An Inventory of Methods to Control Diffuse Water Pollution from Agriculture (DWPA)

USER MANUAL

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January 2007

Prepared as part of Defra Project ES0203

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INTRODUCTION

Previous studies for Defra (NT2511 *Cost curve of nitrate mitigation options*; PE0203 *Cost curve assessment of phosphorus mitigation options relevant to UK agriculture* and ES0121 *COST-DP: Cost effective diffuse pollution management*) have identified a range of methods that could be adopted to reduce diffuse water pollution from agriculture. In the reports from these studies, the methods were generally referred to by a brief title and were not described in any detail. The purpose of this User Manual is to provide succinct information on these methods to assist the user to apply information from these earlier reports in developing policies to control diffuse water pollution. The Manual has been prepared as part of Defra Project ES0203 *The Cost-effectiveness of integrated diffuse pollution mitigation measures*. This project has provided estimates of the cost and effectiveness of the various pollution control methods at the farm scale. These have been summarised in a spreadsheet format (referred to as the Farm Library) and used as the basis of modelling work to quantify costs and benefits of groups of methods at the farm and national scale. The cost and effectiveness values in this User Manual were taken from the most recent version of the Farm Library spreadsheet (as of 09/08/2006) but may differ from those in any subsequent revisions of the Library.

The present document concentrates on the three main pollutants of concern; nitrate, phosphorus (P) and faecal indicator organisms (FIOs). The methods that are covered are based on the 41 selected by Defra from their analysis of the original 57 methods described in the earlier reports. After reviewing this selection, we have rejected one method and reinstated four others on the basis of our preliminary assessment of their effectiveness, giving a total of 44 methods in this Manual.

Several of the original methods were included in more than one Cost Curve report. Where this occurred, the same methods sometimes differed in their detailed definition; for example, if requiring a reduction in stocking rate, this may have been specified as a 50% reduction in one report and as 25% in another. The methods have therefore been described in general terms in this manual and are only strictly defined for the estimates of cost and effectiveness, which are dependent on the exact changes implemented. Where there were differences in the detailed descriptions, these have been revised so that the details of each mitigation method are exactly the same for the estimates of costs and for all three pollutants. Because of the possible changes to the detailed definition of some methods, it should not be assumed that the effectiveness of the current methods is exactly the same as that used in the original reports and in Defra's subsequent analysis. The main assumptions made in deriving estimates of the cost and effectiveness are described in the Cost and Effectiveness sections for each method. Additional details of how costs were derived are provided in Appendix II.

The methods are grouped into the following categories:

- Land use
- Soil management
- Livestock management
- Fertiliser management
- Manure management
- Farm infrastructure

They are not presented in any order of effectiveness.

Each method is given a number and brief title that can be used in tables and for reference. This is followed by a description of the method and its application, arranged into eight sections:-

(i) Description: A description of the actions to be taken to implement the method.

(ii) Rationale: The broad reason for adopting the method as a means of reducing pollution.

(iii) Mechanism of action: A more detailed description of the processes involved and how the method may achieve a reduction in pollution.

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

(v) Practicability: An assessment of how easy the method is to adopt, how it may impact on other farming practices, problems with maximising effectiveness and possible resistance to uptake.

(vi) Costs: Estimates are presented of how much it would cost to implement the method in terms of investment and operational costs. Where relevant, costs are expressed per ha and at the farm level. Farm-level costs relate to a number of specific standard farm types, as previously used in the Cost DP project. These are summarised in Table 1 and fully described in Appendix I. The farm systems were based upon those defined in a previous Defra project (NT2010 *Environmental impacts of solid and liquid manure systems*), in which total livestock numbers, crop areas and animal manure production were determined for each farm type. 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 the different methods. 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. Where land management options result in land not being farmed, this may in turn lead to a loss of support payments under the Single Payment Scheme, but this has not been assumed in this document. Furthermore, reduction in stocking rates or the area of land farmed will have a consequent impact on the agricultural supply industry. Again, this has not been taken into account in the estimates of costs.

