# An Inventory of Mitigation Methods and Guide to their Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture


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## INTRODUCTION

### *Background*

The UK Government is committed to obligations under the EU Water Framework Directive (including the Nitrates Directive, the Freshwater Fish Directive, the Bathing Waters and the Shellfisheries Directives), the UNECE Convention on Long-Range Transboundary Air Pollution (the Gothenburg Protocol), the EU National Emission Ceilings Directive (NECD), the Kyoto Protocol and Climate Change agreements amongst EU countries. As a result of the above Directives and International agreements, the UK is required to:

- achieve good ecological and chemical status of surface and ground waters by 2015 (provided that the cost of doing so is not disproportionately expensive or technically unfeasible);
- reduce ammonia emissions with agreed ceiling targets established for 2010 and ongoing negotiations for revised ceilings to be met by 2020;
- reduce emissions of the principal greenhouse gases (nitrous oxide, methane and carbon dioxide-$CO_2$) by 12.5% below the 1990 level over the first commitment period, 2008-2012.

Furthermore, the UK also has a domestic target to reduce greenhouse gas emissions (including international aviation and shipping emissions) by 80% (below the 1990 level) by 2050. The UK, therefore, has a number of challenging goals that need to be considered in an integrated way, in order to identify where certain actions may have conflicting unintended consequences (i.e. ‘pollution swapping’ situations) and to determine best options (i.e. to identify ’win-win’ situations).

### *Aim*

The purpose of this document is to provide summarised information on a range of mitigation methods (options) to reduce diffuse water pollution, air pollution and greenhouse gas (GHGs) emissions. The aim is to help users in developing policies and selecting suitable mitigation methods to meet the inter-acting and occasionally conflicting obligations listed above.

The document lists mitigation methods (options) and assesses the impact of each method on nitrogen losses (nitrate, nitrite, ammonium), phosphorus (total and soluble), sediment, biological oxygen demand (BOD) and faecal indicator organism (FIO) losses to water, and gaseous emissions (i.e. ammonia, nitrous oxide, methane and carbon dioxide) to air. Where possible, the effect of a mitigation method on emissions to water and air has been quantified for the field area to which the method is applied or on a farm scale basis etc. Where such data are not available, the direction of change in emissions has been indicated.

This document builds upon information contained in the previous “DWPA (Diffuse Water Pollution from Agriculture) User Manual”; the “Ammonia Mitigation User Manual”; and “A Review of Research to Identify Best Practice for Reducing Greenhouse Gases from Agriculture and Land Management”, viz:

**DWPA User Manual** (part of Defra project ES0203) compiled data from previous Defra studies (e.g. projects NT2511, PE0203, and ES0121) to summarise information on the effect of 44 potential upon methods to control diffuse water pollution from agriculture.

**Ammonia Mitigation User Manual** (Defra project AQ0602) compiled evidence from a large body of Defra-funded research on the effect of 25 potential mitigation methods to reduce ammonia emissions from agriculture.

**Review of Research to Identify Best Practice for Reducing Greenhouse Gases from Agriculture and Land Management** (part of Defra project AC0206) compiled evidence from Defra-funded projects (e.g. projects CC0229, CC0262, CC0272, and ES0127) and published scientific studies to assess the effect of 8 main mitigations methods for reducing GHG emissions from agriculture. A further 7 'future potential mitigation methods' and 6 'speculative mitigation methods' were also identified.

### *Farm typologies*

Detailed farm typologies and practices were established from which baseline pollutant losses could be calculated. The farm typologies were based on the 'Robust Farm Types' (RFT) used in the Defra Farm Business Survey (defined by the dominant source of revenue) and the Defra June Agricultural Census for 2004 (Defra, 2004a), Table 1.

**Table 1.** "User Guide" farm typologies and mapping to the Defra 'Robust Farm Types'.

| "User Guide" Farm Typology | 'Robust Farm Type' |
|---|---|
| | |
| Dairy | Specialist Dairy |
| Less Favoured Area (LFA) - Grazing Livestock | Less Favoured Area (LFA) - Grazing Livestock |
| Lowland - Grazing Livestock | Lowland - Grazing Livestock |
| Mixed | Mixed |
| Combinable Crops | Specialist Cereal |
| Roots/Combinable Crops | General |
| Indoor Pigs | Specialist Pig |
| Outdoor Pigs | Specialist Pig |
| Poultry | Specialist Poultry |
| Horticulture | Horticulture |

*Note*: 'Other' RFTs excluded as they were of limited economic (and agricultural) importance.

Total crop areas and livestock numbers for each farm typology were derived from the proportions of the land area occupied by each crop type and the stocking densities of each livestock type in the Defra June Agricultural Census for 2004 (Defra, 2004a). Farm practice information was derived from a number of sources, including the British Survey of Fertiliser Practice for 2004 for fertiliser types, application rates and timings; (Goodlass and Welch, 2005) and Smith *et al*. (2000; 2001a; 2001b) for the timing and rate of livestock manure applications to land. A detailed description of the farm typologies is provided in Appendix I, with summary information provided in Table 2 below.

*Note*: All pig manure production was allocated for the combinable crops farm and all poultry manure production (after accounting for amounts incinerated) to the roots/combinable crops farm to facilitate nutrient flow auditing.

**Table 2.** Summary of twelve farm typologies.

| Farm System | Number of livestock on farm | | | | |
|---|---|---|---|---|---|
| | **Cattle > 1 year** | **Calves < 1 year** | **Sheep & Lambs** | **Pigs** | **Poultry** |
| Combinable crops | 0 | 0 | 0 | 0 | 0 |
| Combinable + pig manure | 0 | 0 | 0 | 0 | 0 |
| Roots/combinable crops | 0 | 0 | 0 | 0 | 0 |
| Roots/combinable + poultry manure | 0 | 0 | 0 | 0 | 0 |
| Dairy | 170 | 45 | 104 | 0 | 0 |
| Grazing-Lowland | 82 | 39 | 354 | 0 | 0 |
| Grazing-LFA | 52 | 20 | 697 | 0 | 0 |
| Mixed | 116 | 40 | 393 | 400 | 2,605 |
| Indoor pigs | 0 | 0 | 0 | 3,524 | 0 |
| Outdoor pigs | 0 | 0 | 0 | 440 | 0 |
| Poultry | 0 | 0 | 0 | 0 | 81,357 |
| Horticulture | 0 | 0 | 0 | 0 | 0 |

| Farm System | Excreta managed as manure (%) | Field area (ha) | Mean fertiliser application rate+ | |
|---|---|---|---|---|
| | | | **kg N/ha** | **kg $P_2O_5$/ha** |
| Combinable crops | 0 | 172 | 182 | 42 |
| Combinable + pig manure | 100 | 172 | 171 | 36 |
| Roots/combinable crops | 0 | 180 | 137 | 44 |
| Roots/combinable + poultry manure | 100 | 180 | 135 | 42 |
| Dairy | 62* | 114 | 115 | 20 |
| Grazing-Lowland | 36* | 101 | 56 | 17 |
| Grazing-LFA | 24* | 146 | 23 | 7 |
| Mixed | 39* | 155 | 92 | 29 |
| Indoor pigs | 100 | 0 | 0 | 0 |
| Outdoor pigs | 0 | 18 | 0 | 0 |
| Poultry | 80** | 0 | 0 | 0 |
| Horticulture | 0 | 18 | 86 | 39 |

* *remainder deposited by grazing livestock in the fields*
** *remainder is sent for energy generation*
+ *mean overall of farm area*

## METHODS

In compiling the 83 methods summarised in this "User Guide", a wide range of sources of information were considered (in addition to the projects mentioned above), viz:

- Cost Action 869: Mitigation Options for Nutrient Reduction in Surface Water and Ground Waters
- Scottish Government: Land Management Contracts
- Scottish Environment Protection Agency (SEPA): Best Management Practices
- United States Environment Protection Agency (USEPA): Best Management Practices
- Methods promoted as part of the England Catchment Sensitive Farming Delivery Initiative (ECSFDI)

The project has provided 'broad' estimates of the cost and effectiveness of the various mitigation methods. On each method sheet:

- *costs are expressed per unit of land, at the farm scale or per $m^3$/tonne of manure etc. (as appropriate for each mitigation method)*
- *effectiveness is expressed for the target area on which the method was applied* or at a farm scale (as appropriate for each mitigation method).

Effectiveness bands, or direction of change, at the farm-scale have also been summarised in spreadsheet format (referred to as the 'farm-scale spreadsheets') for each farm typology and for both 'permeable' and 'impermeable' soils for the 700-900 mm climate band (Six climate bands were used in total for this project; <600mm, 600-700mm, 700-900mm, 900-1200mm, 1200-1500mm and >1500mm). These effectiveness bands provided the basis of modelling work to quantify the effectiveness of groups of methods at the farm and national scale. In another part of this project, the effectiveness values were expanded to account for different impacts by pollutants pathway and source (e.g. slurry, FYM etc.). The main output of this related work was the "FARMSCOPER" tool (FARM SCale Optimisation of Pollutant Emissions Reduction), which estimates baseline pollutant losses and can assess the impacts of individual and multiple methods for a range of farm types.

The mitigations methods were grouped into the following seven categories:

- *Land use change*
- *Soil management*
- *Crop & livestock breeding*
- *Fertiliser management*
- *Livestock management*
- *Manure management*
- *Infrastructure*

The mitigation methods are not presented in any order of effectiveness. Each method is given a number and a brief title for reference. This is followed by a description of the method and its application, arranged into ten sections:

- *Pollutants targeted* (including the direction and approximate magnitude of change where it is possible to provide a range)
- *Farm typologies applicable*

- *Description and Rationale*
- *Mechanism for action*
- *Potential for applying the method*
- *Practicability*
- *Likely uptake*
- *Costs*
- *Effectiveness*
- *Other benefits* (including risk of 'pollution swapping')

**(i) Pollutants targeted:** A table showing the impact of the method in terms of direction and approximate magnitude of change or no impact (~) is provided; based on a combination of available data from the scientific literature and the expert judgement of the project team. Table 3 shows the 'arrow strengths' used in the effectiveness tables and how they link to effectiveness classes.

**Table 3**. Method effectiveness classes, ranges and arrow strengths

| Description | Average | Range | Description | Arrow strength |
|---|---|---|---|---|
| None | **0** | **0** | None | ~ |
| Low | **10** | **1 to 30** | Low | ↓ |
| Moderate | **40** | **20 to 80** | Moderate | ↓↓ |
| High | **70** | **50 to 90** | Very High | ↓↓↓ |

**Note:** Arrow directions may also be upwards where a method increases the loss of a pollutant.

**(ii) Farm typologies applicable:** A table showing the farm typologies to which the method is applicable.

**(iii) Description and rationale**: A description of the actions to be taken to implement the method; and the broad reason for adopting the method as a means of reducing pollutant loss.

**(iv) Mechanism of action**: A more detailed description of the processes involved and how the method achieves a reduction in pollutant loss.

**(v) Potential for applying the method**: An assessment of the farming systems, regions, soils and crops to which the method is most applicable.

**(vi) Practicability**: An assessment of how easy the method is to adopt, how it may impact on other farming practices and possible resistance to uptake.

**(vii) Likely uptake:** The likely level of uptake (in the next ten years) given the current economic climate and levels of regulation and enforcement.

**(viii) Costs**: 'Broad' estimates are presented of how much it would cost to implement each method, taking into account annual running costs and annual charges for any capital investment required (derived by amortising the required investment over the anticipated write-off period at an interest rate of 7%).

Where relevant, costs are presented on a per hectare (ha) basis and/or at a farm scale (as appropriate for each mitigation method). For livestock and manure management methods, costs are also presented per cubic metre of slurry/solid manure or per head of livestock (see Appendix II).

Farm level costs relate to the specific farm typologies summarised in Table 2 (and described more fully in Appendix I). The assumptions used in calculating the costs of each method are summarised in Appendix II. Costs may be one-off costs, annual cash costs, annualised capital costs (amortised) or annual and amortised costs, as appropriate for each mitigation method. The types of cost are indicated for each method. Some of the methods may lead to the land not being farmed, unless compensation is paid or a scheme for land management is provided. Also, reductions in stocking rates or the area of land farmed will have a consequent impact on the agricultural supply industry, which has not been taken into account in the cost estimates.

*Note:* Method costs are *sensitive* to the detail and scale of an individual farm enterprise. Also, the net costs of many mitigation methods are *very sensitive* to short-term changes in the cost of inputs, notably fuel and fertiliser, and the market value of produce. Caution is advised in applying the cost estimates to individual enterprises or scaling up to the national level.

**(ix) Effectiveness**: Effectiveness classes, or direction of change, are provided for the main pollutants affected by each mitigation method. The effectiveness of a method on a specific pollutant was assigned to an effectiveness range, based on currently available research data or where data did not exist the expert judgement (based on the assumed mechanism of action) of the project team; Table 3.

All estimates of effectiveness have a *high level of uncertainty* associated with them, and where a range of effectiveness is given, it is still possible for effectiveness values to fall outside this range in individual circumstances. The effectiveness range provides a band in which the majority of values are likely to fall.

Effectiveness (where possible) is expressed as a percentage reduction relative to the baseline pollutant loss. The effectiveness classes reflect natural variation in their efficiency and variation according to the magnitude of the baseline loss, as well as uncertainty.

***Baseline losses***

For each of the farm typologies, pollutant baseline losses were estimated for 'permeable' (i.e. freely drained) and 'impermeable' (i.e. poorly drained) soils, and for six climate zones based on annual average rainfall values between 1961 and 1990 (< 600mm; 600-700mm; 700-900mm; 900-1200mm; 1200-1500mm; and >1500mm).

Baseline losses were also divided into specific sources (components originating from the soil, from manure/excreta and from fertiliser), areas and loss pathways using environmental models (Anthony, 2006; Anthony *et al*., 2008a), supported by field data and expert judgement. This approach enabled effectiveness classes to be assigned to specific sources and pathways of pollutant loss. The 'overall' effectiveness of a method depends on the relative importance of the baseline losses identified. For example, some methods such as 'adopt reduced cultivation systems' or 'manage over winter tramlines' can have a significant impact on losses of sediment and particulate P, via the surface runoff pathway (Deasy *et al*., 2008). However, on drained soils the overall effectiveness of these methods depends on the relative contribution of the surface compared with sub-surface (i.e. drainflow) pathway to overall pollutant losses. It can be difficult to predict the overall effectiveness of a method without detailed information on the relative contribution of different delivery pathways to total baseline losses. *It is often the case that our predictions are limited by a lack of field data and in* *these instances we are reliant on environmental models (and expert judgement) for guidance*.

The following models were used to support baseline loss calculations for the farm typologies, viz:

***Nitrate***
Nitrate losses were estimated using a combination of the NEAP-N, NITCAT, N-CYCLE, EDEN and MANNER models (Lord and Anthony, 2000; Lord, 1992; Gooday *et al*., 2007; Chambers *et al*., 1999).

***Phosphorus and sediment***
Phosphorus and sediment loads were estimated using the PSYCHIC model (Version 8.1; Davison *et al*., 2008; Stromqvist *et al*., 2008; Collins *et al*., 2007). PSYCHIC is a process based, monthly time-step model, with explicit representation of surface and drainflow hydrological pathways, particulate and solute mobilisation, and incidental losses associated with fertiliser and manure applications. Outputs from PSYCHIC have been used to support phosphorus and sediment gap analyses for rivers and lakes in England (e.g. Anthony *et al*., 2008b), and its use here provides consistency across a number of projects used to support government policy development.

***Ammonia***
Ammonia ($NH_3$-N) emissions from fertiliser applications were estimated using the NT26-*AE* model (Chadwick *et al*., 2005) and fertiliser use for each farm typology was derived from the British Survey of Fertiliser Practice for 2004 (Goodlass and Welch 2005). Ammonia emissions from all other sources were estimated using NARSES (Webb and Misselbrook, 2004).

***Nitrous oxide***
*Direct* nitrous oxide ($N_2O$-N) emissions and *indirect* $N_2O$ emissions (as a result of ammonia volatilisation and nitrate leaching losses from fertiliser, excreta and managed manures) were estimated using the IPCC tier 1 methodology (IPCC, 2006; Baggott *et al*., 2006).

***Methane***
Methane ($CH_4$) emissions were estimated using the IPCC (2006) tier 1 methodology (IPCC, 2006), using default coefficients derived for Western Europe and national data on manure management. For dairy cows, tier 2 calculations were used that took into account animal productivity (litres of milk produced), live weight and fat content of the milk.

Table 4 summarises the range of baseline losses from each of the farm typologies.

***Effectiveness and method implementation***
*The effectiveness classes (bands) assigned to each method was specific to the way the method was implemented and to the farm typologies described*. Where a method cannot be applied to a particular farm type it has been shown as non-applicable (×) in the ‘applicability’ tables.

***Scales of effectiveness***
The effectiveness tables in each method sheet summarise the magnitude of effect on each pollutant for the target area on which the method was applied or at a farm scale (as appropriate for each mitigation method).

Effectiveness classes are provided for nitrate, nitrite and ammonium, phosphorus (total and soluble), sediment, BOD and FIOs, ammonia, nitrous oxide and methane. We have assumed that the behaviour of nitrite ($NO_2$) is closely associated with that of ammonium and nitrate (the two dominant processes involved with $NO_2$-N turnover are the nitrification of $NH_4$-N and the reduction of $NO_3$-N during denitrification). Moreover, Defra project ES0121 (‘COST-DP: Cost effective diffuse pollution mitigation’) concluded that mitigation of nitrite loss was best dealt with through the mitigation of its precursors, particularly $NH_4$-N. For carbon dioxide ($CO_2$), we have taken into account *on-farm energy use*; energy use beyond the farm-gate, such as the manufacture of fertilisers or transport of food products, has not been taken into account, which would be the case for a full life-cycle analysis.

**Table 4.** Total baseline loss ranges for farm typologies

| **Farm System** | ***Main waterborne pollutants (kg/ha)*** | | |
|---|---|---|---|
| | ***Nitrate (N)*** | ***Total phosphorus (P)*** | ***Sediment*** |
| *Combinable crops* | 20 - 40 | 0.02 - 0.8 | 10 - 800 |
| *Combinable + pig manure* | 65 - 115 | 0.2 - 1.0 | 10 - 800 |
| *Roots/combinable crops* | 25 - 45 | 0.02 - 0.9 | 10 - 850 |
| *Roots/combinable + poultry manure* | 40 - 90 | 0.2 - 1.0 | 10 - 850 |
| *Dairy* | 15 - 50 | 0.2 - 0.8 | 5 - 300 |
| *Grazing - Lowland* | 7 - 25 | 0.1 - 0.5 | 5 - 250 |
| *Grazing - LFA* | 5 - 15 | 0.05 - 0.3 | 5 - 150 |
| *Mixed* | 20 - 50 | 0.2 - 0.8 | 10 - 450 |
| *Indoor pigs* | no land | no land | No land |
| *Outdoor pigs** | 100 - 150 | 1 - 3 | 400 - 1200 |
| *Poultry* | no land | no land | no land |
| *Horticulture* | 20 - 35 | 0.01 - 0.7 | 10 - 650 |
| ***Farm System*** | **Main airborne pollutants *(kg/farm)*** | | |
| | ***Ammonia (N)***[x] | ***Nitrous oxide (N)***[xx] | ***Methane ($CH_4$)*** |
| *Combinable crops* | 1,160 | 860 | 0 |
| *Combinable + pig manure* | 5,900 | 1,300 | 0 |
| *Roots/combinable crops* | 860 | 660 | 0 |
| *Roots/combinable + poultry manure* | 5,540 | 950 | 0 |
| *Dairy* | 4,300 | 720 | 21,200 |
| *Grazing - Lowland* | 1,150 | 380 | 7,130 |
| *Grazing - LFA* | 720 | 330 | 6,720 |
| *Mixed* | 5,700 | 930 | 12,840 |
| *Indoor pigs* | 15,700 | 390 | 18,120 |
| *Outdoor pigs* | 180 | 230 | 900 |
| *Poultry* | 16,100 | 240 | 4,850 |
| *Horticulture* | 60 | 80 | 0 |

* Mean over 2 years
[x] Multiply by 17/14 to convert to ammonia ($NH_3$) losses
[xx] Multiply by 44/28 to convert to nitrous oxide ($N_2O$) losses

**(x) Other pollutants:** This section provides an assessment of how the emission of other pollutants (not included in the main 'effectiveness section') might either be reduced or increased if the method was to be adopted.

**The 'broad' cost and effectiveness values for each method relate specifically to the farm typologies used in this project (Table 2). They cannot simply be applied to individual farm enterprises or scaled-up to a national level, without a detailed sensitivity analysis.**

## Method 1A – Convert arable land to unfertilised and ungrazed grass

**Direction of change for target pollutants on the area converted to unfertilised grass.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓↓ | ↓↓↓ | ↓↓↓ | ↓↓ | ↓ | ↓↓ | ~ | ~ | ↓↓↓ | ↓↓↓ | ~ | ↓* |

* Plus enhanced soil carbon storage.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Change the land use from arable cropping to unfertilised grassland (without livestock) and associated manure inputs.

**Rationale:** There are only small losses of nitrate ($NO_3$) in drainage waters from arable reversion grasslands and the permanent vegetation cover minimises the erosion of soil particles and loss of associated particulate phosphorus (P) in surface runoff.

**Mechanism for action:** N uptake by the permanent vegetative cover and N immobilisation into accumulating soil organic matter provide a long-term sink for N. Conversion to permanent grassland also avoids the frequent cultivations that under arable cropping stimulate the mineralisation of organic matter and thereby increase the amount of $NO_3$ that is potentially available for leaching. In most cases, losses of $NO_3$ in drainage waters will respond rapidly to the change of land use.

At elevated soil P levels, significant reductions in the leaching of soluble P are unlikely to be achieved in the short-term (<10 years) because there are effectively no nutrient offtakes in grazed grass/livestock products The more immediate effect of this method would be to reduce particulate P losses in surface runoff, provided that the grassland was not compacted by vehicle traffic.

**Potential for applying the method:** The method is applicable to all arable land, but is potentially most suited to marginal and high erosion risk arable land.

**Practicability:** This is an extreme change in land use that is unlikely to be adopted by farmers without the provision of suitable incentives. It is likely to be particularly suited to areas where the converted land would have amenity or conservation value.

**Likely uptake:** Low, due to the high economic impact on a farm business.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on a reduction in cropped area (assumed to be 10% of all arable land) and loss of gross margin (as fixed costs stay the same). |
|---|---|---|---|---|---|---|---|
| Annual | 200 | 200 | 2,200 | 7,500 | 35,000 | 9,500 | |

**Effectiveness:**

**N:** Conversion to ungrazed grassland would reduce $NO_3$ losses by around 90%; annual losses on converted land would typically be <5 kg N/ha. Ammonium and nitrite losses to water would also be reduced. Similarly, direct and indirect $N_2O$ and $NH_3$ emissions would be reduced by around 90%.

**P and sediment:** Particulate P and associated sediment losses in surface runoff would be reduced by around 50%. Soluble P losses would be reduced in the longer-term.

**Other pollutants:** There would be reductions in energy use and increased carbon storage in the grassland soils; initially in the range 1.9 to 7.0 $tCO_2e$/ha/year. However, it is unlikely that these increases would be sustained over the longer-term (>50 years), as a new soil carbon equilibrium level would be reached.

**Key references:**

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Silgram, M. (2005). *Effectiveness of the Nitrate Sensitive Areas scheme 1994-2003.* Final report for Defra project M272/56. 22 pp.

Defra project NT0801 - To study nitrogen losses and transformations in arable land and to model these processes.

Defra project NT1312 - N measurements on set-aside.

Defra project NT1318 - Effect of cultivation on soil nitrogen mineralisation.

Defra project NT1504 - N mineralisation in arable conditions.

Defra project NT1510/11/12 - The measurement of mineralisation in field soils.

Defra project ES0106 - Developing integrated land use and manure management strategies to control diffuse nutrient losses from drained clay soils: BRIMSTONE-*NPS*.

## Method 1B – Arable reversion to low fertiliser input extensive grazing

**Direction of change for target pollutants on the area converted to extensive grazing.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓↓ | ↓↓ | ↓↓ | ↓↓ | ↓ | ↓↓ | ↑↑ | ↑↑ | ↑↑ | ↓↓ | ↑↑ | ↓* |

*Plus enhanced soil carbon storage.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Change the land use from arable cropping to permanent grassland, with a low stocking rate and low fertiliser inputs.
**Rationale:** There are only small losses of $NO_3$ in drainage waters from arable reversion grasslands and the permanent vegetation cover minimises the erosion of soil particles and loss of associated particulate P in surface runoff.
**Mechanism for action:** N uptake by the permanent vegetative cover and N immobilisation into accumulating soil organic matter provide a long-term sink for N. Conversion to permanent grassland also avoids the frequent cultivations that under arable cropping stimulate the mineralisation of organic matter and thereby increase the amount of $NO_3$ that is potentially available for leaching. In most cases, losses of $NO_3$ in drainage waters will respond rapidly to the change of land use.
At elevated soil P levels, significant reductions in the leaching of soluble P are unlikely to be achieved in the short term (<10 years) because there are only low nutrient offtakes in cut grass/livestock products from extensively grazed systems. The more immediate effect of this method would be to reduce particulate P losses in surface runoff, provided that the grassland was not poached or badly compacted by vehicle traffic.
**Potential for applying the method:** The method is applicable to all arable land, but is potentially most suited to marginal and high erosion risk arable land.
**Practicability:** This is an extreme change in land use that is unlikely to be adopted by farmers without the provision of suitable incentives.
**Likely uptake:** Low, due to high economic impact on the farm business; it would require a significant change in farm business outlook and stockmanship skills.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on arable reversion to lowland grazing; some costs are amortised. |
|---|---|---|---|---|---|---|---|
| Annual | 2,000 | 1,000 | 10,550 | 31,00 | 50,000 | 30,000 | |

**Effectiveness:**
**N:** Conversion to extensively grazed grassland would reduce $NO_3$ losses by around 80-90%; annual losses would typically be <10 kg N/ha. Ammonium and nitrite losses to water would also be reduced. Similarly, direct and indirect $N_2O$ emissions would be reduced (as lower amounts of manufactured fertiliser N would be applied). However, $NH_3$ emissions from directly deposited excreta in the field and handled manures (during housing, storage and following land spreading) would be increased.
**P and sediment:** Particulate P and associated sediment losses in surface runoff would be reduced by around 50%. Soluble P losses would be reduced in the longer-term (provided that the grass was not poached).
**FIOs and BOD:** Losses would be increased due to the presence of livestock.
**Other pollutants:** There would be a reduction in energy use and increased carbon storage in the grassland soils; initially in the range 1.9 to 7.0 $tCO_2e$/ha/year. However, it is unlikely that these increases would be sustained over the longer-term (>50 years) as a new soil carbon equilibrium level would be reached. $CH_4$ and odour emissions would increase through the presence of livestock.
**Key references:**
Defra project NT0605 - To quantify nitrate leaching from swards continuously grazed by cattle.
Defra project NT1825 - Nitrate leaching in sustainable livestock. LINK project (LK0613).
Defra project ES0106 - Developing integrated land use and manure management strategies to control diffuse nutrient losses from drained clay soils: BRIMSTONE-*NPS*.

## Method 2 – Convert arable/grassland to permanent woodlands

**Direction of change for target pollutants on the area converted to woodland.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓↓ | ↓↓↓ | ↓↓↓ | ↓↓ | ↓ | ↓↓ | ↓* | ↓* | ↓↓ | ↓↓↓ | ↓* | ↓** |

* Only for farmland that previously had livestock.
** Plus enhanced soil carbon storage and woodland carbon sequestration.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Change the land use from agricultural land to permanent woodland.
**Rationale:** There are only small losses of $NO_3$ in drainage waters from permanent woodlands and the permanent cover, provided by leaf litter mulch and vegetation, minimises the erosion of soil particles and loss of associated particulate P in surface runoff.
**Mechanism for action:** Conversion to permanent woodland avoids the frequent cultivations that under arable cropping stimulate the mineralisation of organic matter and thereby increase the amount of $NO_3$ that is potentially available for leaching. Changing from arable and (to a lesser extent) grassland agriculture to permanent woodland will reduce soil N and carbon losses.
At elevated soil P levels, significant reductions in the leaching of soluble P are unlikely to be achieved in the short term (<10 years) because there are only low level of nutrient uptake by woodland over this time scale. The more immediate effect of this method would to reduce particulate P losses in surface runoff, provided that the woodland developed vegetation that covered the soil surface.
**Potential for applying the method:** The method is applicable to all farm types with land, but is potentially most suited to marginal arable land with a high erosion risk and/or close to surface waters.
**Practicability:** *This is an extreme change in land use* that is unlikely to be adopted by farmers without the provision of suitable financial incentives. It is likely to be particularly suited to areas where the converted land would have amenity or conservation value. *Note*: Grants are available to establish new woodlands (e.g. the Forestry Commission's English Woodland Grant Scheme).
**Likely uptake:** Low, due to dramatic change in land use and *short-term negative cashflow* in the farming business.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on establishment to harvest management, including timber sales @ 75 years (method applied to 2% of farm area). |
|---|---|---|---|---|---|---|---|---|
| Annual | -350 | -350 | -300 | -450 | -500 | -50 | -50 | |

**Effectiveness:**
**N:** Conversion to woodland would reduce $NO_3$ losses by around 90%; annual losses on converted woodland would typically be <5 kg N/ha. Similarly, direct and indirect $N_2O$ emissions and $NH_3$ emissions would be reduced by around 90% (as no fertiliser N would be applied).
**P and sediment:** Particulate P and associated sediment losses in surface runoff would be expected to be reduced by around 50%; provided that best management practices as outlined in Forestry Commission (2003) were adopted.
**FIOs and BOD:** Losses would be reduced by a small amount (where livestock were previously present).
**Other Pollutants:** Converting arable land to permanent woodland would increase soil carbon storage by 1.9 to 7.0 $tCO_2e$/ha/year. However, it is unlikely that these increases would be sustained over the longer-term (>50 years), as a new soil carbon equilibrium level would be reached. Additional carbon would also be stored in the vegetation itself; estimated to range between 0.3 and 5.6 $tCO_2e$/ha/year depending on the tree species, harvest frequency and climatic conditions - although higher figures (>15 t $tCO_2e$/ha/year) have been reported. Additionally, in the longer-term there may be greenhouse gas substitution benefits through the increased use of timber products. $CH_4$ emissions would be reduced by a small amount (where livestock were previously present).

**Key references:**

Dawson, J.J.C. and Smith, P. (2006). *Review of Carbon Loss from Soil and its fate in the Environment*. Final report for Defra project SP08010.

Forestry Commission (2003). *Forests and Water Guidelines*. Fourth Edition. Forestry Commission, Edinburgh.

## Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)

**Direction of change for target pollutants on the area of land converted to biomass crops.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓ | ↓↓ | ↓↓ | ↓↓ | ↓ | ↓↓ | ↓* | ↓* | ↓ | ↓↓ | ↓* | ↓** |

* Only for farmland that previously had livestock.
* Plus enhanced soil carbon storage and biomass carbon sequestration.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Grow perennial biomass crops (e.g. willow, poplar, miscanthus) to displace fossil fuel use, either through direct combustion or through biofuel generation (e.g. by gasification).
**Rationale:** Cultivation of arable land stimulates the mineralisation of organic matter and release of soil N and carbon. Following the establishment of perennial biomass crops, soils are not cultivated annually which will reduce $NO_3$ leaching losses compared with conventional arable cropping. Also, lower levels of N fertiliser additions are made to willow, poplar and miscanthus (typically no N is applied in the establishment year and 60-80 kg/ha N per annum thereafter) than most arable and grassland cropping systems, which reduces $NO_3$ leaching loss risks.
**Mechanism for action:** Conversion to permanent perennial biomass cropping avoids the frequent cultivations that under arable cropping stimulate the mineralisation of organic matter and manufactured fertiliser N inputs are moderate, thereby reducing the amount of $NO_3$ that is potentially available for leaching.
**Potential for applying the method:** The method is applicable to all forms of farmland. It should be noted that a change of land use from arable/grassland food production to energy cropping has implications for the sustainability of food supplies in the UK. i.e. increased use of prime land for energy crop production could lead to greater reliance on food imports and associated overseas greenhouse gas emissions.
**Practicality:** A change in land use to biomass cropping is unlikely to be adopted by farmers without the provision of suitable financial incentives. Note: Defra's Energy Crop Scheme closed to new applications for establishment grants in June 2006.
**Likely Uptake:** Low, due to changes to the farming business and *short-term negative cash flow,* unless financial incentives are sufficient.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on planting 25% farmland area (with associated reductions in livestock numbers) and no planting grants. *Note:* Costings are very sensitive to market prices and transport costs. |
|---|---|---|---|---|---|---|---|
| Annual | -300 | -250 | -400 | -400 | -450 | -50 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses are likely to be reduced by around 50%. Similarly direct and indirect $N_2O$ emissions and $NH_3$ emissions would be reduced by around 50%.
**P and sediment:** Particulate P and associated sediment losses in surface runoff would be reduced by around 50%; provided that best soil management practices were adopted. Soluble P losses would be reduced in the longer-term.
**FIOs and BOD:** Losses would be reduced by a small amount (where livestock were previously present).
**Other pollutants:** Where land use change was to permanent biomass cropping, increased soil carbon storage would be in the range 1.9 to 7.0 $tCO_2e$/ha/year (depending on soil type and previous land use and climate). Additional carbon would also be stored in the biomass itself. The overall long-term effects of large-scale biomass cropping in the UK are unknown. However, the effects of biomass crops such as willow and miscanthus on biodiversity and wildlife value are encouraging (Sage *et al*., 2006), but not entirely clear. $CH_4$ emissions would be reduced by a small amount (where livestock were previously present).

**Key references:**

Dawson, J.J.C. and Smith, P. (2006). *Review of Carbon Loss from Soil and its Fate in the Environment*. Final report for Defra project SP08010.

Goodlass, G., Green, M., Hilton, B. and McDonough, S. (2007). Nitrate leaching from short-rotation coppice. *Soil Use and Management,* 23, 178-184.

Johnson, P. (1999). *Fertiliser Requirements for Short Rotation Coppice*. ETSU report B/WZ/00579.REP/1.

Sage, R., Cunningham, M. and Boatman, N. (2006). Birds in willow short-rotation coppice compared to other arable crops in central England and a review of bird census data from energy crops in the UK. *Ibis,* 148, 184-197.

Defra project NT2309 - Nitrate leaching from short rotation coppice following establishment, harvest and crop removal.

Defra project IF0104 - Field-scale impacts on biodiversity from new crops.

## Method 4 – Establish cover crops in the autumn

**Direction of change for target pollutants on the area occupied by cover crops.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓ | ↓ | ↓ | ↓↓ | ↓ | ↓↓ | ~ | ~ | ~ | ↓ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | × | ✓ | × | × | × | × |

**Description:**

- If land would be 'bare' over-winter, establish a cover crop immediately post-harvest or, at the latest, by mid-September. Alternatively, undersow spring crops with a cover crop that would be in place to take up nutrients and provide vegetation cover once the spring crop had been harvested.
- In order to protect the soil surface throughout the period when surface runoff could occur, do not destroy the cover until the land is due to be prepared for the following crop.

**Rationale:** Without a cover crop, $NO_3$ can be lost through over-winter leaching and particulate P can be lost through sediment transport in surface runoff. To be effective in reducing $NO_3$ leaching, the crop needs to take up N before the onset of winter drainage, but thereafter the date of destruction is less critical. To be effective in reducing particulate P and sediment losses the crop does not have to be alive (i.e. straw and crop residues can be effective), but the soil must be protected throughout the period when surface runoff can occur.

**Mechanism for action:** Cover crops help to reduce $NO_3$ leaching by taking up N and reduce particulate P losses by protecting the soil from rainfall induced surface runoff and soil erosion. A cover crop will take up soil N (and other nutrients) after the main crop has been harvested in the summer/early autumn, leaving less $NO_3$ available for leaching over-winter. Ensuring that the land is not left exposed helps reduce surface runoff and soil erosion.

**Potential for applying the method:** This method is most applicable to tillage land, particularly light soils, where there are significant areas of spring crops. On light soils, a cover crop can be established using cheap methods (e.g. seed broadcasting followed by a light cultivation/rolling). The method is relatively easy to implement for early harvested crops (e.g. vining peas) and is already used in some grassland systems through the undersowing of maize and spring barley with a grass seed mixture. However, difficulties in 'destroying' the cover crop can have implications for following crops.

**Practicality:** For most autumn-sown arable crops, it is not possible to establish a cover crop that will take up sufficient N to significantly decrease $NO_3$ leaching losses ahead of sowing the main autumn crop. A cover crop could be broadcast into the main crop before harvest, however, this can damage the standing crop and lead to yield losses. Soil structural damage caused by establishing a cover crop (either late or in wet conditions) may compromise cover crop establishment and result in poor utilisation of soil N by both the cover crop and subsequent crops, and increased particulate P and sediment loss risks. Where cover crops were established as part of the Nitrate Sensitive Area scheme, it was shown to be preferable (for agronomic reasons) to destroy the crop in January or February (at the latest).

**Likely uptake:** Low-moderate; will depend on the crop rotation and soil type. A moderate level of uptake could be expected on sandy soils and a low level of uptake on medium/heavy soils.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb/ Roots | Costs based on cover crop establishment through cultivations on 70% of spring cropping area. |
|---|---|---|---|---|---|
| Annual | 400 | 100 | 750 | 3,300 | |

**Effectiveness:**

**N:** $NO_3$ leaching loss reduction of 30-60% are typical in the year of establishment. Reductions tend to be at the upper end of the range in high fertility situations and/or where manures are regularly applied. Ammonium and nitrite losses to water, and indirect $N_2O$ emissions would also be reduced by a small amount.

**P and sediment:** Particulate P and associated sediment losses would be reduced; typically in the range 20-80%.

**Other pollutants:** $CO_2$ emissions would be increased by a small amount through cover crop establishment.

**Key references:**

Lord, E.I., Johnson, P.A. & Archer, J.R. (1999). Nitrate Sensitive Areas – a study of large scale control of nitrate loss in England. *Soil Use and Management,* 15, 1-7.

Shepherd, M.A. and Lord, E.I. (1996). Nitrate leaching from a sandy soil; the effect of previous crop and post-harvest soil management in an arable rotation. *Journal of Agricultural Science,* 127, 215-219.

Silgram, M. & Harrison, R. (1998). Mineralisation of cover crop residues over the short and medium term. *Proceedings of the 3rd Workshop of EU Concerted Action 2108 "Long-term reduction of nitrate leaching by cover crops*", 30 September-3 October 1997, Southwell, UK. AB-DLO, Netherlands.

Defra project NT0402 - To study the use of cover crops in reducing N leaching.

Defra projects NT0401 and NT1508 - To prepare guidelines on the use of cover crops to minimise leaching.

## Method 5 – Early harvesting and establishment of crops in the autumn

**Direction of change for target pollutants on the area of early harvested land.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ~ | ~ | ↓↓ | ↓ | ↓↓ | ~ | ~ | ~ | ↓ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | × | ✓ | × | × | × | × |

**Description:**

- Harvest crops such as potatoes and maize early (e.g. in September rather than October).
- Establish autumn sown crops earlier (i.e. early October or sooner).

**Rationale:** Earlier harvesting of crops, especially those that are traditionally harvested late, would enable harvesting to be undertaken when soil conditions were drier, reducing (severe) compaction and soil structural damage risks, and associated sediment and nutrient losses in surface runoff. Establishment of autumn drilled combinable crops by early October would enable the crop to take up (some) N before the onset of over-winter drainage and provide good vegetation cover (at least 25 to 30%) over the winter months to protect the soil from rainfall induced surface runoff and associated erosion.

**Mechanism for action:** When soils are compacted and there is no growing vegetation to intercept rainfall or take up nutrients, the land is very susceptible to the generation of surface runoff and associated soil erosion. By harvesting/establishing crops early, compaction at harvest would be reduced and the crop would be better established in the autumn to take up N and reduce $NO_3$ leaching losses.

**Potential for applying the method:** The method is most applicable to (main crop) potato and maize crops, and maybe applicable to some sugar beet crops.

**Practicality:** Early harvesting of crops such as maize and potatoes can result in a clash with the harvest of winter cereal crops, creating more work at a time when farmers are already busy.

**Likely uptake:** Low-moderate. The main disincentive is that harvesting can clash with other harvesting and drilling activities, and potential yield losses due to earlier harvesting.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb/ Roots | Dairy/Grazing Low/Mixed – costs based on no yield loss from early maturing maize varieties. Roots combinable – costs based on a yield loss for potatoes and a small increase in following wheat crop yields (due to earlier establishment in better soil conditions). |
|---|---|---|---|---|---|
| Annual | ~ | ~ | ~ | 14,800 | |

**Effectiveness:**

**N:** $NO_3$ leaching losses would be reduced by up to 30% through early winter cereal establishment and associated indirect $N_2O$ emissions.

**P and sediment:** Particulate P and associated sediment losses would typically be reduced in surface runoff by 20-50%.

**Other pollutants:** Impacts on other pollutants are likely to be minimal.

**Key references:**

Withers, P.J.A. and Bailey, G.A. (2003). Sediment and phosphorus transfer in overland flow from a maize field receiving manure. *Soil Use and Management*, 19, 28-35.

Defra project NT1013 - Phosphorus loss in surface runoff from different land uses.

Defra project NT1033 - Field and farm scale investigation of the mobilisation and retention of sediment and phosphate.

Defra project PE0106 - An environmental soil test to determine potential for sediment & phosphorus transfer in runoff from agricultural land (DESPRAL).

Defra project PE0111 - Towards understanding factors controlling transfer of phosphorus within and from agricultural fields.

## Method 6 – Cultivate land for crops in spring rather than autumn

**Direction of change for target pollutants on the spring cropped area.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓ | ↓ | ↓ | ↓↓ | ↓ | ↓↓ | ~ | ~ | ~ | ↓ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:**
- Cultivate arable land for spring crops in spring rather than the autumn.
- Plough out grassland in spring rather than the autumn.

