumption or within 10m of any watercourse.	None permitted	Do not exceed your existing levels. Do not apply within 50m of a spring, well or borehole used for domestic consumption or within 10m of any watercourse.	If necessary you may import FYM subject to written Project Officer approval in advance but no slurry may be imported.
	Tier 1B(i) (Semi-improved permanent grassland)	Lowland hay meadow	None permitted	Do not exceed your existing levels. Do not apply within 50m of a spring, well or borehole used for domestic consumption or within 10m of any watercourse.	None permitted	Do not exceed your existing levels. Do not apply within 50m of a spring, well or borehole used for domestic consumption or within 10m of any watercourse.	If necessary you may import FYM subject to written Project Officer approval in advance but no slurry may be imported.

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
	Tier 1B (ii) (Unimproved permanent grassland)	Lowland hay meadow	None permitted	None permitted	None permitted	None permitted *except* where land in this Tier attracts a Hay Meadow Supplement. In this case do not apply more than your existing application rate and, in any case, do not exceed 8 tonnes ha^{-1} $year^{-1}$.	Do not apply FYM between 1 April and 31 May.
Shropshire Hills (draft)	Tier 1A (All land)	Lowland hay meadow Coastal and floodplain grazing marsh Lowland dry acid grassland	Do not increase existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse. Do not apply within 1 m of any hedge, wall or bank.	Do not increase existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse. Do not apply within 1 m of any hedge, wall or bank.	Do not increase existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse. Do not apply within 1 m of any hedge, wall or bank.	Do not increase existing application rates. Do not apply within 50 m of a spring, well or borehole that supplies water for human consumption or within 10 m of a watercourse. Do not apply within 1 m of any hedge, wall or bank.	
	Tier 1B (Permanent grassland)	Lowland hay meadow Coastal and floodplain grazing marsh Lowland dry acid grassland	None permitted	Do not increase existing application rates	None permitted	Do not increase existing application rates	
	Tier 1C (Extensive permanent grassland)	Lowland hay meadow Coastal and floodplain grazing marsh Lowland dry acid grassland	None permitted	None permitted	None permitted	No FYM may be applied *except* where this grassland is cut for hay, in which case up to 7 tonnes ha^{-1} may be applied every 2 years.	

ESA	Tier	BAP grassland types present[1]	Application rate for organic manures				Timing
			Pig slurry	Cattle slurry	Poultry manure	FYM	
South West Peak	Tier 1 Part 2 (Enclosed permanent grassland)	Lowland hay meadow Coastal and floodplain grazing marsh	Do not exceed your existing application rates.	Do not exceed your existing application rates.	Do not exceed your existing application rates.	Do not exceed your existing application rates.	
	Tier 2 Option 1 (Pastures and meadows)	Lowland hay meadow Coastal and floodplain grazing marsh	None permitted	None permitted	None permitted	None permitted on pastures. On meadows you may each year apply a single dressing of no more than 8 tonnes of well rotted FYM.	
Lake District		All upland habitats					
Pennine Dales	Tier 1B (Meadows, Pastures and Allotments)	Lowland hay meadow Coastal and floodplain grazing marsh Lowland calcareous grassland	None permitted	None permitted	None permitted	Do not exceed your existing level of application on any fields. In any case do not use more than 12.5 tonnes ha^{-1} (5 tons $acre^{-1}$) per year and apply in a single dressing. None permitted on allotment land.	FYM produced off the farm may only be used with the prior written approval of the Project Officer and must be well-rotted.
	Tier 2A (Herb-rich meadows)	Lowland hay meadow	None permitted	None permitted	None permitted	None permitted	
	Tier 2B (Herb-rich pastures and allotments)	Coastal and floodplain grazing marsh Lowland calcareous grassland	None permitted	None permitted	None permitted	None permitted	