Where a method cannot be applied to a particular farm type it has been shown as non-applicable (n/a) in the tables. For example, methods directed at improving solid manure (FYM) use are marked as non-applicable for the dairy and outdoor pig farms because these model farm types only produce slurry. Applicability may differ from that shown in the Farm Library spreadsheet because the Farm Library is used as the basis of modelling work that includes combinations of methods. In these circumstances, a method that is non-applicable on its own may become applicable once another method has been implemented, e.g. after changing from a slurry-based to a solid manure-based system (Method 30).

Table 1. Summary of the model farm systems used for estimating the cost and effectiveness of mitigation methods

Farm System	Animal Count	Excreta (t/year)	Managed as manure (%)	Field area (ha)	Average fertiliser	
					kg N/ha	kg P_2O_5/ha
Arable	0	0	n/a	300	165	60
Arable plus manure	0	2,700	100	300	140	58
Dairy	270	5,040	60	150	190	35
Suckler Beef	220	1,850	50	100	80	30
Broilers	150,000	2,550	100	437	145	48
Breeding Pigs (Indoor)	1,330	2,125	100	71	145	48
Breeding Pigs (Outdoor)	2,536	3,568	0	24	0	0

See Appendix I for a detailed description of the farm systems

(vii) Effectiveness: Estimates are presented of the effectiveness of the method in reducing losses of each of the main pollutants, nitrate, P and FIOs. In most cases, estimates for nitrate and P were taken from the previous Defra projects and adapted using 'expert weightings' to match them more closely to the methods as described in this User Manual. Environmental models were used to assist in the estimation of nitrate and P losses. The NITCAT, NCYCLE and MANNER models were used for nitrate and the PSYCHIC model for P. Baseline losses, in the absence of any mitigation methods, were estimated for the same model farm systems as used for estimating Costs (Table I). The baseline losses were divided between components originating from the soil, from manure/excreta and from fertiliser. These were then used as the basis of determining the likely reduction in loss for each of the mitigation methods. Where possible, reductions in nitrate and P losses are expressed both as kg/ha/year over the area to which the method is applied and averaged over the whole farm area. For each method, effectiveness at the farm scale is presented as a table showing the reduction in loss averaged over the farm area for each system on a clay loam and on a sandy loam soil, for both assuming a medium rainfall (850 mm/year). The baseline losses from the farms in the absence of any mitigation methods are shown in the table in parentheses.

N: For nitrate, assessments of effectiveness were based on the N Cost Curve project (NT2511), although estimates for some methods were recalculated for the current work using the NITCAT and NCYCLE models. Not all of the methods in this User Manual were quantified in the N Cost

Curve model runs. Therefore, estimates of effects for these methods were based on the NT2511 literature review and/or additional model runs (e.g. using MANNER). Wherever possible, nitrate effects are quantified as an average across the farm and rotation. Because arable farms follow a rotational cropping pattern, a particular crop-specific method might only apply to say one third of the farm in any one year but will apply to another third in the following year and to the remaining third in the third year. Hence, the overall loss estimated for one year will be equally representative of other years in the rotation. Baseline nitrate losses and reductions in loss are expressed as kg N/ha (as the element N, not as nitrate).

P: For P, the default source and assumptions underlying the estimates of effectiveness are taken from the Phosphorus Cost Curve project (PE0203), drawing especially from material in Table 8 in the final project report. There are mis-matches between some of the defined methods, model systems and assumptions used in PE0203 and those in the current User Manual. Where the current methods do not exactly match those in PE0203, reasonable analogue methods have been used (as described in the text), accepting that some of the root assumptions may be different. 'Expert weightings' have then been applied to the PE0203 effectiveness values to match them more closely of the current methods. The estimates, therefore, inherit quite a large degree of uncertainty that has to be accepted and put in context when using this work. The values from PE0203 refer to losses of total P (TP) per ha of land to which the method is applied. These are scaled up to an average loss per ha over the whole farm area, as for nitrate. The values for the reduction in P losses refer only to the short-term effect of the method. Some methods will achieve a greater reduction in P losses in the longer term (e.g. >10 years) as a result of a slow reduction in soil P contents. Because of the uncertainties in these estimates, the longer-term effects have not been quantified in this manual. Quantities are expressed as kg of the element P per ha, not as P_2O_5.