**Rationale:** Autumn cultivation of land stimulates the mineralisation of N from organic matter reserves at a time when there is little N uptake by the crop, which will increase the potential for over-winter $NO_3$ leaching losses. By cultivating in spring, there will be less opportunity for mineralised N to be leached and the N will be available for uptake by the established spring crops, and there will be less risk of particulate P losses in surface runoff.

**Mechanism of action:** The cultivation of soil results in mineralisation of organic N and increases the risk of $NO_3$ leaching, with the amount of mineralisation strongly affected by soil temperature, moisture and the N balance of the previous crop. In the case of grassland, mineralisation will generally be higher following cultivation of grazed swards than cut swards and will also be higher where more fertiliser N and manure have been historically applied. Autumn cultivation encourages N mineralisation when, in the absence of an actively growing crop, there is little N uptake. Drainage during the following over-winter period then transports the accumulated $NO_3$ beyond the root zone. Cultivation in spring is better for $NO_3$ and particulate P losses, because bare soil is not exposed during the over-winter period, and an actively growing crop is established soon after cultivation to take up N and provide surface cover.

**Potential for applying the method:** This method is mainly applicable to cultivations on light/medium soils prior to the drilling of spring crops (e.g. spring barley, maize, sugar beet, potatoes) or where there is a switch from winter to spring cereal cropping. The method is also applicable to grassland systems where grass leys are ploughed out and re-seeded.

**Practicality:** Land for spring crops, ploughed in late autumn, has the winter for frost action and wetting and drying cycles to break down soil clods (particularly on medium/heavy soil types). Ploughing in the autumn also allows early establishment of the following spring crop, as only secondary cultivations are required ahead of drilling. On medium/heavy soils, if ploughing is not carried out in late autumn/early winter, delaying cultivations until spring can result in the spring crop being drilled into a drying seedbed, which can impact on crop establishment and yields, and poor utilisation of applied manufactured fertiliser and/or manure N. Delaying cultivation until the spring may also have implications for the control of some weeds. There are also soil structural implications associated with cultivations in a wet spring, particularly on medium/heavy soils. For grassland, reseeding in spring is less reliable than in autumn.

**Likely uptake:** Low-moderate on light/medium soils. On medium/heavy soils, uptake will be low due to farmer concerns over crop establishment/weed problems and the potential for crop yield losses.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on yield losses in spring sown arable crops and grassland. |
|---|---|---|---|---|---|---|---|
| Annual | 300 | 100 | 1,400 | 1,100 | 3,600 | 1,500 | |

**Effectiveness:**

**N:** $NO_3$ leaching losses would typically be reduced by 20-50%; on arable land with manure the reduction is likely to be at the higher end of the range. Indirect $N_2O$ emissions would be reduced by a small amount.

**P and sediment:** Particulate P and associated sediment losses in surface runoff would typically by reduced by 20-50%.

**Other pollutants:** Impacts on other pollutants are likely to be minimal.

**Key references:**

Johnson, P.A., Shepherd, M.A., Hatley, D.J. and Smith P.N. (2002). Nitrate leaching from a shallow limestone soil growing a five course combinable crop rotation: the effects of crop husbandry and nitrogen fertiliser rate on losses from the second complete rotation. *Soil Use and Management*, 18, 68-76.

Silgram, M. & Shepherd, M.A. (1999). The effect of cultivation on soil nitrogen mineralisation. *Advances in Agronomy*, 65, 267-311.

Defra project NT1829 - Further N cycle studies on farmlets.

## Method 7 – Adopt reduced cultivation systems

**Effect on target pollutants where inversion (ploughed) tillage was used previously.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓↓ | (↓) | ↓↓ | ~ | ~ | ~ | (↑) | ~ | ↓* |

( ) Uncertain.
* Plus enhanced soil carbon storage.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | × |

**Description:**
- Reduced cultivations, using discs or tines, to cultivate the soil surface as the primary cultivation in seedbed preparation (typically 10-15cm cultivation depth).
- Direct drilling or broadcasting of seed (i.e. no-till).

**Rationale:** Reduced/no-till cultivations (rather than ploughing) can retain soil surface organic matter and preserve good soil structure, with the resulting soil conditions improving water infiltration rates and thereby reducing loss risks of particulate P and sediment.
**Mechanism of action:** Maintaining good soil structure and improving water infiltration rates reduces soil erosion risks; large reductions in surface runoff can be achieved where a mulch of crop residues is left on the surface. $NO_3$ leaching is generally decreased as there is less soil disturbance and hence less organic matter mineralisation.
**Potential for applying the method:** This method has already been adopted on a large number of arable farms, with around 1.5 million hectares already cultivated using discs or tines. It is most commonly used on medium/heavy soils, although reduced cultivations are increasingly being carried out on light soils. It is less likely to be adopted in wetter parts of the country. In the UK, intermittent ploughing (typically every 3-4 years) is usually part of farm cultivation systems, as a means of minimising compaction near the soil surface and for rotational weed control.
**Practicability:** Reduced cultivation systems are less appropriate in wet autumns and only suitable where soil structural problems have been alleviated. Reduced cultivations may increase resistant weed populations and therefore increase reliance on agro-chemical control. The incorporation of large volumes of straw into a small volume of soil (as part of a reduced cultivation system) may immobilise N and create a small need for additional N application. No-till is generally unsuitable for light soils that are prone to capping.
**Likely uptake:** The largest barrier to uptake is likely to be the purchase of new machinery (in addition to those outlined above) and so is most likely to be adopted on larger combinable crop farms.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Savings are due to reduced cultivation costs. |
|---|---|---|---|---|---|---|
| Annual | -150 | -150 | -1300 | -4,300 | -3,000 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching loss reductions can be up to 20%; reductions are likely to be at the higher end where manures are applied. Indirect $N_2O$ emissions would also be reduced, however, there is some evidence of higher direct $N_2O$ emissions from reduced/no-till land.
**P and sediment:** Particulate P and associated sediment loss reductions can be up to 60% on medium/heavy soils and up to 90% on light soils.
**Other pollutants:** $CO_2$ emissions would be reduced as a result of the lower power requirements of reduced/no-till cultivation. Soil carbon storage would be increased by a small amount typically 0.57 $tCO_2e$/ha/year for reduced tillage and 1.14 $tCO_2e$/ha/year for no-till.

**Key references:**

Bhogal, A., Chambers, B.J., Whitmore, A. and Poulson, D.S. (2008). *The Effects of Reduced Tillage Practices and Organic Material Additions on the Carbon Content of Arable Soils*. Final report for Defra project SP0561, 47pp.

Chambers, B.J., Bhogal, A., Whitmore, A.P. and Poulson, D. (2008). The potential to increase carbon storage in agricultural soils. In: *Land Management in a Changing Environment* – Proceedings of the SAC and SEPA Biennial Conference, (Eds. K. Crighton and R. Audsley), pp.190-196.

Johnson, P.A., Shepherd, M.A., Hatley, D.J. and Smith P.N. (2002). Nitrate leaching from a shallow limestone soil growing a five course combinable crop rotation: the effects of crop husbandry and nitrogen fertiliser rate on losses from the second complete rotation. Soil Use and Management, 18, 68-76.

Lord, E.I., Shepherd, M.A., Silgram, M, Goodlass, G., Gooday, R, Anthony, S.G., Davison, P. and Hodgkinson, R. (2007). *Investigating the Effectiveness of NVZ Action Programme Measures: Development of a Strategy for England*. Final report for Defra Project NIT18.

Silgram, M. and Shepherd, M.A. (1999). The effect of cultivation on soil nitrogen mineralisation. *Advances in Agronomy*, 65, 267-311.

Defra project PE0206 - Field testing of mitigation options (MOPS1).

## Method 8 – Cultivate compacted tillage soils

**Direction of change for target pollutants on tillage land.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ~ | ~ | ~ | ↓↓ | ↓ | ↓↓ | ~ | ~ | ~ | (↓) | ~ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:**

- Cultivate compacted tillage soils to increase aeration and water infiltration rates.
- Endeavour to establish a vegetative cover from a drilled crop, through natural regeneration or broadcast (barley) seed.

**Rationale:** Cultivation disrupts compaction, increases surface roughness and water infiltration rates. The method will reduce particulate P and associated sediment losses.

**Mechanism of action:** The method reduces surface runoff and soil erosion. When soils are compacted or capped and there is little crop residue or vegetation cover to intercept rainfall, soils can be susceptible to surface runoff. Cultivation of the soil surface (during dry conditions) will increase surface roughness, which will enhance water infiltration rates into the soil and reduce surface runoff volumes.

**Potential for applying the method:** The method is applicable to all tillage land where soils are compacted, and particularly sloping land in high rainfall areas.

**Practicability:** The cultivation itself is straightforward. However, for the method to be effective it should be carried out when soils are dry.

**Likely uptake:** If compaction is identified as an issue it is likely to be alleviated by farmers.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Based on a cultivation cost of £25/ha (on 20% of the tillage land area each year). |
|---|---|---|---|---|---|---|---|
| Annual | 100 | 50 | 500 | 1,500 | 1,600 | 150 | |

**Effectiveness:**

**N:** There may be a small reduction in direct $N_2O$ emissions, as a result of increased soil aeration.

**P and sediment:** Particulate P and associated sediment loss reductions would typically be in the range 10 and 50%.

**Other pollutants:** $CO_2$ emissions would be increased by a small amount from the additional cultivation. Impacts on other pollutants are likely to be minimal.

**Key references:**

Catt, J.A., Howse, K.R., Farina, R., Brockie, D., Todd, A., Chambers, B.J., Hodgkinson, R., Harris, G.L. and Quinton, J.N. (1998). Phosphorus losses from arable land in England. *Soil Use and Management*, 14, 168-174.

Chambers, B.J., Garwood, T.W.D. and Unwin, R.J. (2000). Controlling Soil Water Erosion and Phosphorus Losses from Arable Land in England and Wales. *Journal of Environmental Quality*, 29 145-150.

Defra project PE0206 - Field testing of mitigation options (MOPS1).

## Method 9 – Cultivate and drill across the slope

**Direction of change for target pollutants on sloping land.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ~ | ~ | ~ | ↓↓ | ↓ | ↓↓ | ~ | ~ | ~ | ~ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Cultivate and drill land along the slope (contour) to reduce the risk of developing surface runoff.

**Rationale:** On fields with *simple slope patterns*, cultivating and drilling across the slope will reduce the risk of surface runoff being initiated and increase re-deposition rates where surface runoff does occur. The ridges created across the slope increase down-slope surface roughness and provide a barrier to surface runoff. As a result, particulate P and associated sediment losses will be reduced.

**Mechanism of action:** Cultivating across the slope reduces the risk of developing surface sheet and rill flow. Furrows (and tramlines) orientated down the slope will tend to collect water and develop concentrated surface flow paths; this risk can be reduced if they are aligned across the slope.

**Potential for applying the method:** Applicable to all cultivated soils where fields have simple slope patterns.

**Practicability:** The method is more time-consuming and requires greater skill than conventional field operations. Cultivations and drilling should not be carried out across very steep slopes, due to the risk of machinery overturning. Also, as indicated in the Defra "Code of Good Agricultural Practice (2009)", this method is only likely to be effective for crops grown on gently and moderately sloping fields, with simple slope patterns. For steeper sloping fields with complex slope patterns, it is not practical to follow slopes (contours) accurately. In these fields, attempts at cultivation across the slope often leads to channelling of surface runoff waters, particularly in tramlines or wheelings, which can cause severe (gully) erosion on headlands. For furrow crops, such as potatoes and sugar beet, harvesters only work effectively up and down the slope. It may be more effective to stop growing such crops on steeply sloping areas or to use 'tied ridges' to reduce runoff.

**Likely uptake:** Uptake is most likely on fields with gentle/moderate slopes and simple slope patterns, and that are longer across slope than in the upslope direction.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on additional management time (£10/ha) and applied to 30% of tillage land area. |
|---|---|---|---|---|---|---|---|
| Annual | 50 | 20 | 150 | 450 | 500 | 50 | |

**Effectiveness:**

**P and sediment:** Limited evidence indicates that cultivating/drilling across the slope can reduce particulate P and associated sediment losses by 40-80%.

**Other pollutants:** Impacts on other pollutants are likely to be minimal.

**Key references:**

Defra (2009). *A Code of Good Agricultural Practice for Farmers, Growers and Land Managers*. The Stationery Office, Norwich. ISBN 978-0-11-243284-5.

Quinton, J.N. and Catt, J.A. (2004). The effects of minimal tillage and contour cultivation on surface runoff, soil loss and crop yield in the long-term Woburn Erosion Reference Experiment on sandy soil at Woburn, England. *Soil Use and Management,* 20, 343-349.

Defra project PE0206 - Field testing of mitigation options (MOPS1)

## Method 10 – Leave autumn seedbeds rough

**Direction of change for target pollutants on winter cereal area.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ~ | ~ | ~ | ↓ | ~ | ↓ | ~ | ~ | ~ | ~ | ~ | ↓ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | × |

**Description:** Avoid creating a fine autumn seedbed that will ‘slump’ and run together.

**Rationale:** Leaving the autumn seedbed rough encourages surface water infiltration and reduces the risk of surface runoff, thereby reducing particulate P and associated sediment loss risks.

**Mechanism of action:** A more open seedbed is created by using a reduced number of cultivations, particularly from powered cultivation equipment and by avoiding use of a heavy roller. This helps to reduce the risk of surface runoff by preventing soil capping and enhancing surface water infiltration into the soil. A rough seedbed also helps to break up any surface flow that is generated, reducing the risk of sheet wash and rill erosion.

**Potential for applying the method:** Applicable to the establishment of ‘large’ seeded crops on tillage land (particularly on light soils). It is most applicable to winter cereal crops that can establish well in coarse seedbeds. However, ‘patchy’ crop establishment (or indeed crop failure) would reduce yields and lead to an increased risk of sediment losses from bare soils over-winter and could increase $NO_3$ leaching in the following over-winter period.

**Practicability:** Herbicide activity is most effective in firm and fine seedbeds; rough seedbeds can reduce activity. The method is not well suited to ‘small’ seeded crops such as oilseed rape, sugar beet and grass that require fine, clod-free seedbeds. *A rough seedbed may not be appropriate when there is a high risk of slug damage*.

**Likely uptake:** Low, due to pest (particularly slug) and weed control issues.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Costs based on additional pest/weed control inputs and ‘poorer’ crop establishment on 50% of winter cereal area. |
|---|---|---|---|---|---|---|
| Annual | 200 | 100 | 500 | 2,500 | 1,500 | |

**Effectiveness:**

**P and sediment:** Limited field evidence indicates that particulate P and associated sediment losses can be reduced by up to 20%.

**Other pollutants:** $CO_2$ emissions would be reduced by a small amount from less cultivation. Impacts on other pollutants are likely to be minimal.

**Key reference:**

Defra project PE0206 - Field testing of mitigation options (MOPS1)

## Method 11 – Manage over-winter tramlines

**Direction of change for target pollutants on tillage land area with tramlines.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ~ | ~ | ~ | ↓↓ | ↓ | ↓↓ | ~ | ~ | ~ | ~ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | × |

**Description:** Use tines to disrupt tramlines or delay their establishment until the spring.
**Rationale:** Tramlines are generally established in autumn sown combinable crops at the time of drilling; they can result in the channelling of surface water and the development of rills and gullies on sloping erosion susceptible soils. Tramline management to improve water infiltration rates can help to reduce accelerated runoff and the loss of particulate P/sediment.
**Mechanism of action:** Avoiding the use of over-winter tramlines helps prevent surface runoff and associated sediment mobilisation, as 'compacted' tramlines can act as concentrated flow pathways during periods of increased surface runoff. If tramlines are present, for example, as a result of the need to apply agro-chemicals during the autumn period, then tines can be used to disrupt the tramlines, which encourages water to infiltrate into the soil. Using low ground-pressure vehicles also helps to limit soil compaction and maintain water infiltration rates.
**Potential for applying the method:** This method (either avoiding or disrupting tramlines) is applicable to winter cereal cropped land, particularly on light/medium textured soils on sloping land in higher rainfall areas.
**Practicability:** Not establishing over-winter tramlines is potentially applicable to all winter sown combinable crop land, but is less applicable to oilseed rape crops due to the (common) need to apply agro-chemical in autumn/winter.
**Likely uptake:** Low-moderate.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Costs based on additional tine cultivation of tramlines (on 30% of tillage land area). |
|---|---|---|---|---|---|---|
| Annual | 10 | 20 | 150 | 750 | 400 | |

**Effectiveness:**
**P and sediment:** Limited field evidence indicates that tramline disruption can reduce particulate P and associated sediment losses by 30-50% on winter cereal cropped land.
**Other pollutants:** $CO_2$ emissions would be increased by a small amount from the additional tine cultivation. Impacts on other pollutants are likely to be minimal.
**Key references:**

Chambers, B.J. and Garwood, T. (2000). Monitoring of water erosion on arable farms in England and Wales: 1989-1990. *Soil Use and Management,* 8, 163-170.

Silgram, M., Jackson, B., Quinton, J., Stevens, C. and Bailey, A. (2007). Can tramline management be an effective tool for mitigating phosphorus and sediment loss? *Proceedings of the 5th International Phosphorus Transfer Workshop (IPW5)*, 3-7 September 2007, Silkeborg, Denmark (ed. G. Heckrath, G. Rubaek and B. Kronvang). pp 287-290. ISBN 87-91949-20-3.

Withers, P.J.A., Hodgkinson, R.A., Bates, A. and Withers C. (2006). Some effects of tramlines on surface runoff, sediment and phosphorus mobilization on an erosion-prone soil. *Soil Use and Management,* 22, 245-255.

Defra project PE0206 - Field testing of mitigation options (MOPS1).

## Method 12 – Maintain and enhance soil organic matter levels

**Direction of change for target pollutants on arable land receiving organic manures.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | (↓↑) | ↑ | ↓ | ↑ | ↑ | ↑ | ↑ | ~ | ↑* |

( ) Uncertain.
* Plus enhanced soil carbon storage.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | × | × | ✓ | ✓ | × | × | × | ✓ |

**Description:** Maintain and enhance soil organic matter levels by the regular addition of organic materials (e.g. livestock manures, biosolids, compost, digestate) and retention of crop residues.
**Rationale:** Low soil organic matter levels are a concern in some arable systems; they can give rise to soil structural problems and increased risks of soil erosion. Maintaining and enhancing soil organic matter levels helps to reduce the risks of surface runoff and erosion, enables improved water retention and the efficient use of soil and added nutrients. The long-term benefits of improved soil structure etc. should be effective in reducing particulate P and associated sediment losses.
**Mechanism of action:** Maintaining soil organic matter levels helps to maintain good soil structure, fertility and aggregate stability. Good structure enhances the infiltration, retention and movement of water through the soil, and improved soil microbial activity helps to increase plant nutrient uptake from soil reserves. Well-structured soils are more easily cultivated, resulting in more uniform crop establishment and growth and associated nutrient uptake (particularly N). To minimise soil P accumulation (and associated soluble P losses) and mineral N levels in the soil, it is important that the implementation of this method is accompanied by a reduction in manufactured fertiliser use to take account of the additional nutrients supplied by the organic materials (or crop residues).
**Potential for applying the method:** This method is applicable to all arable farming systems; particularly on low organic matter soils that are structurally unstable.
**Practicability:** Depends on the local availability of organic materials. Where the farm is in a Nitrate Vulnerable Zone (NVZ), the application of organic materials, must comply with NVZ Action Programme field N application rate limit and ‘closed spreading periods for high readily available N materials (e.g. slurry, poultry manure and digestate).
**Likely uptake:** Moderate-high, due to the increasing cost of manufactured fertilisers and importance of organic matter supply to arable soils.
**Cost:**

| Total *cost* for farm system (£/farm) | Comb Crops | Comb/ Roots | Hort | Costs based on the receiving farm paying the transport cost of the organic materials from 3 km and 10 km distances. |
|---|---|---|---|---|
| Annual @3km | -6,500 | -6,800 | -350 | |
| Annual @10km | 800 | 850 | 50 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be increased, particularly where high readily available manures are applied in the autumn period (by up to 20% of total N applied). Similarly direct and indirect $N_2O$ emissions and $NH_3$ emissions would be increased. However, manufactured fertiliser N inputs would be reduced.
**P and sediment:** Particulate P and associated sediment loss reductions would be expected through building up organic matter reserves and better soil structure over a period of years. However, there would be an increased risk of incidental P losses from the added organic materials, particularly where rainfall occurs soon after the application of slurry to ‘wet’ soils.
**FIOs and BOD:** Losses would be increased by a small amount from the organic material applications.
**Other pollutants:** $CO_2$ emissions would be increased by a small amount through transporting and applying the organic materials.

**Key references:**

Bhogal, A., Chambers, B.J., Whitmore, A. and Poulson, D.S. (2008). *The Effects of Reduced Tillage Practices and Organic Material Additions on the Carbon Content of Arable Soils*. Final report for Defra project SP0561, 47pp.

Chambers, B.J., Bhogal, A., Whitmore, A.P. and Poulson, D. (2008). The potential to increase carbon storage in agricultural soils. In: *Land Management in a Changing Environment* – Proceedings of the SAC and SEPA Biennial Conference, (Eds. K. Crighton and R. Audsley), pp.190-196.

Defra project NT1831 - The effect of organic manures on medium-term N cycling and nitrate leaching.

Defra project NT1835 - The effects of manure application to land on N loss pathways to air and water

Defra project OF0164 - Understanding soil fertility in organically farmed systems.

Defra project SP0530 - Organic Manure and Crop Organic Carbon Returns - Effects on Soil Quality (Soil-QC).

Defra project ES0106 - Developing integrated land use and manure management strategies to control diffuse nutrient losses from drained clay soils: BRIMSTONE-*NPS*.

## Method 13 – Establish in-field grass buffer strips on tillage land

**Direction of change for target pollutants in tillage fields where buffer strips established.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓↓ | ↓ | ↓↓ | ~ | ~ | ~ | ↓ | ~ | ↓* |

* Plus enhanced soil carbon storage.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ |

**Description:** On sloping tillage fields and outdoor pig land, establish (unfertilised) grass buffer strips along the land contour, in valley bottoms or on upper slopes to reduce and slow down surface runoff.
**Rationale:** In-field grass buffer strips can reduce particulate P and associated sediment losses by slowing surface runoff and intercepting sediment delivery.
**Mechanism of action:** An in-field grass buffer strip is a vegetated area of land, located along the land contour, on upper slopes or in valley bottoms; it is usually a permanent feature, although it can be temporary. Both the Entry Level and Higher Level Environmental Stewardship (ELS/HLS) schemes have options to establish in-field grass areas to prevent surface runoff and erosion. Buffer strips can also act as a sediment-trap, helping to reduce nutrient and other associated losses in surface runoff.
**Potential for applying the method:** In-field buffer strips are applicable to all arable farming systems, particularly on sloping land. They are particularly suited to fields with long slopes where high volumes of surface runoff can be generated.
**Practicability:** Buffer strips require ‘investment’ to establish, but once established they generally require little maintenance. They reduce the length of fields and can increase the time taken for field operations, but are generally well accepted by farmers who are keen to improve the environmental potential of their farm. They are most effective when combined with additional riparian buffer strips (Method 14). Buffer strips are less effective where they are compacted as a result of use by vehicles, and there can be issues with weed control; hence they should (generally) be cut.
**Likely uptake:** Low-moderate; ‘poor’ patches are ideal for buffer strips. Farmers are less likely to establish buffers along the midslope contour, unless financial incentives are available (e.g. through ELS/HLS).
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Out Pigs | Hort | Costs based on crop yield losses and topping management (buffer strips assumed to occupy 1% of tillage/outdoor pig farm area). |
|---|---|---|---|---|---|---|---|---|
| Annual | 1,000 | 50 | 500 | 800 | 3,500 | 1,200 | 1,000 | |

**Effectiveness:**
**N:** $NO_3$ leaching loss reductions from the strip area would be similar to that from ungrazed/zero-N grassland i.e. around a 90% reduction; annual losses from converted land would typically by <5 kg N/ha (see Methods 1A/B). Ammonium and nitrite losses would also be reduced by a small amount. Similarly, direct and indirect $N_2O$ emissions would be reduced, as manufactured fertiliser N would not be applied to the buffer strips.
**P and sediment:** Particulate P and associated sediment losses reductions would typically be in the range 20-80%.
**Other pollutants:** $CO_2$ emissions would be reduced from the un-farmed strips and soil carbon storage increased (see Methods 1A/B). Impacts on other pollutants are likely to be minimal.
**Key references:**

Dillahar, T.A. and Inamadar, S.P. (1997). Buffer zones as sediment traps or sources. In: Haycock, N.E., Burt, T.P., Goulding, K.W.T. and Pinay, G. (Eds.) *Buffer Zones: Their Processes and Potential in Water Quality Protection.* Quest Environmental, Harpenden, UK, pp. 33-42.

Muscutt, A.D., Harris, G.L., Bailey, S.W. and Davies, D.B. (1993). Buffer zones to improve water quality: a review of their potential use in UK agriculture. *Agriculture, Ecosystems and Environment,* 45, 59-77.

Defra project PE0206 - Field testing of mitigation options (MOPS1).

## Method 14 – Establish riparian buffer strips

**Direction of change for target pollutants in fields when riparian buffer strips established.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓↓ | ↓ | ↓↓ | ↓* | ↓* | ~ | ↓ | ~ | ↓** |

* Where livestock were previously present/manures spread.
** Plus enhanced soil carbon storage.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ |

**Description:** Establish vegetated (and unfertilised) grass/woodland buffer strips alongside watercourses.
**Rationale:** The grass/woodland strip will act as a 'natural' buffer feature to reduce the transfer of pollutants from agricultural land to water.
**Mechanism of action:** Riparian buffer strips can reduce pollution delivery in two ways. They distance agricultural activity from watercourses and therefore reduce direct pollution from fertiliser and organic manure additions, and can restrict direct livestock access to watercourses. They can also intercept surface runoff from agricultural land before it reaches the watercourse, therefore acting as a sediment trap and filter for nutrients.
Riparian strips should ideally be free-draining and have a good surface porosity to intercept surface runoff. The Entry Level Environmental Stewardship scheme offers options for buffer strips between 2 and 6 m in width, and 10 m around in-field ponds.
**Potential for applying the method:** Riparian buffer strips are most effective at retaining sediment when overland flow is shallow and slow; they are particularly suited to low-lying and gently undulating landscapes where the topography does not concentrate the flow into channels. The effectiveness of riparian buffers is dependent upon their design and implementation, the density of the vegetation, the species used and the age of the buffer itself. They are potentially applicable to all farming systems where watercourses are present.
**Practicability:** Riparian strips require a certain amount of 'investment' to establish, but once established generally require little maintenance. They are generally well accepted by farmers who are keen to improve the environmental potential of their farm, but there can be issues with weed control from the strips. Buffer strips are less effective where they are compacted as a result of use by vehicles.
**Likely uptake:** Medium; 'poor' field area at the waters edge are ideal. The establishment of riparian areas is less likely on 'better' land, unless financial incentives are available (through ELS or other schemes).
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Out Pigs | Hort | Costs based on loss of gross margin (on 3% of farmed area), plus establishment and topping costs, and fencing in grassland fields. |
|---|---|---|---|---|---|---|---|---|
| Annual | 3,400 | 650 | 2,300 | 2,400 | 10,600 | 4,500 | 2,800 | |

**Effectiveness:**
**N:** $NO_3$ leaching loss reductions from the strip area would be the same as from ungrazed/zero–N grassland i.e. around a 90% reduction; annual losses from converted land would typically be <5 kg N/ha (see Methods 1A/B). Ammonium and nitrite losses would also be reduced by a small amount. Similarly, direct and indirect $N_2O$ emissions would be reduced, as manufactured fertiliser N would not be applied to the riparian strips.
**P and sediment:** Particulate P and associated sediment losses would typically be reduced by 20-80%.
**FIOs and BOD:** Losses would be reduced by a small amount (where livestock were previously present).
**Other pollutants:** $CO_2$ emissions would be reduced from the un-farmed strip and soil carbon storage increased (see Methods 1A/B)

**Key references:**

Muscutt, A.D., Harris, G.L., Bailey, S.W. and Davies, D.B. (1993). Buffer zones to improve water quality: a review of their potential use in UK agriculture. *Agriculture, Ecosystems and Environment,* 45, 59-77.

Defra project PE0205 - Strategic placement and design of buffering features for sediment and P in the landscape.

## Method 15 – Loosen compacted soil layers in grassland fields

**Direction of change for target pollutants in loosened grassland fields.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ~ | ~ | ~ | ↓↓ | ~ | ↓↓ | ↓ | ↓ | ↓* | ↓ | ~ | ↑ |

* Where slurry applied.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × |

**Description:** Reduce surface runoff from grassland fields by loosening to disrupt compacted soil layers, as required in relation to the depth of soil compaction. These operations should be carried out in moist soil conditions so as not to damage the grass sward.
**Rationale:** Compacted soil layers reduce the infiltration of rainwater and slurry into the soil. Disrupting these compacted layers allows more rapid percolation of rainwater/slurry into the soil and reduces the risk of pollutants being transported to watercourses in surface runoff.
**Mechanism of action:** Trampling by livestock (both cattle and sheep) and the passage of heavy farm machinery can compact grassland soils in both grazing and silage fields. Compaction may build-up over a number of years and persist in the long-term. Topsoil loosening and shallow spiking/slitting can break up compacted layers and allow more rapid rainwater and slurry infiltration, thus reducing surface runoff. In addition, soil aeration can be improved and result in roots being able to penetrate deeper into the soil, which will increase nutrient uptake from deeper soil layers.
**Potential for applying the method:** The method is potentially applicable to all grassland farms, but particularly those with high stocking rates.
**Likely uptake:** Moderate to high on fields where soil compaction has been identified.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Based on a loosening cost of £40/ha (applied to 25% of grassland area). |
|---|---|---|---|---|---|
| Annual | 1,000 | 1,500 | 1,000 | 1,000 | |

**Effectiveness:**
**N:** Effects on $NO_3$ leaching losses are likely to be minimal. As a result of improved soil aeration direct $N_2O$ emissions are likely to be reduced, and as a result of improved soil infiltration rates $NH_3$ emissions are likely to be reduced following slurry application.
**P and sediment:** Particulate P and associated sediment losses would typically be reduced by 10-50%.
**FIOs and BOD:** Losses would be reduced by a small amount.
**Other pollutants:** $CO_2$ emissions would be increased by a small amount through the loosening operation.
**Key references:**
Heathwaite, A.L., Burt, T.P. and Trudgill, S.T. (1990). Land-use Controls on Sediment Production in a Lowland Catchment, South-west England. In: J. Boardman, I.D.L. Foster and J.A. Dearing (Editors), *Soil Erosion on Agricultural Land*. John Wiley and Sons Ltd., Chichester, UK.

Ruser R., Flessa H., Russow R., Schmidt G., Buegger F. & Munch J.C. (2006). Emission of $N_2O$, $N_2$ and $CO_2$ from soil fertilised with nitrate: effect of compaction, soil moisture and rewetting. *Soil Biology and Biochemistry*, 38, 263-274.

Yamulki S. & Jarvis S. C. (2002) Short-term effects of tillage and compaction on nitrous oxide, nitric oxide, nitrogen dioxide, methane and carbon dioxide fluxes from grassland. *Biology and Fertility of Soils*, 36, 224-231.

## Method 16 – Allow field drainage systems to deteriorate

**Direction of change for target pollutants on soils with artificial under drainage.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓ | (↓) | (↓) | (↓) | ~ | (↓) | (~) | (~) | ~ | ↑ | ~ | ~ |

( ) Uncertain.
Change arrows apply to grassland.
*Note: Maintenance of an effective drainage system is taken as 'baseline' management for arable land, as without an effective drainage system, economically sustainable arable cropping would not be possible on most medium/heavy soils.*

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |

**Description:**

- Allow existing (old) drainage systems to naturally deteriorate i.e. cease to maintain them.
- Some drainage systems will survive for decades with little management, therefore this can be a long-term option.

**Rationale:** Drainage systems can accelerate the delivery of pollutants from land to a watercourse, by acting as a preferential (by-pass) flow route. Allowing drainage systems to deteriorate therefore reduces hydrological connectivity and the potential transfer of pollutants to watercourses, although surface runoff would be increased.

**Mechanism of action:** When drains have deteriorated, water is forced to percolate through the soil at a slower rate, which increases the opportunity for the retention (or transformation) of potential pollutants through physical filtration and biological activity in the soil. Allowing drains to deteriorate will result in a higher water table being maintained, thereby reducing N mineralisation from soil organic matter and $NO_3$ leaching, but will potentially increase the risk of incidental losses in surface runoff.

**Potential for applying the method:** There are around 6 million hectares of drained soils in England and Wales. This method is most applicable to the grassland sector on medium/heavy soils. It is a relatively easy option to implement, but is unlikely to be popular with farmers, particularly where waterlogging is a problem. Undrained grassland will wet up earlier in autumn so that stock need to be removed earlier to avoid poaching. *Excess water and waterlogging in parts of fields may lead to poor crop establishment, restricted nutrient uptake and will increase soil compaction risks; minimising soil compaction is cross-compliance requirement of the Single Payment Scheme.* Drainage deterioration is compatible with the Higher Level Environmental Stewardship Scheme, where farmers may be able to obtain payment for restoring traditional water meadows.

If the drainage status deteriorated greatly, it is likely that a farmer would revert the arable land to grassland or on other alternative land use (see Methods 1A/B; 2; 3).

**Practicability:** The method is easy to implement as no action is necessary. However, there would be considerable resistance from farmers to adopting the method as a deliberately managed activity, without financial incentive. It is also probable that with increasing soil wetness, it would be necessary to either reduce the length of the grazing season (Method 35) or reduce stocking rates on livestock farms (Method 37). In many grassland areas, the deterioration of field drainage systems is probably occurring in practice, because farmers do not have the funds to replace ageing systems.

**Likely uptake:** Low, without financial incentives. It is highly unlikely that farmers would deliberately allow drainage systems to deteriorate, due to the large impact this can have on production.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Costs based on loss of production due to poor drainage. |
|---|---|---|---|---|---|
| Annual | 1,200 | 450 | 900 | 2,500 | |

**Effectiveness:**

**N:** $NO_3$ leaching loss reductions would typically be in the range of 10-50%, with reductions at the upper end of the range from higher input grassland systems. Ammonium and nitrite losses would also be reduced, and indirect $N_2O$ losses as a result of lower $NO_3$ leaching losses. However, direct $N_2O$ emissions would be increased as a result of greater soil wetness and associated denitrification losses.

**P and sediment:** Particulate P and associated sediment losses would typically be reduced by up to 10%, provided that livestock were removed when the soil was wet i.e. that poaching was not increased.

**Other pollutants:** Impacts on other pollutants are likely to be minimal.

**Key references:**

Ruser R., Flessa H., Russow R., Schmidt G., Buegger F. & Munch J.C. (2006). Emission of $N_2O$, $N_2$ and $CO_2$ from soil fertilised with nitrate: effect of compaction, soil moisture and rewetting. *Soil Biology and Biochemistry*, 38, 263-274.

Withers, P.J.A., Davidson, I.H. and Roy, R.H. (2000). Prospects for controlling non-point phosphorus losses to water: A UK perspective. *Journal of Environmental Quality*, 29, 167-175.

Defra project NT1012 - Phosphate loss from cracking clay soils.

Defra project ES0106 - Developing integrated land use and manure management systems to control diffuse nutrient losses from drained clay soils: BRIMSTONE-*NPS*.

## Method 17 – Maintain/improve field drainage systems

**Direction of change for target pollutants on soils with artificial under drainage.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑↑ | (↑) | (↑) | (↑) | ~ | (↑) | (~) | (~) | ~ | ↓ | ~ | ↑ |

( ) Uncertain.
Change arrows apply to grassland.
*Note: Maintenance of an effective drainage system is taken as 'baseline' management for arable land, as without an effective drainage system, economically sustainable arable cropping would not be possible on most medium/heavy soils.*

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | ✓ |

**Description:** Actively maintain field drainage systems through jetting, re-installation and renewed moling.
**Rationale:** A functioning drainage system ensures that water is able to move through the soil profile, allowing the soil to be maintained in a 'well drained' condition and extending the window of opportunity for machinery operations and livestock grazing, particularly in autumn and spring. Maintaining field drainage systems minimises the risk of poaching, compaction and waterlogging, and can reduce surface runoff; an important pathway for the loss of particulate P and sediment (particularly from tillage land).
**Mechanism for action:** The method reduces the period when soils are at risk from compaction and poaching, and reduces the risk of surface runoff and associated particulate P/sediment losses. However, drainflow losses of nutrients (particularly $NO_3$ and P) are likely to be increased.
**Potential for applying the method:** The method is applicable to all drained fields, particularly on medium/heavy soils types and in grassland farming systems. The Method is inter-linked with Method 18 (ditch maintenance).
**Practicality:** The method is relatively easy to apply, assuming that the drainage system has not already deteriorated. In most circumstances, a functioning drainage system would result in better crop yields and increased nutrient uptake.
**Likely uptake:** High, mainly due to the impact that poor drainage can have on crop production and management versatility of the land.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on moling 20% of the farm each year, as a 'proxy' cost for maintaining drainage systems (no yield increases have been included). |
|---|---|---|---|---|---|---|---|---|
| Annual | 350 | 50 | 200 | 750 | 1,500 | 1,650 | 150 | |

**Effectiveness:**
**N:** On grassland, $NO_3$ leaching losses would typically be increased by 10-50% compared with drainage deterioration. Ammonium and nitrite losses would also be increased and indirect $N_2O$ losses as a result of higher $NO_3$ leaching losses. However, direct $N_2O$ emissions would be decreased as a result of more aerobic soils conditions and lower denitrification losses.
**P and sediment:** Particulate P and associated sediment losses would typically be increased by up to 10%, as a result of greater drainflow losses.
**Other pollutants:** $CO_2$ emissions would be increased by a small amount from the moling operation. Impacts on other pollutants are likely to be minimal.
**Key references:**
Ruser R., Flessa H., Russow R., Schmidt G., Buegger F. & Munch J.C. (2006). Emission of $N_2O$, $N_2$ and $CO_2$ from soil fertilised with nitrate: effect of compaction, soil moisture and rewetting. *Soil Biology and Biochemistry*, 38, 263-274.
Defra project NT1012 - Phosphate loss from cracking clay soils.

Defra project ES0106 - Developing integrated land use and manure management systems to control diffuse nutrient losses from drained clay soils: BRIMSTONE-*NPS*.

## Method 18 – Ditch management

**Direction of change for target pollutants on the area of the farm with ditches.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ↑ | ~ | ↑ | ~ | ~ | ~ | ↓ | ~ | ↑ |

*Note: The assessment below assumes that ditches are not well managed before method implementation.*

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✓ |

**Description:** Clear out ditches on a regular basis to ensure field drainage systems are able to function. This may include cutting vegetation in the bottom of the ditch to prevent flooding.
**Rationale:** To ensure a drainage system functions at its optimum the water needs to be able to exit the ditch system. Clearing out ditches will achieve this.
**Mechanism for action:** This method will allow field drainage systems to function thereby reducing the risk of waterlogging, soil compaction, poaching and surface runoff.
**Potential for applying the method:** The method is applicable to all farms with ditches and a drainage system. This method is inter-linked with Method 17 – 'maintain/improve field drainage systems'.
**Practicality:** The method is relatively easy to apply, assuming that access to the ditch is straightforward. In most circumstances, a functioning ditch/drainage system will result in better crop yields and improved nutrient uptake.
**Likely uptake:** High, mainly due to the impact that poor drainage (and localised flooding) can have on crop production and the management versatility of land.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Out Pigs | Hort | Costs based on each field having a ditch on one side and that 20% of ditches are cleaned each year. |
|---|---|---|---|---|---|---|---|---|---|
| Annual | 400 | 300 | 350 | 550 | 550 | 600 | 200 | 50 | |

**Effectiveness:**
**N:** $NO_3$ leaching losses would typically be increased by up to 20%. Ammonium and nitrite losses would also be increased and indirect $N_2O$ losses as a result of higher $NO_3$ leaching losses. However, direct $N_2O$ emissions would be decreased as a result of more aerobic soil conditions and lower denitrification losses.
**P and sediment:** Particulate P and associated sediment losses would typically be increased by up to 10%, and as a result of increased drainflow losses.
**Other pollutants:** $CO_2$ emissions would increase by a small amount as a result of the ditch cleaning operation. Impacts on other pollutants are likely to be minimal.
**Key references:**
Ruser, R., Flessa, H., Russow, R., Schmidt, G., Buegger, F. & Munch J.C. (2006). Emission of $N_2O$, $N_2$ and $CO_2$ from soil fertilised with nitrate: effect of compaction, soil moisture and rewetting. *Soil Biology and Biochemistry*, 38, 263-274.

## Method 19 – Make use of improved genetic resources in livestock

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ~ | ~ | ↓ | ↓ | ↓ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × |

**Description:** Use genetic resources to improve lifetime efficiency of livestock systems.
**Rationale:** The selection of useful traits that relate to improved animal robustness (e.g. health, fertility) can result in:

- Increased efficiency of individual animals.
- Increased longevity (including calving ease for dairy cows), fertility and other non-yield traits.