[1] Critchley *et al* 1999

Appendix II. United Kingdom Register of Organic Food Standards: Organic production and care of the environment

a. Organic production systems are designed to produce optimum quantities of food of high nutritional quality by using management practices which aim to avoid the use of agri-chemical inputs and which minimise damage to the environment and wildlife.

b. These systems entail the adoption of management practices which underpin and support the principles and aims of organic production. The principles include:

- working with natural systems rather than seeking to dominate them.
- the encouragement of biological cycles involving micro-organisms, soil flora and fauna, plants and animals;
- the maintenance of valuable existing landscape features and adequate habitats for the production of wildlife with particular regard to endangered species;
- careful attention to animal welfare considerations;
- the avoidance of pollution;
- consideration for the wider social and ecological impact of the farming system.

c. When applied these principles result in production practices whose key characteristics are:

- the adoption of sound rotations;
- the extensive and rational use of animal manure and vegetable wastes;
- the use of appropriate inputs;
- appropriate cultivation, weed and pest control techniques; and
- the observance of conservation principles.

THE EUROPEAN COMMUNITY REGULATION EEC NO. 2092/91 AND THE UKROFS STANDARDS

d. UKROFS Standards must accord with the European Community Regulation EEC No. 2092/91 which came into effect on 1 January 1993. However, in interpreting the Regulation and its Standards UKROFS will assess and apparent infringement in relation to any breach of one or more of the principles, set out above. The observance, or otherwise, of the following practices will be relevant to such an assessment.

e. The specific practices needed to respect the conservation principles of organic production will depend upon the individual circumstances on each farm. However, the role of conservation in organic farming is considered so important by UKROFS that for guidance additional principles are as follows:

- Concern for the environment should manifest itself in willingness to consult appropriate conservation bodies and in high standards of conservation management throughout the organic holding.

- Natural features such as streams, ponds, wetlands, heathland and species-rich grassland should be retained as far as possible.

- Grazing management of natural (or semi-natural) habitats such as grassland, heath, moorland, heather and bog and rushy upland, should aim to prevent poaching of the soil and overgrazing. Localised heavy stocking particularly in the nesting season should be avoided.

- Hedges and walls should be retained and managed using traditional methods and materials as far as possible.

- In hedge and ditch maintenance the nesting season and wildlife requirements for winter feeding or shelter should be taken into account. Hedge trimming and ditch cleaning should generally not take place between 1 March and 31 August. Where practicable, the maintenance of hedges should result in hedges at diverse stages of growth.

- If it is considered that there are reasonable grounds for alteration to hedges or to field boundaries these should first be discussed with a Conservation Adviser. If alteration does prove to be necessary, consideration should be given to the need for compensatory environmental work.

- The retention and management of trees in accordance with local custom and woodland practice is essential. Where re-planting is to take place, indigenous varieties of trees and shrubs should be given preference. Where practicable, natural regeneration and coppicing of appropriate species should be practised.

- Clear felling should be restricted so as to retain a diversity of age classes and habitat within the woodland areas of the holding.

- Care should be taken in the spreading of manures and slurry. The application of manure within 10 metres of ditches and watercourses and within 50 metres of wells and bore holes should be avoided. The spreading of manure or slurry on frozen ground or on saturated ground should be avoided, so as to prevent excess run off.

- The land management should seek to preserve features of archaeological or historical value or interest avoiding, for example, the levelling of ridge and furrow, and the cultivation of monuments or earth works.

- New buildings should be designed and located to have minimum impact on the landscape.
- Existing rights of access should be maintained.