FIOs: An 'expert judgement' approach was used to estimate baseline losses of FIOs and the effectiveness of mitigation methods. This assessment expresses FIO losses in terms of *relative units* per ha, where the baseline load for the Dairy Farm System on a clay loam soil (medium rainfall) is arbitrarily set at 100 units/hectare. The assessment was largely based upon previous work undertaken in Defra projects WA0804 *Investigations of the routes by which pathogens associated with livestock slurries and manure may be transferred from the farm to the wider environment* and ES0121 *COST-DP: Cost effective diffuse pollution management*.

This assessment only takes into account losses from farm livestock and does not specifically address 'background' losses due to wildlife, pets, human inputs, etc. The livestock farming assessments recognise four major FIO loss routes, viz:

- losses during and following livestock grazing in the field (potentially 40 relative units)
- losses following the landspreading of manure (potentially 40 relative units)
- losses from hardstandings, livestock tracks, etc. (potentially 10 relative units)
- losses from excreta deposited directly into streams, etc. (potentially 10 relative units)

The effectiveness of mitigation methods is expressed as the percentage reduction in loss of FIOs compared to the baseline farm. Effectiveness is allocated to one of the following categories; -10% (i.e. the method *increases* the potential transfer of FIOs to water), no change or a reduction of 10, 20, 30, 40 or 50%.

For all pollutants, the effectiveness of methods at the farm scale depends on the proportion of the farm to which the method is applied. This proportion is defined for each method. For example, several methods that reduce the risk of run-off on arable soils are assumed to be applied to 20% of the model farm area so that the farm-level effectiveness will only be one fifth of the direct effect on the area to which the method is applied. Where a method cannot be applied to a particular farm type it has been shown as non-applicable (n/a) in the tables.

Because the cost and effectiveness values relate specifically to the standard Model Farm Systems described in Table 1, they cannot be simply extrapolated and applied to the whole of a farming sector (e.g. intensive grassland or cereal production) across farms of different sizes and in different regions. The more detailed modelling required to extend these assessments to the regional scale has been done elsewhere in this project.

The assessments cannot be applied to a specific farm unless the details of the farm match those of one of the Model Farm System. Even within a single farm type, there may be appreciable differences between the model farm and the range of farms found within that sector, with corresponding differences in the applicability and effectiveness of the mitigation methods. For example, the model dairy system is defined as an all-grass farm so that mitigation methods aimed at arable land will be of limited applicability. In practice, however, many dairy farms grow large areas of forage maize, where these arable-based methods could be applied. In spite of these limitations, the estimates do provide a basis for comparing the effectiveness of methods for a 'typical' farm within a given sector.

(viii) Other benefits or risk of pollution swapping: This section provides an assessment of how the emission of other pollutants included in the previous COST-DP study (i.e. nitrite, ammonium, BOD and sediment inputs to water and ammonia, nitrous oxide, methane and carbon dioxide emissions to the atmosphere) might either be reduced or increased if the method were to be adopted. Some forms of pollution are closely related, so that reductions in one pollutant are often accompanied by reductions in the other. For example, methods that reduce P losses by reducing soil erosion will generally achieve equivalent reductions in the amounts of silt entering water bodies. Similarly, the liquid fraction of manure contains ammonium-N and dissolved organic matter (BOD) as well as P and FIOs, so methods that reduce surface run-off of manures will tend to reduce losses of all these pollutants. Conversely, where pollution swapping occurs, reductions in one form of loss may be accompanied by increased losses of another pollutant or *via* another pathway. For example, reducing the amount of nitrate lost in water may retain more N in the soil in a form that is susceptible to denitrification and thereby increase losses of nitrous oxide.

Limits to the use of the estimates *The cost and effectiveness values for each method relate specifically to the standard Model Farm Systems (Table 1). They cannot be simply extrapolated and applied to the whole of a farming sector.*

Similarly, the estimates of cost and effectiveness should not be applied to a specific farm, except where the farm closely resembles one of the Model Farm Systems.