For the last few decades selection goals have focussed more on animal production characteristics than on health and robustness characteristics. While this approach has achieved large advances in animal production (meat, milk and eggs), other beneficial heritable traits were largely deemed to be of lesser importance. Incorporation of health and robustness characteristics into breeding programmes could result in improved nutrient use efficiency within livestock systems.
**Mechanism of action:** Livestock farmers generally aim to improve their stock as a matter of course, however, there is still considerable scope for improvement particularly in the beef and sheep sectors.
Uptake of the 'best' genetics is generally good in the poultry, dairy and pig industries, largely through highly integrated breeding and rearing mechanisms used in poultry (meat and egg) production, and the use of artificial insemination (AI) in the dairy and (increasingly) in the pig industry. There is still much scope for health and fertility traits to be included along with yield related traits; this could potentially improve the efficiency of livestock production.
Reduced residual feed intake (food consumption in excess of that required for production) is heritable and breeding programmes that incorporate this trait could result in a permanent reduction in $CH_4$ emissions. Individual ruminants can have innately reduced $CH_4$ outputs, possibly associated with rumen protozoal populations, and may be of use in breeding programmes. Breeding for lower residual feed intake in beef cattle and restoring dairy cow fertility levels to 1995 levels could reduce annual methane emissions over a 25 year period by between 10-25% at the farm scale. Increasing the longevity of cows will decrease $CH_4$ emissions and increase lifetime N use efficiency.
**Potential for applying the method:** The method is applicable to all livestock systems, but the greatest gains are expected in the beef and sheep sectors.
**Practicality:** The use of AI on dairy and pig farms mean that new genetics can be introduced very easily to herds. The use of AI in sheep flocks is likely to increase in the future and will enable more rapid development of genetics, as has occurred with dairy cows and pigs.
**Likely uptake:** Moderate-high, it will take time for widespread adoption in the beef and sheep sectors.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Costs based on a 10% reduction in feed inputs for the same livestock productivity. |
|---|---|---|---|---|---|
| Annual | -7,000 | -8,500 | -4,500 | -2,000 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ losses and $NH_3$ emissions would be reduced by up to 10% (from manure management).
**P:** Losses would be reduced by up to 10% (from manure management).
**Methane:** Losses could potentially be reduced by up to 10%.
**Other pollutants:** Impacts on other pollutants are likely to be minimal.

**Key references:**

Alford, A. R., R. S. Hegarty, P. F. Parnell, O. J. Cacho, R. M. Herd, and G. R. Griffith. (2006). The impact of breeding to reduce residual feed intake on enteric methane emissions from the Australian beef industry. *Australian Journal of Experimental Agriculture*, 46, 813-820.

Del Prado, A. and Scholefield, D. (2008). Use of SIMSDAIRY modelling framework system to compare the scope on the sustainability of a dairy farm of animal and plant genetic-based improvements with management-based changes. *Journal of Agricultural Science*, 146, 1-17.

Garnsworthy, P.C. (2004). The environmental impact of fertility in dairy cows: A modelling approach to predict methane and ammonia emissions. *Animal Feed Science and Technology*, 112, 211-223.

Goopy, J.P., Hegarty, R.S. and Dobos, R.C. (2006). The persistence over time of divergent methane production in lot fed cattle. *International Congress Series*, 1293, 111-114.

Defra project AC0204 - A study of the scope for the application of research in animal genomics and breeding to reduce nitrogen and methane emissions from livestock based food chains.

Defra project IS0213 - Longevity and lifetime efficiency of dairy cows.

Defra project LK0645 - Endocrine management of bovine infertility (EMBI).

Defra project LK0657 - Identifying and characterising robust dairy cows.

Defra project AC0206 - A review of research of identify best practice for reducing greenhouse gas emissions from agriculture and land management.

## Method 20 – Use plants with improved nitrogen use efficiency

**Direction of change for target pollutants on cropped land.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ~ | ~ | ~ | ~ | ~ | ↓ | ↓ | ~ | ↓ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Develop new plant varieties with improved genetic traits for the capture of soil N.
**Rationale:** During the growing period, the efficiency of uptake of applied manufactured fertiliser N typically ranges between 55 and 70%, according to site conditions, the amount of soil N and the inherent physiology of the plant. If the plant can be rendered more competitive for soil N, reduced emissions of N to water and air would be expected. Improving N use efficiency of plants could potentially therefore:

- Reduce fertiliser N additions to agriculture.
- Improve nutritional characteristics of new forage plant varieties (e.g. improved amino acid profile, reduced rumen protein degradation, improve fibre digestibility).
- Improve N efficiency in agriculture.

**Mechanism of action:** Plants remove more mineral N from the soil and so reduce the amount that can be lost to water and air.
**Potential for applying the method:** Can be applied (in principle) to all sectors of agricultural crop production, but has most potential for arable crops.
**Practicality:** Depends on existence of high N use efficiency plants, with seed at cost-effective prices (and no accompanying management or food quality disbenefits).
**Likely uptake:** Depends on the increase in cost *vs*. the reduction in crop N requirement. If this ratio is positive, then uptake is likely to be high.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costings assume a 10% reduction in N inputs to arable crops (no account has been taken of possible associated yield benefits). |
|---|---|---|---|---|---|---|---|
| Annual | -200 | -100 | -900 | -2,500 | -3,000 | -250 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions, and $NH_3$ emissions would be reduced by up to 10%.
**Other pollutants:** $CO_2$ emissions would be reduced by a small amount as a result lower fertiliser N use (and production). Impacts on other pollutants are likely to be minimal.
**Key references:**
MAFF (2000). *Fertiliser Recommendations for Agricultural and Horticultural Crops*. RB209. Seventh Edition, The Stationery Office, Norwich.
Defra project OC9412 - Genetic manipulation of the nitrogen efficiency of wheat.
Defra project LK0979 - Breeding oilseed rape with a low requirement for nitrogen fertiliser.
Defra project LK0959 - Genetic reduction of energy use and emissions of nitrogen in cereal production, GREEN grain.

## Method 21 – Fertiliser spreader calibration

**Direction of change for target pollutants on the area where fertilisers are applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ~ | ~ | ~ | ~ | ~ | ~ | ↓ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Improve the accuracy and spread pattern of fertiliser spreaders.
**Rationale:** Inaccurate fertiliser spreading (i.e. poor spread patterns) result in the under-application of fertiliser on some areas and over-application on other areas. Under-application of N fertiliser results in reduced yields and over-application can also result in reduced yields (through lodging) and increased $NO_3$ leaching losses.
**Mechanism of action:** Tray tests are used to determine the coefficient of variation (CV) and accuracy of a fertiliser spreader. A low CV (less than 10%) ensures that fertiliser is spread evenly and all parts of the field receive the recommended rate. This optimises the uptake of soil and fertiliser nutrients, and reduces the amount of residual (autumn) mineral N available for leaching over-winter. Fertiliser spreaders should be checked at least annually and, ideally, whenever the fertiliser type is changed.
**Potential for applying the method:** The method is applicable to all farm types where manufactured fertiliser is used.
**Practicality:** The method is easily applied, with qualified testers available throughout the country.
**Likely uptake:** Moderate -high. A low cost method which will improve crop growth, as well as reducing diffuse pollution. The method is encouraged under crop assurance schemes and under NVZ Action Programme rules.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on contractor rates (no account is taken of any associated yield improvements). |
|---|---|---|---|---|---|---|---|---|
| Annual | 150 | 150 | 100 | 150 | 200 | 200 | 50 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 5% and associated direct and indirect $N_2O$ emissions.
**Other pollutants:** Impacts on other pollutants are likely to be minimal.
**Key references:**

Chaney, K. (1990). Effect of nitrogen fertilizer rate on soil nitrate nitrogen content after harvesting winter wheat. *J. Agric. Sci. Camb.,* 114, 171-176.

Defra/EA (2008). *Guidelines for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.

Shepherd, M.A. and Sylvester-Bradley, R. (1996). Effect of nitrogen fertiliser applied to winter oilseed rape on soil mineral nitrogen after harvest and on the response of a succeeding crop of winter wheat to nitrogen. *Journal of Agricultural Science,* 126, 63-74.

WAgriCo - http://www.wagrico.org.uk

## Method 22 – Use a fertiliser recommendation system

**Direction of change for target pollutants on the area where fertiliser is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ~ | ~ | ↓ | ↓ | ~ | ↓ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Use a recognised fertiliser recommendation system (e.g. RB209, PLANET and other supplementary guidance) to plan *manufactured fertiliser applications* to all crops; do not exceed recommended rates. Time fertiliser applications to minimise the risk of nutrient losses (e.g. avoid autumn N use and manage early spring applications to drained soils). Take full account of manure nutrient supply when planning manufactured fertiliser applications. Use a professional FACTS (Fertiliser Advisers Certification and Training Scheme) qualified adviser.

**Rationale:** Fertiliser recommendation systems take account of the following factors: soil nutrient supply (based on soil analysis), winter rainfall, previous cropping and soil type, crop nutrient requirements for a given soil and climate, crop requirement for nutrients at various growth stages, the amount of nutrients supplied to the crop by added organic manures and by previous manure applications, soil pH and the need for lime. Use of a fertiliser recommendation system will reduce the risk of applying more nutrients than the crop needs and will minimise the risks of causing diffuse water and air pollution.

**Mechanism of action:** A good fertiliser recommendation system ensures that the necessary quantities of nutrients are available when required for uptake by the crop. Nutrients are only applied when the supply of nutrients from all other sources is insufficient to meet crop requirements. As a result, the amount of excess nutrients in the soil is reduced to a minimum. Use of a recommendation system should also ensure that the soil is in a sufficiently fertile state to maximise the efficient use of nutrients already in the soil, or supplied from other sources such as fertilisers/organic manures. Maintaining an appropriate balance between different nutrients (i.e. NPK) is also important to maximise the efficient uptake of all nutrients and reduce environmental losses to a minimum.

**Potential for applying the method:** Fertiliser recommendation systems can be used in all farming systems, but are particularly useful in high output grassland, arable and horticultural systems. The method would have less impact in extensive grassland systems, as manufactured fertiliser addition rates are low/moderate.

**Practicability:** The method would require additional investment in education and guidance on some farms.

**Likely uptake:** Moderate/high. As long as fertiliser prices are 'high' relative to the value of the crop farmers will want to optimise nutrient inputs. Improvements are most likely when organic manures are used.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on a 5% reduction in fertiliser use. |
|---|---|---|---|---|---|---|---|---|
| Annual | -2,200 | -1,400 | -2,000 | -3,100 | -3,200 | -3,800 | -400 | |

**Effectiveness**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 5% and associated direct and indirect $N_2O$ emissions, and $NH_3$ emissions.

**P:** P losses would be reduced by up to 5% (from applied fertilisers).

**Other pollutants:** $CO_2$ emissions would be reduced by a small amount as a result of lower fertiliser use (and production). Impacts on other pollutants are likely to be minimal

**Key references:**

Defra (2010). *Fertiliser Manual (RB209)*, 8th Edition. The Stationery Office, Norwich. ISBN 978-0-11-243286-9.

Chaney, K. (1990). Effect of nitrogen fertilizer rate on soil nitrate nitrogen content after harvesting winter wheat. *J. Agric. Sci. Camb.,* 114, 171-176.

Haygarth, P. M. and Jarvis, S. C. (1999). Transfer of phosphorus from agricultural soils. *Advances in Agronomy*, 66, 195-249.

Lord, E.I., Shepherd, M.A., Silgram, M, Goodlass, G., Gooday, R, Anthony, S.G., Davison, P. and Hodgkinson, R. (2007). *Investigating the Effectiveness of NVZ Action Programme Measures: Development of a Strategy for England*. Report for Defra Project NIT18.

MAFF (2000). *Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209).* 7th edition. The Stationery Office, Norwich.

Shepherd, M.A. and Sylvester-Bradley, R. (1996). Effect of nitrogen fertiliser applied to winter oilseed rape on soil mineral nitrogen after harvest and on the response of a succeeding crop of winter wheat to nitrogen. *Journal of Agricultural Science,* 126, 63-74.

Withers, P. J. A., Clay, S. D. and Breeze, V. G. (2001). Phosphorus transfer in runoff following application of fertilizer, manure and sewage sludge. *Journal of Environmental Quality*, 30, 180-188.

Withers, P. J. A., Ulen, B., Stamm, C. and Bechmann, M. (2003). Incidental phosphorus loss – is it significant and can it be predicted? *Journal of Soil Science and Plant Nutrition*, 166, 459-468.

www.Planet4farmers.co.uk.

## Method 23 – Integrate fertiliser and manure nutrient supply

**Direction of change for target pollutants on the area where manure and fertilisers are applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ~ | ~ | ↓ | ↓ | ~ | ↓ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ |

**Description:** Use a recognised fertiliser recommendation system (e.g. RB209, PLANET, MANNER-*NPK* and other supplementary guidance) to make *full allowance of the nutrients applied in organic manures* and reduce manufactured fertiliser inputs accordingly. Use laboratory analysis to gain a better understanding of manure nutrient contents and supply. Use a professional FACTS (Fertiliser Advisers Certification and Training Scheme) qualified adviser.

**Rationale:** Recommendation systems should be used to provide a robust estimate of the amount of nutrients supplied by organic manure applications (e.g. RB209, PLANET, MANNER-*NPK*). This information can then be used to determine the amount and timing of additional manufactured fertilisers needed by the crop. Fertiliser use statistics suggest that, in many cases, this will result in a reduction in fertiliser inputs (particularly on arable and maize crops) compared with current practice and a concomitant reduction in diffuse nutrient pollution. The British Survey of Fertiliser Practice indicates that farmers *do not always* make full allowance for the nutrients supplied by organic manures when calculating fertiliser application rates.

**Mechanism of action:** Manufactured fertiliser application rates are reduced to no more than required for optimum economic production levels and to maintain adequate nutrient levels in the soil. Where soil P and K levels are satisfactory (i.e. ADAS Index 2), manure inputs will usually meet the needs of the next crop grown. Indeed, repeated manure applications can lead to a build-up of soil P reserves.

**Potential for applying the method:** Most applicable to arable and high output grassland systems (including maize). The method is effective wherever manufactured fertilisers are used to 'top-up' the nutrients supplied by organic manures.

**Practicability:** The method could be easily implemented *via* advice, education and guidance. Particular guidance is required with manure (and soil) sampling, the use of on-farm slurry analysis methods, and the interpretation of results.

**Likely uptake:** Moderate-high, mainly as a result of the increasing cost of manufactured fertilisers, meaning the nutrient inputs from manures are more likely to be taken into account in order to reduce costs.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on a 10-15% reduction in fertiliser use where manures applied. |
|---|---|---|---|---|---|---|---|---|
| Annual | -4,500 | -2,900 | -4,100 | -6,300 | -6,500 | -7,600 | -800 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 10% and associated direct and indirect $N_2O$ emissions, and $NH_3$ emissions. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.

**P:** P losses would be reduced by up to 10% (from applied fertiliser).

**Other Pollutants:** $CO_2$ emissions would be reduced by a small amount as a result of lower fertiliser use (and production). Impacts on other pollutants are likely to be minimal.

**Key references:**

Chambers, B.J., Lord, E.I., Nicholson, F.A. and Smith, K.A. (1999). Predicting nitrogen availability and losses following application of organic manures to arable land: MANNER. *Soil Use and Management*, 15, 137-143.

Chambers, B.J., Smith, K.A. and Pain, B.F. (2000). Strategies to encourage better use of nitrogen in animal manures. *Soil Use and Management, Tackling Nitrate from Agriculture*, 16, 157-161.

Chaney, K. (1990). Effect of nitrogen fertilizer rate on soil nitrate nitrogen content after harvesting winter wheat. *J. Agric. Sci. Camb.* 114, 171-176.

Defra (2010). *Fertiliser Manual (RB209),* 8th Edition. The Stationery Office, Norwich. ISBN 978-0-11-243286-9.

Haygarth, P. M. and Jarvis, S. C. (1999). Transfer of phosphorus from agricultural soils. *Advances in Agronomy*, 66, 195-249.

Lord, E.I., Shepherd, M.A., Silgram, M, Goodlass, G., Gooday, R, Anthony, S.G., Davison, P. and Hodgkinson, R. (2007). *Investigating the Effectiveness of NVZ Action Programme Measures: Development of a Strategy for England*. Report for Defra Project NIT18.

MAFF (2000). *Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209)*. 7th edition. The Stationery Office, Norwich.

Shepherd, M.A. and Sylvester-Bradley, R. (1996). Effect of nitrogen fertiliser applied to winter oilseed rape on soil mineral nitrogen after harvest and on the response of a succeeding crop of winter wheat to nitrogen. *Journal of Agricultural Science,* 126, 63-74.

Withers, P. J. A., Clay, S. D. and Breeze, V. G. (2001). Phosphorus transfer in runoff following application of fertilizer, manure and sewage sludge. *Journal of Environmental Quality,* 30, 180-188.

Withers, P. J. A., Ulen, B., Stamm, C. and Bechmann, M. (2003). Incidental phosphorus loss – is it significant and can it be predicted? *Journal of Soil Science and Plant Nutrition,* 166, 459-468.

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## Method 24 – Reduce manufactured fertiliser application rates

**Direction of change for target pollutants on the area where fertiliser is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ~ | ~ | ↓ | ↓ | ~ | ↓ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Reduce the amount of manufactured N and P fertiliser applied to crops *below the economic optimum rate*.

**Rationale:** Limiting the amount of N fertiliser applied to crops will reduce the quantity of residual $NO_3$ in the soil after harvest. Limiting P fertiliser will in the short-term reduce the amount of soluble P lost and in the longer-term will reduce the amount at risk of loss as particulate P.

**Mechanism of action:** The amount of fertiliser applied is reduced at source. There will be a reduction in the amount of residual soil $NO_3$ available for leaching in the autumn, however, there will be no effect on the amount of $NO_3$ mineralised from soil organic matter that will also be available for leaching over-winter. Limiting P fertiliser applications in any one year will reduce the amount of soluble P at risk of loss in surface runoff or drainflow and in the longer-term (where soil P reserves have run down) there will be a reduction in both soluble and particulate P losses.

**Potential for applying the method:** The method is applicable to all farming systems where fertiliser is used.

**Practicability:** The method would have a significant impact on crop yields (other than legumes). For example, a 20% reduction in fertiliser N use (below the economic optimum rate) would typically result in a 2-10% reduction in crop yields. The impact of reducing fertiliser P use would be greatest for responsive crops (e.g. potatoes and some vegetable crops). It is important that any reduction in fertiliser use should take account of the interactions between nutrients and not create an imbalance in the soil. A shortage of one nutrient may limit uptake of another and potentially increase losses of the second nutrient.

**Likely uptake:** Low, due to impact on yields and farm income. Small reductions in yield can have a (disproportionately) large effect on the economic viability of a farm business. Financial incentives would be required to encourage uptake.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Gross margin calculations take into account crop yield and 20% nutrient use reductions. |
|---|---|---|---|---|---|---|---|---|
| Annual | 10,200 | 1,200 | 1,100 | 6,000 | 13,000 | 54,000 | 14,000 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 10% (from a 20% reduction in N fertiliser rates) and associated direct and indirect $N_2O$ emissions, and $NH_3$ emissions.

**P:** Soluble P losses would be reduced by up to 10% (from a 20% reduction in P fertiliser rates) plus longer-term reductions through reduced soil P status.

**Other pollutants:** $CO_2$ emissions would be reduced by a small amount as a result of lower fertiliser use (and production). Impacts on other pollutants are likely to be minimal.

**Key references:**

Chambers. B.J. and Chalmers, A.G. (1994). Effects of combinable crop output values on the economics of fertiliser use. *Aspects of Applied Biology, Arable Farming under CAP Reform*, 40, 377-386.

Chaney, K. (1990). Effect of nitrogen fertilizer rate on soil nitrate nitrogen content after harvesting winter wheat. *J. Agric. Sci. Camb.* 114, 171-176.

Haygarth, P. M. and Jarvis, S. C. (1999). Transfer of phosphorus from agricultural soils. *Advances in Agronomy,* 66, 195-249.

MAFF (2000). *Fertiliser Recommendations for Agricultural and Horticultural Crop*s (RB209). 7th edition. The Stationery Office, Norwich.

Shepherd, M.A. and Sylvester-Bradley, R. (1996). Effect of nitrogen fertiliser applied to winter oilseed rape on soil mineral nitrogen after harvest and on the response of a succeeding crop of winter wheat to nitrogen. *Journal of Agricultural Science,* 126, 63-74.

Sylvester-Bradley, R. and Chambers, B.J. (1992). The implications of restricting use of fertiliser nitrogen for the productivity of arable crops, there profitability and potential pollution by nitrate. *Aspects of Applied Biology, Nitrate and Farming Systems*, 85-94.

Withers, P. J. A., Clay, S. D. and Breeze, V. G. (2001). Phosphorus transfer in runoff following application of fertilizer, manure and sewage sludge. *Journal of Environmental Quality,* 30, 180-188.

Withers, P. J. A., Ulen, B., Stamm, C. and Bechmann, M. (2003). Incidental phosphorus loss – is it significant and can it be predicted? *Journal of Soil Science and Plant Nutrition*, 166, 459-468.

Defra project NT1830 - Effects of crop yield: management and N fertiliser rate on nitrate leaching, yield and soil N status.

## Method 25 – Do not apply manufactured fertiliser to high-risk areas

**Direction of change for target pollutants on the area where fertiliser is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ~ | ↓ | ~ | ~ | ~ | ↓ | ↓ | ~ | ↓ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Do not apply manufactured fertiliser at any time to field areas where there are direct flow paths to watercourses. For example, areas with a dense network of open drains, wet depressions (flushes) draining to a nearby watercourse, or areas close to road culverts/ditches.
**Rationale:** The risk of N and P pollution is reduced by not applying fertiliser at any time to areas where it could easily be transferred to a watercourse.
**Mechanism of action:** Avoiding fertiliser spreading to hydrologically well connected areas helps prevent the transfer of pollutants to water.
**Potential for applying the method:** This method is potentially applicable to all farming systems, but is probably most applicable to the grassland sector, where open drains and waterlogged areas are most common. It is also applicable to all fields with ditches and areas close to road culverts.
**Practicability:** It is an easy option to implement, although (some) farmers may still want to apply fertiliser to grassland that contains areas prone to waterlogging or with a dense network of open drains.
**Likely uptake:** Moderate to high. A no fertiliser spreading buffer of 2 m from surface waters is mandatory in Nitrate Vulnerable Zones.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on loss of gross margin on 1% of farm area. |
|---|---|---|---|---|---|---|---|---|
| Annual | 100 | 20 | 20 | 50 | 1,000 | 3,600 | 950 | |

**Effectiveness:**
**N:** Nitrate (plus ammonium and nitrite) leaching losses would be reduced by a small amount (up to 2%) and there would be associated small reductions in direct and indirect $N_2O$ emissions, and $NH_3$ emissions.
**P:** Soluble P losses would be reduced by up to 10%, as hydrologically well connected areas can make a large contribution to P losses.
**Other pollutants:** $CO_2$ emissions would be reduced by a small amount as a result of lower fertiliser use (and production). Impacts on other pollutants are likely to be minimal.
**Key references:**

Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i
Haygarth, P.M., Heathwaite, A.L., Jarvis, S.C. and Harrod, T.R. (2000). Hydrological factors for phosphorus transfer from agricultural soils. *Advances in Agronomy*, 69, 153-178.
Haygarth, P. M. and Jarvis, S. C. (1999). Transfer of phosphorus from agricultural soils. *Advances in Agronomy*, 66, 195-249.
Withers, P. J. A., Clay, S. D. and Breeze, V. G. (2001). Phosphorus transfer in runoff following application of fertilizer, manure and sewage sludge. *Journal of Environmental Quality*, 30, 180-188.
Withers, P. J. A., Ulen, B., Stamm, C. and Bechmann, M. (2003). Incidental phosphorus loss – is it significant and can it be predicted? *Journal of Soil Science and Plant Nutrition*, 166, 459-468.

## Method 26 – Avoid spreading manufactured fertiliser to fields at high-risk times

**Direction of change for target pollutants on the area where fertiliser is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ~ | ↓ | ~ | ~ | ~ | ↓ | ↓ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:**

- Do not spread manufactured fertiliser at times when there is a high-risk of surface runoff or rapid movement to field drains i.e. when soils are 'wet'.
- Do not spread N fertiliser between September and February when there is little or no crop uptake and there is a high-risk of $NO_3$ leaching loss; unless there is a specific crop requirement during this period.

**Rationale:** Fertiliser timing affects the potential for mobilisation of nutrients from land to water. Avoiding spreading fertiliser to fields at high-risk times reduces the availability of N and P for loss in surface runoff or drainflow.

**Mechanism of action:** Surface runoff is most likely to occur when rain falls on sloping ground, when soils are 'wet', frozen or snow covered. The rapid preferential flow, through the soil, of N and P from applied fertilisers is most likely to occur from (drained) soils when they are 'wet' and rainfall follows soon after application. This method aims to prevent nutrients being added at times when there is potential for rapid transfer to water. Avoiding N fertiliser application in the autumn/winter reduces the amount of $NO_3$ available for leaching by over-winter rainfall.

**Potential for applying the method:** The method is potentially applicable to all farming systems, which use fertilisers. Closed spreading periods for manufactured fertiliser N already exist in NVZs, unless a specific crop requirement can be justified.

**Practicability:** The method would be acceptable to most farmers, although restrictions on the timing of manufactured N (and P) applications to 'wet' soils in spring may cause practical difficulties for some farmers. The adoption of this method would require a degree of education and advisory activity to 'persuade' farmers that the spreading of fertiliser at high-risk times (e.g. when soils are 'wet' and surface runoff or drainflow losses may occur) should not be undertaken.

**Likely uptake:** Moderate to high. However, farmers may be reluctant not to apply fertiliser N to 'wet' soils in spring to support early season crop growth.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on small crop yield penalty through delayed spring fertiliser application. |
|---|---|---|---|---|---|---|---|---|
| Annual | 100 | 30 | 70 | 300 | 800 | 850 | 100 | |

**Effectiveness:**

**N:** Nitrate (plus ammonium and nitrite) leaching losses would be reduced by a small amount (up to 5%) and direct and indirect $N_2O$ emissions, and $NH_3$ emissions.

**P:** Soluble P losses would be reduced by up to 10%, as hydrologically well connected areas can make a large contribution to P losses.

**Other pollutants:** Impacts on other pollutants are likely to be minimal.

**Key references:**

Chalmers, A. and Froment, M. (1992). The effect of seedbed nitrogen and straw incorporation for winter oilseed rape on leaching losses of nitrate in sandy and chalk soils. *Aspects of Applied Biology*, 30, 275-278.

Hart, M., Quin, B. and Nguyen, M. (2004) Phosphorus runoff from agricultural land and direct fertiliser effects: a review. *Journal of Environmental Quality*, 33, 1954-1972.

Lord, E.I. and Mitchell, R.D. (1998). Effect of nitrogen inputs to cereals on nitrate leaching from sandy soils. *Soil Use and Management*, 14, 78-83.

Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.

## Method 27 – Use manufactured fertiliser placement technologies

**Direction of change for target pollutants where fertiliser placement is used.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ~ | ↓ | ~ | ~ | ~ | ↓* | ↓ | ~ | ↑ |

* Where urea fertiliser placed.

**Farm typologies applicable:**

| Dairy* | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | ×* | ×* | × | ✓ | × | × | × | ✓ |

* Fertiliser placement for maize is part of farm 'baseline' i.e. is normal practice.

**Description:** Place nutrients close to germinating or established crops to increase fertiliser N and/or P recovery.
**Rationale:** Placement of nutrients close to plant seeds and roots increases nutrient uptake efficiency.
**Mechanism of action:** Fertiliser placement can be particularly useful in low P status soils to increase uptake efficiency and can also enable reductions in fertiliser application rates through improved nutrient recovery (without any impact on yield). Placement also reduces exposure of fertiliser at the soil surface, thereby reducing the potential for incidental losses in surface runoff from sloping ground.
**Potential for applying the measure:** Fertiliser placement technology is applicable to a wide range of vegetable and potato (and maize) crops; where the method is already widely used.
**Practicality:** Fertiliser placement technology is readily available and tailor-made liquid fertiliser products are made to meet high value crop nutrient requirements.
**Likely uptake:** Moderate to high. Uptake of fertiliser placement technology may increase further as manufactured fertiliser prices continue to rise over the longer-term. Due to the initial capital expenditure required, it is most likely to be taken up by large arable/vegetable businesses or where contractors are used.
**Cost:**

| Total *cost* for farm system (£/farm) | Comb/ Roots | Hort | Costs based on additional operational inputs (no change in fertiliser inputs). |
|---|---|---|---|
| Annual | 50 | 20 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by a small (up to 2%) amount and direct and indirect $N_2O$ emissions, and $NH_3$ emissions (through reduced volatilisation losses from urea).
**P:** Soluble P losses would be reduced by up to 5% (through reduced surface runoff risks).
**Other pollutants:** $CO_2$ emissions would be increased by a small amount through the use of placement technology. Impact on other pollutants are likely to be minimal.
**Key references:**
Withers, P. J. A., Ulen, B., Stamm, C. and Bechmann, M. (2003). Incidental phosphorus loss – is it significant and can it be predicted? *Journal of Soil Science and Plant Nutrition*, 166, 459-468.
Defra project NT1209 - Improving the efficiency of nitrogen fertiliser use by fertiliser placement.

## Method 28 – Use nitrification inhibitors

**Direction of change for target pollutants where inhibitors used.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| (↓) | (↑) | (↑) | ~ | ~ | ~ | ~ | ~ | (↑) | (↓↓) | ~ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Addition of nitrification inhibitors (NIs) to applied manufactured N fertilisers, organic manures and to grazed pastures.
**Rationale:** NIs are chemicals that slow the rate of conversion of $NH_4$ to $NO_3$, so that $NO_3$ is formed at a rate that is in better 'synchrony' with crop demand (i.e. slow release) and will thereby increase N use efficiency and reduce $N_2O$ emissions and $NO_3$ leaching.
**Mechanism of action:** NI compounds such as dicyandiamide (DCD), nitrapyrin and 3,4-dimethylpyrazole phosphate (DMPP) have been shown to be effective in reducing $N_2O$ emissions and $NO_3$ leaching losses from fertiliser/animal manure additions and grazed pastures, and to improve crop N use efficiency.
**Potential for applying the method:** NIs can be included in manufactured N fertiliser formulations, added to manures, applied to grazed pastures and to animals (via slow release boluses). Work in New Zealand has shown that $NO_3$ leaching losses can be reduced by up to 35%. Similarly, research in New Zealand has shown that NIs can reduce $N_2O$ emissions by 30-70% under field conditions. However, in New Zealand, most grazing paddocks are on free draining soils and the growing season is much longer than in the UK.
**Practicability:** NIs can be included in fertiliser/manure applications and applied to grazed pastures.
**Likely uptake:** Low-moderate. NIs are relatively expensive, which is likely to reduce uptake by farmers. However, reductions in manufactured fertiliser N requirements, through reduced N losses/additions, may offset this cost.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Based on use cost of £20/ha. |
|---|---|---|---|---|---|---|---|---|
| Annual | 2,000 | 1,300 | 1,800 | 1,900 | 3,200 | 3,000 | 300 | |

**Effectiveness:**
**N:** $NO_3$ leaching loss reductions of up to 35% (and associated indirect $N_2O$ emissions) and direct $N_2O$ emission reduction of up to 70% have been measured. However, $NH_3$ emissions to air and ammonium/nitrite losses to water may be increased by a small amount.
*Note:* Ongoing Defra-funded research (project AC0113) is assessing the potential of NIs to reduce $N_2O/NO_3$ emissions and the potential for 'pollution swapping' with other N forms (e.g. $NH_3$ emissions to air).
**Other pollutants:** $CO_2$ emissions would be increased by a small amount through NI use (and production). Impacts on other pollutants are likely to be minimal.
**Key references:**

Chambers, B.J., Smith, K.A. and Pain, B.F. (2000). Strategies to encourage better use of nitrogen in animal manures. *Soil Use and Management, Tackling Nitrate from Agriculture*, 16, 157-161.

Di, H.J., Cameron, K.C. and Sherlock, R.R. (2007). Comparison of the effectiveness of a nitrification inhibitor, dicyandiamide, in reducing nitrous oxide emissions in four different soils under different climatic and management conditions. *Soil Use and Management,* 23, 1-9.

Dittert, K., R. Bol, R. King, D. Chadwick, and D. Hatch. (2001). Use of a novel nitrification inhibitor to reduce nitrous oxide emission from N-15 labelled dairy slurry injected into soil. *Rapid Communications in Mass Spectrometry*, 15, 1291-1296.

Hatch, D., H. Trindade, L. Cardenas, J. Carneiro, J. Hawkins, D. Scholefield, and D. Chadwick. (2005). Laboratory study of the effects of two nitrification inhibitors on greenhouse gas emissions from a slurry treated arable soil: impact of diurnal temperature cycle. *Biology and Fertility of Soils*, 41, 225-232.

Moir, J.L., Cameron, K.C. and Di, H.J. (2007). Effects of the nitrification inhibitor dicyandiamide on soil mineral N, pasture yield, nutrient uptake and pasture quality in a grazed pasture system. *Soil Use and Management,* 23, 111-120.

## Method 29 – Replace urea fertiliser with another nitrogen form (e.g. ammonium nitrate)

**Direction of change for target pollutants on the area where manufactured urea fertiliser applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↓ | ↓ | ~ | ~ | ~ | ~ | ~ | ↓↓↓ | (↑) | ~ | ~ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Replace urea or urea-based (e.g. urea ammonium nitrate - UAN) fertiliser, with another form of manufactured fertiliser N (*e.g.* ammonium nitrate - AN).
**Rationale:** Urea and urea-based fertilisers are associated with higher $NH_3$ emissions (typically around 20% of total N applied for urea and 10% for UAN) than other forms of manufactured fertiliser N.
**Mechanism of action:** Following land application, urea will undergo hydrolysis to form ammonium carbonate (the rate depends on temperature, moisture and presence of the urease enzyme). This process greatly increases pH around the urea fertiliser and leads to an enhanced potential for $NH_3$ emissions. This is in contrast to fertiliser forms such as ammonium nitrate, where $NH_4$ (and dissolved $NH_3$) will be in equilibrium at a much lower pH, greatly reducing the potential for $NH_3$ emissions.
**Potential for applying the method:** All currently used urea and urea-based fertilisers could be replaced with AN or other form of N (*e.g.* AN, ammonium phosphate, ammonium sulphate).
**Practicability:** There should be no practical reasons why urea and urea-based fertilisers cannot be replaced with another fertiliser N type, although such a method may not be enforceable (under World Trade Agreements). Lower cost per unit of N is the main reason for urea use.
**Likely uptake:** Low, the main reason urea is used is due to the lower cost per unit of N. Farmers are often 'unaware', or don't recognise, the potential for elevated $NH_3$ emissions and associated potential yield losses from urea use.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Cost savings based on ammonium nitrate being more cost-effective than urea (when applied at the same rate). |
|---|---|---|---|---|---|---|---|---|
| Annual | -500 | -300 | -500 | -200 | -800 | -900 | -100 | |

**Effectiveness:**
**N:** $NO_3$ leaching losses are likely to be increased by a small amount (up to 5%) and associated indirect $N_2O$ emissions, and direct $N_2O$ emissions (*c.*20%) as more mineral N is retained in the soil through reduced $NH_3$ emissions to air (*c*.20% of total N applied). Ammonium and nitrite losses to water maybe decreased by a small amount. *Overall* crop N use efficiency would be increased.
**Other pollutants:** Impacts on other pollutants are likely to be minimal.
**Key references:**
Defra (2010). *Fertiliser Manual (RB209)*. 8th Edition. The Stationery Office, Norwich. ISBN 978-0-11-243286-9.
Chambers, B.J. and Dampney, P. (2009). Nitrogen efficiency and ammonia emissions from urea-based and ammonium nitrate fertilisers. *International Fertiliser Society Proceedings*, No. 657, 20pp.
Harrison, R. and Webb, J. (2001). A review of the effect of N fertilizer type on gaseous emissions. *Advances in Agronomy,* 73, 65-108.
Misselbrook, T.H., Sutton, M.A. and Scholefield, D. (2004). A simple process-based model for estimating ammonia emissions from agricultural land after fertilizer applications. *Soil Use and Management,* 20, 365-372.
Defra project NT2605. The behaviour of some different fertiliser N materials – main experiments.

## Method 30 – Incorporate a urease inhibitor with urea fertiliser

**Direction of change for target pollutants on the area where manufactured urea fertiliser is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓↓ | ↑ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description** Incorporate a urease inhibitor into solid urea, liquid urea/ammonium nitrate (UAN) solutions etc.
**Rationale:** Urease inhibitors delay the conversion of urea to ammonium carbonate; this delay allows urea fertiliser to be solubilised and 'washed' into the soil and also reduces the pH rise around the urea fertiliser.
**Mechanism of action:** Urease inhibitors, such as N-(n-butyl)-thiophosphoric triamide (nBTPT) or other similar products, slow the hydrolysis of urea by inhibiting the urease enzyme in the soil. Slowing urea hydrolysis allows more time for urea to be 'washed' into the soil and reduces the soil pH increase in close proximity to the applied urea and thereby the potential for $NH_3$ emissions.
**Potential for applying the method:** A urease inhibitor could potentially be incorporated into solid urea and UAN solutions. nBTPT has been shown in UK research to reduce $NH_3$ emissions from solid urea by a mean of 70% and from liquid UAN by a mean of 40%.
**Practicability:** Other than costs and product registration issues there are no major barriers to use.
**Likely uptake:** Low-moderate. The main issue would be justifying the cost-benefit of use, as many farmers are 'unaware'/don't 'recognise' the potential for elevated $NH_3$ emissions and associated yield losses from urea use.
**Cost:** No net cost; as ammonia emission reductions are likely to be 'balanced' by the cost of the urease inhibitor.
**Effectiveness:**
**N:** $NH_3$ emissions would be reduced by around 70% from solid urea and around 40% for UAN. There would be associated small increases in $NO_3$ (ammonium and nitrite) leaching losses to water and direct and indirect $N_2O$ emissions to air; as more mineral N is retained in the soil. Crop N use efficiency would also increase.
**Other pollutants:** Impacts on other pollution are likely to be minimal.
**Key references:**

Chambers, B.J. and Dampney, P. (2009). Nitrogen efficiency and ammonia emissions from urea-based and ammonium nitrate fertilisers. *International Fertiliser Society Proceedings* No. 657, 20pp.
Defra project NT2605. The behaviour of some different fertiliser N materials – main experiments.

## Method 31 – Use clover in place of fertiliser nitrogen

**Direction of change for target pollutants on the area of grassland.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ~ | ~ | ~ | ~ | ~ | ↓↓ | ↓↓ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |

**Description:** Use clover in place of fertiliser N to fix nitrogen from the air, resulting in lower manufactured fertiliser N use.

**Rationale:** By using clover in a grass sward the need for additional manufactured N fertiliser is reduced.

**Mechanism of action:** *Rhizobium trifolii* present in root nodules of the host clover plant fix di-nitrogen gas, which is then nitrified within the plant system. However, fixation by legumes can be repressed through the application of fertiliser N.

**Potential for applying the method:** This method is applicable to most grassland systems, but may entail a reduction in stocking rates where high rates of manufactured N fertiliser have previously been used.

**Practicality:** The method would be reasonably simple to implement on farms looking to maintain (slightly reduce) stock numbers on low-moderate output systems, and should reduce costs by replacing manufactured N fertiliser with biologically fixed N. However, for higher output systems careful management would be need to ensure that grassland production was not compromised.

**Likely uptake:** Moderate; with little uptake on high N fertiliser systems.

**Cost:** No net cost; we have assumed that the cost of establishing clover was offset by savings in fertiliser N use (*c*.50%) on low-moderate output systems.

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 20%. There would be associated reduction in direct (up to 50%) and indirect (up to 20%) $N_2O$ emissions, and $NH_3$ emissions (*c*.50%).

**Other pollutants**: Impacts on other pollutants are likely to be minimal.

**Key references:**

Cuttle, S.P. and James, A.R. (1995). Leaching of lime and fertilisers from a reseeded upland pasture on a stagnogley soil in mid-Wales. *Agricultural Water Management,* 28, 95-112.

Cuttle, S.P. and Scholefield, D. (1995). Management options to limit nitrate leaching from grassland. *Journal of Contaminant Hydrology,* 20, 299-312.

Defra project NT1602 - Understanding the grassland nitrogen cycle in order to improve fertiliser recommendations (previously NT0601).

Defra project NT1806 - To develop a predictive capacity for N loss from grassland.

Defra project NT1825 - Nitrate leaching in sustainable livestock LINK project (LK0613).

Defra project NT2511 - Cost curve of nitrate mitigation options.

## Method 32 – Do not apply P fertiliser to high P index soils

**Direction of change for target pollutants on high P Index soils.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ~ | ~ | ~ | ↓ | ↓↓ | ~ | ~ | ~ | ~ | ~ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Do not apply manufactured P fertiliser to soils that have an ADAS soil P Index of 4 or above.

**Rationale:** The amount of P lost via soil erosion or leaching depends on the soil P status. Losses in solution increase rapidly once soil P reserves reach elevated levels (e.g. ADAS Soil P index 4 or above). Losses can be minimised by maintaining soil P levels at Index 2 or by allowing the P content of high P index soils to run-down overtime.

**Mechanism of action:** If manufactured P fertiliser is not applied and the P content of high P index soils is allowed to decline, the amount of P lost with eroded soil particles and in solution will be reduced. Phosphorus is adsorbed onto soil particles and is lost when sediment is eroded from fields (in surface runoff/drainflow); the higher soil P reserves the greater the amount of P lost. However, the run-down of high soil P reserves is a gradual process and full benefits will only be achieved in the longer-term (>10 years). Also, the amount of P lost in soil solution is greater from high P index soils.

**Potential for applying the method:** The method is potentially applicable to all farming systems, but would most likely be applied to high output grassland, arable and horticultural farms.

**Practicability:** The method could easily be implemented via advice, education and guidance i.e. soil sampling, analysis and interpretation of soil P Index levels. There may be resistance to adopting the method for those crops (e.g. potatoes/vegetable crops) that are most responsive to P inputs.

**Likely uptake:** Moderate. ‘High’ P fertiliser prices mean that there is an increasing tendency for farmers to run-down high P status soils (i.e. they are already likely not to be using P fertilisers where they are not needed).