Appendix III. Quantities and nitrogen content of livestock excreta

Table A3.1. Quantities and nitrogen content of livestock excreta - cattle and sheep

Type of Livestock	Age Range or Average	Body Weight kg	Production of Excreta		Occupancy	Excreta Analysis		Annual N Excretion	Animal numbers per ha to comply with max N loading (kg ha^{-1})		
			Daily kg or l	Annual m^3 or t	% of year	DM %	N kg m^{-3}	kg	170	210	250
Cattle											
Dairy cow		650	64	23.2	100	10	5	116	1.47	1.81	2.16
Dairy cow		550	53	19.2	100	10	5	96	1.77	2.19	2.6
Dairy cow		450	42	15.3	100	10	5	76	2.24	2.76	3.29
Dairy heifer replacement	>2 years	500	32	11.7	100	10	5	58	2.93	3.62	4.31
Beef suckler cow	>2 years	500	32	11.7	100	10	5	58	2.93	3.62	4.31
Grower fattener	>2 years	500	32	11.7	100[1]	10	5	58	2.93	3.62	4.31
Grower fattener	12-24 months	400	26	9.4	100[1]	10	5	47	3.62	4.47	5.32
Grower fattener	6-12 months	180	13	2.4	50[1]	10	5	12	14.17	17.5	20.83
Calf	0-6 months	100	7	1.3	50[1]	10	5.5	7	24.29	30	35.71
Sheep											
Adult ewes	>1 year	65	4.1	1.5	100	15	6	9	18.9	23.3	27.8
Lambs	6 months	35	1.1	0.2	50[2]	15	6	1.2	141.7	175	208.3

Notes:
1. "Occupancy" for growing/fattening cattle variable on farms and should be assessed.
2. Lambs on average kept for 6 months.

Table A3.2. Quantities and nitrogen content of livestock excreta - pigs and poultry

Type of Livestock	Age Range or Average	Body Weight kg	Production of Excreta		Occupancy	Excreta Analysis		Annual N Excretion	Animal numbers per ha to comply with max N loading (kg ha^{-1})		
			Daily kg or l	Annual m^3 or t	% of year	DM %	N kg m^{-3}	kg	170	210	250
Pigs											
Maiden gilts		90-130	7.1	2.6	100[1]	6	5	13	13.1	16.1	19.2
1 sow place, including litters	Progeny to 7 kg	130-225	10.9	3.95	100	6	5	19.5[2]	8.7	10.8	12.8
Weaners	3-7.5 weeks	7-18	1.3	0.43	90	10	7	3	56.7	70	83.3
Growers, dry meal	7.5-11 weeks	18-35	2.7	0.88	90	10	7	6.1	27.9	34.4	41
Light cutter, meal fed	11-20 weeks	35-85	4.1	1.35	90	10	7	9.4	18.1	22.3	26.6
Bacon, dry meal fed	11-23 weeks	35-105	4.5	1.5	90	10	7	10.5	16.2	20	23.8
Bacon, liquid fed (@ 4:1)	11-23 weeks	35-105	7.2	2.35	90	6	4.5	10.5	16.2	20	23.8
Poultry											
1000 Laying hens		2200	115	41	97	30	16	660	260	320	380
1000 Broiler places	42 days	2200	60	16.5[4]	76	60	30	495[4]	345	425	505
1000 Broiler breeders	280 days	3400	217	61	77	30	16	975[6]	175	215	255
1000 Replacement pullets	20 weeks	1600	56	7.8[3]	38	30	16	125	1360	1680	2000
1000 Turkeys (male)	140 days	13500	159	46.4[5]	80	60	30	1390	120	150	180
1000 Turkeys (female)	120 days	6500	74	21.7[5]	80	60	30	650	260	325	385
1000 Ducks	50 days	3400	290	90	85	30	10	900	190	235	280

Notes:-
1. Maiden gilts, assuming all year round accommodation
2. Sows based on 2.3 lactations, covering 23% of year and dry period 77% of year. Combined output 19.5 kg N/ sow /year
3. Replacement pullets, output per 20 week cycle, assuming manure N content similar to layer manure
4. Broilers, output per 6.6 crops /year, 42 day cycle (76% occupancy)
5. Turkeys, assuming 2.1 or 2.4 crops per year, male and female birds.
6. Estimate based on N balance calculations, adjusted for estimated ammonia loss, in the absence of other measurements on breeders.