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on fertiliser P input reduction of 10%. |
|---|---|---|---|---|---|---|---|---|
| Annual | -500 | -350 | -500 | -750 | -750 | -900 | -100 | |

**Effectiveness:**

**P:** Soluble P losses would be reduced (over the longer-term) by up to 50% and particulate P losses by up to 30% (over the longer-term).

**Other pollutants:** Impacts on other pollutants are likely to be minimal.

**Key references:**

Haygarth, P.M., Heathwaite, A.L., Jarvis, S.C. and Harrod, T.R. (2000). Hydrological factors for phosphorus transfer from agricultural soils. *Advances in Agronomy*, 69, 153-178.

Haygarth, P. M. and Jarvis, S. C. (1999). Transfer of phosphorus from agricultural soils. *Advances in Agronomy*, 66, 195-249.

Smith, K.A., Chalmers, A.G., Chambers, B.J. and Christie, P. (1998). Organic manure phosphorus accumulation, mobility and management. *Soil Use and Management*, 14, 154-159.

Withers, P. J. A., Clay, S. D. and Breeze, V. G. (2001). Phosphorus transfer in runoff following application of fertilizer, manure and sewage sludge. *Journal of Environmental Quality,* 30, 180-188.

Withers, P. J. A., Ulen, B., Stamm, C. and Bechmann, M. (2003). Incidental phosphorus loss – is it significant and can it be predicted? *Journal of Soil Science and Plant Nutrition,* 166, 459-468.

## Method 33 – Reduce dietary N and P intakes

**Direction of change for target pollutants on livestock farms.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ~ | ~ | ↓ | ↓ | ↓* | ~ |

* Where maize included in dairy cow diets.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✗ |

**Description:** Adjust the composition of livestock diets to reduce the total intake of N and P per unit of production.

**Rationale:** Avoiding excess N and P in the diet and/or making dietary N and P more available allows nutrient concentrations in the diet to be reduced, without adversely affecting animal performance. These methodologies reduce the amount of N and P excreted, either directly to fields or *via* handled manures, and thereby minimise additions as sources of diffuse pollution.

**Mechanism of action:** Farm animals are often fed diets with higher than recommended contents of N and P, as a safeguard against a loss of production, arising from a deficit of these nutrients. However, surplus N and P will not be utilised by the animal and will be excreted. Restricting diets to recommended levels of N and P will limit the amounts excreted.

Nutrient excretion can also be reduced by changing the composition of the diet to increase the proportion of dietary N and P utilised by the animal; for example, by optimising the balance of N to carbohydrate in ruminant diets or by reducing the proportion of rumen-degradable protein. Additionally, in non-ruminants, N excretion can be reduced by increasing the digestibility of the ration. In both ruminants and non-ruminants, feeding a ration that supplies amino acids in the ideal proportions required for protein synthesis will reduce the quantities of 'surplus' amino acids that remain un-utilised and contribute to N excretion. Supplementing the diet of pigs and poultry with the enzyme phytase, increases the availability of P in the feed and allows total P contents to be reduced without affecting productivity (this is not applicable to ruminants as rumen microbes produce phytase naturally).

**Potential for applying the method:** Benefits are likely to be greatest on dairy, pig and poultry units, and least on beef/sheep units that feed a largely forage-based diet. The extent to which these methods can be applied depends on the proportion of farms currently feeding excess N and P, or not already using feed supplements. Opportunities for reducing N and P in ruminant diets are probably limited, as very little is added to beef feeds and recent reductions in dairy diets have removed a significant proportion of any excess; although education is still needed. Precise formulation of diets requires accurate analytical data about the chemical composition of the feedstuffs, which may not be readily available for forages.

For pigs, there is potential and the technical know-how to reduce N inputs, but implementation has been limited (by the lack of economic incentives). There is little scope for further reducing P inputs, which have already been reduced because of economic pressures; phytase enzymes are universally included in pig diets.

For poultry, considerable steps have already been made through the use of whole wheat feeding and synthetic amino acid inclusion in broiler diets; there is limited scope for further reducing the N content of poultry diets, without reducing outputs.

**Practicability:** Many protein feeds are rich in P and it can be difficult to formulate least-cost rations, with optimum contents of both N and P. Within the dairy sector, there is already a focus on lowering total diet crude protein contents, optimising the protein:energy balance in the rumen and supplying adequate metabolisable protein. Reducing the crude protein content of the diet (to 14%) may be a significant challenge in areas relying on grass silage production for forage. Also, matching performance to requirement has cost, labour and housing implications.

For poultry, there are concerns that reducing nutrient inputs further may have adverse effects on reproductive performance and carcass quality. The scope to use more digestible materials in broiler diets is also limited, as most diets already include feed materials of high digestibility. There is an economic incentive to use phytase, but (presently) this has not been widely adopted by the broiler industry.

For pigs, there is scope to reduce N inputs, but (presently) this has not been widely adopted by the industry.

**Likely uptake:** Low-moderate in dairy sector. In the pig sector, uptake for P is already high and uptake for N would be higher with stronger economic incentives. In the poultry sector, uptake for N and P is already high, although there is potential to increase phytase use in the broiler industry.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Indoor pigs | Out pigs | Poultry | Costs based on additional feed and management inputs to avoid excess N & P. |
|---|---|---|---|---|---|---|---|---|
| Annual | 5,900 | 1,100 | 1,300 | 2,500 | 4,000 | 6,250 | 600 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 10% and direct and indirect $N_2O$ emissions, and $NH_3$ emissions (by up to 10%).

**P:** Soluble P losses would be reduced by up to 10% and in the longer-term particulate P losses.

**Other pollutants:** $CH_4$ emissions would be reduced by a small amount if dairy cow N intake was reduced by maize use in place of grass silage. Impacts on other pollutants are likely to be minimal.

**Key references:**

Del Prado, A. and D. Scholefield. (2008). Use of SIMSDAIRY modelling framework system to compare the scope on the sustainability of a dairy farm of animal and plant genetic-based improvements with management-based changes. *Journal of Agricultural Science*, 146, 1-17.

Dourmad, J.Y. and Jondreville, C. (2007). Impact of nutrition on nitrogen, phosphorus, Cu and Zn in pig manure on emissions of ammonia and odours. *Livestock Science,* 112, 192-198.

Misselbrook, T. H., Powell, J. M., Broderick, G. A. and Grabber, J. H. (2005). Dietary manipulation in dairy cattle: laboratory experiments to assess the influence on ammonia emissions. *Journal of Dairy Science,* 88, 1765-1777.

Misselbrook, T. H., Chadwick, D. R., Pain, B. F. and Headon, D. M. (1998). Dietary manipulation as a means of decreasing N losses and methane emissions and improving herbage N uptake following application of pig slurry to grassland. *Journal of Agricultural Science,* 130, 183-191.

Offer, N. W., R. E. Agnew, B. R. Cottrill, D. I. Givens, T. W. J. Keady, C. S. Mayne, C. Rymer, T. Yan, J. France, D. E. Beever. and C. Thomas. (2002). Feed into Milk - An applied feeding model coupled with a new system of feed characterisation. In *Recent Advances in Animal Nutrition,* (Eds. P. C. Garnsworthy and J. Wiseman), Nottingham University Press, Nottingham, pp167-194.

Defra project LK0604 - An improved system for characterising ruminant feeds leading to the development of a nutritional model for dairy cows.

Defra project IS0214 - New integrated dairy production systems: specification, practical feasibility and ways of implementation.

## Method 34 – Adopt phase feeding of livestock

**Direction of change for target pollutants for phase fed livestock.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ~ | ~ | ↓ | ↓ | ↓* | ~ |

* From ruminants (and to a lesser extent pigs).

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | ✓ | × | × | ✓ | × | ×* | × |

* Standard practice in farm 'baseline'.

**Description:**
- Manage livestock in smaller groups, divided on the basis of their individual feed requirements.
- Feed groups separately with rations matched to the optimum N and P requirements of the animals within each group.

**Rationale:** Phase feeding allows more precise matching of the ration to the individual animal's nutritional requirements. Nutrients are utilised more efficiently and less dietary N and P is excreted, thereby reducing the N and P content of manures, which reduces the amount of N and P at risk of loss.

**Mechanism of action:** Livestock at different growth stages or stages of their reproductive/lactation cycle, have different optimum feed requirements. However, because of limited labour and housing facilities, livestock with different feed requirements are often grouped together and receive the same ration. As a result, some stock will receive higher levels of N and P than they can utilise efficiently and will excrete the surplus (see Method 33). Greater division and grouping of livestock on the basis of their feed requirements allows more precise formulation of individual rations. This will reduce N and P surpluses in the diet and reduce the amounts excreted.

**Potential for applying the method:** This method is applicable to all livestock systems, except those primarily based on grazing.

**Practicability:** The method is most suited to larger units, where there would be greater numbers of animals in individual feeding groups. Also, it would be most effective if adopted in combination with Method 33 'reduce dietary N and P intakes'.

In the ruminant sector, this method reflects current practice where dairy cows are grouped according to milk yield. However, practical application can be difficult on some dairy units where cows are fed a single diet across all yields. There is potential for phase feeding in the pig sector to reduce N and P excretion. There is limited scope for improvement in the poultry sector, where phase feeding is already widely used.

**Likely uptake:** Low in the pig sector, without financial incentives. Uptake is already moderate-high in the dairy sector.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Mixed | Indoor pigs | Costs based on the purchase of capital equipment and are amortised. |
|---|---|---|---|---|
| Annual | 1,800 | 350 | 1,250 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 5%, and direct and indirect $N_2O$ emissions, and $NH_3$ emissions (by up to 5%).

**P:** Soluble P losses would be reduced by up to 10% and in the longer-term particulate P losses.

**Other pollutants:** There may be a decrease in $CH_4$ emissions from ruminants (depending on the diet formulation). Impacts on other pollutants are likely to be minimal.

**Key references:**

Del Prado, A. and D. Scholefield. (2008). Use of SIMSDAIRY modelling framework system to compare the scope on the sustainability of a dairy farm of animal and plant genetic-based improvements with management-based changes. *Journal of Agricultural Science,* 146, 1-17.

Defra project IS0214 - New integrated dairy production systems: specification, practical feasibility and ways of implementation.

Defra project WA0301 - Dietary manipulation to reduce nitrogen excretion by pigs.

Defra project WA0304 - Dietary manipulation to reduce nitrogen excretion by dairy cattle.

Defra project WA0305 - Alternative strategies for reducing nitrogen pollution from dairy cows.
Defra project WA0306 - Manipulation of nitrogen and phosphorus utilisation in dairy cows.
Defra projects WA0309 and WA0317 - Phase feeding of pigs to reduce nutrient pollution.

## Method 35 – Reduce the length of the grazing day/grazing season

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↑ | ↓ | (↑) | ↑ |

( ) Uncertain estimate.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × |

**Description:** Reduce the length of time livestock graze in the fields, either by keeping stock inside during the night or by shortening the length of the grazing season.
**Rationale:** Urine patches are a major source of $NO_3$ leaching and $N_2O$ emissions to air. Reducing the time animals spend at grazing reduces the amount of urine deposited in fields.
**Mechanism of action:** Urine patches deposited by grazing livestock contain high concentrations of $NH_4$-N and act as 'hotspots', with high losses of leached $NO_3$ and emitted $N_2O$. Urine deposited later in the season, when there is little opportunity for the grass sward to utilise the added N, make the greatest contribution to $NO_3$ leaching losses. Therefore, implementing this mitigation method in autumn will have the greatest benefit, as collected excreta can be returned to the fields in a more uniform (and less concentrated form) via slurry spreading. The method will also reduce particulate P/sediment and FIO losses from excreta deposited directly in the field.
**Potential for applying the method:** The method is applicable to livestock farms where animals graze outside between spring and autumn, and where there is suitable housing.
**Practicability:** Reducing the length of the grazing day/season is most suited to dairy farms, where cows can be kept indoors. However, this will increase the time that animals are housed and associated labour, manure management and forage production costs.
**Likely uptake:** Low-moderate, due to additional labour and associated costs.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Costs based on additional forage production and manure management activities (assuming a 20% reduction in the duration of grazing). |
|---|---|---|---|---|---|
| Annual | 5,250 | 3,500 | 2,200 | 1,000 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 20% and direct and indirect $N_2O$ emissions. However, $NH_3$ emissions would be increased by up to 20% through greater housing, storage and land spreading emissions.
**P and sediment:** Particulate/soluble P and associated sediment losses would be reduced by up to 10%, as a result of lower amounts of poaching damage.
**FIOs and BOD:** Losses would be reduced as less excreta is deposited directly in the field.
**Other pollutants:** $CH_4$ emissions would increase as greater amounts of manure are stored. $CO_2$ emissions would increase as a result of greater forage production and manure management activities.
**Key references:**
Cuttle, S.P. and Scholefield, D. (1995). Management options to limit nitrate leaching from grassland. *Journal of Contaminant Hydrology,* 20, 299-312.
Defra project NT1602 - Understanding the grassland nitrogen cycle in order to improve fertiliser recommendations.
Defra project NT1902 - Control over losses of nitrogen from grassland soils.

## Method 36 – Extend the grazing season for cattle

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ | ↓ | ↑ | (↓) | ↓ |

( ) Uncertain estimate.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × |

**Description:** Where soil conditions allow, the grazing season is extended (either earlier in the spring or later in the autumn).

**Rationale:** Urine deposition by cattle at grazing rapidly infiltrates into the soil and is therefore associated with lower $NH_3$ emissions, compared with higher emissions from urine deposition on concrete floors within cattle housing (and associated emissions during storage and following manure spreading).

**Mechanism of action:** When cattle are grazing at pasture, excreta returns (urine and faeces) are deposited directly in the field. $NH_3$ emissions derive predominantly from the urea content of the urine, which must first be hydrolysed to ammonium carbonate before $NH_3$ emissions can occur. Urine will generally rapidly infiltrate into pasture land and hydrolysis will occur within the soil. The soil presents a physical (by reducing air movement) and chemical (by binding $NH_4$) barrier to $NH_3$ emissions, compared with urine deposited on a concrete (impermeable) floor in cattle housing.

**Potential for applying the method:** This method can be applied to all farms where cattle are housed, however, *soil conditions are likely to limit the potential of the method on many farms* because of unacceptable soil damage through poaching.

**Practicability:** The method is unlikely to be favoured by high output dairy farmers who like to closely control herd nutrition (see Methods 33 and 34). However, split herds may be operated, where lower yielders/dry cows and followers are managed on an extended grazing system, and the higher yielders are housed. Also, many farmers may be unwilling to risk the sward damage and soil compaction that can be associated with grazing under marginal conditions.

**Likely uptake:** Low, limited by suitable soil types and climate. Lower output systems may extend the grazing season, thereby avoiding the costs associated with forage production and storing/handling additional amounts of manure. High output systems are less likely to adopt the method.

**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Costings based on the reduced need for forage production and manure management activities (assuming a 20% increase in duration of grazing). |
|---|---|---|---|---|---|
| Annual | -1,300 | -250 | -250 | -250 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be increased by up to 20%, and direct and indirect $N_2O$ emissions. However, $NH_3$ emissions would be reduced by up to 20%, through lower emissions at grazing.

**P and sediment:** Particulate/soluble P and associated sediment losses would be increased by up to 10%, as a result of greater poaching damage.

**FIOs and BOD:** Losses would be increased as more excreta is deposited directly in the field.

**Other pollutants:** $CH_4$ emissions would reduce as smaller amounts of manure are stored. $CO_2$ emissions would reduce as a result of lower forage production and manure management activities.

**Key references:**

Webb, J., Anthony, S. G., Brown, L., Lyons-Visser, H., Ross, C., Cottrill, B., Johnson, P. and Scholefield, D. (2005). The impact of increasing the length of the cattle grazing season on emissions of ammonia and nitrous oxide and on nitrate leaching in England and Wales. *Agriculture Ecosystems & Environment,* 105, 307-321.

## Method 37 – Reduce field stocking rates when soils are wet

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↑ | ↓ | (↑) | ↑ |

( ) Uncertain estimate.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |

**Description:** When soils are 'wet', the number of livestock per unit area and/or the time stock spend in the field is reduced to avoid (severe) poaching and compaction of the soil.
**Rationale:** Soils are most easily poached/compacted when they are 'wet'. Reducing livestock numbers or the duration of grazing when soils are 'wet' reduces poaching damage and the potential for mobilisation and transport of pollutants to watercourses.
**Mechanism of action:** Poaching/compaction reduces soil water infiltration rates and increases the risk of surface runoff. Lower stocking rates will also reduce the amount of excreta deposited and pollutant amounts available for loss.
**Potential for applying the method:** This method is applicable to all livestock farms where animals are kept outside and is particular to those with high stocking rates, where extended grazing is practised or where stock are wintered outdoors. Poaching is likely to be more severe with cattle grazing than sheep. Medium/heavy soils are most susceptible to poaching, particularly in high rainfall areas.
**Practicability:** Implementation will be easier on farms with access to freely draining soils that can provide alternative grazing ground during 'wet' periods, and where there is alternative housing available.
**Likely uptake:** Low-moderate, due to added labour and associated forage production/manure costs.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Costs based on additional forage production and manure management activities (assuming a 20% reduction in the duration of grazing). |
|---|---|---|---|---|---|
| Annual | 5,200 | 3,500 | 2,200 | 1,000 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 20% and direct and indirect $N_2O$ emissions. However, $NH_3$ emissions would be increased by up to 20% through greater housing, storage and land spreading emissions.
**P and sediment:** Particulate/soluble P and associated sediment losses would be reduced by up to 10%, as a result of lower amounts of poaching damage.
**FIOs and BOD:** Losses would be reduced as less excreta is deposited directly in the field.
**Other pollutants:** $CH_4$ emissions would increase as greater amounts of manure are stored. $CO_2$ emissions would also increase as a result of greater forage production and manure management activities.
**Key references:**
Defra project NT1002 - Sheet erosion and phosphate loss
Defra project NT1004 - Phosphorus loss from agriculture
Defra project NT1005 - Phosphorus loss from grassland soils
Defra project NT1013 - Phosphorus loss in surface runoff from different land uses
Defra project NT1028 - Measurements of phosphorus loss from manures
Defra project PE0102 - Rationalising risk and scaling-up of on-farm practices to classify rates of phosphorus transfer to grassland catchments

## Method 38 – Move feeders at frequent intervals

**Direction of change for target pollutants on grazed grassland area.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ | × | × |

**Description:** Feed troughs, feeding racks etc. for outdoor stock are re-positioned at regular intervals to reduce damage to the soil; they should be moved more frequently when the soil is 'wet' and most easily poached. They should not be sited close (i.e. within 10m) to water courses.
**Rationale:** Regular re-positioning of feeding troughs/racks reduces poaching around these points and reduces the quantity of excreta deposited in any single area, both of which can exacerbate diffuse pollution losses in surface runoff.
**Mechanism of action:** Animal movements in fields concentrate around feeding points that result in large inputs of excreta deposited on these areas, which can be a source of high levels of nutrient and FIO losses to water. As a result of frequent treading, soils around these positions also get heavily poached, which further increases the risk of surface runoff and diffuse pollution losses. Also, damage to the grass sward has the secondary effect of reducing plant uptake that would otherwise reduce $NO_3$ losses. Moving feeders frequently prevents the accumulation of elevated nutrients and FIOs in localised areas, and reduces the severity of poaching.
**Potential for applying the method:** The method is most applicable to beef/sheep systems (particularly where livestock are wintered outside) and outdoor pigs. The potential to reduce poaching will be greatest for beef/sheep systems on medium/heavy soils. In all cases, feeders should be located away from watercourses to break the hydrological link between the poached area and surface water
**Practicability:** The regular re-positioning of feeding troughs is a simple method, with few limitations to implementation. The method will be most effective when applied in combination with Method 37 - 'reduce field stocking rates when soils are wet'.
**Likely Uptake:** Moderate-high. A simple method, though regular management is needed to be effective.
**Cost:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Out Pigs | Costs based on moving feeders fortnightly and are amortised. |
|---|---|---|---|---|---|---|
| Annual | 300 | 120 | 100 | 300 | 450 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by a small amount (<2%). Direct and indirect $N_2O$ emissions and $NH_3$ emissions would also be reduced, as a result of less soil compaction/poaching.
**P and sediment:** Particulate/soluble P and associated sediment losses would be reduced by up to 10%, as a result of lower amounts of 'severe' poaching damage.
**FIOs and BOD:** Losses would be reduced as a result of less surface runoff.
**Other pollutants:** $CH_4$ emissions would be reduced from lower amounts of compaction/poaching damage. $CO_2$ emissions would increase by a small amount as a result of greater feeding trough movements.

## Method 39 – Construct water troughs with a firm but permeable base

**Direction of change for target pollutants on the grazed grassland area.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × |

**Description:** Construct water troughs with a firm base to reduce poaching damage to the soil.
**Rationale:** Using a firm, yet permeable base reduces poaching of the soil around water troughs.
**Mechanism for action:** Animal activity is concentrated around drinking points that results in large inputs of excreta to these areas, which can be a source of nutrient and FIO losses to water. Also, soils around water troughs get heavily poached, which further increases anaerobicity and the risks of surface runoff and diffuse pollution. Also, damage to the sward has the secondary effect of reducing plant uptake that would otherwise reduce $NO_3$ losses. Water troughs, with a firm yet permeable base, reduce poaching and allow the rapid infiltration of urine, reducing the risks of surface runoff and transfer of pollutants to watercourses.
**Potential for applying the method:** This method is applicable to all beef/sheep/dairy systems where livestock are grazed. The potential to reduce poaching will be greatest on medium/heavy soils.
**Practicality:** The construction of the permeable base is relatively straightforward. If it is necessary to move an existing trough, there will be a need to install new pipe work.
**Likely uptake:** Moderate. In ECSFDI catchments grants are available for installing permeable bases for livestock water troughs (and feeders).
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Costs based on construction of a permeable base and are amortised. |
|---|---|---|---|---|---|
| Annual | 700 | 250 | 200 | 700 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by a small amount (<2%). Direct and indirect $N_2O$ emissions and $NH_3$ emissions would be reduced, as a result of less soil compaction/poaching.
**P and sediment:** Particulate/soluble P and associated sediment losses would be reduced by up to 10%, as a result of lower amounts of 'severe' poaching damage.
**FIOs and BOD:** Losses would be reduced as a result of less surface runoff.
**Other pollutants:** $CH_4$ emissions would be reduced due to lower amounts of compaction/poaching damage. $CO_2$ emissions would increase by a small amount as a result of base construction.

## Method 40 – Low methane livestock feeds

**Direction of change for target pollutants for ruminants fed on low methane diets.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ↓ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × |

**Description:** Formulate livestock rations to minimise potential for enteric $CH_4$ production.
**Rationale:** Developing a low $CH_4$ diet for ruminants could significantly reduce $CH_4$ emissions - enteric fermentation accounts for *c.*80% of $CH_4$ emissions from agriculture.
**Mechanism of action/detection:** *In vitro* techniques can be used to measure $CH_4$ production under rumen-like conditions in the laboratory. One such method (the gas production technique) uses rumen fluid as an inoculum, with $CH_4$ production following the incubation of a wide variety of feeds measured. Furthermore, the use of near-infrared spectroscopy (NIRS) to predict $CH_4$ production from specific feedstuffs offers potential for more rapid and cheaper assessments of $CH_4$ production. However, the results from these techniques do not correlate well with *in vivo* measurements. Notably, there is presently no way of knowing how much $CH_4$ is produced by a ruminant from a given diet, unless it is fed to the animal and measured using direct or indirect calorimetric techniques.
**Potential for applying the method:** Any method that could predict $CH_4$ emissions from specific feeds could be incorporated into a ration formulation system to minimise $CH_4$ outputs.
**Practicability:** A laboratory-based method would be relatively easy to implement, particularly as the composition of most feeds is now predicted using NIRS. However, the interaction between different feeds when fed to an animal makes the prediction of $CH_4$ production from complete diets difficult.
**Likely Uptake:** This method is under development, but uptake is potentially moderate to high.
**Effectiveness:**
**Methane:** Until the potential for adjusting ruminant diets to produce low $CH_4$ emission feeds is assessed, it is difficult to estimate the potential for reducing $CH_4$ emissions from enteric fermentation.
*Note:* Work is ongoing in Defra project AC0115 to evaluate and develop low $CH_4$ diets for ruminant livestock.
**Other Pollutants:** Impacts on other pollutants are likely to be minimal; unless the low $CH_4$ diet increased feed use efficiency (and thereby associated reductions in N & P excretion).
**Key references:**
Defra project AC0209 - Ruminant nutrition regimes to reduce methane and nitrogen emissions.
Defra project CC0220 - Use of laboratory procedure for estimating the methane potential of diets.
Defra project AC0115 - Improved National Inventory – Methane.

## Method 41 – Reduce overall stocking rates on livestock farms

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | ✓ | ✓ | ✓ | × |

**Description:** Reduce the total number of livestock on the farm i.e. the number of stock per unit of land area.
**Rationale:** Reducing the stocking rate reduces the amount of nutrients and FIOs in field deposited excreta and in handled manures at an individual farm level. Associated manufactured fertiliser inputs and poaching risks would also be reduced.
**Mechanism of action:** Livestock excreta deposited in the field and applied in handled manures are important sources of N, P and FIOs; reducing the number of stock will reduce the amounts of excreta and manure produced per unit area. As a result of lower stocking rates on cattle/outdoor pig farms, there will be fewer urine patches and less $NO_3$ available for loss by leaching or $N_2O$ emission, and poaching risks will be reduced. A smaller number of animals will also produce less manure, which could ease pressures on manure storage capacity and provide greater flexibility for application to avoid high-risk times (Method 26). As the farm will need to produce less forage, manufactured fertiliser rates would also be reduced.
**Potential for applying the method:** The method is potentially applicable to all livestock farms, and in particular more intensively stocked units that produce large quantities of excreta and manure. The method would also apply to indoor pig and poultry units, as less manure would be produced.
**Practicability:** The method would be relatively simple to implement, but would have a *serious impact* on farm profitability. Some high output dairy farms could convert to a more extensive dairy system or beef/sheep farming. A moderate reduction in the overall stocking rate could also be achieved on dairy farms by reducing the cow replacement rate, so that fewer young stock are kept on the farm.
Notably, reducing stock numbers is likely to encourage farmers to become more reliant on clover-based swards to reduce manufactured fertiliser N costs. *Note:* The farm manure N loading rate limit in Nitrate Vulnerable Zones of 170 kg/ha total N (Defra/EA, 2008) is effectively a stocking rate limit.
**Likely Uptake:** Very low, due to the *large negative impact* on overall farm profitability.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Indoor Pigs | Out Pigs | Poultry | Loss in gross margin (through a 20% reduction in livestock numbers) and associated inputs. |
|---|---|---|---|---|---|---|---|---|
| Annual | 11,000 | 8,000 | 5,000 | 6,000 | 33,000 | 19,000 | 17,000 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 20% and direct and indirect $N_2O$ emissions, and $NH_3$ emissions.
**P and sediment:** Particulate/soluble P and associated sediment losses would be reduced by up to 30%.
**FIOs and BOD:** Losses would be reduced by up to 20%.
**Other pollutants:** $CH_4$ and $CO_2$ emissions would be reduced by up to 20%
**Key references:**
Cuttle, S.P. and Scholefield, D. (1995). Management options to limit nitrate leaching from grassland. *Journal of Contaminant Hydrology,* 20, 299-312.
Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.
Defra projects NT1602/NT1902 - To develop strategies to reduce N loss from grassland.
Defra project NT1806 - To develop a predictive capacity for N loss from grassland.

## Method 42 – Increase scraping frequency in dairy cow cubicle housing

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓ | ↑ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | ✓ | × | × | × | × | × | × |

**Description:** Increase the number of times that cubicle passages are scraped from twice to three (or more) times per day.

**Rationale:** More frequent removal of urine and faeces from the cubicle passage floor reduces the amount of time that $NH_3$ emissions (from a given quantity of excreta) will occur, thereby reducing the overall potential for emissions.

**Mechanism of action:** $NH_3$ emissions from dairy cow cubicle housing predominantly occur from urine, following hydrolysis of the urea content to $NH_4$-N, through the action of the ubiquitous urease enzyme. More frequent removal of urine and faeces by scraping will increase the proportion of excreta removed from the floor surface (prior to hydrolysis) and also leave a smaller 'pool' of material from which $NH_3$ emissions occur at any one time. Also, a build-up of dung on the floor can impede the natural drainage of urine, so more frequent removal will also increase the volume of urine reaching the slurry store by natural drainage and thereby further reduce emissions.

**Potential for applying the method:** The method is applicable to cattle housing with scraped passages, but is best suited to those with a gently sloping floor to assist the rapid drainage of urine. Some modern houses are already fitted with automatic scraper belts.

**Practicability:** For tractor-scraped systems, increasing the frequency of scraping will require labour that might otherwise be employed elsewhere on the farm. There should be no practical limitations to operating automatic scraper systems in a frequent removal mode. It may be possible to retro-fit automatic scraper systems to some existing dairy cow cubicle houses.

*Note:* It is important to use this method in combination with Method 54 – 'install covers on slurry stores', Method 55 – 'allow cattle slurry to develop a natural crust' and Methods 70 or 71 at land spreading.

**Likely Uptake:** Low to moderate.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Mixed | Costs based on one extra cleaning, including labour and tractor operation. |
|---|---|---|---|
| Annual | 5,500 | 2,300 | |

**Effectiveness:**

**N:** $NH_3$ emissions would be reduced by up to 20% (from cubicle housing). However, as a result of the greater readily available (i.e. $NH_4$) N content of the slurry, $NH_3$ emissions during storage and following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.

**Other pollutants:** $CO_2$ emissions would be increased by a small amount through the additional scraping operation. Impacts on other pollutants are likely to be minimal.

**Key references:**

Braam, C. R., Ketelaars, J. and Smits, M. C. J. (1997). Effects of floor design and floor cleaning on ammonia emission from cubicle houses for dairy cows. *Netherlands Journal of Agricultural Science,* 45, 49-64.

## Method 43 – Additional targeted straw-bedding for cattle housing

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ~ | ~ | ~ | ~ | ~ | ↓↓ | (↓) | ~ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × |

**Description:** Add 25% extra straw bedding to the cattle house and target the additional straw to 'wetter/dirtier' areas of the house.
**Rationale:** Increasing straw bedding use will enhance the physical and microbiological emissions reduction properties of FYM.
**Mechanism of action:** Straw bedding reduces $NH_3$ emissions from cattle housing by providing a physical barrier between urine (which has infiltrated into the bedding) and the air above the bedding, and by encouraging microbial immobilisation of $NH_4$ (readily available) N. Adding 25% additional straw above standard practice enhances these effects, particularly when the additional straw is specifically targeted to the 'wettest/dirtiest' areas of the house (e.g. around water or feeding troughs). Further reductions may be achieved by using even more additional bedding, but there is a risk that too much bedding could cause the litter temperature to rise (due to greater aeration and associated oxygen supply) and actually lead to an increase in $NH_3$ emissions.
**Potential for applying the method:** The method is applicable to all cattle farms where a solid manure system is used.
**Practicability:** The method involves buying, storing and handling additional straw. Greater quantities of FYM will also be generated which will need storing and spreading, and there may be a requirement to remove manure from the building on more occasions over the housing period if the bedding depth becomes too great.
**Likely Uptake:** Low-moderate, due to the additional cost and limited availability of extra straw, and the associated increase in FYM to be handled.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Costs based on the need to purchase additional straw bedding and to spread additional FYM. |
|---|---|---|---|---|---|
| Annual | 700 | 1,200 | 1,400 | 900 | |

**Effectiveness:**
**N:** $NH_3$ emission reductions of up to 50% have been measured from housing; plus lower $NH_3$ emissions during storage and following land spreading. $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would also be reduced by a small amount.
**Other Pollutants:** $CO_2$ emissions would be increased by a small amount because of additional straw use and increased FYM amounts that need to be managed. Impacts on other pollutants are likely to be minimal.
**Key reference:**

Defra project AM0103 - Evaluation of targeted or additional straw use as a means of reducing ammonia emissions from buildings for housing pigs and cattle.

## Method 44 – Washing down dairy cow collecting yards

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓↓ | ↑ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | ✓ | × | × | × | × | × | × |

**Description:** Dairy cows are 'collected' on concrete yard areas prior to milking. These areas are usually scraped at least once per day to remove excreta. This method involves pressure washing (or hosing and brushing) of the yards immediately following dairy cow use to more effectively remove the excreta.

**Rationale:** Urine deposited on collecting yard surfaces is a major source of $NH_3$ emissions. Reducing the quantity of urine on the yard surface and the time it remains there will reduce $NH_3$ emissions.

**Mechanism of action:** The urea content of urine is rapidly hydrolysed to form $NH_4$-N by the urease enzyme, which is present in the faecal deposits of dairy cows. Excreta are typically removed from dairy cow collecting yards once per day (following the morning milking event) by either a hand or tractor-mounted scraper. Scraping has been estimated to remove 60% of the excreta from the yard surface, but still leaves a film remaining from which emissions can occur. The removal of excreta by pressure washing or by hosing and brushing, immediately following each milking event, will remove a greater proportion of excreta from the yard surface (>90%) prior to urea hydrolysis.

**Potential for applying the method:** The method could potentially be applied to all collecting yards used by dairy cows.

**Practicability:** The main practical issue is the extra labour involved in cleaning the yard (typically twice per day) and the extra volume of slurry produced from the added water use.

*Note:* It is important to use this method in combination with Method 54 – 'install covers on slurry stores', Method 55 – 'allow cattle slurry stores to develop a natural crust' and Methods 70 or 71 at land spreading.

**Likely Uptake:** Low, due to extra labour and slurry/handling.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Mixed | Costs allow for an additional 25 litres of washwater per cow per day, plus labour. |
|---|---|---|---|
| Annual | 7,500 | 1,400 | |

**Effectiveness:**

**N:** $NH_3$ emissions would be reduced by up to 90% from dairy cow collecting yards. However, as a result of the greater readily available (i.e. $NH_4$) N content of the slurry, $NH_3$ emissions during storage and following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount.

**Other Pollutants:** $CO_2$ emissions would be increased by a small amount from the additional pressure washing/hosing and brushing operations and greater amounts of slurry handled. Impacts on other pollutants are likely to be minimal.

**Key references:**

Misselbrook, T. H., Pain, B. F. and Headon, D. M. (1998). Estimates of ammonia emission from dairy cow collecting yards. *Journal of Agricultural Engineering Research,* 71, 127-135.

Misselbrook, T. H., Webb, J. and Gilhespy, S. L. (2006). Ammonia emissions from outdoor concrete yards used by livestock - quantification and mitigation. *Atmospheric Environment,* 40, 6752- 6763.

## Method 45 – Outwintering of cattle on woodchip stand-off pads

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ↓ | (↓↓) | (↓) | (↓) | ~ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × |

**Description:** For cattle, as an alternative to winter housing in a building, construct purpose-built woodchip pads (including an impermeable liner and drainage collection system), with a feeding area.
**Rationale:** $NH_3$ emissions from urine deposition on to a woodchip stand-off pad are likely to be lower than from a concrete yard or a cattle house, because of rapid infiltration into the woodchip matrix.
**Mechanism of action:** The rapid infiltration of urine into the woodchip medium will increase the physical barrier to $NH_3$ volatilisation in a similar way to straw bedding in livestock housing (Method 43) and the soil when cattle are at grazing (Method 36). There may also be some direct adsorption of $NH_4$ by the woodchip medium and microbial immobilisation by the bacterial community within the woodchip pad. Additionally, drainage from the stand-off pad is likely to be lower in volume (because of evaporation losses), N content and dry matter (compared with slurry from cattle housing), and so the potential for $NH_3$ emissions following land application is likely to be lower, because of more rapid infiltration of the lower dry matter slurry into the soil. Additionally, the (solid) woodchips need periodically to be recycled to land, but present a low runoff risk.
**Potential for applying the method:** This method is potentially applicable to all beef and dairy farms where cattle are housed (or kept on concrete yards) for at least part of the year.
**Practicability:** Farmers are unlikely to replace existing cattle housing facilities with stand-off pads, but may install them where they are expanding herd numbers, but have insufficient housing, or where they currently outwinter a proportion of their cattle.
**Likely Uptake:** Low-moderate.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Costs based on excavation, drainage, liner (materials and installation) and woodchip inputs, and are amortised. |
|---|---|---|---|---|---|
| Annual | 7,500 | 2,500 | 3,000 | 2,800 | |

**Effectiveness:**
**Ammonia:** $NO_3$ (plus ammonium and nitrite) leaching losses are *likely* to be lower as a result of the lower volume and N content of the leachate from the woodchip pads (compared with slurry spreading from cattle housing). Also, $NH_3$ emissions from the woodchip pad (compared with concrete yards/housing) and $NH_3$ and direct and indirect $N_2O$ emissions at land spreading are *likely* to be lower.
**P:** Soluble and particulate P losses are likely to be lower as a result of the lower volume and P content of the leachate from woodchip lads (compared with slurry from cattle housing), as excreta solids (and associated P) are retained in the woodchip matrix.
**Other Pollutants:** $CH_4$ emissions are likely to be reduced as stored leachate volumes are lower than from cattle housing and there is likely to be less $CH_4$ generation from the woodchip matrix than from a slurry store.
**Key references:**
Smith, K.A., Agostini, F.A. and Laws, J.A. (2005). *Survey of Woodchip Corrals and Stand-off Pads in England and Wales*: *Construction, Operation and Management Practices and Potential Environmental Impacts*. Environment Agency report, 45pp.
LINK project LK0676 – Woodchip pads for sustainable over-wintering of livestock.

## Method 46 – Frequent removal of slurry from beneath-slatted storage in pig housing

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓ | ↑ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | × | × | × | × | ✓ | × | × | × |

**Description:** Replace slurry storage beneath slats, with frequent removal of slurry to an outside store, using vacuum removal systems operated at least twice per week.
**Rationale:** $NH_3$ emissions from slatted-floor pig housing occur from both manure deposited on slat surfaces and also slurry in the below slatted-floor storage area. Frequent removal of beneath-slat slurry will reduce $NH_3$ emissions from pig housing.
**Mechanism of action:** This method relies on the removal of slurry as a source of $NH_3$ emissions from pig housing to an outside store where $NH_3$ emissions are lower; because of cooler outdoor storage temperatures. A key factor in the success of this method is that the slurry should be removed completely each time (twice per week), otherwise an emitting surface will still be present. $NH_3$ emissions from outdoor slurry storage can be further reduced by using a store cover (see Method 54).
**Potential for applying the method:** This method could potentially be applied to all slatted-floor pig housing, subject to sufficient outside storage capacity being available.
**Practicability:** The method is most suited to purpose-built new installations and could be combined with Method 47 to reduce the emitting surface area. There may be practical difficulties in the retro-fitting of some existing pig housing.
**Likely Uptake:** Low, due to likely difficulties with the retro-fitting of existing pig housing and the cost of new buildings and slurry storage capacity.
*Note:* It is important to use this method in combination with Method 54 – 'install covers on slurry stores' and Methods 70 or 71 at land spreading.
**Costs:**

| Total *cost* for farm system (£/farm) | Indoor Pigs | Costs based on additional pumping out from under floor storage and the provision of additional slurry storage, and are amortised. |
|---|---|---|
| Annual | 11,000 | |

**Effectiveness:**
**N:** $NH_3$ emissions would be reduced by up to 25% from pig housing. However, there would be a greater readily available ($NH_4$) N content of the slurry and $NH_3$ emissions during storage and following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**Other Pollutants:** $CO_2$ emissions would be increased by a small amount as a result of more frequent slurry removal. Impacts on other pollutants are likely to be minimal.
**Key references:**
BREF document: European Commission 2003. Integrated Pollution Prevention and Control Reference document on best available techniques for intensive rearing of poultry and pigs.

## Method 47 – Part-slatted floor design for pig housing

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓↓ | ↑ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | × | × | × | × | ✓ | × | × | × |

**Description:** Replace fully-slatted floors, with a part-slatted floor, including a domed solid floor area and beneath-slat slurry storage with sloping sides.
**Rationale:** The method aims to reduce the overall emitting surface area of slurry.
**Mechanism of action:** $NH_3$ emissions from pig housing occur from both manure deposited on slat surfaces and also slurry below in the slatted-floor storage area. Providing a solid floor lying area and a slatted-floor dunging area can reduce $NH_3$ emissions compared with a fully-slatted design. A 50:50 void:floor area (compared with traditional 80:20) can further reduce the fouled floor area. Also, a domed lying area will encourage any deposited urine to quickly drain to the below-slat storage. The ventilation airflow direction is critical to the success of this system, incoming airflows should be drawn downwards to the lying area and then horizontally across the slatted surface. This encourages the pigs to lie on the lying area and dung over the slatted area, and also results in less air mixing above the slatted-floor slurry storage area.
**Potential for applying the method:** This method is potentially applicable to all slurry-based pig housing.
**Practicability:** The method is most suited to larger units and to purpose-built *new* installations. The practicality of retro-fitting existing buildings will depend on their design, and would not be possible for many older buildings.
**Likely Uptake:** Low, due to likely difficulties with the retro-fitting of existing pig housing and the cost of new buildings.
*Note:* It is important to use this method in combination with Method 54 – 'install covers on slurry stores' and Methods 70 or 71 at land spreading.
**Costs:**

| Total *cost* for farm system (£/farm) | Indoor Pigs | Costs based on solid concrete floor with part-slatting and are amortised. |
|---|---|---|
| Annual | 13,500 | |

**Effectiveness:**
**N:** $NH_3$ emissions would be reduced by up to 50% from pig housing. However, there would be a greater readily available ($NH_4$) N content of the slurry and $NH_3$ emissions during storage and following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**Other Pollutants:** Impacts on other pollutants are likely to be minimal.
**Key references:**
Defra project WA0720 - Demonstrating opportunities for reducing ammonia emissions from pig housing.

## Method 48 – Install air-scrubbers or biotrickling filters to mechanically ventilated pig housing

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓↓↓ | ↑ | ~ | ↑↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ |

**Description:** Treat exhaust air from mechanically-ventilated pig housing, using acid scrubbers or biotrickling filters, to remove $NH_3$.
**Rationale:** This method removes $NH_3$ from the exhaust air-stream, thereby reducing emissions to the wider environment.
**Mechanism of action:** $NH_3$ is very readily absorbed in low pH solutions. Acid scrubbers typically use sulphuric acid in their recirculation water to 'capture' $NH_3$, as ammonium sulphate, which can then be used on land as a N fertiliser. In biotrickling filters, $NH_3$ is converted to $NO_3$ through microbial activity in the biomass held on the synthetic supporting material (organic materials tend to have a short lifetime) and in the recirculation water. As with acid scrubbers, N in the recirculation water can be used on land as a fertiliser.
**Potential for applying the method:** This method is potentially applicable to all mechanically-ventilated pig housing.
**Practicability:** The requirement for specific ventilation designs adapted to these specialist treatment technologies, restricts the practical application of this method to *new* purpose-built buildings.
**Likely Uptake:** Low; only practically applicable to new build sites.
*Note:* It is important to use this method in combination with Methods 70 and 71 at land spreading.
**Costs:**

| Total *cost* for farm system (£/farm) | Indoor Pigs | Costs based on the installation of air-scrubbers/bio-filters and are amortised. |
|---|---|---|
| Annual | 32,000 | |

**Effectiveness:**
**N:** $NH_3$ emissions would be reduced by up to 90% from pig housing. However, there would be a greater readily available ($NH_4$) N content of the slurry and $NH_3$ emissions during storage and following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**Other Pollutants:** $CO_2$ emissions would be increased through additional energy use. Treatment of the exhaust air would also remove other air pollutants (e.g. particulates, odour etc.). Impacts on other pollutants are likely to be minimal.
**Key references:**
Aarnink, A.J.A., van Hattum, T., Hol, A. and Zhao, Y. (2007). *Reduction of Fine Dust Emission by Combiscrubber of Big Dutchman.* Report No. 66, Animal Sciences Group Wageningen, NL. ISSN 1570-8616.

## Method 49 – Convert caged laying hen housing from deep-pit storage to belt manure removal

**Direction of change for target pollutants at farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓↓ | ↑ | ↓ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | × | × | × | × | × | × | ✓ | × |

**Description:** In a deep-pit storage system, manure from laying hens drops in to a pit below the tiered cages where it is stored for a period (of months) prior to removal. This is replaced by a series of belts below each tier of cages, which remove manure from the house (usually on a weekly basis).

**Rationale:** $NH_3$ emissions from a deep-pit laying hen house occur from the accumulated manure in the deep-pit storage area. With a belt removal system, operating weekly, most of the $NH_3$ emissions from a given quantity of manure will occur after the manure has been removed from the house.

**Mechanism of action:** Birds excrete nitrogen as uric acid (compared to urea from mammals). The hydrolysis of uric acid to $NH_4$ is generally more prolonged than the rapid hydrolysis of urea, so $NH_3$ emissions may take one or more days to develop (depending also on temperature and moisture content). Therefore, compared with a deep-pit system where the accumulation of manure will result in continuous and elevated $NH_3$ emission rates, those from a belt removal system will be substantially lower, as a result of more frequent removal from the house to a lower surface area outdoor storage heap.

**Potential for applying the method:** This method is potentially applicable to all deep-pit laying hen systems.

**Practicability:** The method is most appropriate to new build units. The practicalities of converting existing buildings will depend on their design and age.

**Likely Uptake:** Low, due to likely difficulties with retro-fitting existing laying hen housing.

*Note:* It is important to use this method (where appropriate) in combination with Method 73 – 'incorporate manure into the soil'.

**Costs:**

| Total *cost* for farm system (£/farm) | Poultry | Costs based on installation of new cages and belts and are amortised. |
|---|---|---|
| Annual | 15,000 | |

**Effectiveness:**

**N:** $NH_3$ emissions from laying hen houses with belt clean systems are around 50% lower than from deep-pit laying hen houses. However, there would be greater readily available (i.e. $NH_4$ and uric acid) N content of the layer manure and $NH_3$ emissions during storage and following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.

**Other Pollutants:** Air quality (including odorant concentrations) within the house should be improved. Impacts on other pollutants are likely to be minimal

**Key references:**

Nicholson, F. A., Chambers, B.J., and Walker, A. W. (2004). Ammonia emissions from broiler litter and laying hen manure management systems. *Biosystems Engineering,* 89, 175-185.

Defra project WA0651 - Ammonia fluxes within broiler litter and layer manure management systems.

## Method 50 – More frequent manure removal from laying hen housing with belt clean systems

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓↓ | ↑ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | × | × | × | × | × | × | ✓ | × |

**Description:** Laying hen houses with manure belts typically operate weekly manure removal. This method increases the frequency of manure removal to twice weekly.
**Rationale:** The method relies on the rapid removal of manure from the house prior to the peak rate of $NH_3$ emission.
**Mechanism of action:** Birds excrete nitrogen as uric acid (compared with urea from mammals). The hydrolysis of uric acid to $NH_4$ is generally more prolonged than the rapid hydrolysis of urea, so $NH_3$ emissions may take one or more days to develop (depending also on temperature and moisture content). For a weekly manure removal system, measurements have shown that $NH_3$ emissions can increase substantially on the last two days prior to manure removal. Twice weekly manure removal will therefore remove the emitting source prior to the peak emission.
**Potential for applying the method:** This method is potentially applicable to all laying hen houses with belt systems for manure removal.
**Practicability:** There should be few (or no) practical reasons why this method could not be adopted by farmers with belt manure removal systems.
**Likely Uptake:** High. The method involves a doubling in manure removal frequency and associated labour/energy costs.
*Note:* It is important to use this method (where appropriate) in combination with Method 73 – ‘incorporate manure into the soil’.
**Costs:**

| Total *cost* for farm system (£/farm) | Poultry | Costs based on a small increase in energy use. |
|---|---|---|
| Annual | 250 | |

**Effectiveness:**
**N:** $NH_3$ emissions would be reduced by *c.*50% compared with weekly manure removal. However, there would be a greater readily available (i.e. $NH_4$ and uric acid) N content of the layer manure and $NH_3$ emissions during storage and following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**Other Pollutants:** $CO_2$ emissions would be increased by a small amount through additional energy use. Air quality (including odorant concentrations) within the house should be improved. Impacts on other pollutants are likely to be minimal.
**Key references:**
Nicholson, F. A., Chambers, B. J. and Walker, A. W. (2004). Ammonia emissions from broiler litter and laying hen manure management systems. *Biosystems Engineering,* 89, 175-185.
Defra project WA0651 - Ammonia fluxes within broiler litter and layer manure management systems.

## Method 51 – In-house poultry manure drying

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓↓ | ↑ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | × | × | × | × | × | × | ✓ | × |

**Description:** Install ventilation/drying systems to reduce the moisture content of laying hen manure (in deep-pit or on belts) or poultry litter within the house.
**Rationale:** Drying will inhibit the hydrolysis of uric acid N in the manure, slowing the formation of $NH_4$-N and thereby reducing $NH_3$ emissions.
**Mechanism of action:** Birds excrete nitrogen as uric acid, which is subsequently converted to $NH_4$-N by hydrolysis. Drying the manure/litter to achieve a dry matter content of 60-80% will greatly reduce the rate of hydrolysis.
**Potential for applying the method:** This method is potentially applicable to all poultry housing systems.
**Practicability:** Most laying hen houses with belt-removal or deep-pit systems should be suitable for the retro-fitting of drying systems. For broiler housing, the practicalities of installing forced manure drying to a litter-based system will depend on the existing building design and age; many buildings are likely to have practical limitations.
**Likely Uptake:** Low-moderate, due to practical limitations.
*Note:* It is important to use this method (where appropriate) in combination with Method 73 – 'incorporate manure into the soil'.
**Costs:**

| Total *cost* for farm system (£/farm) | Poultry | Costs based on the installation and running of drying equipment, and are amortised. |
|---|---|---|
| Annual | 1,000 | |

**Effectiveness:**
**N:** $NH_3$ emissions would be reduced by up to 50% from the poultry housing. However, there would be a greater readily available (i.e. $NH_4$ and uric acid) N content of the poultry manure, and $NH_3$ emissions during storage and following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**Other Pollutants:** $CO_2$ emissions would be increased by a small amount through additional energy use. Air quality (including odorant concentrations) within the house should be improved. Impacts on other pollutants are likely to be minimal
**Key references:**
Smith, K.A., Jackson, D.R. and Metcalfe, J.P. (2001). Low cost aerobic stabilisation of poultry layer manure. In: *Sustainable Handling and Utilisation of Livestock Manure from Animals to Plants*, Proceedings of NJF Seminar No 320 (Eds. Rom, H.B. and Sorenesen, C.G.), Danish Institute of Agricultural Sciences Report No 21, Animal Husbandry.
Defra project WA0638 - Low cost aerobic stabilisation of poultry layer manure.

## Method 52 – Increase the capacity of farm slurry (manure) stores to improve timing of slurry applications

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓↓ | ~ | ↓ | ↓ | ↑ | (↓) | (↑) | ~ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | ✓ | × | × | ✓ | × | × | × |

**Description:** On farms where there is currently limited slurry storage capacity, expand facilities for the collection and storage of slurry, to allow spreading at times when there is a low-risk of runoff and when there is an actively growing crop to utilise nutrients applied in the slurry.
**Rationale:** The collection and storage of slurry provides increased flexibility in land application timing. There will be fewer occasions when a lack of storage capacity forces slurry application to occur when here is a high-risk of surface runoff or drainflow losses to water i.e. when soils are 'wet'.
**Mechanism of action:** If a farm has little or no storage capacity for slurry, this will inevitably result in applications at times when there is a risk of surface runoff or drainflow losses of nutrients, FIOs and BOD. Adequate storage facilities provide greater freedom in choosing when to apply slurry to fields.
**Potential for applying the method:** The method is applicable to livestock farms that have limited slurry (manure) storage facilities; the provision of adequate storage facilities is most important on farms that handle their manure as slurry. Solid manures can be stored in the animal house or in field heaps, prior to land spreading, at a time of year that presents a lower risk of pollution.
**Practicability**: The method will be most effective if implemented in conjunction with Methods 54/55 which will reduce $NH_3$ emissions from slurry storage, and Methods 68 and 70/71 that will reduce diffuse pollution risks following land spreading.
**Likely Uptake:**
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Mixed | Indoor Pigs | Costs based on construction of additional slurry storage and are amortised. |
|---|---|---|---|---|
| Annual | 2,000 | 5,000 | 1,500 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 10% and associated indirect $N_2O$ emissions. However, $NH_3$ emissions would be increased by a small amount due to an increase in the slurry store surface area and application to 'dry' soils in the summer period, and direct $N_2O$ emissions would also decrease by a small amount from increased soil mineral N levels. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs would be reduced.
**P:** Particulate and soluble P losses would be reduced by up to 20% through avoiding slurry application to 'wet' soils when runoff risks are high.
**FIOs and BOD:** Losses would be reduced through avoiding slurry application to 'wet' soils.
**Other Pollutants:** $CH_4$ emissions would be increased as a result of increasing the duration of slurry storage.
**Key references:**
Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.
Lord, E.I., Shepherd, M.A., Silgram, M, Goodlass, G., Gooday, R, Anthony, S.G., Davison, P. and Hodgkinson, R. (2007). *Investigating the Effectiveness of NVZ Action Programme Measures: Development of a Strategy for England*. Report for Defra Project NIT18.
Thorman, R.E., Sagoo, E., Williams, J.R., Chambers, B.J., Chadwick, D.R., Laws, J.A. and Yamulki, S. (2007). The effect of slurry application timings on direct and indirect $N_2O$ emissions from free draining grassland soils. *In: Towards a Better Efficiency of N Use*. (Eds. Bosch, A.D., and Villor, J.M.), 15th Nitrogen Workshop, Spain, pp.297-299.
Defra project ES0106 - Developing integrated land use and manure management systems to control diffuse nutrient losses from drained clay soils: BRIMSTONE-*NPS*.
Defra project ES0115 - Optimising slurry application timings to minimise nitrogen losses: OPTI-*N*.

## Method 53 – Adopt batch storage of slurry

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ~ | ~ | ~ | ~ | ~ | ~ | ↓ | ↓↓ | ↑ | ~ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | ✓ | × | × | ✓ | × | × | × |

**Description:** Store slurry in batches for at least 90 days before land spreading; do not add fresh slurry to the store during this storage period.
**Rationale:** FIOs die-off during storage. However, adding fresh slurry results in re-inoculation with viable microorganisms, so for effective reduction in FIO loads, slurry needs to be batch stored without fresh additions. As there are few microorganisms on the batch stored slurry (after 90 days), the risk of FIOs entering water bodies *via* surface runoff or drainflow losses (after slurry application) is greatly reduced.
**Mechanism of action:** Numbers of FIOs decline during storage, which can be an effective means of reducing microbial pathogen numbers in slurry. If there is any surface runoff or drainflow soon after slurry application FIOs losses will be lower compared with 'fresh' slurry.
**Potential for applying the method:** This method is potentially applicable to all livestock farms that produce slurry.
**Practicability:** The method needs slurry to be stored without any fresh additions for 90 days, which will require (at least) two stores.
**Likely Uptake:** Low, due to the need for (at least) two slurry stores.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Mixed | Indoor Pigs | Costs based on the construction of additional slurry storage and are amortised. |
|---|---|---|---|---|
| Annual | 2,500 | 500 | 2,500 | |

**Effectiveness:**
**N:** $NH_3$ emissions would be increased by a small amount as a result of the greater slurry store surface area.
**FIOs and BOD:** FIO loss risks to surface water would be reduced by > 90% and BOD losses by up to 50% from managed slurry.
**Other Pollutants:** Impacts on other pollutants are likely to be minimal.
**Key references:**

Nicholson, F.A., Groves, S. and Chambers, B.J. (2005). Pathogen survival during livestock manure storage and following land application. *Bioresource Technology*, 96, 135-143.
Defra project WA0656 - Implications of potential measures to control pathogens associated with livestock manure management.

## Method 54 – Install covers on slurry stores

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ↓ | ↓ | ~ | ~ | ~ | ↓ | ↑ | (↓) | ↓ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | ✓ | × | × | ✓ | × | × | × |

**Description:** Open slurry stores (tanks or lagoons) are fitted with a cover (either a rigid cover with a vent or a floating flexible cover).

**Rationale:** Covering slurry stores reduces $NH_3$ emissions and where rainfall is diverted reduces the volume of slurry collected.

**Mechanism of action:** $NH_3$ will volatilise from a slurry store surface (the rate depends on factors such as $NH_4$-N concentration, pH, temperature and air movement) and will be replenished in the surface layer from lower levels in the slurry store. Natural air movement above the store will ensure that the emitted $NH_3$ is removed and is continually replaced by air with a lower $NH_3$ concentration. By placing a cover above or on the slurry surface and preventing the removal of emitted $NH_3$ by advection, a higher $NH_3$ concentration will soon develop in the enclosed airspace. This higher concentration will reduce further $NH_3$ emissions from the slurry, so the overall emission rate will decline. Most covers include some vents (to prevent a build up of $CH_4$), so emissions will not stop entirely, but will be greatly reduced compared with a situation of free air movement above the slurry store. Placing a cover over the slurry store prevents the collection of rainfall (where the rainfall is diverted) and in high rainfall areas can result in a significant reduction in overall slurry volumes.

**Potential for applying the method:** This method could potentially be applied to all open slurry stores. There may be less benefit in applying the method to cattle slurry stores where natural crusts often develop and give effective $NH_3$ emission reductions (see Method 55). The method is most relevant to pig and dairy farms that separate slurry liquid: solid fractions.

**Practicability:** Rigid covers are applicable to concrete and steel tanks, but *may not be suitable* for all existing stores (e.g. where the existing store has insufficient structural support for a rigid cover). Plastic (floating) covers are applicable to tanks and small earth-banked lagoons, but can be difficult to fit and manage on larger lagoons. 'Low technology' floating covers (*e.g.* oilbased liquids, chopped straw, peat, bark, LECA balls etc.) can be used on the surface of tanks, but are less suited to earth-banked lagoons where wind drift can cause problems with retaining a complete surface cover. These covers do not divert rainwater and require management time during store filling, mixing and emptying.

**Likely Uptake:** Low to moderate, due to cost implications, logistical issues with lagoons and existing tanks with insufficient structural support.

*Note:* It is important to use this method is used in combination with Methods 70 or 71 at land spreading.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Mixed | Indoor Pigs | Costs based on provision of a store cover and are amortised. |
|---|---|---|---|---|
| Annual | 700 | 150 | 500 | |

**Effectiveness:**

**N:** $NH_3$ emissions from slurry stores have been shown to be reduced from using rigid store covers by 80%, plastic sheeting by 60% and 'low technology' floating covers by 40%. However, as a result of the greater readily available ($NH_4$) N and higher dry matter content of the slurry, $NH_3$ emissions following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.

**P:** Particulate and soluble P loss risks would be reduced where the cover diverts rainfall, as lower amounts of slurry would need to be spread.

**Other Pollutants:** $CO_2$.emissions would be reduced (where the cover diverts rainfall) as lower amounts of slurry would need to be spread, and $CH_4$ emissions could also be reduced by a small amount. Odour emissions from the slurry store would also be reduced.

**Key references:**

Pain, B. and Webb, J. (2002). *Ammonia in the UK*. Chapter II – Overview of research on methods for reducing emission from agriculture. Defra publications, London. PB6865.

Portejoie, S., Martinez, J., Guiziou, F., and Coste, C. M. (2003). Effect of covering pig slurry stores on the ammonia emission processes. *Bioresource Technology,* 87, 199-207.

Scotford, I. M. and Williams, A. G. (2001). Practicalities, costs and effectiveness of a floating plastic cover to reduce ammonia emissions from a pig slurry lagoon. *Journal of Agricultural Engineering Research,* 80, 273-281.

## Method 55 – Allow cattle slurry stores to develop a natural crust

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓ | ↑ | (↓) | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | ✓ | × | × | × | × | × | × |

**Description:** Retain a surface crust on stores, composed of fibre and bedding material present in cattle slurry, for as long as possible. In most cattle systems, it is possible to retain an intact crust for the majority of the year.
**Rationale:** The surface crust acts as a physical barrier between the $NH_4$-N in slurry and the free air above the crust, and thereby reduces $NH_3$ emissions.
**Mechanism of action:** Fibre from undigested plant material and bedding within cattle slurry floats to the surface of the slurry store aided by uprising $CH_4$ bubbles produced by bacterial action within the slurry. Thereafter, evaporative forces from wind and solar radiation cause the crust to dry, increasing its strength and integrity. The viscosity of the surface layer increases the time taken for $NH_4$ at the surface emitting layer to be replenished from deeper within the slurry store, and thereby reduces $NH_3$ emissions.
**Potential for applying the method:** This method is applicable to all slurry stores with the potential to form a crust; these tend to be cattle slurry stores in the UK (as pig slurry does *not* tend to crust). However, there are circumstances where cattle slurry stores do not form a crust (*e.g.* where they contain dilute or separated slurries).
**Practicability:** Management of the slurry store in order to maintain an effective crust is critical to the success of this method; regular agitation is therefore not an option, unless it can be achieved without breaking the crust. Some top filling slurry stores may not form a complete crust. Tank emptying can be difficult if the crust becomes too thick and solid, for this reason, it is recommended that the crust is completely broken-up during tank emptying at least once per year.
**Likely Uptake:** Low; it is estimated that 80% of cattle slurry stores already have natural crusts present.
*Note*: It is important to use this method in combination with Methods 70 or 71 at land spreading.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Mixed | Costs based on purchasing and running a 'larger' stirrer to break up the crust prior to emptying, and are amortised. |
|---|---|---|---|
| Annual | 100 | 50 | |

**Effectiveness:**
**N:** $NH_3$ emissions during slurry storage have been estimated to be reduced by 50%, compared with non-crusted cattle slurry. However, as a result of the greater readily available ($NH_4$) N content of the slurry, $NH_3$ emissions following land spreading would be increased, but by a lower amount. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**Other Pollutants:** $CO_2$ emissions would be increased by a small amount due to the need for more stirring to break-up the surface crust. There is some evidence that $CH_4$ emissions would be reduced by a small amount, due to microbial oxidation of $CH_4$, as it passed through the slurry crust. Odour emission would be reduced by the crust. Impacts on other pollutants are likely to be minimal.
**Key references:**
Misselbrook, T. H., Brookman, S. K. E., Smith, K. A., Cumby, T. R., Williams, A. G. and McCrory, D. F. (2005). Crusting of stored dairy slurry to abate ammonia emissions: pilot-scale studies. *Journal of Environmental Quality,* 34, 411-419.

Petersen, S. O., Amon, B. and Gattinger, A. (2005). Methane oxidation in slurry storage surface crusts. *Journal of Environmental Quality,* 34, 455-461.

Smith K., Cumby, T. Lapworth, J., Misselbrook, T.H. and Williams, A. (2007). Natural crusting of slurry storage as an abatement measure for ammonia emissions on dairy farms. *Biosystems Engineering,* 97, 464-471.
Sommer, S. G., Petersen, S. O. and Sogaard, H. T. (2000). Greenhouse gas emissions from stored livestock slurry. *Journal of Environmental Quality,* 29, 744-751.

## Method 56 – Anaerobic digestion of livestock manures

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ↓ | ↓ | (↑) | (↑) | ↓ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | × | × | ✓ | × | ✓ | × |

**Description:** Use anaerobic digestion (AD) of livestock manures to generate $CH_4$ for biogas production.

**Rationale:** $CH_4$ generated from livestock manures during (mesophilic) anaerobic digestion can be used to produce heat and power, and to replace fossil fuel use. Also, $CH_4$ emissions during subsequent manure storage prior to land spreading will be reduced

**Mechanism of action:** Anaerobic digestion of organic materials by microbial populations in a sealed container to generate $CH_4$ that is used to produce heat and power. During AD, organic N is mineralised to ammonium $NH_4$ (i.e. readily available) N; typically $NH_4$-N is increased by around 10% of the total N content. As a result of the digestion process, FIO numbers and BOD and the dry matter of the digestate is reduced

**Potential for applying the method:** Farms with significant numbers of housed livestock (e.g. pigs and zero-grazed dairy cows) would be most appropriate for on-farm installations.

**Practicability:** There are significant start-up and running costs for on-farm (and centralised) AD facilities, which discourage the uptake of this technology. Financial incentives are likely to be required to encourage adoption of AD facilities, using livestock manure as a feed source. *Note:* by including food-waste gas yields can be boosted and associated 'gate-fees' provide a revenue stream

**Likely Uptake:** Low, due to poor economics. The availability of capital grants and 'high' renewable energy prices would be needed to stimulate on farm AD facilities.

*Note:* It is important that this method is used in combination with Method 54 – 'install covers on slurry stores' and Methods 70 or 71 at land spreading.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Indoor Pigs | Poultry | Costs based on an on-farm AD plant and are amortised. |
|---|---|---|---|---|---|---|
| Annual | 13,000 | 2,800 | 2,500 | 15,000 | 55,000 | |

**Effectiveness:**

**Methane:** $CH_4$ emissions from slurry storage (post AD) would be reduced, plus heat and power would be produced.

**N:** An increase in the readily available ($NH_4$) N content of the digestate would increase $NH_3$ emissions during storage and most likely following land spreading (although the lower dry matter content of the digestate is likely to increase soil infiltration rates), and associated direct and indirect $N_2O$ emissions. Similarly, $NO_3$ (plus ammonium and nitrite) leaching losses would be increased by a small amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.

**FIOs and BOD:** Microbial pathogen numbers would be reduced by around 2 logs during mesophilic AD and BOD by around 50%.

**Other Pollutants:** $CO_2$ emissions would be increased due to greater energy use in mixing the digestate during AD etc. However, overall greenhouse gas (and energy production) benefits would be positive.

**Key references:**


ADAS/SAC. (2007). *Nutritive Value of Digestate from Farm-based Biogas Plants in Scotland*. Report for Scottish Executive Environmental and Rural Department (ADA/009/06).

Burton, C.H. and Turner, C. (2003). *Manure Management: Treatment Strategies for Sustainable Agriculture*. Silsoe Research Institute.

Chantigny, M.H., Rochette, P., Angers, D.A., Masse, D. and Cote, D. (2004). Ammonia volatilization and selected soil characteristics following application of anaerobically digested pig slurry. *Soil Science Society of America Journal,* 68, 306-312.

Martinez J., Guiziou F., Peu P. and Gueutier V. (2003). Influence of treatment techniques for pig slurry on methane emissions during subsequent storage. *Biosystems Engineering,* 85, 347-354.
Morgan, J. and Pain, B.F. (2008). Anaerobic digestion of farm manures and other products for energy recovery and nutrient recycling. *International Fertiliser Society Proceedings*, No. 632, 38pp.
Defra project AC0406 - The optimisation and impacts of expanding biogas production.
Defra project AC0206 - A review of the research to identify best practice for reducing greenhouse gases from agriculture and land management.

## Method 57 – Minimise the volume of dirty water (and slurry) produced

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ↓ | ~ | ~ | ~ | ↓ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | ✓ | × | ✓ | × |

**Description:** Minimise the volume of dirty water produced by:

- Minimising unnecessary dirty yard areas.
- Avoiding excessive use of water in washing down yards, buildings, etc.
- Preventing unnecessary mixing with clean water from uncovered clean yard areas, from roofs etc.
- Roofing over yard areas and covering dirty water and slurry stores.

**Rationale:** Minimising the volume of dirty water produced reduces the volume to be stored and spread. Farms will be less likely to run out of storage space and be forced to spread dirty water (or slurry) at times when there is a high risk of runoff.

**Mechanism of action:** On some farms, dirty water is collected separately and spread on fields, whereas on others it is added to the main slurry store. Keeping the fouled yard area as small as possible minimises the volume of water required to wash it down and hence the volume of dirty water (or slurry) produced. Roofing such yards would avoid additional inputs from rainwater. Poorly designed or badly maintained drains and gutters can allow rainwater from non-fouled yards and roofs to mix with dirty water (or slurry) and further increase the volume. This clean water should be managed separately e.g. to a soak-away.

Avoiding unnecessary inputs of water reduces the volume of dirty water (or slurry) produced and increases the number of days of storage capacity. This helps to avoid the need to apply dirty water (or slurry) when soils are 'wet' and reduces the likelihood of surface runoff and drainflow losses of nutrients and FIOs/BOD to (surface) water systems. Also, covering dirty water and slurry stores prevents rainfall from adding to the volume to be stored.

**Potential for applying the method:** This method is mainly applicable to farms with cattle, particularly dairy farms; although most livestock farms produce dirty water. Preventing unnecessary inputs of rainwater will be most beneficial in high rainfall areas.

**Practicability:** There are few limitations to the adoption of this method, although there may be practical issues to the roofing of foul-yards and covering of dirty water stores.

**Likely Uptake:** Moderate to high, due to the low cost of many of the options. Capital grants are available in ECSFDI priority catchments.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | In Pigs | Poultry | Costs based on roofing of collecting yards and foul-yard areas, and are amortised. |
|---|---|---|---|---|---|---|---|
| Annual | 1,400 | 500 | 550 | 700 | 1,600 | 2,200 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching loses would be reduced by a small (<1%) amount due to the better timing of dirty water (slurry) applications; as a result of increased storage capacity.

**P:** P losses would be reduced by a small amount (<2%) due to the better timing of dirty water (slurry) applications.

**FIOs and BOD:** Losses would be reduced as result of better timing of dirty water (slurry) applications.

**Other pollutants:** $CO_2$ emissions would be reduced as there would be less dirty water (slurry) to be managed. Impacts on other pollutants are likely to be minimal.

**Key references:**

Defra project ES0106 – Developing integrated land use and manure management systems to control diffuse nutrient loss from drained clay soils: BRIMSTONE-*NPS*.

## Method 58 – Adopt (batch) storage of solid manures

**Direction of change for target pollutants at the farm scale**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ~ | ~ | ~ | ~ | ↓↓ | ↓ | (↓↑) | ↑ | ~ |

( ) Increased during storage, reduced at land spreading – balance uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | ✓ | × | ✓ | × |

**Description:** Store 'fresh' solid manure in separate batches (for at least 90 days) before land spreading.
**Rationale:** FIOs die-off during storage; as a result there will be fewer microbial pathogens in the spread manure and lower loss risks in runoff. Also, the readily available N content of stored farmyard manure (FYM) is lower than in 'fresh' FYM, due to losses during storage, which will lessen the risk of $NO_3$ leaching losses and $NH_3$ emissions.
**Mechanism of action:** FIO numbers decline during solid manure storage, with the rate of decline accelerated if high temperatures (i.e. passive composting) develop in the heap; this happens naturally in most FYM and poultry litter heaps. Hence, there are fewer microbial pathogens in the manure when it is spread and therefore less risk of FIO losses in surface runoff and drainflow. Storage is effective at reducing bacterial numbers, but is less effective in reducing populations of the protozoan parasite, *Cryptosporidium*. There will be gaseous losses of $NH_3$ and $N_2O$ and immobilisation of N during storage, which will reduce the readily available N content of FYM at the end of storage. 'Fresh' FYM typically contains 20-25% $NH_4$-N compared with 10-15% where FYM has been stored for more than 3 months. There will also be a reduction in the total N amount, with typically 30-50% of total N being lost during FYM storage (either as $NH_3$, $N_2O$ or di-nitrogen gas, or in leachate). For poultry manure, about 10-15% of total N is lost during storage, but the proportion of readily available N remains similar to that in the 'fresh' material (typically in the range 35-50% of total N).
**Potential for applying the method:** This method is applicable to livestock farms that produce solid manure and apply 'fresh' solid manure to land (or where manure is continuously added to existing heaps). *Note:* Around 30% of FYM and 60% of poultry manure is applied 'fresh' to land.
**Practicability:** The method is practical where it is possible to store solid manure in separate field heaps or where it is possible to subdivide an existing store.
**Likely Uptake:** Moderate – high, where field heaps can be used for batch storage.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Indoor Pigs | Poultry | Costs based on the provision of a concrete base (with pads for vehicle movements) and are amortised. |
|---|---|---|---|---|---|---|---|
| Annual | 250 | 350 | 550 | 1,500 | 1,800 | 500 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced as a result of the lower readily available N content of FYM and lower amounts of total N in FYM/poultry manure spread to land, and associated direct and indirect $N_2O$ and $NH_3$ emissions at land spreading. However, $NH_3$ (and $N_2O$) emissions would be increased during storage, but by a lower amount. Effects on the balance of $N_2O$ emissions at the farm scale are uncertain.
**FIOs:** Losses would be reduced compared with 'fresh' manure applications
**Other Pollutants:** $CH_4$ emissions would be increased (compared with the application of 'fresh' manure to land). Odour emissions would be reduced at land spreading. Impacts on other pollutants are likely to be minimal.
**Key references:**
Defra (2010). *Fertiliser Manual (RB209)*. 8th Edition. The Stationery Office, Norwich. ISBN 978-0-11-243286-9.
Chadwick, D.R., Matthews, R.A., Nicholson, R.J., Chambers, B.J. and Boyles, L.O. (2002). Management practices to reduce ammonia emissions from pig and cattle manure stores. In: *Proceedings of the 10th International Conference of the FAO RAMIRAN Network on Recycling of*

*Agricultural, Municipal and Industrial Residues in Agriculture* (Eds. J. Venglovsky and G. Greserova), pp.219-223.

Nicholson, F.A., Groves, S. and Chambers, B.J. (2005). Pathogen survival during livestock manure storage and following land application. *Bioresource Technology*, 96, 135-143.

Sagoo, E., Williams, J.R., Chambers, B.J., Boyles, L., Matthews, R. and Chadwick, D.R. (2004). Integrated management practices to minimise losses and maximise crop nitrogen values of broiler litter. In: *Proceedings of the 11th International Conference of the FAO RAMIRAN Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture* (Eds. Bernal, M.P., Moral, R., Clemente, R. and Paredes, C.), Vol. 1, pp.249-252.

Defra project WA0656 - Implications of potential measures to control pathogens associated with livestock manure management.

Defra project WA0716 - Management techniques to reduce ammonia emissions from solid manures.

## Method 59 – Compost solid manure

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ~ | ~ | ~ | ~ | ↓↓ | ↓ | (↑↓) | ↑ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | ✓ | × | ✓ | × |

**Description:**
- Encourage the breakdown of solid manure by active composting.
- Turn the solid manure windrow twice in the first seven days of composting to facilitate aeration and the development of high temperatures within the windrow.

**Rationale:** The aim is to facilitate naturally occurring microflora to degrade cellulose and other carbon compounds in the manure to produce a friable, stable and spreadable material, with reduced volume. As part of the composting process, the manure is 'sanitised' and the readily available N content is reduced, thereby lowering the risks of FIO and $NO_3$ losses when the composted manure is spread to land.

**Mechanism of action:** Increased temperatures during *active composting* inactivate microbial pathogens and most weed seeds; and reduce the readily available N content of FYM. Composting has little effect on the proportion of readily available N in poultry manure. The readily available N content of FYM is typically reduced from 20-25% (in 'fresh' FYM) to 10-15% of total N (in composted FYM). The whole process should be monitoring to ensure that temperatures increase to above 55$^oC$ for three days after each turn. Turning of the heap ensures that all parts are treated (i.e. composted).

**Potential for applying the method:** Applicable to farms with solid manures, particularly where windrows can be established safely in fields or on an impermeable base. Composting typically results in 40-50% of the total N in FYM and around 15-20% in poultry litter being lost (either as $NH_3$, $N_2O$ or di-nitrogen gas, or in leachate).

**Practicability:** Can be incorporated into normal farm operations, using standard farm machinery.

**Likely Uptake:** Low-moderate, most likely where there is an incentive to reduce solid manure volumes prior to transport and spreading, and where sanitation is important prior to land spreading (e.g. in front of ready to eat crops etc.).

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Indoor Pigs | Poultry | Costs based on turning of solid manure windrows twice. |
|---|---|---|---|---|---|---|---|
| Annual | 600 | 750 | 1,200 | 3,500 | 4,500 | 2,000 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced as a result of the lower readily available N content of FYM and lower amounts of total N in FYM/poultry manure spread to land, and associated direct and indirect $N_2O$ and $NH_3$ losses at land spreading. However, $NH_3$ emissions would be increased during composting, but by a lower amount. Effects on the balance of $N_2O$ emissions at the farm scale are uncertain.

**FIOs:** FIOs would be reduced (compared with 'fresh' manure application).

**Other Pollutants:** $CH_4$ emissions would be increased (compared with 'fresh' manure application). $CO_2$ emissions would be increased by the turning operations. Odour emissions would be reduced at land spreading. Impacts on other pollutants are likely to be minimal.

**Key references:**

Defra (2010). *Fertiliser Manual (RB209)*. 8th Edition. The Stationery Office, Norwich. ISBN 978-0-11-243286-9.

Defra project WA0656 - Implications of potential measures to control pathogens associated with livestock manure management.

Defra project WA0716 - Management techniques to reduce ammonia emissions from solid manures.

## Method 60 – Site solid manure field heaps away from watercourses/field drains

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ↓ | ~ | ↓ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | × |

**Description:** Where solid manure is stored in a field heap it should not be sited within 10m of a watercourse or (effective) field drain.

**Rationale:** Keeping solid manure heaps away from watercourses and field drains reduces the risk of pollutant losses in surface runoff or drainflow.

**Mechanism of action:** An adequate separation distance between field heaps and watercourses reduces the risk that any leachate from a heap might run over the soil surface directly into a watercourse. Similarly, siting solid manure heaps away from field drains reduces the risk of preferential flow of leachate through the soil that could transport nutrients, FIOs and oxygen depleting pollution to watercourses. There can be an increased risk of surface runoff from the area immediately surrounding a field heap, because of damage to soil structure caused by farm machinery when loading/unloading manure.

**Potential for applying the method:** This method is applicable to all farms that produce or import solid manure and store it in a field heap, where watercourses and field drains are present. Benefits are likely to be greatest on medium/heavy soils where surface runoff risks are highest and field drains are likely to be present.

**Practicability:** The method is simple to implement, with few limitations to its use. However, it can be difficult to find suitable positions for field heaps on farms where fields have closely-spaced drains.

**Likely Uptake:** Moderate-high. This method is a legal requirement in NVZs.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Costs based on added time to carefully plan the location of fields heaps. |
|---|---|---|---|---|---|---|---|
| Annual | 100 | 150 | 100 | 100 | 100 | 100 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by a small (<1%) amount and associated indirect $N_2O$ emissions.

**P:** P losses would be reduced by a small (<1%) amount.

**FIOs and BOD:** Losses would be reduced.

**Other Pollutants:** Impacts on other pollutants are likely to be minimal.

**Key references:**

Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.

Defra project WA0517 - Impacts of farm waste stores on groundwater quality.

Defra project WA0712 - Management techniques to minimise ammonia emissions during storage and land spreading of poultry manures.

Defra project WA0716 - Management techniques to reduce ammonia emissions from solid manure.

Defra project WA0632 - Ammonia fluxed within solid and liquid manure management systems.

## Method 61 – Store solid manure heaps on an impermeable base and collect leachate

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ↓ | ↑ | (~) | ~ | ~ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | ✓ | × | ✓ | × |

**Description:** Manure heaps are sited on an impermeable base, with leachate collection facilities.
**Rationale:** The impermeable base and leachate collection prevents the direct loss of pollutants in surface runoff and drainflow.
**Mechanism of action:** If stored directly on the soil surface, leachate from solid manure heaps will seep into the soil and/or flow over the soil surface in response to rainfall events. Storing manure on an impermeable base prevents the seepage and accumulation of nutrients in the soil below the heap, which may subsequently be lost in surface runoff/drainflow or leaching to ground water. Also, storage on an impermeable (e.g. a concrete base) reduces soil compaction caused by farm machinery, during the forming and subsequent spreading of field heaps. The leachate collected can be spread at a later date when soil conditions are suitable and the nutrients can be utilised by crops, or the leachate may be added back to the heap or into a slurry store.
**Potential for applying the method:** This method is applicable to all livestock farms that produce or import solid manure. Benefits will be greatest on medium/heavy soils where surface runoff risks are highest and where field drains are likely to be present.
**Practicability:** The cost of constructing solid manure storage facilities, with an impermeable base and leachate collection facilities is the main obstacle to adopting this method.
**Likely Uptake:** Low, because of the capital costs of construction.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Indoor Pigs | Poultry | Costs based on construction of a concrete pad with leachate collection facilities and are amortised |
|---|---|---|---|---|---|---|---|
| Annual | 250 | 350 | 550 | 1,500 | 1,800 | 500 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by a small (<5%) amount and associated indirect $N_2O$ losses. However, $NH_3$ emissions would be increased as a result of conserved N in the recycled leachate. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**P:** Soluble/particulate P losses would be reduced by a small (<2%) amount.
**FIOs and BOD:** Losses would be reduced as the leachate is collected.
**Other Pollutants:** Impacts on other pollutants are likely to be minimal.
**Key references:**
Defra project ES0138 - Review of livestock manure management options in European NVZs.
Defra project WA0712 - Management techniques to reduce ammonia emissions during storage and land spreading of poultry manures.
Defra project WA0716 - Management techniques to reduce ammonia emissions from solid manure.

## Method 62 – Cover solid manure stores with sheeting

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ↓ | ↓ | (↑↓) | ↑ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ | ✓ | ✗ |

**Description:** Solid manure field heaps are covered (e.g. with heavy duty polythene sheeting) in a similar manner to a silage clamp.
**Rationale:** The sheeting provides a physical barrier preventing the release of $NH_3$ from the manure heap to the air.
**Mechanism of action:** $NH_3$ volatilises from the $NH_4$-N content of a manure heap and diffuses through the heap into the free air stream above. Covering a heap with polythene sheeting provides a physical barrier, which the $NH_3$ gas cannot pass through. The cover prevents the advection of volatilised $NH_3$ away from the heap, so a high $NH_3$ concentration develops in the air spaces within the heap and between the heap and cover. This high concentration will inhibit further $NH_3$ emissions from the manure, so the overall emission rate will decline rapidly.
**Potential for applying the method:** This method could be applied to all solid manures that are stored in heaps. The method will be most effective where used in combination with Method 73 – 'incorporate manure into the soil'.
**Practicability:** Covering purpose-built manure 'clamps' (as with silage) would represent an ideal solution, but would represent significant investment, if such facilities were not already available. Long, low field heaps which are typical of in-field manure storage prior to land application would require large amounts of sheeting for covering; so heaps should be shaped to minimise their overall surface area. This method is less appropriate for management systems that involve regular additions of manure to existing heaps (e.g. daily, twice weekly) where there would be a continual need for sheet removal and replacement.
**Likely Uptake:** Low-moderate. *Note*: In NVZs it is mandatory to cover field heaps of layer manure with an impermeable sheet.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Indoor Pigs | Poultry | Costs based on provision of plastic sheeting and additional management time. |
|---|---|---|---|---|---|---|---|
| Annual | 150 | 150 | 250 | 700 | 1,00 | 500 | |

**Effectiveness:**
**N:** $NH_3$ emissions have been shown to be reduced by up to 90% (mean reduction *c*.60%) by covering solid manure heaps with an impermeable sheet, however, $N_2O$ emissions are likely to be increased during storage. $NO_3$ (plus ammonium and nitrite) leaching losses and associated indirect $N_2O$ emissions would be reduced through lower leachate losses. Overall, $NO_3$ losses and $NH_3$ emissions would be decreased (i.e. the emission reduction during covering would be greater than increases following land spreading). Effects on the balance of $N_2O$ emissions at the farm scale are uncertain. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**P:** Losses would be reduced as less leachate would be produced.
**FIOs and BOD:** Losses would be reduced.
**Other Pollutants:** $CH_4$ emissions would be increased due to the greater propensity of anaerobic conditions under the sheeting. $CO_2$ emissions would increase by a very small amount as a result of heap covering activities. Odour emissions may be increased at heap break-out as a result of anaerobic heap storage conditions.
**Key references:**
Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.
Chadwick, D. R. (2005). Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. *Atmospheric Environment,* 39, 787-799.
Chadwick, D.R., Matthews, R.A., Nicholson, R.J., Chambers, B.J. and Boyles, L.O. (2002). Management practices to reduce ammonia emissions from pig and cattle manure stores. In:

*Proceedings of the 10th International Conference of the FAO RAMIRAN Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture* (Eds. J. Venglovsky and G. Greserova), pp.219-223.

Sagoo, E., Williams, J.R., Chambers, B.J., Boyles, L., Matthews, R. and Chadwick, D.R. (2004). Integrated management practices to minimise losses and maximise crop nitrogen value of broiler litter. In: *Proceedings of the 11th International Conference of the FAO RAMIRAN Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture* (Eds. Bernal, M.P., Moral, R., Clemente, R. and Paredes, C.), Vol. 1, pp.249-252.

Defra project WA0716 - Management techniques to reduce ammonia emissions from solid manures.

## Method 63 – Use liquid/solid manure separation techniques

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ↓ | (↑↓) | (↑↓) | ~ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | × | × | × | ✓ | × | × | × |

**Description:** Use a separator to remove the suspended solids from slurry. This typically results in a 5-10% reduction in the volume of pig slurry and a 15-20% reduction in the volume of cattle slurry that needs to be stored and spread (Defra/EA, 2008).
**Rationale:** Separating the suspended solids from slurry means that the two manure streams can be handled separately. The solid fraction can be stored on a concrete pad or in a field heap, while the liquid fraction can be stored and transported/pumped to fields for land application. Separation enables greater flexibility in manure management and application timing.
**Mechanism for action:** Centrifuge, screw and drum separators reduce the amount of liquid manure to store; with the solid and liquid fractions being managed separately thereafter.
**Potential for applying the method:** This method is particularly applicable to farms with slurry that have outlying fields (to which slurry is rarely applied) and in helping farmers comply with the 250 kg/ha total N field limit in NVZs and as recommended in the Code of Good Agricultural Practice.
**Practicability:** The method usually involves a change in farm infrastructure, in addition to the cost of equipment purchase and maintenance etc. In some parts of England and Wales, capital grants are available for the purchase of slurry separators and associated infrastructure.
**Likely uptake:** Moderate, but could be high on large livestock farms to improve the logistics of slurry management.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Indoor Pigs | Costs based on the purchase of a slurry separator and provision of a concrete pad to store the solids, and are amortised. |
|---|---|---|---|
| Annual | 2,600 | 4,600 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by a small (<2%) amount, as there is less slurry to be handled and hence there is greater flexibility in application timing, and associated indirect $N_2O$ emissions. The overall effect on $NH_3$ and $N_2O$ emissions at the farm scale is uncertain.
**P:** Losses are likely to be reduced by a small amount due to improved logistics of manure management.
**FIOs and BOD:** Losses are likely to be reduced.
**Other Pollutants:** $CO_2$ emissions would be increased by a small amount through operation of the separation equipment.
**Key references:**
Defra (2009). *A Code of Good Agricultural Practice for Farmers, Growers and Land Managers*. The Stationery Office, Norwich, ISBN 978-0-11-243284-5.
Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.
Defra project WA0511 - An innovative approach to the treatment of farm effluent.
Defra project WA0507 - Quantifying factors which affect the fate of BOD from land applied wastes.

## Method 64 – Use poultry litter additives

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ↓ | ~ | ~ | ↓ | ↓↓ | ↑ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | × | × | × | × | × | × | ✓ | × |

**Description:** Add aluminium sulphate (Alum) to poultry litter during housing to reduce the pH of the litter; this will precipitate soluble P and reduce $NH_3$ emissions.

**Rationale:** Poultry litter contains 'high' concentrations of P and readily available (uric-acid and ammonium) N. Research has shown that P concentrations in surface runoff are closely related to the soluble P content of the manure. Alum additions to poultry litter precipitate P into a form that is not water-soluble. Also, Alum additions reduce $NH_3$ emissions from poultry litter which can result in heavier birds, better feed conversion efficiency and lower mortality.

**Mechanism for action:** Alum is applied to poultry litter at a rate equivalent to 5-10% by weight. For typical broiler operations growing 6 week-old birds, this is equivalent to adding 50-90 g Alum per bird. Aluminium (in Alum) reacts with P to form insoluble aluminium phosphate which is far less susceptible to soluble P loss in runoff. The reduction in $NH_3$ emissions is due to the acidity produced when Alum is added to the litter; the reduction in litter pH also causes pathogen numbers to decrease.

**Potential for applying the method:** This method is potentially applicable to all poultry operations that have 'dry' litter (e.g. broilers, breeders and turkeys).

**Practicability:** The method involves the application of Alum to new litter between each flock of birds. Alum (coarse powder/granules) can be applied using a range of 'small' fertiliser spreaders or litter 'de-caking' machines. To ensure that the birds do not consume the granules of Alum, it is best to incorporate the product into the litter.

**Likely uptake:** Low, due to costs and practicalities of application.

**Costs:**

| Total *cost* for farm system (£/farm) | Poultry | Costs based on Alum application to litter. |
|---|---|---|
| Annual | 1,800 | |

**Effectiveness:**

**N:** $NH_3$ emission reductions of around 70% have been reported from housing; and are also likely to be reduced during storage and following land spreading, as a result of the low litter pH. However, as a result of the higher readily available N content of the poultry litter $NO_3$ (plus ammonium and nitrite) leaching losses would be increased by a small amount (up to 20% of total N applied) and direct and indirect $N_2O$ emissions following land spreading. *Overall* manure N use efficiency would be increased and manufacture N inputs reduced.

**P:** Soluble P losses in surface runoff have been shown to be reduced by up to 80% (in the short-term).

**FIOs:** FIO losses would be reduced as a result of the low litter pH.

**Other pollutants:** $CO_2$ emissions would be increased by a very small amount through Alum management. Impacts on other pollutants are likely to be minimal.

**Key references:**

Moore, P.A., Jr, Daniel, T.C. and Edwards, D.R. (2000). Reducing phosphorus runoff and inhibiting ammonia loss from poultry manure with aluminium sulfate. *Journal of Environmental Quality,* 29, 37-49.

Shreve, B.R., Moore, P.A., Daniel, T.C., Edwards, D.R. and Miller, D.M. (1995). Reduction of phosphorus runoff from field-applied poultry litter using chemical amendments. *Journal of Environmental Quality,* 24, 106-111.

## Method 65 – Change from a slurry to solid manure handling system

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓ | ↓↓ | ↓↓ | ↓ | ↓↓ | ~ | ↓ | ↓ | ↓↓ | (↑) | ↓ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ |

**Description:** Change from a system where the manure from housed animals is collected as a liquid (i.e. slurry) to one where animals are kept on bedding (e.g. straw) to produce solid manure.
**Rationale:** Solid manures are more easily stored than slurries and present less risk of pollutant loss during and following land spreading. Straw use also encourages bacterial immobilisation of readily available nitrogen, resulting in a lower potential for $NH_3$ emissions during housing, storage and following land spreading
**Mechanism of action:** Sufficient bedding is provided in animal housing to soak up the liquid portion of excreta to produce a solid manure that can be stacked and does not flow under gravity. Manure is generally allowed to accumulate in the house throughout the production cycle and is generally followed by storage in field heaps or on an impermeable base and then spreading to land. FIOs decline during storage as a result of elevated heap temperatures. ‘Fresh’ FYM typically contains 20-25% of its total N content as readily available N compared with *c.*45% for cattle slurry and *c.*70% for pig slurry. Also, as a result of their higher dry matter content, solid manures can be spread on fields with a much lower risk of nutrients and FIOs entering watercourses in surface runoff or via field drains.
**Potential for applying the method:** This method is applicable to cattle/pig farms with housed stock that currently handle all or part of their manure as slurry. It is not applicable to sheep or poultry units as these do not produce slurry.
**Practicability:** Solid manures require a source of suitable bedding materials and are less-suited to regions where little straw is produced (e.g. southwest England and Wales). There will be additional labour requirements associated with managing straw in the animal house and handling FYM. Also, some buildings may not be suitable for conversion to a solid manure system.
**Likely Uptake:** Low, due to the high costs of building conversion and cost/limited availability of straw.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Indoor Pigs | Costs based on changing livestock buildings to a straw management system, purchase of straw and additional manure management activities, and are amortised. |
|---|---|---|---|
| Annual | 15,000 | 73,000 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 50% and direct and indirect $N_2O$ emissions, and $NH_3$ emissions at land spreading would also be reduced; as a result of the lower readily available N content of FYM. $NH_3$ emissions would be reduced during housing and storage; although there is some evidence of higher $NH_3$ emissions from FYM based pig housing than from slurry based slatted-floor housing. $N_2O$ emissions would be increased during FYM storage and reduced at land spreading; on balance $N_2O$ emissions would (probably) be increased.
**P:** Soluble and particulate P losses would be reduced because of lower runoff risks.
**FIOs and BOD:** Losses would be reduced as a result of FIO die-off and BOD reductions during solid manure storage.
**Other Pollutants:** $CH_4$ emissions would be lower from solid manure systems. $CO_2$ emissions would be increased by additional manure handling activities. Odour emissions would be lower.
**Key references:**
Chambers, B.J., Williams, J.R., Cooke, S.D., Kay, R.M., Chadwick, D.R. and Balsdon, S.L. (2003). Ammonia losses from contrasting cattle and pig manure management systems. In: *Agriculture, Waste and the Environment* (Eds. I. McTaggart and L. Gairns), The Scottish Agricultural College, pp.19-25.
Defra project CC0234 - Nitrous oxide emissions from slurry-based and straw-based animal production systems.
Defra project IS0214 - New integrated dairy production systems: specification, practical feasibility and ways of implementation.

Defra project WA0632 - Ammonia fluxes within solid and liquid manure management systems.
Defra project WT0706 - Benefits and pollution swapping: cross-cutting issues for Catchment Sensitive Farming Policy.

## Method 66 – Change from a solid manure to slurry handling system

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑↑ | ↑↑ | ↑↑ | ↑ | ↑↑ | ~ | ↑ | ↑ | ↑↑ | (↓) | ↑ | ↓ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | ✓ | × | × | × |

**Description:** Change from a system where the manure from housed animals is collected as a solid to one where animals are kept on a liquid (i.e. slurry) based system.

**Rationale:** Slurry-based systems have a greater risk of pollutant losses during and following land spreading. However, solid manures contain both aerobic (and anaerobic) micro-sites where $NH_4$-N can be nitrified to $NO_3$-N, providing a source of $NO_3$ for $N_2O$ emission (by denitrification). This can occur as the bedding material builds up in the animal house, and particularly once the bedding has been removed from the building for storage prior to land spreading. Slurry, on the other hand, is anaerobic (until the time it is spread onto land) and there is little or no $N_2O$ emission from slurry-based buildings/stores.

**Mechanism of action:** Converting from a solid manure system to one that is slurry-based gives little or no possibility for slurry $NH_4$-N to be converted into $NO_3$, until it is spread onto land. Hence, $N_2O$ emissions from housing and storage are lower from slurry-based systems than solid manure systems.

**Potential for applying the method:** This method is potentially applicable to those farms with housed stock that currently handle all or part of their manure as solid manure.

**Practicability:** Slurry-based systems will require storage facilities that a farmer would not necessarily have required for the storage of solid manure (e.g. a circular store, lagoon etc.). Pumps and slurry spreading equipment would be required, but less energy would be required to handle and spread slurry than solid manure. Also, existing building structures would need to be changed, with slatted flooring and slurry collection pits or new buildings constructed.

**Likely Uptake:** Low, due to the high costs of conversion and slurry storage provision. Additionally, changing to a slurry system is unlikely if the farm is located within an NVZ, where manure management regulations are much stricter for slurry than solid manures.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Indoor Pigs | Costs based on installation of cubicles and construction of a slurry storage tank, and are amortised. |
|---|---|---|---|---|---|---|
| Annual | 14,000 | 3,000 | 3,500 | 5,500 | 27,000 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be increased by up to 50% and direct and indirect $N_2O$ emissions, and $NH_3$ emissions at land spreading would also be reduced; as a result of the higher readily available N content of slurry. $NH_3$ emissions would be increased during housing and storage; although there is some evidence of lower $NH_3$ emissions from slurry based slatted-floor housing (compared with straw bedding). $N_2O$ emissions would be reduced during slurry storage and increased at land spreading; on balance $N_2O$ emissions would (probably) be reduced.

**P:** Soluble and particulate P losses would be increased because of higher runoff risks.

**FIOs and BOD:** Losses would be increased as a result of lower FIO die-off rates and BOD reductions in stored slurry.

**Other Pollutants:** $CH_4$ emissions would be increased from slurry compared with solid manure storage. $CO_2$ emissions would be reduced through manure management as slurry. Odour emissions would be higher.

**Key references:**

Chambers, B. J., Williams, J. R., Cooke, S. D., Kay, R. M., Chadwick, D. R. and Balsdon, S. L. (2003). Ammonia losses from contrasting cattle and pig manure systems. In: *Agriculture, Waste and the Environment,* (Eds. I. McTaggart and L. Gairns), The Scottish Agricultural College, pp.19-25

Del Prado, A. and D. Scholefield. (2008). Use of SIMSDAIRY modelling framework system to compare the scope on the sustainability of a dairy farm of animal and plant genetic-based improvements with management-based changes. *Journal of Agricultural Science,* 146, 1-17.
Defra project IS0214 - New integrated dairy production systems: specification, practical feasibility and ways of implementation.
Defra project WA0632 - Ammonia fluxes within solid and liquid manure management systems.
Defra project WA0646 - Fate of N following land application of solid and liquid pig manures.
Defra project WT0706 - Benefits and pollution swapping: cross-cutting issues for Catchment Sensitive Farming Policy.

## Method 67 – Manure Spreader Calibration

**Direction of change for target pollutants.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ~ | ~ | ~ | ↓ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Determine the actual rate and evenness of manure (slurry and solid manure) applied by a spreader, and adjust it to obtain the desired agronomic rate.
**Rationale:** The even application of manure ensures that all parts of the field receive similar amounts of total and crop available nutrients.
**Mechanism for action:** The uneven spreading of manure can result in a variable supply of nutrients to the crop that is difficult to take into account as part of the farm nutrient management plan; so farmers tend to fertiliser to meet crop nutrient needs on under-applied areas. Over application of N results in higher post-harvest soil mineral N levels and greater potential for $NO_3$ leaching losses over-winter. Runoff risks would also be reduced.
**Potential for applying the method:** This method is applicable to all farms where manure is applied.
**Practicability:** Spreader calibration needs (ideally) to be repeated whenever there is a significant change in manure characteristics, or when a different application rate is used.
**Likely uptake:** Moderate
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on annual calibration and associated management time. |
|---|---|---|---|---|---|---|---|---|
| Annual | 250 | 250 | 200 | 300 | 350 | 350 | 100 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses and associated indirect $N_2O$ emissions would be reduced by a small (<5%) amount. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**P:** Losses would be reduced by a small amount from slurry applications.
**Other pollutants:** Impacts on other pollutants are likely to be minimal.

## Method 68 – Do not apply manure to high-risk areas

**Direction of change for target pollutants where manure is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ↓ | ~ | ↓ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Do not apply manure to field areas where there is a high-risk of direct loss to watercourses. For example, directly adjacent to a watercourse, borehole or road culvert, to shallow soils over fissured rock or widely cracked soils over field drains, to areas with a dense network of open (surface) drains, spring lines or wet depressions (flushes).
**Rationale:** These areas have a high-risk of rapid transport of manure-borne pollutants to watercourses, so manure applications (particularly of slurry) should be avoided wherever possible.
**Mechanism of action:** The method applies to areas where there is a high degree of hydrological connectivity between the field and watercourse; avoiding applications to such areas reduces the risk of pollutant transfer. The Code of Good Agricultural Practice advises that slurry and solid manures should not be spread within 10 m of a watercourse or within at least 50 m of a spring, well or borehole (used to supply water for human consumption or use in farm dairies). And in NVZs these rules are mandatory.
**Potential for applying the method:** This method is applicable to all farms applying manure, where there is a high degree of hydrological connectivity between the field and watercourse; these situations are most likely to be present in the wetter part of England (i.e. the west and south-west) and Wales.
**Practicability:** Although most hydrologically well-connected areas are likely to be easily identified, some old, but still functioning, drainage networks may not be known to the farmer (e.g. open surface drains, wet drained depressions, spring lines).
**Likely Uptake:** Moderate to high.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on the additional time needed to plan manure management activities to avoid high-risk areas. |
|---|---|---|---|---|---|---|---|---|
| Annual | 130 | 130 | 100 | 150 | 180 | 180 | 30 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses and indirect and direct $N_2O$ emissions would be reduced by a small (<1%) amount.
**P:** Soluble and particulate P losses would be reduced by a small (<2%) amount.
**FIOs and BOD:** Losses would be reduced by a small amount.
**Other Pollutants:** Impacts on other pollutants are likely to be minimal.
**Key references:**
Defra (2009). *A Code of Good Agricultural Practice for Farmers, Growers and Land Managers*. The Stationery Office, Norwich ISBN 978-0-11-243284-5.
Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.
Defra project NT1835 - The effects of manure application to land on N loss pathways to air and water.

## Method 69 – Do not spread slurry or poultry manure at high-risk times

**Direction of change for target pollutants were manure is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓ | ↓↓ | ↓↓ | ↓↓ | ↓↓ | ~ | ↓ | ↓ | ↑ | ↓ | ↑ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | × | ✓ | ✓ | × | × | × | × |

**Description:**

- Do not apply slurry or poultry manure to fields at times when there is a high-risk of surface runoff e.g. in winter when soils are 'wet' or frozen hard, or when heavy rain is expected in the next few days.
- Do not apply slurry or poultry manure to fields at times when there is a high-risk of rapid percolation to field drains e.g. in winter and spring when soils are 'wet'.
- Do not apply slurry or poultry manure to fields late in the growing season (i.e. autumn/early winter) when there is no crop to utilise the added N.

**Rationale:** Slurries and poultry manures have 'high' readily available N contents (>30% of total N). Avoiding the application of these materials at times when surface runoff or rapid preferential flow to field drains is likely to occur reduces water pollution risks. Also, avoiding application in autumn/early winter will help to reduce over-winter $NO_3$ leaching losses.

**Mechanism of action:** The method reduces the likelihood of recently applied slurry/poultry manure causing water pollution, via surface runoff or preferential flow in soil cracks to field drains. Also, slurry/ poultry manure applications in autumn/early winter add readily available N to the soil at a time when there is little N uptake by crops and will increase over-winter $NO_3$ leaching losses, particularly from nitrate 'leaky' sandy and shallow soils. Applications later in winter/spring present less of a risk, as there is less opportunity for $NO_3$ to be leached before crop growth commences.

**Potential for applying the method:** All farms producing (or importing) slurry and poultry manure. High-risk times will be most frequent in high rainfall areas, on sloping land and where soils are artificially drained (there are around 6 million hectares of drained soils in England and Wales).

**Practicability:** The method will be most applicable to farms that have sufficient slurry storage capacity to allow a choice of land application timing. However, even where storage is adequate for normal conditions, exceptional weather (and/or poor planning) can create a situation where stores are full during a high-risk period, so that land spreading is the only option.

**Likely Uptake:** Moderate to high.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Comb Crops | Comb/ Roots | Costs based on additional time to plan manure management activities. |
|---|---|---|---|---|
| Annual | 130 | 180 | 180 | |

**Effectiveness:**

**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by up to 20% of total manure N applied and associated indirect $N_2O$ emissions. However, $NH_3$ emissions would be increased by a small amount, as a result of more slurry being applied to dry (grassland) soils in summer. *Overall* manure N use efficiency would be increased and manufactured fertiliser N use reduced.

**P:** Soluble/particulate P losses would be reduced by up to 50%.

**FIOs and BOD:** Losses would be reduced as a result of lower runoff risks.

**Other pollutants:** $CH_4$ emissions would be increased by a small amount through the longer duration of storage. Impacts on other pollutant losses are likely to be minimal.

**Key references:**

Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.

Withers, P.J.A., Davidson, I.H. and Roy, R.H. (2000). Prospects for controlling non-point phosphorus losses to water: A UK perspective. *Journal of Environmental Quality*, 29, 167-175.

Lord, E.I., Shepherd, M.A., Silgram, M, Goodlass, G., Gooday, R, Anthony, S.G., Davison, P. and Hodgkinson, R. (2007). *Investigating the Effectiveness of NVZ Action Programme Measures: Development of a Strategy for England.* Report for Defra Project NIT18.

Thorman, R. E., Sagoo, E., Williams, J. R., Chambers, B. J., Chadwick, D. R., Laws, J.A. and Yamulki, S. (2007). The effect of slurry application timings on direct and indirect $N_2O$ emissions from free draining grassland soils. In. *Proceedings of the 15th Nitrogen Workshop*, Spain, pp. 297-299.
Defra project ES0106 - Developing integrated land use and manure management systems to control diffuse nutrient loss from drained clay soils: BRIMSTONE-*NPS*.
Defra project ES0115 - Optimising slurry application timings to minimise nitrogen losses: OPTI-*N*.

## Method 70 – Use slurry band spreading application techniques

**Direction of change for target pollutants where slurry is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓↓ | (↑) | ~ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | × | × | × | × | × |

**Description:** Apply slurry to land in a series of narrow bands (typically 5 cm in width at a spacing of 20-30 cm). For applications with *trailing hose* equipment, the slurry is delivered via hoses just above the soil surface. For applications with *trailing shoe* equipment, slurry is delivered just behind a forward facing 'shoe', which ensures that the slurry is delivered directly to the soil surface below the grass sward/crop canopy.
**Rationale:** $NH_3$ volatilisation occurs from the surface of the applied slurry. Reducing the overall surface area of slurry, by application in narrow bands, will lead to a reduction in $NH_3$ emissions (provided that slurry infiltration into the soil is not delayed by the increased hydraulic loading rate on the slurry bands compared with broadcast spreading). In addition, if slurry is placed beneath the crop canopy, the canopy will also provide a physical barrier to reduce the rate of $NH_3$ loss.
**Mechanism of action:** *Trailing hose* – slurry is placed in narrow bands on the soil surface, via trailing hoses. As $NH_3$ volatilisation occurs from the slurry surface, applying the same volume of slurry in narrow bands rather than as an overall (broadcast) surface cover, will reduce the surface area to volume ratio of the applied slurry, reducing the area from which emission can occur. However, band spreading also increases the hydraulic loading rate per unit area, which can on some occasions (usually for high dry matter content slurries) impede infiltration into the soil. Also, for taller crops slurry will be delivered below the canopy, which will reduce air movement and temperatures at the emitting surface, thereby reducing $NH_3$ emissions.
*Trailing shoe* – slurry is placed in narrow bands on the soil surface, with a reduced surface area and increased hydraulic loadings as for the trailing hose above. Where a crop canopy is present, reduced air movement and temperatures at the soil surface, will also reduce $NH_3$ emissions.
**Potential for applying the method:** This method is applicable for all slurry applications to grassland (for which the trailing shoe is designed) and arable land (for which the trailing hose is designed). Applying slurry beneath the crop canopy (grassland or arable) avoids contamination of the crop with slurry and reduces odour emissions. For grassland, this reduces the required period between slurry application and grazing or silage harvest, extending the window of opportunity for slurry application. For arable crops, this extends the window for slurry application later into the spring when crop height would normally exclude conventional surface broadcast slurry application (because of crop damage and contamination risks). Trailing hose and trailing shoe equipment also deliver more uniform slurry applications, in comparison with conventional broadcast equipment which can be affected by wind and relies on the even matching of lapped spreading widths.
**Practicability:** Band spreading is generally a slower operation (with lower application rates) than conventional surface broadcast slurry application, so there may be some issues with labour availability. Many trailing hose slurry applicators have a boom width of less than 24m (although 24m booms are available), so for combinable crops with greater tramline spacings than the applicator boom width, slurry application will require travelling on the crop between tramlines, which may result in some crop damage (depending on growth stage at the time of application). On sloping land, the higher centre of gravity and additional width of some machines can increase the risk of 'tipping over'.
**Likely Uptake:** Moderate, due to investment cost of new machines; although 'high' fertiliser N prices are encouraging increased use, particularly via contractors.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Costs based on additional contractor charges (and do not take into account improved crop N recovery). |
|---|---|---|---|---|---|
| Annual | 1,500 | 400 | 250 | 1,700 | |

**Effectiveness:**
**N:** $NH_3$ reduction efficiencies for slurry spreading are typically 30% for trailing hose and trailing shoe equipment when the grass is short, and 60% for trailing shoe equipment when the grass is long (>10 cm) compared with broadcast application; although reductions can vary from 0-90%. Reducing $NH_3$ emissions from applied slurry will increase the potential for $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions. *Overall* manure N use efficiency would be increased and manufactured fertiliser N use reduced.
**Other Pollutants:** $CO_2$ emissions would be increased by a small amount. Odour emissions would be reduced. Impacts on other pollutants are likely to be minimal.
**Key references:**
Misselbrook, T. H., Smith, K. A., Johnson, R. A. and Pain, B. F. (2002). Slurry application techniques to reduce ammonia emissions: Results of some UK field-scale experiments. *Biosystems Engineering,* 81, 313-321.
Smith, K. A., Jackson, D. R., Misselbrook, T. H., Pain, B. F. and Johnson, R. A. (2000). Reduction of ammonia emission by slurry application techniques. *Journal of Agricultural Engineering Research,* 77, 277-287.
Williams, J.R., Chambers, B.J., Smith, K.A., Misselbrook, T.H. and Chadwick, D.R. (2000). Integration of farm manure nitrogen supply within commercial farming systems. In: *Proceedings of the Ninth International Conference of the FAO ESCORENA Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture: Technology Transfer* - RAMIRAN 2000 (Ed. F. Sangiorgi), University of Milan, pp.263-268.
Defra project ES0115 - Optimising slurry application timings to minimise nitrogen losses: OPTI-*N*.
Defra project CC0254 - Nitrous oxide from slurry applied to grass.
Defra project WA0637 - Denitrification and nitrous oxide emissions following new slurry application techniques for reducing ammonia losses.
Defra project KT0105 - MANure Nutrient Evaluation Routine. MANNER-*NPK*.

## Method 71 – Use slurry injection application techniques

**Direction of change for target pollutants where slurry is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ~ | ~ | ~ | ~ | ~ | ↓↓↓ | (↑) | ~ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✗ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ |

**Description:** Deliver slurry to the soil in shallow surface slots (5-10 cm depth, at 20-25 cm spacing) which are cut by preceding discs, or much deeper into the soil (*c.*25 cm depth) where slurry placement is behind a tine.

**Rationale:** $NH_3$ volatilisation occurs from the surface of applied slurry. Reducing (for open slot shallow injection) or eliminating (for closed slot deep injection) the surface area of applied slurry reduces $NH_3$ emissions.

**Mechanism of action:** Placing slurry in narrow surface slots, via shallow injection, greatly reduces the exposed slurry surface area. Placing slurry deeper into the soil behind cultivation tines, as with deep injection, eliminates the exposed slurry surface area. $NH_4$-N in the slurry placed in the soil, will also be fixed on to clay particles, further reducing the potential for $NH_3$ emission.

**Potential for applying the method:** Shallow injection is most suited to grassland, where field slopes and/or stoniness are not limiting (estimated to rule out *c.*30% of agricultural land), and on arable land prior to crop establishment. Deep injection is most suited to arable land prior to crop establishment; current deep injector designs are generally not suited to application to growing crops, where crop damage can be great. Slurry injection will reduce crop contamination and odour emissions, and can (to some extent) increase the window of spreading opportunity compared with surface broadcast application. Also, slurry is applied much more uniformly across the entire application width in comparison with conventional broadcast equipment which can be affected by wind and relies on the even matching of lapped spreading widths.

**Practicability:** Work rates are slower (particularly for deep injection) than for conventional surface broadcast application. Also, injection equipment has a 'high' draught force, so large tractors are required (particularly for deep injection) and under hot and dry conditions can result in significant grassland sward damage. Shallow injection (particularly of dilute slurries) on sloping land can result in runoff along the injection slots. With deep injection, it is important to avoid slurry application directly into gravel backfill over field drains.

**Likely Uptake:** Moderate, due to investment costs of new machinery; although 'high' fertiliser N prices are encouraging increased use, particularly via contractors.

**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Costs based on additional contractor charges for shallow injection (and do not take into account improved crop N recovery). |
|---|---|---|---|---|---|
| Annual | 2,200 | 600 | 400 | 2,500 | |

**Effectiveness:**

**N:** Deep injection would typically achieve >90% reduction and shallow injection around a 70% reduction in $NH_3$ emissions compared with surface broadcast application. Reducing $NH_3$ emissions from applied slurry will increase the potential for $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions. *Overall* crop N use efficiency would be increased and manufactured fertiliser N use reduced.

**Other Pollutants:** $CO_2$ emissions would be increased by a small amount. Odour emissions would be reduced. Impacts on other pollutants are likely to be minimal.

**Key references:**

Misselbrook, T. H., Smith, K. A., Johnson, R. A. and Pain, B. F. (2002). Slurry application techniques to reduce ammonia emissions: Results of some UK field-scale experiments. *Biosystems Engineering,* 81, 313-321.

Smith, K. A., Jackson, D. R., Misselbrook, T. H., Pain, B. F., and Johnson, R. A. (2000). Reduction of ammonia emission by slurry application techniques. *Journal of Agricultural Engineering Research,* 77, 277-287.

Williams, J.R., Chambers, B.J., Smith, K.A., Misselbrook, T.H. and Chadwick, D.R. (2000). Integration of farm manure nitrogen supply within commercial farming systems. In: *Proceedings of the Ninth International Conference of the FAO ESCORENA Network on Recycling of Agricultural, Municipal and Industrial Residues in Agriculture: Technology Transfer* - RAMIRAN 2000 (Ed. F. Sangiorgi), University of Milan, pp.263-268.

Defra project CC0254 - Nitrous oxide from slurry applied to grass.

Defra project ES0115 - Optimising slurry application timings to minimise nitrogen losses: OPTI-N.

Defra project WA0637 - Denitrification and nitrous oxide emissions following new slurry application techniques for reducing ammonia losses.

Defra project KT0105 – MANure Nutrient Evaluation Routine. MANNER-*NPK*.

## Method 72 – Do not spread FYM to fields at high-risk times

**Direction of change for target pollutants where FYM is applied.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ↓ | ~ | ↓ | ~ | ~ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | × | × |

**Description:** Avoid spreading (straw-based) FYM to fields at times when there is a high-risk of surface runoff or drainflow, for example, where rain falls shortly after applying FYM to 'wet' soils.
**Rationale:** There is a risk of pollution if solid manures are spread under conditions where heavy rain following application could transport nutrients and FIOs to surface water systems.
**Mechanism of action:** As FYM is stackable and has a lower moisture content than slurry, it will not add sufficient water to the soil to initiate surface runoff or preferential flow to field drains; pollutants will only be transported to watercourses when there is heavy rainfall following application. 'Fresh' FYM has a higher content of readily available N and FIOs, and generally presents a greater risk of pollution than 'old' FYM that has been stored for several months. High-risk times will be most frequent in winter when soils are 'wet', particularly in high rainfall areas.
**Potential for applying the method:** The method is applicable to all livestock farms producing (or importing) FYM. The risks of surface runoff are greatest on sloping land on medium/heavy soils and where soils are artificially drained.
**Practicability:** Provided that the farm has an FYM storage area or the FYM can be left in the animal house until spreading conditions improve, there are few limitations to adopting this method.
**Likely Uptake:** High
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Costs based on additional time needed to plan manure management activities. |
|---|---|---|---|---|---|---|
| Annual | 130 | 130 | 100 | 150 | 150 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by a small (<5%) amount and associated indirect $N_2O$ emissions. *Overall* crop N use efficiency would be increased (by a small amount) and manufactured fertiliser N use reduced.
**P:** Losses in runoff would be reduced by a small (up to 5%) amount.
**FIOs and BOD:** Losses would be reduced by a small amount.
**Other Pollutants:** Impact on other pollutants are likely to be minimal.
**Key references:**
Chambers, B.J., Lord, E.I., Nicholson, F.A. and Smith, K.A. (1999). Predicting nitrogen availability and losses following application of organic manures to arable land: MANNER. *Soil Use and Management,* 15, 137-143.
Chambers, B. J., K. A. Smith, and B. F. Pain. (2000). Strategies to encourage better use of nitrogen in animal manures. *Soil Use and Management*, 16, 157-161.
Defra project OC8906 - Nitrogen leaching risk from livestock manures.

## Method 73 – Incorporate manure into the soil

**Direction of change for target pollutants on the area where manure is soil incorporated.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↑ | ↑ | ↑ | ↓ | ↓ | ~ | ↓ | ↓ | ↓↓ | (↑) | ~ | ~ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | × |

**Description:** Incorporate manure rapidly into the soil using a plough, discs or tines.
**Rationale:** The rapid soil incorporation of manure can reduce pollutant losses in runoff and also reduce the exposed surface area of manure from which $NH_3$ emissions can occur.
**Mechanism of action:** Incorporation of manure can reduce the detachment and entrainment of manure particles by increasing surface roughness, promoting infiltration and preventing the exposure of manure to the hydrological forces of raindrop impact, surface runoff and drainflow loss. The rapid soil incorporation of manure (e.g. within 6 hours of spreading for slurry and 24 hours for solid manures) also reduces $NH_3$ volatilisation by reducing exposure to the air. $NH_3$ emission reductions depend on the time period between manure application and soil incorporation, and also on the cultivation technique employed. There is a considerable decrease in the abatement efficiency achieved if soil incorporation is delayed; incorporation as soon as possible after application should be the aim.
**Potential for applying the method:** Applicable to tillage land crops and reseeded grassland.
**Practicability:** In most circumstances, this method can be carried out as part of normal field preparations, although there may be a need to reschedule field operations to synchronise manure spreading and rapid soil incorporation activities. Where contractors are carrying out the manure spreading, it will require a degree of co-ordination between the contractor and farmer. If the rapid cultivation policy damages soil structure, this may compromise crop yields and result in applied fertiliser and organic manure N being poorly utilised by crops, and increase the risks of $NO_3$ leaching over the next winter drainage period.
**Likely Uptake:** Moderate to high. The soil incorporation of slurry and poultry manure where applications are made to uncropped land, as soon as possible and within 24 hours at the latest, is a mandatory requirement in NVZs.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Costs based on an additional cultivation (and do not take into account improved crop N recovery). |
|---|---|---|---|---|---|---|
| Annual | 350 | 250 | 1,700 | 7,000 | 6,000 | |

**Effectiveness:**
**N:** $NH_3$ emissions would be reduced by around 60% where soil incorporation by ploughing occurred 6 hours after slurry application, and around 40% where FYM and 70% where poultry manure was incorporated by ploughing after 24 hours. $NO_3$ (plus ammonium and nitrite) leaching losses (especially where the manure was applied in the autumn) would be increased and direct (probably) and indirect $N_2O$ emissions. *Overall* manure N use efficiency would be increased and manufactured fertiliser N inputs reduced.
**P:** Losses in surface runoff would be reduced.
**FIOs and BOD:** FIO and BOD losses would be reduced.
**Other Pollutants:** Impacts on other pollutants are likely to be minimal.
**Key references:**
Huijsmans, J. F. M., and de Mol, R. M. (1999). A model for ammonia volatilization after surface application and subsequent incorporation of manure on arable land. *Journal of Agricultural Engineering Research,* 74, 73-82.
Webb, J., Anthony, S. G., and Yamulki, S. (2006). Validating the MAVIS model for optimizing incorporation of litter-based manures to reduce ammonia emissions. *Transactions of the Asabe,* 49, 1905-1913.
Defra project NT2001 - Improved manure management: nutrient demonstration farms.

Defra project NT2008 - Nitrogen value of solid manures: effect of contrasting manure management practices.
Defra project WA0716 - Management techniques to reduce ammonia emissions from solid manures.
Defra project KT0105 - MANure Nutrient Evaluation Routine. MANNER-*NPK*.

## Method 74 – Transport manure to neighbouring farms

**Direction of change for target pollutants on farm exporting manure.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓ | ↓↓ | ↓↓ | ↓↓ | ↓↓ | ~ | ↓↓ | ↓↓ | ↓↓ | ↓↓ | ↓ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | × | × | × | × | ✓ | × | ✓ | × |

**Description:** For farms in NVZs where livestock manure N loadings exceed 170 kg total N/ha each year organic manure N in excess of this limit needs to be transported to farms that do not have surplus N (or a grassland derogation applied for, stocking rates reduced etc). This situation is most likely on dairy and pig farms (usually as slurry), and poultry farms (i.e. layer manure and poultry litter).
**Rationale:** Where there is a surplus of nutrients, manures can be exported to neighbouring farmland with spare livestock manure N capacity. As a result, exporting farms are able to 'balance' nutrients inputs with the capacity of crops to utilise those nutrients.
**Mechanism of action:** Nutrients are removed and exported to neighbouring farmland. This reduces the nutrient load on the farm and thereby reduces the risk of diffuse pollution from that farm. The export of manure should also enable the remaining manure to be managed in a more integrated way i.e. there will be less pressure to spread manures during high-risk periods and to better time applications in relation to crop demand.
**Potential for applying the method:** The method is most likely to be applicable to dairy, indoor pig and poultry farms.
**Practicability:** The method is reasonably easy to implement where receiving farm holdings are in close proximity (e.g. within 5-20 km).
**Likely Uptake:** Low/moderate on dairy farms and moderate/high on pig/poultry farms within NVZs. Low outside NVZ areas.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Indoor Pigs | Poultry | Costs based on the need to transport 25% of dairy slurry and all pig slurry/poultry manure 5-10 km. |
|---|---|---|---|---|
| Annual | 2,200 | 16,000 | 7,000 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced on the exporting farm (by up to 10% on the dairy farm and up to 50% of pig/poultry farms) and increased (to a lesser extent) on the receiving farm with capacity to accommodate the excess manure. $NH_3$ and direct and indirect $N_2O$ emissions would be reduced on the exporting farm.
**P:** Losses would be reduced on the exporting farm.
**FIOs and BOD:** Losses would be reduced on the exporting farm.
**Other Pollutants:** $CH_4$ emissions would be reduced on the exporting farm. $CO_2$ emissions would be increased by a small amount as a result of manure transport. Odour emissions may be increased as a result of manure transport. Biosecurity issues need to be considered.
**Key references:**
Defra/EA (2008). *Guidance for Farmers in Nitrate Vulnerable Zones*. Defra leaflets PB12736 a to i.

Fealy, R. (2008). Energy use and nutrient values in relation to manure transport distances. Proceedings 642. *International Fertiliser Society*, York, UK.

## Method 75 – Incinerate poultry litter for energy recovery

**Direction of change for target pollutants on combinable/root crop farm receiving poultry litter.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓ | ↓↓ | ↓↓ | ↓ | ↓ | ~ | ↓ | ↓ | ↓↓ | ↓↓ | ↓ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | × | × | × | ✓ | × | × | × | × |

**Description:** Transport poultry litter to an incinerator where it is burnt for energy recovery.
**Rationale:** Manure nutrients and FIOs are removed from the farm as a source of diffuse pollution.
**Mechanism of action:** Exporting the manure from the farm removes the source of pollution, with the ash (generally) returned to other farmland as a P and K fertiliser, where there is a requirement for these nutrients.
**Potential for applying the method:** The method is only applicable to poultry litter and some ‘dry’ layer manures. The moisture content of straw-based FYM is too high for incineration.
**Practicability:** Applicability is dictated by the availability of suitable incineration facilities within an acceptable distance of broiler/turkey farms (generally <100 km).
**Likely Uptake:** Currently, *c*.30% of broiler and turkey litter is sent for incineration in England.
**Costs:**

| Total *cost* for farm system (£/farm) | Comb/ Roots | Costs based on the need to replace poultry litter nutrients with manufactured fertiliser inputs. |
|---|---|---|
| Annual | 4,500 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses and ammonia emissions would be reduced, and direct and indirect $N_2O$ emissions.
**P:** Losses would be reduced.
**FIOs and BOD:** Losses would be reduced.
**Other Pollutants:** $CO_2$ emissions would be increased as a result of poultry litter transport (plus emissions during incineration), however, energy would be produced during incineration. $CH_4$ emissions would be reduced (by a small amount) as litter would not be stored before land spreading.

## Method 76 – Fence off rivers and streams from livestock

**Direction of change for target pollutants in grazed fields with streams.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ~ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | × | × | × | × | × | × |

**Description:** Erect stock-proof fences in grazing fields and on trackways adjoining rivers and streams.
**Rationale:** Trampling by livestock can erode river/stream banks and increase sediment inputs to watercourses. Livestock can also add pollutants directly by urinating and defecating into the water. Preventing access eliminates this source of pollution.
**Mechanism of action:** Livestock, particularly cattle, can cause severe damage to river and stream banks when attempting to gain access to drinking water. The vegetative cover is destroyed and the soil badly poached, leading to erosion of the bank and increased transport of soil particles and associated nutrients into watercourses. Livestock also add nutrients and FIOs by defecating and urinating directly into the water. Fencing to prevent bank access eliminates this source of pollution.
**Potential for applying the method:** This method is applicable to all farms with grazing livestock and river/stream banks. Benefits will be greatest on farms with large cattle or sheep numbers. The method is not applicable to outdoor pigs, as these are securely fenced and do not have direct access to rivers or streams.
**Practicability:** The method is less applicable to upland beef/sheep farms with extensive areas of rough grazing and considerable lengths of unfenced river/stream banks. There is likely to be a need to provide an alternative source of drinking water. This method will be most effective when combined with Method 77 – ‘construct bridges for livestock crossing rivers/streams’ (if applicable).
**Likely Uptake:** Moderate. There are capital grants available for fencing off streams and rivers in England Catchment Sensitive Farming Delivery Initiative (ECSFDI) priority catchments. The fencing of watercourses is also supported by Higher Level Scheme (HLS) funding in England and Tir Gofal funding in Wales.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Costs are based on provision of standard fencing and water troughs and are amortised. |
|---|---|---|---|---|---|
| Annual | 2,000 | 1,000 | 1,300 | 2,000 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) losses would be decreased by a small (<2%) amount.
**P:** Particulate/soluble P and associated sediment losses would be reduced by a small (up to 5%) amount.
**FIOs and BOD:** Losses would be reduced by a small (up to 5%) amount.
**Other Pollutants:** $CO_2$ emissions would be increased by a very small amount through fencing/water trough installation. Impacts on other pollutants are likely to be minimal.
**Key references:**
Defra project ES0126 - Integrated Catchment Management at Whittle Dene - Phase II.

## Method 77 – Construct bridges for livestock crossing rivers/streams

**Direction of change for target pollutants in grazed fields with river/stream crossings.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↑ | ~ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | × | × | × | × | × | × |

**Description:** Construct bridges to allow livestock and vehicles to cross rivers and streams without damaging the banks, and to prevent animals urinating and defecating directly into the water.
**Rationale:** Where livestock ford rivers and streams, they can erode banks, disturb the stream bed and increase inputs of sediment to watercourses. Stock can also add pollutants directly by urinating and defecating into the water. Provision of bridges removes the need for fording watercourses and eliminates this source of pollution.
**Mechanism of action:** Trampling by livestock and damage from wheeled traffic will cause sediment loss on either side of the fording position and stir up sediment on the river/stream bed. This will increase the transport of sediment and associated nutrients downstream; although this will be less of a problem where there is a coarse, stony river bed. Also, livestock may defecate and urinate directly into the watercourse, providing a direct input of nutrients and FIOs. Providing bridges to avoid the need for animals (and traffic) to enter the stream will eliminate this source of pollution.
**Potential for applying the method:** This method is applicable to all livestock farms where there are stream crossings without bridges, and particularly dairy farms where cows are typically moved between the fields and milking parlour twice a day. This method will be most effective when combined with Method 76 – 'fence off rivers and streams from livestock'.
**Practicability:** There are few circumstances that would limit the adoption of this method, although it would be less practical on upland farms with extensive areas of rough grazing and many river/stream crossing points.
**Likely Uptake:** Moderate**.**
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Costs based on the construction of two bridges per farm and are amortised. |
|---|---|---|---|---|
| Annual | 1,200 | 1,000 | 1,500 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) losses would be reduced by a small (<2%) amount. There would be a small increase in $NH_3$ emissions from urine deposition on the impermeable (bridge) surface.
**P:** Particulate/soluble P and associated sediment losses would be reduced by a small (up to 5%) amount.
**FIOs and BOD:** Losses would be reduced by a small (up to 5%) amount.
**Other Pollutants:** $CO_2$ emissions would be increased by a small amount through bridge construction.
**Key references:**
Defra project ES0126 - Integrated Catchment Management at Whittle Dene - Phase II.

## Method 78 – Re-site gateways away from high-risk areas

**Direction of change for target pollutants in fields with gates in high-risk areas.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | × | ✓ |

**Description:** Move gateways located in high-risk surface runoff areas, such as at the bottom of a slope and near to a watercourse, to lower-risk areas on upper slopes.
**Rationale:** Many fields have gateways located at the bottom of a slope and near to a watercourse. Increased activity occurs around gateways, including trampling by livestock (particularly on dairy farms) and compaction by machinery. Repositioning the gateway would decrease the potential for sediment and associated nutrient (and FIOs from grazed grass fields) losses, by reducing hydrological connectivity.
**Mechanism of action:** A gateway at the bottom of a slope provides a break in the field boundary which might otherwise retain surface runoff within the field. In addition to the poaching and compaction that occurs around gateways, ruts from tractor wheelings and animal tracks tend to converge on these points and channel surface runoff to these positions. Re-siting gateways away from the lower boundary of fields lessens the risk of surface runoff transporting sediment, associated nutrients and FIOs out of sloping fields and directly into watercourses or onto roads etc.
**Potential for applying the method:** This method is applicable to all farming systems on sloping land, with gateways in high runoff risks, areas and is relatively easy to implement.
**Practicability:** Re-locating gates from high-risk to lower-risk areas should be practicable on most fields in sloping areas. Farmers may be reluctant to re-locate gateways, but if it improves opportunities for access, then it may be seen as advantageous, particularly in wet years. Practicability will be reduced where new tracks have to be constructed in addition to new gateways.
**Likely Uptake:** Low to moderate. There are capital grants available for moving and resurfacing gateways in England Catchment Sensitive Farming Delivery Initiative (ECSFDI) priority catchments.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Outdoor Pigs | Hort | Costs based on the relocation of gateways in approximately one third of fields and are amortised. |
|---|---|---|---|---|---|---|---|---|---|
| Annual | 1,600 | 1,000 | 900 | 1,200 | 4,000 | 4,000 | 450 | 150 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses would be reduced by a small (<1%) amount and associated indirect and direct $N_2O$ emissions.
**P:** Particulate/soluble P and associated sediment losses would be reduced by up to 10%.
**FIOs and BOD:** Losses would be reduced by a small (<1%) amount from grazed grassland fields.
**Other Pollutants:** $CO_2$ emissions would be increased by a small amount through gateway relocation. Impacts on other pollutants are likely to be minimal.

## Method 79 – Farm track management

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ~ | ↓ | ~ | ↑ |

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:**
- Create well-drained tracks with appropriate surfaces;
- Avoid routes with steep slopes;
- Improve track surfaces and repair any damage promptly;
- Provide good drainage and divert runoff to adjacent grassed areas, soakaways or swales;
- Avoid directing runoff towards bare soil, roads or watercourses.

**Rationale:** Farm tracks are used to transport vehicles and livestock on a regular basis (especially on dairy farms) and can become 'rutted' very quickly. On sloping land in wet conditions, these ruts form channels and that generate significant volumes of surface runoff. Also, waterlogged tracks can cause problems to livestock, including foot, mastitis and teat and udder damage. Improving track drainage and diverting surface runoff to adjacent grass, soakaways or swales can reduce the mobilisation and transport of pollutants.
**Mechanism for action:** Tracks can quickly become waterlogged in wet conditions. On sloping land, surface runoff can be generated mobilising sediment and manure-borne pollutants. Constructing tracks from appropriate materials can improve drainage and reduce runoff volumes. Cross drains and soakaways reduce the energy of overland flow, reduce pollutant mobilisation and increase the opportunity for the retention of mobilised pollutants. The location and route of tracks is also important; following contours and avoiding steep slopes can minimise concentrated flows and reduce the risk of track and adjacent field erosion.
**Potential for applying the method:** The method is applicable to all farms that have farm tracks and is most applicable to dairy farms on steeply sloping land where the animals are moved regularly.
**Practicability:** Track maintenance and repair requires time and investment. Changing track routes to avoid steep slopes or erodible soils is less likely to occur due to cost and land use implications.
**Likely uptake:** Moderate. There is a financial and welfare incentive to maintain and/or improve existing tracks. In England Catchment Sensitive Farming Delivery Initiative (ECSFDI) priority catchments, there are capital grants available for installing livestock and farm machinery tracks, cross drains, sediment traps and swales.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on installing sumps and maintaining silt traps, and are amortised. |
|---|---|---|---|---|---|---|---|---|
| Annual | 200 | 200 | 150 | 200 | 200 | 250 | 80 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) losses and associated indirect $N_2O$ emissions would be reduced by a very small (<1%) amount.
**P:** Particulate/soluble P and associated sediment losses would be reduced by a small (<2%) amount.
**FIOs and BOD:** Losses would be reduced by a small (<2%) amount.
**Other Pollutants:** $CO_2$ emissions would be increased by a very small amount through track management activities.
**Key references:**
Environment Agency (2008). *Best Farming Practices*. Environment Agency. 97pp.

## Method 80 – Establish new hedges

**Direction of change for target pollutants at the farm scale.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓↓ | ↓ | ↓↓ | ↓* | ↓* | ~ | ↓ | ~ | ↑ |

* Farms with livestock/manures.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | × | ✓ |

**Description:** Plant new hedges along fence lines and use them to break-up the hydrological connectivity of the landscape.
**Rationale:** Increasing the number of hedgerows can help to reduce sediment and associated nutrient losses by ‘trapping’ and lowering surface runoff volumes. Hedges can also help to protect soils from wind erosion.
**Mechanism of action:** Installing hedges reduces the slope length and helps to prevent the delivery of pollutants in surface runoff by reducing the force of flow. Hedges also act as ‘natural’ buffer strips and sediment traps, and enable separate parts of the landscape to be managed in different ways.
**Potential for applying the method:** This method is applicable to most farming systems, but is likely to be more applicable to the arable sector where hedgerows have been removed, particularly on erosion susceptible sandy and silty soils on sloping land.
**Practicability:** Planting hedges and making fields smaller, will increase the time required for field operations and may be resisted by some larger arable farms. On grassland farms it may help with stock management and provide useful shelter in summer. As laying hedges involves considerable time and investment on most farms it would be carried out over a number of years to fit in with farming operations. The method is compatible with Environmental Stewardship Schemes.
**Likely Uptake:** Low to moderate, as a result of time and cost implications.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing LFA | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Outdoor Pigs | Hort | Cost based on planting new hedges, installing new gateways and back fencing, and are amortised. |
|---|---|---|---|---|---|---|---|---|---|
| Annual | 4,000 | 3,000 | 2,500 | 4,500 | 4,800 | 8,000 | 2,200 | 1,400 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses and direct and indirect $N_2O$ emissions would be reduced by a small (<1%) amount; as a result of the land area (*c.*1%) being taken out of production.
**P:** Particulate/soluble P and associated sediment losses would be reduced by up to 20%.
**FIOs and BOD:** Losses would be reduced by a small amount (<1%) from grazed grassland fields.
**Other pollutants:** $CO_2$ emissions would be increased by a small amount through hedge planting activities etc.

## Method 81 – Establish and maintain artificial wetlands

**Direction of change for target pollutants on the farm area where runoff is intercepted by the wetland.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓ | ↓ | ↓ | ↓↓ | ↓ | ↓↓ | ↓↓↓* | ↓↓↓* | ~ | ↑ | ↑ | ↑ |

( ) Uncertain
*Runoff from dairy hardstandings

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × | ✓ |

**Description:** Construct (or establish) wetlands with fences and channels that will be sufficient to capture runoff and sediment from a field group of fields or farm hardstandings.
**Rationale:** Constructed wetlands can be used for the 'treatment' of lightly contaminated runoff from farm hardstanding areas and to intercept runoff water from a field or group of fields. They can trap sediment and through the retention of runoff, reduce nutrient and FIO loads in water exiting the wetland.
**Mechanism of action:** Wetlands act by intercepting pollutant delivery through providing a 'buffer zone' and can potentially clean up polluted water. They can be natural or artificial, permanent or temporary, with water that is static or slow flowing. Constructed wetlands can be either surface (overland) flow or subsurface (percolation) flow systems. A surface flow wetland is akin to a natural wetland; in the form of a reed bed, bog, wet grassland, wet woodland, sedimentation pond or lake. A subsurface flow wetland is generally a highly engineered, confined system of graded gravels and reeds. A range of biological, physical and chemical processes occur in the wetland environment, which can reduce nutrient and FIO concentrations in water that passes through the wetland.
**Potential for applying the method:** Wetlands can potentially be applied to all farming systems on medium/heavy soils with moderate to poor drainage, but are particularly suited to land where 'elevated' sediment and associated nutrient losses occur. They are not effective on free-draining soils, where drainage water moves to groundwater. There will be a need to liaise with the Environment Agency (EA) regarding construction criteria etc.
**Practicability:** Wetlands can be difficult to construct and will inevitably involve the loss of some agricultural land. However, where they can be used to address a pollution problem they are likely to be reasonably acceptable to farmers. The outflow of water from artificial wetlands into a watercourse may require a discharge consent from the EA; there will also be a need to obtain EA approval if the wetland is being used to treat farm hardstandings runoff. Constructed subsurface flow systems require maintenance, due to the deposition of sediment, which can result in some sections becoming impermeable. Wetlands may also result in the re-mobilisation of pollutants and will need cleaning-out periodically as sediment levels etc. build-up.
**Likely Uptake:** Low, due to construction costs, loss of agricultural land and need for EA approval.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Grazing Low | Mixed | Comb Crops | Comb/ Roots | Hort | Costs based on a reedbed for dairy steadings and field wetlands for arable land (occupying 0.25% of farm area) and are amortised. |
|---|---|---|---|---|---|---|---|
| Annual | 200 | 100 | 1,000 | 2,200 | 2,400 | 300 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) losses could be reduced by up to 20%. However, $N_2O$ emissions may be increased from the wetland itself.
**P:** Particulate P and associated sediment losses could be reduced by up to 80% from arable fields draining to the wetland. Soluble P losses could be reduced by a small amount (up to 20%).
**FIOs and BOD:** Losses could be reduced by up to 90%.
**Other Pollutants:** $CO_2$ emissions would be increased due to wetland construction. $CH_4$ emissions are likely to increase, particularly where the wetlands are treating lightly contaminated runoff from hardstandings.

**Key references:**

Reay, D.S. and Paul, G. (2008). Novel quantification of methane emissions from a constructed wetland in the Scottish Borders. In, *Land Management in a Changing Environment*. Proceedings of the SAC and SEPA Biennial Conference, Edinburgh, 26-27 March 2008, pp.183-189.

Søvik, A.K., Augustin, J., Heikkinen, K., Huttunen, J.T., Necki, J.M., Karjalainen, S.M., Kløve, B., Liikanen, A., Mander, Ü., Puusinen, M., Teiter, S. and Wachniew, P. (2006). Emission of the greenhouse gases nitrous oxide and methane from constructed wetlands in Europe. *Journal of Environmental Quality,* 35, 2360-2373.

Defra project ES0132 - A review of 'soft engineering' techniques for on-farm bioremediation of diffuse and point sources of pollution.

## Method 82 – Irrigate crops to achieve optimum yields

**Direction of change for target pollutants on the area of irrigated crops.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ↓↓ | ↓ | ↓ | ↑ | ~ | ↑ | ~ | ~ | ~ | (↓) | ~ | ↑ |

( ) Uncertain.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| × | × | × | × | × | ✓ | × | × | × | ✓ |

**Description:** Irrigate crops (potatoes, vegetables and soft fruit) to reduce soil moisture deficits at critical times during growth to optimise yields and nutrient uptakes.
**Rationale:** The supply of water at appropriate times during the growing season ensures optimal crop growth and nutrient uptake, and reduces the amount of $NO_3$ available for leaching over the following winter, as a result of restricted N uptake due to drought.
**Mechanism for action:** Irrigation scheduling is designed to maintain soil moisture at optimum levels at critical times in the growing season. Yields are optimised, such that more N is taken up by the crop and less $NO_3$ is available for leaching post-harvest.
**Potential for applying the method:** The method is most applicable to high value crops (e.g. potatoes, vegetable and soft fruit crops) in low rainfall areas *e.g.* sandy soils in eastern and central England.
**Practicability:** Irrigation supply requires either a constant source of water (extraction licence or mains) or a storage reservoir.
**Likely uptake:** Low, as water availability and the costs of implementing the required infrastructure can be high.
**Costs:**

| Total *cost* for farm system (£/farm) | Comb/ Roots | Hort | Costs based on installation of a reservoir/borehole, irrigation equipment, licensing and application costs and are amortised. No account has been taken of increased crop yields and quality. |
|---|---|---|---|
| Annual | 6,000 | 5,500 | |

**Effectiveness:**
**N:** $NO_3$ (plus ammonium and nitrite) leaching losses and associated indirect $N_2O$ emissions would be reduced by around 40%. However, there is a potential for increase direct $N_2O$ emissions as a result of 'wet' soil conditions through irrigation water application.
**P:** Particulate P and associated sediment losses could be increased on sloping sandy/silty soils by up to 20%.
**Other pollutants:** $CO_2$ emissions associated with reservoir construction/borehole installation and water application would be increased.
**Key references:**
Groves, S.J. and Bailey, R.J. (1997). The influence of sub-optimal irrigation and drought on crop yield, N uptake and risks of N leaching from sugar beet. *Soil Use and Management*, 13, 190-195.
Defra projects NT0110/NT1306/NT1807/NT1808 - Nitrate leaching: management practices in crop rotations.
Defra projects NT0201/NT1307 - To provide guidelines for improved nitrogen use on potatoes, oilseed rape & sugar beet.
Defra project NT1805 - Effects of crop rotation and management practice on nitrate leaching from a sandy soil.

## Method 83 – Establish tree shelter belts around livestock housing and slurry storage facilities

**Direction of change for target pollutants.**

| Nitrogen | | | Phosphorus | | Sediment | BOD | FIOs | Ammonia | Nitrous Oxide | Methane | Carbon Dioxide |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nitrate | Nitrite | Ammonium | Part | Sol | | | | | | | |
| ~ | ~ | ~ | ~ | ~ | ~ | ~ | ~ | ↓ | ~ | ~ | ~* |

* Plus carbon storage in vegetation and soil.

**Farm typologies applicable:**

| Dairy | Grazing LFA | Grazing Low | Mixed | Combinable Crops | Combinable Roots | In Pigs | Out Pigs | Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|
| ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✗ |

**Description:** Plant tree shelter belts around livestock housing and slurry storage facilities.
**Rationale:** The tree shelter belt will disrupt air flows around the building or slurry storage facility, reducing $NH_3$ emission rates and will also directly re-capture a proportion of the emitted $NH_3$.
**Mechanism of action:** Planting tree shelter belts upwind and downwind of livestock housing or slurry storage facilities will reduce $NH_3$ emissions in two ways. Firstly, the shelter belt will result in a lower wind speed directly above and around the building or slurry store, and thereby will increase the time taken for emitted $NH_3$ to be transported away in the air stream. Secondly, the trees will re-capture a proportion of the emitted $NH_3$ both directly though cuticular uptake and also indirectly by increased deposition.
**Potential for applying the method:** This method could potentially be applied to all livestock housing facilities (where spare is available). The effectiveness of the method in reducing $NH_3$ emissions will depend on the height and canopy density of the shelter belt, and the prevailing environmental conditions.
**Practicability:** A shelter belt of sufficient height (to be effective) will take a number of years to establish.
**Likely Uptake:** Low-moderate, due to financial costs and land area loss.
**Costs:**

| Total *cost* for farm system (£/farm) | Dairy | Indoor Pigs | Costs based on the establishment of a 30m deep shelter belt of trees around the perimeter of the livestock building/slurry store and are amortised (they assume no loss of crop production). |
|---|---|---|---|
| Annual | 400 | 800 | |

**Effectiveness:**
**N:** $NH_3$ emission could be reduced by up to 10%.
**Other Pollutants:** Shelter belts can offer additional benefits including visual screening, enhanced biodiversity and carbon sequestration. However, there may be some disbenefits, including loss of the land from agricultural production, shading of adjacent farmland etc. Impacts on other pollutants are likely to be minimal.
**Key references:**

Dragosits, U., Theobald, M. R., Place, C. J., ApSimon, H. M. and Sutton, M. A. (2006). The potential for spatial planning at the landscape level to mitigate the effects of atmospheric ammonia deposition. *Environmental Science & Policy,* 9, 626-638.

Defra project WA0719 - Impact of vegetation and/or other on-farm features on net ammonia emissions from livestock farms.

# APPENDIX I. DESCRIPTION OF THE FARM TYPOLOGIES

The Mitigation Methods – User Guide effectiveness and cost *estimates* were calculated for twelve defined farm typologies from which baseline pollutant losses were calculated (based on established baseline farm infrastructures and farm practices). The cost estimates and ranges of effectiveness of methods detailed in this Guide should therefore be considered with reference to the farm typology descriptions set out below.

## Farm typology – Cropping and livestock numbers

The farm typologies were based on the nine 'Robust Farm Types' (RFTs) used by the Farm Business Survey and defined by the dominant source of revenue (MAFF, 1993). The farm typologies excluded 'Other' RFTs which define holdings that either do not fit in well with mainstream agriculture or are of limited economic importance.

The farm typology sizes (total arable crop and grassland areas) were based on the average farm areas given in the Farm Business Survey for 2006 (for England).
*Note*. The farms surveyed by the Farm Business Survey are generally larger than the average census farm, as the survey excludes minor holdings. The proportions of the land area occupied by each crop type and the stocking densities of each livestock type were derived for each farm type from the Defra June Agricultural Census for 2004. The crop areas and stock numbers were then 'benchmarked' so that the totals across all farms agreed with the published census data; this also accommodated the relatively small land area and livestock numbers on the 'Other' RFTs.

To ensure that the farm typologies had physically realistic crop rotations and livestock numbers, some adjustments were made to the average farm statistics. For example, very small numbers of pigs and poultry were removed from the 'Dairy' farm and the total numbers of cattle were adjusted to achieve a typical economic stocking rate. These adjustments were necessary to convert a statistical farm definition averaged across all surveyed farms of a type, into a more realistic and recognisable farm typology.

Tables A1 to A3 summarise the farm typology cropping rotations and livestock numbers.

## Farm typology – Practices

Farm infrastructure and detailed practices within each farm typology were based on survey and research data where this was available, and on expert judgement.

The farm typologies include information on N and P excretion/production from livestock (Cottrill and Smith, 2010); the amount of excreta managed as manure (Webb *et al*., 2004; Misselbrook *et al*., 2007); livestock activity data (Webb *et al*., 2001; Farm Practice Survey data for 2001 (Scott *et al*., 2002) and 2004 (Defra, 2004b); hardstanding areas (Webb *et al*., 2001); wash water use (Laws and Chadwick, 2005); cultivation type and timing (Scott *et al*., 2002); average fertiliser application rates, with and without manure (Goodlass and Welch, 2005); the proportion of N fertiliser applied as urea (Goodlass and Welch, 2005); and the timing of fertiliser, manure and dirty water applications (Goodlass and Welch, 2005; Smith *et al*., 2000; 2001a; 2001b).

Table A1 Summary of cropping (ha) on each of the representative farm typologies.

| | Crops | Dairy | Grazing – LFA | Grazing - Lowland | Mixed | Combinable Cropping | Roots Cropping | Indoor Pigs | Outdoor Pigs | Specialist Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Farm Typologies** | | | | | | | | | |
| Grassland (ha) | Permanent grassland | 71 | 62 | 75 | 74 | - | 15 | - | - | - | 3 |
| | < 5 year rotational grassland | 24 | 5 | 16 | 22 | - | - | - | 18 | - | - |
| | Rough grazing* | 6 | 79 | 4 | 5 | 5 | 2 | - | - | - | - |
| | Sub-total | **101** | **146** | **95** | **101** | **5** | **17** | **-** | **18** | **-** | **3** |
| Tillage land (ha) | Winter Wheat | 2 | - | 0 | 15 | 102 | 65 | - | - | - | 0 |
| | Winter Barley | 0 | - | 4 | 10 | 16 | 9 | - | - | - | 0 |
| | Spring Barley | 3 | - | 1 | 8 | 11 | 8 | - | - | - | 0 |
| | Maize | 6 | - | 1 | 5 | 0 | 0 | - | - | - | 0 |
| | Sugar Beet | 0 | - | 0 | 0 | 0 | 25 | - | - | - | 0 |
| | Oilseed Rape | 0 | - | 0 | 8 | 31 | 0 | - | - | - | 0 |
| | Potatoes | 0 | - | 0 | 0 | 0 | 18 | - | - | - | 0 |
| | Fodder Crops e.g. Stubble Turnips | 2 | - | 0 | 2 | 0 | 0 | - | - | - | 0 |
| | Other Crops e.g. Peas, Beans, Linseed etc | 0 | - | 0 | 6 | 7 | 28 | - | - | - | 0 |
| | Vegetables for Human Consumption | 0 | - | 0 | 0 | 0 | 10 | - | - | - | 8 |
| | Horticultural Crops e.g. Top Fruit etc | 0 | - | 0 | 0 | 0 | 0 | - | - | - | 7 |
| | Sub-total | **13** | **-** | **6** | **54** | **167** | **163** | **-** | **-** | **-** | **15** |
| **Total (ha)** | | **114** | **146** | **101** | **155** | **172** | **180** | **-** | **18** | **-** | **18** |

* or rough land/set-aside

Table A2. Summary of cattle and sheep numbers on each of the representative farm typologies (by stock type and age).

| Livestock Categories | | Dairy | Grazing – LFA | Grazing - Lowland | Mixed | Combinable Cropping | Roots Cropping | Indoor Pigs | Outdoor Pigs | Specialist Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Farm Typologies** | | | | | | | | | |
| **Cattle** | Dairy Cows | 110 | - | - | 31 | - | - | - | - | - | - |
| | Dairy Heifers in Calf, >2 years | 14 | - | - | - | - | - | - | - | - | - |
| | Dairy Heifers in Calf, <2 years | 14 | - | - | - | - | - | - | - | - | - |
| | Beef Cows and Heifers | - | 22 | 27 | 21 | - | - | - | - | - | - |
| | Beef Heifers in Calf >2 Years | - | 3 | 2 | 3 | - | - | - | - | - | - |
| | Beef Heifers in Calf <2 Years | - | 1 | 1 | 2 | - | - | - | - | - | - |
| | Bulls | 1 | 1 | 1 | 1 | - | - | - | - | - | - |
| | Other Cattle, >2 Years | - | 11 | 14 | 5 | - | - | - | - | - | - |
| | Other Cattle, 1-2 Years | 31 | 14 | 37 | 53 | - | - | - | - | - | - |
| | Other Cattle, <1 Year | 45 | 20 | 39 | 40 | - | - | - | - | - | - |
| | **Total** | **215** | **72** | **121** | **156** | **-** | **-** | **-** | **-** | **-** | **-** |
| **Sheep** | Sheep | 50 | 358 | 184 | 190 | - | - | - | - | - | - |
| | Lambs, <1 Year | 54 | 339 | 170 | 203 | - | - | - | - | - | - |
| | **Total** | **104** | **697** | **354** | **393** | **-** | **-** | **-** | **-** | **-** | **-** |

Table A3. Summary of pig and poultry numbers on each of the representative farm typologies (by stock type and age).

| Livestock Categories | | Farm Typologies: Dairy | Grazing – LFA | Grazing - Lowland | Mixed | Combinable Cropping | Roots Cropping | Indoor Pigs | Outdoor Pigs | Specialist Poultry | Horticulture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pigs | Sows in Pig and Other Sows | - | - | - | 18 | - | - | 159 | 294 | - | - |
| | Gilts in Pig and Barren Sows | - | - | - | 2 | - | - | 71 | 62 | - | - |
| | Gilts Not Yet in Pig | - | - | - | 9 | - | - | 133 | 78 | - | - |
| | Boars | - | - | - | 2 | - | - | 6 | 6 | - | - |
| | Other Pigs >110kg | - | - | - | 4 | - | - | 32 | - | - | - |
| | Other Pigs 80-110kg | - | - | - | 65 | - | - | 247 | - | - | - |
| | Other Pigs 50-80kg | - | - | - | 92 | - | - | 621 | - | - | - |
| | Other Pigs 20-50kg | - | - | - | 102 | - | - | 983 | - | - | - |
| | Other Pigs <20kg | - | - | - | 106 | - | - | 1,272 | - | - | - |
| | **Total** | **-** | **-** | **-** | **400** | **-** | **-** | **3,524** | **440** | **-** | **-** |
| Poultry | Layers | - | - | - | 252 | - | - | - | - | 14,709 | - |
| | Pullet | - | - | - | 60 | - | - | - | - | 4,191 | - |
| | Broilers | - | - | - | 928 | - | - | - | - | 55,772 | - |
| | Turkeys | - | - | - | 642 | - | - | - | - | 1,379 | - |
| | Breeding Bird | - | - | - | 358 | - | - | - | - | 2,602 | - |
| | Ducks | - | - | - | 365 | - | - | - | - | 2,704 | - |
| | **Total** | **-** | **-** | **-** | **2,605** | **-** | **-** | **-** | **-** | **81,357** | **-** |

## Livestock N and P production

Cottrill and Smith (2010) estimated livestock N (and P) excretion/production to underpin implementation of the Nitrate Pollution Prevention Regulations 2008; with the N production values summarised in Defra/EA (2008). The proportions of manure spread direct from housing (or other minimal storage) and the amounts of manure handled as slurry or FYM were derived from NARSES (National Ammonia Reduction Strategy Evaluation System) outputs; Defra projects AM0101 and AC0102.

## Manure stores and hardstandings

The type and size of manure stores was derived from the Farm Practice Surveys for 2001 (Scott *et al*., 2002) and 2004 (Defra, 2004b). The area of hardstandings was taken from Webb *et al.* (2001) and the amount of wash water used from Laws and Chadwick (2005).

## Livestock and crop calendar

The proportion of time that animals spent in housing, gathering yards, the milking parlour or at grazing was estimated by month for each livestock type based on data in Misselbrook *et al*. (2007), Webb *et al*. (2001) and the Farm Practice Survey for 2001 (Scott *et al*., 2002). The winter housing period for grazed livestock was taken from Cottrill and Smith (2010). During the grazing season livestock were distributed across the farm with 30% of the grassland area cut twice for conservation, 30% cut once and 40% grazed throughout the season. Within the grazing typologies, sheep and lambs made use of rough grazing and fodder crops, as well as the permanent/temporary grassland areas. For arable (tillage) land, the type and timing of cultivations was taken from the Farm Practice Survey for 2001 (Scott *et al*., 2002); with drilling and harvest dates taken from Soffe (2003).

## Fertiliser Practice

Nitrogen and phosphate fertiliser use was taken from *overall* use figures reported in the British Survey of Fertiliser Practice - BSFP (Goodlass and Welch, 2005), with application rates adjusted to account for livestock manure use (where appropriate). The type and timing of fertiliser applications was taken from a detailed analysis of BSFP returns for 2003, undertaken in support of Defra project NT2605 (Chadwick *et al*., 2005).

## Manure Management

The farm typologies provide a detailed calendar of the amount of each manure type spread to each crop type. The volume of dirty water generated on hard standing areas and the dilution of slurry in open stores was also calculated. The total amounts of N remaining in manures post housing and storage losses was estimated using the figures provided by Cottrill and Smith (2010). The timing and location of manure spreading to land was based on data from Smith *et al*. (2000; 2001a; 2001b) and additional information from the British Survey of Fertiliser Practice on monthly timings (Goodlass and Welch, 2005). The method of manure spreading and delay to soil incorporation (where applicable) were based on NARSES (Webb and Misselbrook, 2004) outputs. The mass (or volume) of FYM and slurry applied to each crop in each month was back-calculated using the total amount of N applied and the ‘typical’ total N content of manures (kg/t or $m^3$) given in the “Fertiliser Recommendations booklet RB209” (MAFF, 2000).

## Farm typology descriptions

Farm-scale estimates of the cost and effectiveness of the mitigation methods refer to the twelve farm typologies presented in Tables A1 to A3, which are described in further detail below. Effectiveness was assessed for the area each method was applied to (at the farm scale) on each farm typology for permeable (free drained) and impermeable (poorly drained) soils located in the moderate to high rainfall (700-900 mm) climate. For farms on medium/heavy soils, the fields were assumed to have functioning drains on 70% of the land area.

### Dairy

The dairy farm typology had 110 dairy cows, 28 heifers and an additional 59 followers (i.e. cattle more that one year old). Ten percent of the grassland area was re-seeded each year. The average field size was 8 ha. The farm also had 5 ha of cereals, 6 ha of forage maize and 2 ha of stubble turnips (total area 114ha).

Total excreta production was estimated at 3,246 tonnes. The dairy cows were 'housed' for 248 days each year (including time spent on collecting yards and in the milking parlour during the grazing season), and used collecting yards, feeding yards and self-feed silage yards (in winter only). A total of 62% of the excreta was deposited during 'housing' (with the remainder at grazing) and was managed as slurry and stored for 3 months. The slurry was assumed to be stored in a tin tank 4 m tall and 15 m diameter. All managed slurry was assumed to be spread across the grassland area. Sheep and cattle (less than two years old) were kept on straw and FYM was stored in an open field site. A total of 70% of the FYM was spread after storage and 30% spread direct (i.e. 'fresh').

The managed slurry was diluted during storage (due to rainfall and wash water inputs), so that the dry matter content was reduced from 10 to 6%. Total N production was 18,400 kg N annually, giving a livestock manure N farm loading of 161 kg N/ha. The total amount of slurry produced was around 2,600 tonnes. Dirty water was collected in a separate store and spread on 5% of the permanent grassland area. Approximately 50% of the grassland area received slurry at 50 $m^3$/ha and 70% of the forage maize area received FYM at 35 t/ha, with approximately 70% of the slurry spread between November and April and 70% of the FYM spread in the spring (February to April). The grassland area also received an average N fertiliser application rate of 127 kg N/ha and average phosphate application rate of 18 kg $P_2O_5$/ha, with 7% of N fertiliser applied as urea.

### LFA (Less Favoured Area) Grazing

An all grass farm of 146 ha; with 67 ha of enclosed (permanent and temporary) grassland and 79 ha of rough grazing. The cattle herd had 37 adult beef animals, plus 35 progeny (20 calves and 15 yearlings). There were also 358 sheep and 339 lambs. Fertiliser N rates were 47 kg N/ha on permanent grassland and 90 kg N/ha on temporary grassland. No fertiliser was applied to the rough grazing land. In total, 43 ha of land was used for silage making (a single cut was taken on 19 ha and two cuts on the remaining 24 ha) and 25 ha was grazed only. Overall (average) fertiliser application rates were 50 kg/ha N and 15 kg/ha $P_2O_5$.

Total N production was 8,890 kg N annually, giving a livestock manure N farm loading of 61 kg N/ha. Calving was assumed to take place in spring, with young stock taken through two winters before being sold at 18-24 months of age. Adult cattle and yearlings had access to concrete yards for feeding in winter. No significant quantities of slurry were generated. Lambs were weaned for five months and sold as store lambs in the autumn. FYM production was estimated at around 440 tonnes per annum; 70% of the FYM was stored for 3 months in field heaps prior to land spreading and 30% was spread direct (i.e.' fresh'). Approximately 25% of the FYM was applied in autumn (August-October), 30% in winter (November-January), 35% in spring (February-April) and 10% in summer (May-July) at an average application rate of 20 t/ha.

### Lowland Grazing

The lowland grazing farm had an area of 101 ha comprising 91 ha of enclosed (permanent/temporary) grassland, 4 ha of rough grazing and 6 ha of arable land. The cattle herd had 44 adult beef cattle and 77 progeny (39 calves and 38 yearlings). The sheep flock had 184 sheep and 170 lambs. Fertiliser N rates were 47 kg N/ha on permanent grassland

and 90 kg N/ha on temporary grassland. No fertiliser was applied to the rough grazing land. In total, 66 ha of land was used for silage making (a single cut was taken on 28 ha and two cuts on the remaining 38 ha) and 36 ha was grazed only. Overall (average) grassland fertiliser application rates were 55 kg/ha N and 16 kg/ha $P_2O_5$. The average fertiliser N rates applied to winter barley, spring barley and maize were 118, 95 and 31 kg/ha, respectively.

Total N production was 9,012 kg N annually, giving a livestock manure N farm loading of 89 kg N/ha. Calving was assumed to take place in spring, with young stock taken through two winters before being sold at 18-24 months of age. Adult cattle and yearlings had access to concrete yards for feeding in winter. No significant quantities of slurry were generated. Lambs were weaned for three to four months and finished primarily on grass to 10-12 months of age. FYM production was estimated at around 650 tonnes per annum. 70% of the FYM was stored for 3 months in field heaps prior to spreading and 30% was spread direct (i.e. 'fresh'). Approximately 30% of the FYM was applied in autumn (August-October), 25% in winter (November-January), 30% in spring (February-April) and 10% in summer (May-July) at an average application rate of 20 t/ha.

## Mixed

The 'mixed' farm had an area of 155 ha, with 96 ha of enclosed grassland (permanent/temporary), 5 ha of rough grazing and 54 ha of tillage land. All cereal land was ploughed and 'heavy' discs were used for oilseed rape establishment. There were 31 adult dairy cows, 32 followers, 52 beef cattle, 40 calves, 190 sheep and 203 lambs on the farm. The (small) pig enterprise had 2 boars, 5 dry sows (120 kg liveweight-lwt), 15 farrowing sows (200 kg lwt), 9 gilts not yet in pig, 106 weaners (10 kg lwt), 102 first stage grower (35 kg lwt) places, 92 second stage grower (65 kg lwt) places, 65 finisher (95 kg lwt) places and 4 pigs over 110 kg lwt. The (small) poultry unit had 2,605 bird places, including layers, pullets, broilers, turkeys, breeding birds and ducks. Ninety percent of pig diets, 90% of layer and 40% of broiler rations contained phytase. All cattle were kept on FYM; pig manure was managed as both FYM and slurry. The laying hens were on a solid manure system, ducks on a straw-based system and the remaining birds on a litter based system.

Total manure N production was 19,975 kg N annually, giving a livestock manure N farm loading of 129 kg N/ha. Total manure production was around 1,900 tonnes (Cottrill and Smith, 2010). Seventy percent of cattle, sheep and pig FYM was stored before spreading, and 50% of poultry manure was stored ahead of spreading, with the remainder spread direct (i.e. 'fresh'). Pig slurry was stored in a pit below the buildings and solid manure was stored in field heaps (for 3 months or more). Washwater and runoff from the dairy and beef collecting and feeding yards was collected in a dirty water store. The manures were spread across the grassland and tillage land areas.

The enclosed grassland received an average fertiliser N application rate of 77 kg/ha N and average phosphate fertiliser application rate of 29 kg/ha $P_2O_5$. Arable (tillage) land received an average fertiliser N application rate of 128 kg/ha N and average phosphate fertiliser application rate of 30 kg $P_2O_5$/ha. On tillage land, 30% of fertiliser N was applied as urea and on grassland 7% of fertiliser N was applied as urea.

## Combinable cropping

The combinable cropping farm had 172 ha of (mixed) combinable crops. The average field size was 8 ha. The crops received an average fertiliser N application rate of 188 kg N/ha and an average phosphate fertiliser application rate of 43 kg $P_2O_5$/ha. Thirty percent of fertiliser N was applied as urea. Around 10% of the farm area grew spring combinable crops. All the cereal land was ploughed, with 'heavy' discs used for oilseed rape establishment.

### Combinable cropping–with manure

The combinable cropping-farm with manure had an area of 172 ha, with the same cropping and cultivation practices as the combinable cropping farm without manure. This farm typology received all of the solid farmyard manure (FYM) and slurry produced on the 'indoor pigs' farm, which amounted to 25,100 kg total N and had a livestock manure N farm loading of 146 kg N/ha. Thirty percent of the pig FYM was spread direct from housing (i.e. 'fresh') and 70% was stacked in field heaps (for >3 months) prior to land spreading. The FYM was spread at a rate of 35 t/ha and pig slurry at 50 $m^3$/ha. Approximately 50% of the pig slurry was applied in autumn (August-October), 20% in winter (November-January), 30% in spring (February-April) and none in summer (May-July). For pig FYM, 80% was applied in autumn (August-October), 10% in winter (November-January), 10% in spring (February-April) and none in summer (May-July). The crops received an average fertiliser N application rate of 180 kg N/ha and average phosphate fertiliser application rate of 38 kg $P_2O_5$/ha; fields where manure was applied had their fertiliser application rates adjusted based on date from Goodlass and Welch (2005). Thirty percent of fertiliser N was applied as urea.

### Roots and combinable cropping

The roots/combinable cropping farm had an area of 180 ha. The average field size was 8 ha. The crops received an average fertiliser N application rate of 151 kg N/ha and an average phosphate fertiliser application rate of 48 kg $P_2O_5$/ha. Thirty percent of fertiliser N was applied as urea. Around 50% of the farm area grew spring combinable crops, and had 15 ha of permanent grassland. All of the tillage land was ploughed.

### Roots and combinable cropping–with manure

The roots/combinable cropping farm with manure had an area of 80 ha; with the same cropping and cultivation practices as for the roots/combinable cropping farm without manure. This farm typology received poultry manure from the 'specialist poultry' farm. This amounted to 16,280 kg total N (i.e. half the amount produced by each 'specialist poultry' farm) and had a livestock manure N farm loading of 90 kg N/ha. Half of the poultry manure was spread direct from housing (i.e. 'fresh') and half was stacked in field heaps (for >3 months) prior to spreading. The poultry manure was spread at a rate of 10 t/ha, with approximately 65% applied in autumn (August-October), 15% in winter (November-January), 20% in spring (February-April) and none in summer (May-July). The crops received an average fertiliser N application rate of 149 kg N/ha and average phosphate fertiliser application rate of 47 kg $P_2O_5$/ha; fields where manure was applied has their fertiliser application rates adjusted based on data from Goodlass and Welch (2005). Thirty percent of fertiliser N was applied as urea.

### Indoor pigs

The 'indoor pigs' farm had no land for crop production. There were 6 boars, 204 dry sows (120kg lwt), 159 farrowing sows (200kg lwt), 1,272 weaners (10 kg lwt), 983 first stage grower (35 kg lwt) places, 621 second stage grower (65 kg lwt) places, 247 finisher (95 kg lwt) places and 32 pigs over 110 kg lwt. Total (undiluted) excreta production was 4,390 tonnes annually, which was handled as both FYM and slurry. Slurry was stored in a pit below slatted floors in the livestock building, with 3 months storage capacity. During storage the slurry was diluted with rain/wash water etc. resulting in a slurry volume of 1,500 $m^3$ and a dry matter content of 4%. Total N production was 25,100 kg N annually. Ninety percent of diets were assumed to contain phytase. All of the pig slurry and FYM was exported to the 'Combinable cropping–with manure' farm typology.

### Outdoor Pigs

The 'Outdoor pigs' farm had a breeding unit, with piglets moved to a growing unit at 7 kg. These were 140 dry sows, 294 farrowing sows and 6 boars.

The sows were assumed to deposit excreta across the whole of the free range dunging area; the approximate stocking rate was 25 sows/ha, over an area of 18 ha. Farrowing huts were moved after every litter, but there was no collection or storage of manure. Annual excreta production was 1,500 $m^3$, with a total N content of 9,200 kg N (Cottrill and Smith, 2010).

### Specialist poultry

The 'specialist poultry' farm had no land for crop production. There were 81,351 bird places, including laying hens, pullets, broilers, turkeys, breeding birds and ducks. In total, 90% of laying hen and 40% of broiler rations contained phytase. The laying hens produced solid manure, the ducks straw-based FYM and the remaining birds poultry litter. Total manure production was 2,160 tonnes (Cottrill and Smith, 2010), with 34% of broiler and turkey litter sent for incineration (Webb and Misselbrook, 2004), leaving 1720 tonnes of poultry manure for land spreading. The total annual N content of all the manures (post housing and storage) was 32,570 kg N. All of the manure from each specialist poultry farm was spread on the equivalent of two 'roots and combinable cropping–with manure' farms.

### Horticulture

The 'horticulture' farm had an area of 18 ha, with no livestock and no imported manures. There were 3 ha of permanent grassland and 15 hectares of horticultural crops; including cauliflowers (4 ha), carrots (4 ha), apples (5 ha) and strawberries (2 ha). The crops received an average fertiliser N application rate of 103 kg N/ha and average phosphate fertiliser application rate of 47 kg $P_2O_5$/ha. Eleven percent of N fertiliser was applied as urea.

## APPENDIX II. ASSUMPTIONS USED IN DERIVING COST-ESTIMATES

**The ‘broad’ cost estimates below should be used for guidance only and will vary with the detail of method implementation, farm size, the make-up of the farm enterprise and the response of the farming system to method implementation.**

***Negative figures are negative costs i.e. they represent a saving or increased income.***

Many of the costs involve amortised capital which is indicated against each method. The annual charge for any capital investment required was derived by amortising the required investment over the anticipated write-off period (at an interest rate of 7%).

**Method 1a – Convert arable land to unfertilised and ungrazed grassland**
The method was applied to 10% of all arable land on the relevant farm type, no manure or fertiliser was applied to the arable reversion land. The land was left to regenerate following harvest with no cultivation and no grass seeding; the regrowth was ‘topped’ one year in five. No sale of machinery was involved. Costs were based on loss of income, using figures from Nix (2008).

Cost: £100/ha

**Method 1B – Arable reversion to low fertiliser input extensive grazing**
All of the arable land was converted to extensive grassland at low stocking rates. Costs were based on the sale of machinery, net the cost of the livestock used on the extensive grassland. Costs cover loss of income from arable cropping and grassland establishment.
It was assumed that the farm had general purpose buildings which could be used to store machinery or to house livestock. Livestock depreciation was included at 25%, along with the amortised costs (over 10 years) of fencing, hedging and water supply provision. No allowance was made for any issues of redundancy and accommodation if any farm workers were involved. A loss of rental value of the land was included at £50/ha.

Costs: £100/ha for arable land; £2,000/ha for horticultural land.

**Method 2 – Convert arable/grassland to permanent woodlands**
This is a long-term change where broadleaf woodland is grown in place of agricultural crops, with a rotation length of around 75 years. During this time, some income may be generated, but most of the value will be realised when the woodland is clear felled. The negative cost will vary with farm type dependent on net margin; the figure was not subject to amortisation or net present value calculations.

Cost: -£150/ha (based on whole life cycle cost/income over 75 years).

**Method 3 – Convert land to biomass cropping**
As with woodlands, this is a change in land use and profitability will depend on the market value of the output at the time of harvest (which can vary significantly within and between markets). The market was assumed to be power station co-firing (for local use the income would be more). The figures were not amortised or expressed as net present value. Costs were based on income from *Miscanthus* on a 15 year rotation and no planting grant, minus the gross margin loss from previous agricultural cropping.

Cost: -£10/ha (but may be up to - £150/ha).

**Method 4 – Establish cover crops in the autumn**
Costs based on cultivating and drilling a cover crop (not simply leaving the land to regenerate following the previous crop).

Cost: £60/ha.

**Method 5 – Early harvesting and establishment of crops in the autumn**
Costs based on a change to earlier harvested maize varieties which produce the same yield. For potatoes, a change from maincrop to second earlies produced a lower gross margin for that crop, which was only partly compensated by an improved gross margin in the following wheat crop.

Cost: £800/ha for potatoes.

**Method 6 – Cultivate land for crops in spring rather than autumn**
Costs based on a 25% reduction in spring combinable crop yields. Costs for grassland were based on ploughing out in spring and a 25% loss in grass yields.

Cost: £100/ha.

**Method 7 – Adopt reduced cultivation systems**
A contractor was assumed to be used and the plough retained for occasional use in difficult seasons. The net effect from selling most cultivation equipment and using a contractor was a saving of -£40/ha.

Cost: -£40/ha

**Method 8 – Cultivate compacted tillage soils**
Costs based on a light cultivation @ £25/ha (carried out annually on 20% of the arable land).

Cost (overall): £5/ha.

**Method 9 – Cultivate and drill across the slope**
Costs based on additional time taken for contour cultivations @ £10/ha.

**Method 10 – Leave autumn seedbeds rough**
Costs based on ‘poorer’ crop establishment (and a small yield loss) plus additional costs for pest/weed control.

Cost: £40/ha.

**Method 11 – Manage over-winter tramlines**
Costs based on a light cultivation to remove the compaction and channelling created by tramlines.

Cost: £10/ha.

**Method 12 – Maintain and enhance soil organic matter levels**
On the farms receiving organic manures, the costs include savings on manufactured fertiliser inputs and the costs of transport over 3 km and 10 km distances

Cost: -£170/ha for 3 km
Cost: £20/ha for 10 km.

**Method 13 – Establish in-field grass buffer strips**
Costs based on grass strip establishment in cropped fields (with no backfencing), the loss of output and topping management.

**Method 14 – Establish riparian buffer strips**
On grassland fields, the costs include fencing, but not grass establishment. On arable fields, the costs include cover establishment, but not fencing. Costs were based on loss of output, grass establishment (and fencing) and topping management activities.

**Method 15 – Loosen compacted soil layers in grassland fields**
Costs based on topsoil loosening @ £40/ha (carried out every four years on each of the grassland fields).

Cost (overall): £10/ha.

**Method 16 – Allow field drainage systems to deteriorate**
Yield losses were estimated to be in the range 5-10%, due to poor drainage on both arable land and grassland.

Costs: £50/ha arable; £10/ha grassland.

**Method 17 – Maintain/improve field drainage systems**
Costs based on the need to mole drain every five years (on to 20% of the farm annually).

Cost (overall): £10/ha.

**Method 18 – Ditch management**
Ditch clearance was costed at contractor rates, using a machine with an excavation bucket on 20% of the farm annually.

Cost (overall): £18/ha.

**Method 19 – Make use of improved genetic resources in livestock**
Variable (input) costs were estimated to be reduced by around 10% for the same amount of livestock output.

Cost: -£80 per dairy cow.

**Method 20 – Use plants with improved nitrogen use efficiency**
Costs based on reduced fertiliser N inputs for the same amount of crop production.

Cost: Arable -£20/ha.

**Method 21 – Fertiliser spreader calibration**
Costs based on average contractor rates.

Cost: £150 per farm.

**Method 22 – Use a fertiliser recommendation system**
Cost savings based on more efficient use of manufactured fertiliser inputs.

Cost: -£5/ha grassland; -£10/ha arable land.

**Method 23 – Integrate fertiliser and manure nutrient supply**
Cost savings based on greater allowance being made for manure nutrients and associated reductions in manufactured fertiliser inputs where manure applied.

Cost: -£15/ha grassland; -£30/ha arable land

**Method 24 – Reduce manufactured fertiliser application rates**
Estimated to produce a reduction in gross margin (costs vary across the farm types).

**Method 25 – Do not apply manufactured fertiliser to high-risk areas**
Costs based on (small) yield reductions on high-risk areas.

Costs: £5/ha arable land: £1/ha grassland.

**Method 26 – Avoid spreading manufactured fertiliser to fields at high-risk times**
Costs based on a (small) yield reduction as a result of 'delayed' fertiliser application.

Cost: £5/ha arable land; £1/ha grassland.

**Method 27 – Use manufactured fertiliser placement technologies**
Costs based on additional operational inputs.

Cost: £2/ha.

**Method 28 – Use nitrification inhibitors**
Costs based on inhibitor purchase/application.

Cost: £20/ha.

**Method 29 - Replace urea fertiliser with another nitrogen form**
Although urea is cheaper than ammonium nitrate per unit of N, higher ammonia losses from urea result in a (small) yield penalty compared with ammonium nitrate.

Cost: -£5/ha.

**Method 30 - Incorporate a urease inhibitor into urea fertilisers**
Costs based on urease inhibitor being added to the fertiliser at source and that the increased fertiliser cost was balanced by increased crop yields (as a result of lower $NH_3$ losses). Cost: neutral.

**Method 31 - Use clover in place of fertiliser nitrogen**
Costs based on productivity being maintained, with the cost of establishing (and managing) clover in grass swards offset by savings in manufactured fertiliser N use. Cost: neutral.

**Method 32 - Do not apply P fertiliser to high P index soils**
Costs based on P fertiliser savings on high P index soils (estimated to occupy 10% of farm area).

Cost (overall): -£3 to 6/ha.

**Method 33 - Reduce dietary N and P intakes**
Costs based on cereal feed being used to replace high N forage.

Cost: £0.01/head for poultry and £45/dairy cow.

**Method 34 – Adopt phase feeding of livestock**
Costs based on collars (with transponders) being fitted to dairy cows and sows, along with the use of feed dispensers. Costs have been amortised over 5 years.

Cost: £0.75/$m^3$ slurry (amortised).

**Method 35 – Reduce the length of the grazing day/grazing season**
Costs based on additional building floor scraping and slurry handling, together with additional silage production to feed the housed livestock. We have assumed that no additional slurry storage was needed.

Cost: £0.70-1.80/$m^3$ slurry.

**Method 36 – Extend the grazing season for cattle**
Cost savings based on the reduced need for building floor scraping and slurry handling, together with reduced silage production costs.

Cost: -£0.50/$m^3$.

**Method 37 – Reduce field stocking rates when soils are wet**
Costs based on additional silage production, floor scraping and slurry handling. We have assumed that no additional slurry storage was needed.

Cost: £0.70-1.80/$m^3$ slurry.

**Method 38 – Move feeders at frequent intervals**
Costs based on moving feeding troughs on a fortnightly basis for dairy/beef cattle during the grazing season, and for pigs throughout the year. Costs include capital purchase of feeders and were amortised over 10 years

Cost: £10-30/ha (amortised).

**Method 39 – Construct troughs with a firm but permeable base**
Costs based on constructing a concrete base for existing troughs and are amortised over 10 years (large round troughs for dairy cattle, and conventional troughs for beef, sheep and pigs).

Cost: £2-5/ha (amortised)

**Method 40 – Improved feed characterisation**
Costs of feed formulation have been assessed to be balanced by improved feed utilisation (i.e. there is no net cost). Cost: neutral

**Method 41 – Reduce overall stocking rates on livestock farms**
Costs are based on the loss of gross margin.

**Method 42 – Increase scraping frequency in dairy cow cubicle housing**
Costs are based on the extra working time for a tractor and worker (and assume no need for further capital investment).

Cost: £2/$m^3$ slurry.

**Method 43 – Additional targeted bedding for straw-bedded cattle housing**
Costs based on the additional time to remove and spread FYM, and additional straw costs.

Cost: £3/tonne FYM.

**Method 44 – Washing down of dairy cow collecting yards**
Costs based on an additional 25 litres of washwater per cow.

Cost: £70/dairy cow.

**Method 45 – Outwintering of cattle on woodchip stand-off pads**
Costs based on the need to excavate to 0.75m depth, line the pad and install drainage, and were amortised over 5 years.

Cost: £50/head of cattle (amortised).

**Method 46 – Frequent removal of slurry from beneath-slatted storage in pig housing**
Costs based on more frequently pumping out of underfloor storage and the provision of additional slurry storage and were amortised over 20 years.

Cost: £2/$m^3$ slurry (amortised).

**Method 47 – Part-slatted floor design for pig housing**
Costs based on replacing a solid concrete floor with part slats and were amortised over 20 years.

Cost: £2.50/$m^3$ slurry (amortised).

**Method 48 – Install air-scrubbers or biotrickling filters to mechanically ventilated pig housing**
Costs based on the installation of air-scrubbers or filters and were amortised over 5 years.

Cost: £5.50/$m^3$ slurry (amortised).

**Method 49 – Convert caged laying hen housing from deep storage to belt manure removal**
Costs base on the installation of new cages and belts and were amortised over 10 years.

Cost: £35/t manure (amortised).

**Method 50 – More frequent manure removal from laying hen housing with belt clean systems**
Costs based on the increased frequency of running belt systems.

Cost: £0.10/t manure.

**Method 51 – In-house poultry manure drying**
Costs based on the installation and running of drying equipment and were amortised over 5 years.

Cost: £0.50/t manure (amortised).

**Method 52 – Increase the capacity of farm manure (slurry) stores to improve timing of slurry applications**
Costs based on the construction of additional slurry storage and were amortised over 20 years.

Cost: £4/$m^3$ slurry (amortised).

**Method 53 – Adopt batch storage of slurry**
Costs based on the construction of additional slurry storage and were amortised over 20 years.

Cost: £4/$m^3$ slurry (amortised).

**Method 54 – Install covers on slurry stores**
Costs based on the installation of a store cover and were amortised over 10 years.

Cost: £1.10/$m^3$ slurry (amortised).

**Method 55 – Allow cattle slurry stores to develop a natural crust**
Costs based on the installation and running of a 'larger' stirrer to facilitate emptying and were amortised over 5 years.

Cost: £0.15/$m^3$ slurry (amortised).

**Method 56 – Use anaerobic digestion for farm manures**
Costs based on the capital investment needed to set-up an anaerobic digestion plant (with no additional slurry storage needed) and were amortised over 20 years.

**Method 57 – Minimise the volume of dirty water produced**
Costs based on additional roofing (over dirty concrete areas) and diversion of 'clean' water and were amortised over 20 years.

Cost: £40/$m^2$ roof (amortised).

**Method 58 – Adopt batch storage of solid manure**
Costs based on the construction of concrete pad/leachate collection facilities and associated areas for vehicle movements, and were amortised over 20 years.

Cost: £1/t solid manure (amortised).

**Method 59 – Compost solid manure**
Costs based on the turning of FYM windrows (twice), using a tractor and front-end loader.

Cost: £2.60/t solid manure.

**Method 60 – Site solid manure heaps away from watercourses/field drains**
Costs based on the additional time needed to plan the siting of manure heaps.

Cost: £1/ha.

**Method 61 – Store solid manure heaps on concrete and collect leachate**
Costs based on the construction of concrete pad/leachate collection facilities and associated areas for vehicle movements, and were amortised over 20 years.

Cost: £1/t solid manure (amortised).

**Method 62 – Cover solid manure stores with sheeting**
Costs based on the provision of sheeting.

Cost: £0.50/t solid manure.

**Method 63 – Use liquid/solid manure separation techniques**
Costs cover purchase of a slurry separator and provision of a concrete pad to store the solids (the separated liquid is pumped to a slurry store) and were amortised over 10 years.

Cost: £2-4/$m^3$ of slurry (amortised).

**Method 64 – Manure additives (e.g. Alum)**
Costs based on Alum purchase and addition to poultry litter.

Cost: £3/t litter.

**Method 65 – Change from a slurry to solid manure handling system**
Costs based on changes to livestock buildings for housing, straw costs and additional labour requirements. On the indoor pig farm, the method would involve complete renewal of stock due to the break in production while the housing system was being re-designed. Costs were amortised over 20 years.

Costs: around £13,000 for dairy unit; around £30,000 for pig unit.

**Method 66 – Change from solid manure to slurry handling system**
Costs based on the installation of cubicles in cattle housing and construction of a slurry storage tank and were amortised over 20 years.

Costs: around £18,000 for dairy unit; around £30,000 for pig unit.

**Method 67 – Manure spreader calibration**
Costs based on the time needed to assess evenness of manure spreading and field application rates.

Cost: £200 per farm.

**Method 68 – Do not apply manure to high-risk areas**
Costs based on additional management time to plan manure spreading activities.

Cost: £1/ha.

**Method 69 – Do not spread slurry or poultry manure at high-risk times**
Costs based on additional management time to plan manure spreading activities.

Cost: £1/ha.

**Method 70 – Use slurry band spreading application techniques**
Costs based on the use of a contractor (above standard broadcast spreading costs).

Cost: £1/$m^3$ slurry.

**Method 71 – Use slurry injection application techniques**
Costs based on the use of a contractor (above standard broadcast spreading costs).

Cost: £1.50/$m^3$ slurry.

**Method 72 – Do not spread FYM to fields at high-risk times**
Costs based on additional management time to plan FYM spreading activities.

Cost: £1/ha.

**Method 73 – Incorporate manure into the soil**
Costs based on an additional plough-based cultivation.

Cost: £45/ha.

**Method 74 – Transport manure to neighbouring farms**
Costs based on the need to transport manure over 5 km.

Cost: £5/$m^3$ slurry; £4/t solid manure.

**Method 75 – Incinerate poultry litter for energy recovery**
Costs based on the need to replace poultry litter nutrients with manufactured fertiliser nutrients (on the 'roots and combinable crops' farm); transport of the litter to the energy plant is generally cost neutral for the poultry producer.

Cost: £30/ha.

**Method 76 – Fence off rivers and streams from livestock**
Costs based on the provision of standard seven wire fencing and water troughs and were amortised over 10 years.

Cost: £5-15/ha (amortised)

**Method 77 – Construct bridges for livestock crossing rivers/streams**
Costs based on the construction of two bridges per farm and were amortised over 10 years.

Cost: £5-30/ha (amortised)

**Method 78 – Re-site gateways away from high-risk areas**
Costs based on the removal of gateways and replacement with back fenced hedging on *c.*30% of fields and were amortised over 10 years.

Cost: £2-4/ha (amortised)

**Method 79 – Farm track management**
Costs based on digging out a soakaway and installing French drains across farm tracks, plus maintenance and clearing out every four years, and were amortised over 10 years.

Cost: £1-3/ha (amortised)

**Method 80 – Establish new hedges**
Costs based on new hedge establishment, installing new gateways and back fencing, and were amortised over 10 years.

Cost: £25-70/ha (amortised)

**Method 81 – Establish and maintain artificial wetlands**
Costs based on a reedbed for dairy steadings, and a wetland (bunded and fenced) for arable land (covering 0.25% of the arable area) and associated crop production losses. Investment costs were amortised over 20 years.

Costs: £15/ha of arable land; £200 for dairy farm (amortised)

**Method 82 – Irrigate crop to achieve maximum yield**
Costs based on licensing, water storage and irrigation equipment, and the annual operational costs of water application. Costs were amortised over 20 years.

Cost: around £1,000/ha (amortised)

**Method 83 - Establish tree shelter belts around livestock housing**
Costs based on the establishment of a 30m deep shelter belt of trees around the perimeter of the livestock building/slurry store (approximately 1 ha was required on the dairy unit and 2 ha on the pig unit). Costs were amortised over 20 years.

Costs: around £400 for dairy farm; £800 for pig farm (amortised)

## APPENDIX III. GLOSSARY

Definitions followed by [R] are taken from Pain, B. & Menzi, H. (2003). *Glossary of Terms on Livestock Manure Management.*

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| AGGREGATE STABILITY | The cohesive strength of the forces binding together individual soil particles within a crumb or block of soil. |
| AMINO ACIDS | The chemical units that link together to form proteins and are of fundamental importance to life. [R] |
| AMMONIA | $NH_3$. A gas derived from urea excreted by livestock (and from uric-acid excreted by poultry) and implicated in acidification and N enrichment of sensitive ecosystems. [R]. $NH_3$ volatilisation can occur from urine patches in the field, from animal houses and yards, during and following manure application, and from some N fertilisers etc. |
| AMMONIUM | $NH_4^+$. Positively charged ionic form of mineral N, present in soils, fertilisers and manures. It is not readily leached from soils because it is attracted to soil particles, but can be lost in surface RUNOFF and MACRO-PORE FLOW where there is only limited contact between the flowing water and soil surfaces. Ammonium in soils is converted to nitrate by the process of NITRIFICATION. |
| AMORTISED CAPITAL COST | An annual cost derived from spreading the capital cost of an item over a given number of years, at a given interest rate. The number of years will vary with the durability of the item; for example, a concrete pad may be costed over 20 years and a fence over 5 years. |
| ANAEROBIC | Condition of soils, manures etc. where there is an absence of free oxygen. This restricts biological activity to those organisms that can live and grow without free oxygen. |
| ARABLE REVERSION GRASSLAND | Arable land that has been changed to (low input) grassland, either through natural regeneration or by seeding with a suitable grass/wild flower mixture. Usually managed by cutting and grazing to maximise wildlife benefits. |
| BATCH STORAGE | Treatment method for manures in which, once a quantity of manure has been collected, it is stored without further additions of 'fresh' manure. |
| BIOLOGICALLY FIXED N | Refers to N obtained by the process of symbiotic N fixation in legumes, whereby N-fixing bacteria (*Rhizobia*) in nodules on the roots of leguminous plants fix di-nitrogen gas from the atmosphere and supply the host plant with N in exchange for a supply of carbohydrate. This fixed N is able to substitute for N uptake from the soil, mineral fertiliser or manure additions. |
| BOD | Biochemical Oxygen Demand. A measure of the (water) pollution potential of organic materials etc. A laboratory test is used to measure the amount of dissolved oxygen consumed by chemical and biological action when a sample is incubated at $20^oC$ for a given number of days. [R]; usually 5 days. Surface waters with a high BOD, contain high concentrations of potentially oxidisable organic matter, and decomposition utilises dissolved oxygen in the water, depleting free oxygen levels and the ability of the water body to support many forms of animal life. |
| BOLTING | Early flowering of a plant (e.g. cabbages, lettuce) before it fully develops as a crop. |
| BROADCAST | Sowing by scattering seed (uniformly) over the surface of an area of land (as opposed to placement of seed in drills or rows). Similarly, refers to broadcasting of fertiliser or manure over the whole surface of an area of land. |

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| BROILER | A chicken reared for meat production. [R] |
| BUFFER FEED | Typically hay or silage fed to livestock in the field, at times during the grazing season, when fresh grass is in short supply. |
| BUFFER STRIP | A strip of grassland or other vegetation located between cultivated areas or fields to minimise surface runoff and soil erosion. Also, used between fields and watercourses. [R] |
| BY-PASS FLOW | See MACRO-PORE FLOW |
| CAPPING | Creation of a thin crust on the surface of soil, which restricts the infiltration of rainwater and increases surface RUNOFF. |
| CARBON SEQUESTRATION | A process that removes carbon dioxide from the atmosphere to mitigate global warming, for example, through increasing the amount of carbon (organic matter) in soils by reverting arable land to grassland, establishing woodlands etc. |
| CLOSED PERIOD | Nitrate Vulnerable Zone rules define closed (spreading) periods for arable land and grassland, during which applications of N fertiliser and high readily available N manure applications (e.g. livestock slurries, poultry manure applications) are not permitted. |
| COARSE-TEXTURED SOILS | Soils with a high proportion of sand and coarse silt particles. These soils are free draining and are easily worked; and generally contain less than 18% clay. |
| COMBINABLE CROPS | Crops that produce a hard seed that is suitable for harvesting with a combine harvester (e.g. cereals, beans, oilseed rape etc.). |
| COMPACTION | An increase in soil bulk density (mass per unit volume) and decrease in porosity resulting from applied loads, vibration or pressure. Soil compaction decreases the water holding capacity and air content of the soil, can impede plant (root) growth and increases the risk of surface runoff and erosion. [R] |
| COMPOSTING | The breakdown (stabilisation) of SOLID MANURES (materials) in the presence of free oxygen i.e. under aerobic conditions. ‘Active’ composting can be achieved by mechanical turning or mixing a heap or pile to incorporate air. [R] |
| COMPOUND (FEED) | Livestock feed composed of several different feeding stuffs, minerals and trace elements in proportions to provide a balanced ration or diet. [R] |
| CONSTRUCTED WETLAND | A constructed, semi-natural area of land typically comprising beds of specialised plants such as reeds (*Phragmites* spp.) and gravel filled channels [R]. |
| COVER CROP | A (rapidly) growing crop sown in autumn for the purpose of taking up soil mineral nitrogen which would otherwise be at risk of loss by over-winter nitrate leaching and/or protecting the soil from the erosive impact of rainfall. |
| CROP OFFTAKE | Amount of nutrients removed from a field in the harvested crop. |
| CROP RESIDUES | The unharvested part of a crop that is left in the field e.g. straw, leaf material and stubble (and crop roots). |
| CUBICLE (house) | A building divided into rows of individual stalls or cubicles in which animals lie when at rest, but are not restrained. A small amount of bedding (e.g. sawdust, wood shavings, chopped straw, sand, rubber or plastic mats) is placed in each cubicle. Faeces and urine are excreted into passageways between the cubicles, with the passageways periodically cleaned and the manure removed as SLURRY. [R] |
| DAIRY CAKE | A general term for processed feedstuffs for dairy cattle, with a high food value relative to volume and a low fibre content. May be rich in protein, carbohydrate or fat. [R] |

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| DENITRIFICATION | The transformation, most commonly by bacteria, of nitrate to nitrous oxide and di-nitrogen gas. An anaerobic process that occurs in soils and manure stores and some manure treatment methods after nitrification. [R] |
| DI-NITROGEN | $N_2$. The (harmless) form of nitrogen gas that constitutes 78% of the earth's atmosphere. |
| DIRTY WATER | Water derived from washing of equipment and floors in milking parlours, rainfall runoff from concrete or hard-standing areas used by livestock and contaminated with faeces, urine, waste animal feed etc. Contains organic matter and so poses a risk of water pollution, but has a negligible (low) fertiliser value. [R] |
| EROSION | Wearing away and loss of soil, principally topsoil, by wind and running water. [R] |
| FACTS | Fertiliser Advisers Certification and Training Scheme |
| FARMYARD MANURE (FYM) | Faeces and urine mixed with large amounts of bedding (usually straw) on the floors of cattle or pig housing. May also include horse or stable manure. [R] |
| FERTILISER RECOMMENDATION SYSTEM | A system to provide advice to farmers about how much fertiliser to apply to obtain the best financial return, while minimising nutrient losses to the wider environment. Recommendations take account of crop requirements, soil type, existing levels of nutrients in the soil and the nutrients supplied by organic manures etc. This information can be supplied in book form (e.g. "The Fertiliser Manual (RB209)" or as a computer-based package (e.g. PLANET; www.planet4farmers.co.uk). |
| FINE-TEXTURED SOILS | Soils with a high proportion of clay and fine silt particles. They usually have poor natural drainage and are 'difficult' to work; and generally contain more than 18% clay. |
| FINISHING (pigs) | Growth stage of pigs, between 60 kg and slaughter. [R] |
| FIO | Faecal Indicator Organism. Microorganisms excreted by and present in livestock excreta and manures. Their presence in water indicates contamination by excreta manure; *E.coli* is the most commonly used FIO. |
| FIXED N | See BIOLOGICALLY FIXED N |
| FLATLIFTING | Method of soil loosening using specialised mechanical equipment to break-up compacted soil pans (above a depth of *c*.35cm), but with minimal surface disturbance. |
| FOLLOWERS | Young stock on a dairy farm not yet in milk, but growing to become dairy cows. [R] |
| FORAGE | Crops consumed in the green state by livestock e.g. grass, kale, maize, lucerne, or made into silage. [R] |
| 'FRESH' SOLID MANURE | Solid manure immediately after removal from livestock housing. [R] |
| GROUNDWATER | Water that flows or seeps downwards and saturates soil or rock, supplying springs and wells. The upper surface of the saturated zone is called the WATER TABLE. [R] |
| GULLY EROSION | A more severe development of RILL EROSION, in which the further concentration of surface water flow into erosion channels increases the flow rate and erosive force of the water sufficiently to remove large quantities of topsoil and subsoil to create deep, wide gullies that cannot be 'corrected' by normal agricultural field operations. |
| HARDSTANDING | A general term for any outdoor, normally unroofed, area with a hard surface, usually of concrete (including dairy cow collecting yards, feeding yards, farmyard manure storage areas). [R] |

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| HEAVY SOILS | See FINE-TEXTURED SOILS |
| HILLSIDE COMBINE | Combine harvester designed to operate efficiently when travelling across a slope. |
| HYDROLOGICAL CONNECTIVITY | Water-mediated transfer of matter, energy and/or organisms, within or between, elements of the hydrologic cycle. Water flow paths that run into one another (e.g. field drains or a culvert running directly into a stream) will have a high degree of connectivity. |
| INCIDENTAL LOSSES | Pollutant losses that occur when rainfall creates runoff shortly after the land application of fertiliser, manure and excreta, even where good practice has been followed. |
| K | Potassium |
| LAYING (of hedges) | Practice of hedge management necessary for the establishment of hedges and to prevent their deterioration. Partly-cut stems are bent and laid sideways to reinvigorate growth and to help plants bush out to form a thick, stock-proof hedge. |
| LEACHING | The loss of soluble elements and compounds from soil in drainage waters to the aqueous environment, including both ground and surface waters. This applies especially to nitrate leaching. [R]; and soluble P losses from high P status soils. |
| LEY | Land temporarily sown to grass and then ploughed. [R] |
| LIGHT SOILS | See COARSE-TEXTURED SOILS. |
| LIVESTOCK UNIT | A unit used to compare or aggregate numbers of animals of different species or categories. Equivalences are defined on the feed requirements (or sometimes nutrient excretion). [R] |
| LOOSE-HOUSING | Animals have free access over the whole area of the building or pen. It is common for a deep layer of bedding (usually straw) to be spread over the floor, that is removed from the building, typically once or twice per winter, as FARMYARD MANURE. [R] |
| MACRO-PORE FLOW | Rapid vertical (and lateral) flow of water through 'large' diameter soil cracks, pores, earthworm burrows and old root channels. As the flow by-passes soil aggregates, it is less effective in leaching soluble nutrients from within the main soil matrix. |
| MAINTENANCE APPLICATION (of fertiliser) | Fertiliser application rate that when applied to soils with an optimum nutrient status will maintain this status over the longer-term by replacing the nutrients removed in harvested crops and in unavoidable losses, without increasing the amount stored in the soil. |
| MAINTENANCE DIET | Diet to provide the amount of food needed by an animal to keep it healthy and maintain a constant liveweight. [R] |
| MANUFACTURED (MINERAL) FERTILISER | Fertiliser manufactured by a chemical process or mined, as opposed to an organic material (manure) that contains carbon. [R] |
| MANURE | A general term to denote any organic material that supplies organic matter to soils together with plant nutrients, usually in lower concentrations compared with manufactured fertilisers. [R] |
| MARGINAL LAND | Land used for agriculture, but which has serious limitations (e.g. because of slope, soil depth, climate, wetness) that make it difficult to manage. As a result, crop yields and financial returns are generally lower than those provided by better quality land. |
| MATRIX FLOW | Predominantly vertical and relatively uniform flow of water through the soil, as opposed to more rapid MACRO-PORE FLOW that is confined to 'large' diameter soil cracks/pores etc. As there is greater contact with soil surfaces |

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| | and finer pores, matrix flow is more effective at leaching soluble nutrients from the main soil matrix. |
| METHANE | $CH_4$. A greenhouse gas produced during anaerobic fermentation of organic matter, especially from the enteric fermentation in ruminants and storage of liquid manure. A constituent of biogas. [R]; methane has a global warming potential around 20-fold greater than carbon dioxide. |
| MINERALISATION | The transformation by microorganisms of organic compounds into organic compounds e.g. nitrogen/carbon in soils and stored manures. [R] |
| MINIMAL (REDUCED) CULTIVATION | Method of reduced (shallow) cultivation for tillage soils, using discs and tines, without ploughing and inverting the soil. As there is less disturbance of the soil, there is less mineralisation of soil organic matter and nitrogen, than following ploughing. |
| MONOGASTRIC | An animal with one simple stomach, such as pigs; as opposed to a RUMINANT. [R] |
| N | Nitrogen |
| NATURAL REGENERATION | Process by which vegetation is allowed to develop on a site from the seeds already present in the soil e.g. from weeds or grain shed by the previous crop. |
| NITRIFICATION | The transformation by bacteria of ammonium-N to nitrite and then to nitrate-N. An aerobic process that occurs in soils and during aeration of liquid manures. [R] |
| NITROUS OXIDE | $N_2O$. A greenhouse gas derived mainly from the DENITRIFICATION process. [R]; nitrous oxide has a global warming potential around 300-fold greater than carbon dioxide. |
| NSA | Nitrate Sensitive Area |
| NVZ | Nitrate Vulnerable Zone |
| ORGANIC FERTILISER | A fertiliser derived from organic origin, such as animal products (e.g. livestock manure, dried blood, hoof and bone meal), plant residues or human origin (e.g. sewage sludge). [R] |
| ORGANIC MANURE | See MANURE |
| OVERLAND FLOW | See RUNOFF |
| P | Phosphorus |
| P INDEX | ADAS Soil P Index; a method of expressing the results of laboratory soil extractable P analysis on a scale of 0 (low) to 9 (very high). The target status for most agricultural crops is Index 2 or 3. |
| P SATURATED SOIL | Soils in which the retention capacity of P is exceeded, resulting in the potential for LEACHING of P. [R] |
| PHASE FEEDING | The provision of different rations or diets to livestock at different stages of growth or performance, to match the ration closely to the requirements of the animal. [R] |
| PHYTASE | Type of enzyme that releases inorganic P from organic forms of P (phytate) in grain and thereby makes the P more available to animals. |
| POACHING | The puddling of soil as a result of trampling by livestock under wet conditions. |
| POLLUTION SWAPPING | Refers to pollution mitigation methods, where a method is effective at reducing losses of the target pollutant, but in doing so increases the loss of another pollutant e.g. where a reduction in nitrate leaching losses leads to increased nitrous oxide or ammonia emissions. |
| PREFERENTIAL FLOW | Broadly equivalent to MACRO-PORE FLOW. |

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| RB209 | "Reference Book 209. Fertiliser Recommendations for Agricultural and Horticultural Crops", 7th Edition (2000), The Stationery Office, Norwich. Or "The Fertiliser Manual (RB209)", 8th Edition (2010). The Stationery Office, Norwich. |
| REPLACEMENT RATE | The percentage of milking cows in a herd that are culled and replaced each year by younger animals; this is determined by the number of lactations that each cow has in the herd. |
| RESPONSE CURVE | The shape of a relationship between crop yield and the amount of (manufactured) fertiliser applied. Typically, this shows an initial steep increase in yield with increasing fertiliser rate, which gradually levels off and remains constant or declines at high rates of fertiliser use. |
| RILL EROSION | Soil erosion caused by surface runoff water collecting and concentrating into channels e.g. along depressions or tractor wheelings; the concentration of water into channels increases flow rates and the erosive force of the water. Further removal of sediment and deepening of the channel may lead to GULLY EROSION. |
| RILL FLOW | Flow of surface water in shallow to moderately deep erosion channels, as part of the process of RILL EROSION. |
| RIPARIAN | Located alongside a natural water course, such as by a stream or river. |
| ROUGH GRAZING | Poor quality grazing land, usually with natural or semi-natural vegetation. |
| RUMEN-DEGRADABLE PROTEIN | The proportion of protein in ruminant diets that is broken down in the rumen to liberate ammonia, which is utilised by other microorganisms in the rumen to synthesise microbial protein and is then digested in the small intestine. |
| RUMINANT | An animal that has a complex digestive system, including a four-part stomach. Includes cattle, sheep, goats and deer. [R] |
| RUNOFF | The flow of rainfall, irrigation water, liquid manures etc. from land; referred to as surface runoff where losses are from the soil surface. Runoff can cause pollution by transporting pollutants e.g. from manures to surface waters. [R] |
| SEDIMENT | Refers to soil particles washed into surface waters from agricultural land; such particles will settle onto the stream/river bed when the flow rate of the water is insufficient to keep them in suspension and can be important contributors to diffuse nutrient pollution, for example, from P adsorbed on their surfaces. |
| SHALLOW SOILS | Soils over chalk, limestone or other rock where the parent material is within 40 cm of the soil surface. |
| SHEET EROSION | Removal of a (uniform) thin layer of topsoil by raindrop splash and surface water runoff. Less visible than RILL or GULLY EROSION. |
| SHEET FLOW | Water accumulating on a slope and flowing as a thin sheet over the soil surface. May cause SHEET EROSION. |
| SHEET WASH | See SHEET FLOW |
| SLITTING | A mechanical soil treatment to penetrate shallow compacted/impermeable layers in grassland soils, by creating regular shallow slits in the upper topsoil, to improve surface water infiltration and root penetration. |
| SLUMPING | Process that can occur in sandy and silty soils, where raindrop impact and wetting causes the soil surface structure to collapse and a thin crust to develop that prevents surface water infiltration and increases RUNOFF. See CAPPING. |
| SLURRY | Mixture of faeces and urine produced by housed livestock that flows under gravity and can be pumped. [R] |

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| SOAK-AWAY | Pit where unpolluted or slightly contaminated water is collected and allowed to soak into the surrounding ground. |
| SOIL AERATION | Process of increasing the porosity and permeability of a soil to allow greater entry of air and exchange with the atmosphere. |
| SOIL CAPPING | See CAPPING |
| SOIL COMPACTION | See COMPACTION |
| SOIL EROSION | See EROSION |
| SOIL ORGANIC MATTER | Collective term for the different forms of organic material in soil, including fresh plant residues, microbial biomass and more fully decomposed (relatively) stable humus. |
| SOIL STRUCTURE | The way in which individual particles comprising a soil (sand, silt, clay and organic matter) are organised into aggregates, with pores and channels between them. |
| SOLID MANURE | Manure from housed livestock that does not flow under gravity, cannot be pumped, but can be stacked in a heap. May include manure from cattle, pigs, poultry, horses, sheep and goats. [R]; usually includes bedding (e.g. straw, wood shavings etc.). |
| SOM | SOIL ORGANIC MATTER |
| SPIKING | A mechanical soil treatment to penetrate shallow compacted/impermeable layers in grassland soils, by creating many closely-spaced vertical holes, to improve surface water infiltration and root penetration. |
| SPRING TINE (harrow) | A lightweight cultivation implement, typically used for seedbed preparation, weeding crops, breaking-up capped soil or clearing moss and thatch from the base of grass swards. |
| STEADING | The main area of buildings and yards of a farm, traditionally adjoining the farm house. |
| STRIP GRAZING | A grazing system e.g. for cattle, in which the animals are given access to a limited area of fresh pasture (usually up to twice daily) by means of a moveable fence. Grazed strips are commonly 'back-fenced' (i.e. behind the cattle) to allow for regrowth of the grass. [R] |
| STRUCTURAL DAMAGE (of soil) | Physical damage to SOIL STRUCTURE, caused by livestock trampling or passage of farm machinery, particularly under wet conditions. Soil aggregates are broken down, leading to an increase in bulk density and reduced porosity, water infiltration, aeration and root penetration. See COMPACTION and POACHING. |
| SUBSOILING | A mechanical soil treatment to break up compacted/impermeable (usually deep) layers in a soil to improve water infiltration and root penetration. Achieved by drawing widely spaced tines through the soil, at the required depth, to produce a shattering effect. |
| SUCKLER COW | A cow that is allowed to rear its own calf before being used for beef production, rather than for milk production. [R] |
| SURFACE RUNOFF | See RUNOFF |
| SURFACE WATER | Water that flows in streams and rivers, natural lakes, wetlands and reservoirs constructed by humans. [R] |
| TILLAGE | General term for the process of soil cultivation. |
| TP | Total phosphorus |
| TRAMLINES | Accurately spaced, narrow pathways left in e.g. a cereal crop to provide wheel guide marks for tractors and machinery used in subsequent operations, e.g. fertiliser application, plant protection product application. [R] |

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| TRANSPONDER | A wireless communications device that picks up and automatically responds to an incoming signal. Used in dairies, mounted in a collar on each cow, to automatically identify the particular animal and allow only that cow to access its allocated feed. |
| ULTRA-VIOLET LIGHT | A component of the spectrum of sunlight, which is harmful to organisms and accelerates the death of microorganisms, for example, when they are exposed on the soil surface. |
| UMBILICAL SPREADING SYSTEM | Liquid manure (slurry) is fed through a long hose to an applicator fitted directly on the rear of a tractor. The hose is supplied with liquid manure direct from the store or from a buffer tank by a pump. [R] |
| UNDERSOWN | Process of sowing a second crop into an already established crop, which develops as an understory and grows on after the main crop has been harvested. This avoids an interval of bare soil between crops and continued uptake of plant nutrients from the soil. |
| URINE PATCH | Localised area of grazed grassland that has received urine from (generally) a single urination and contains high concentrations of urea, which breaks down to form ammonium-N and following NITRIFICATION nitrate-N. |
| VOLATILISATION | The process by which AMMONIA gas is released from solution. [R] Refers to the loss of AMMONIA from urine and from MANURES during housing, storage and following land application. |
| VOLUNTEER (plants) | Plants that result from natural germination, as opposed to having been planted, including plants that re-occur in subsequent seasons following their harvest e.g. through germination of shed seed. |
| WATER MEADOWS | Low-lying grassland areas adjoining water courses, where the stream or river is allowed to naturally flood the fields during winter and the land is grazed during the drier summer period. Water levels may also be managed by a system of dams and sluices. |
| WATER TABLE | The level in a soil below which the ground is completely saturated with water. |
| WATERLOGGED SOIL | A soil that is saturated with water i.e. the pores are completely filled with water and air is excluded. [R] |
| WEANER | A piglet aged between 3 to 10 weeks that has been weaned from the sow’s milk. |

## APPENDIX IV. REFERENCES

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