TABLE OF METHODS TO CONTROL DWPA

Category	No.	Method
Land use	1	Convert arable land to extensive grassland
Soil management	2	Establish cover crops in the autumn
	3	Cultivate land for crop establishment in spring rather than autumn
	4	Adopt minimal cultivation systems
	5	Cultivate compacted tillage soils
	6	Cultivate and drill across the slope
	7	Leave autumn seedbeds rough
	8	Avoid tramlines over winter
	9	Establish in-field grass buffer strips
	10	Loosen compacted soil layers in grassland fields
	11	Maintain and enhance soil organic matter levels
	12	Allow field drainage systems to deteriorate
Livestock management	13	Reduce overall stocking rates on livestock farms
	14	Reduce the length of the grazing day or grazing season
	15	Reduce field stocking rates when soils are wet
	16	Move feed and water troughs at regular intervals
	17	Reduce dietary N and P intakes
	18	Adopt phase feeding of livestock
Fertiliser management	19	Use a fertiliser recommendation system
	20	Integrate fertiliser and manure nutrient supply
	21	Reduce fertiliser application rates
	22	Do not apply P fertilisers to high P index soils
	23	Do not apply fertiliser to high-risk areas
	24	Avoid spreading fertiliser to fields at high-risk times
Manure management	25	Increase the capacity of farm manure (slurry) stores
	26	Minimise the volume of dirty water produced
	27	Adopt batch storage of slurry
	28	Adopt batch storage of solid manure
	29	Compost solid manure
	30	Change from slurry to a solid manure handling system
	31	Site solid manure heaps away from watercourses and field drains
	32	Site solid manure heaps on concrete and collect the effluent
	33	Do not apply manure to high-risk areas
	34	Do not spread farmyard manure to fields at high-risk times
	35	Do not spread slurry or poultry manure to fields at high-risk times
	36	Incorporate manure into the soil
	37	Transport manure to neighbouring farms
	38	Incinerate poultry litter
Farm infrastructure	39	Fence off rivers and streams from livestock
	40	Construct bridges for livestock crossing rivers and streams
	41	Re-site gateways away from high-risk areas
	42	Establish new hedges
	43	Establish riparian buffer strips
	44	Establish and maintain artificial (constructed) wetlands

DETAILS OF METHODS

1. Convert arable land to extensive grassland

Description: Reduce losses of N and P by changing the land use from arable cropping to permanent grassland, either ungrazed or with a low stocking rate and zero or low fertiliser input.

Rationale: There are only small losses of nitrate in drainage waters from arable reversion grassland and the permanent vegetation cover minimises the erosion of soil particles and loss of associated P in surface run-off.

Mechanism of action: Low inputs ensure that high levels of N do not accumulate in the soil. In addition, uptake by the continuous vegetative cover and immobilisation into accumulating soil organic matter provide a sink for the N that is available. Conversion to grassland also avoids the frequent cultivations that under arable cropping stimulate the mineralisation of organic matter and thereby increase the amount of nitrate that is potentially available for leaching. Changing from intensive arable agriculture to extensive grassland is therefore expected to markedly reduce N losses.

In most cases, losses of nitrate in drainage water will respond rapidly to the change of land use. However, where previous intensive fertiliser use has raised soil P contents, significant reductions in the leaching of soluble P are unlikely to be achieved in the short term (<10 years) because there are only low off-takes of nutrients from extensive systems and elevated levels of P will continue to be recycled through the soil. The more immediate effect of this method will be to reduce P losses in surface run-off, provided that the grassland is not poached. The change to soil with a permanent vegetative cover will reduce soil erosion and the transport of sediment and associated P to watercourses. If grazed, there is a risk of a small increase in FIO losses, compared with arable land that does not receive manure.

Potential for applying the method: The method is applicable to all forms of arable farmland but is potentially most suited to marginal arable land that was historically kept as grazing land. Benefits will be greatest on sandy and silty soils that are most prone to erosion.

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

Cost: See Appendix II for the assumptions used to estimate costs. The tables (below) show costs separately for the alternatives of (a) leaving the land ungrazed after conversion and (b) using the land for grazing.

(a) Costs where the land is left ungrazed after conversion and no livestock is purchased

Costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Capital outlay	0	n/a	n/a	n/a	n/a	n/a
Loss of net output £/ha pa	90	“	“	“	“	“
Cost (topping 1year in 5) £/ha	5	“	“	“	“	“
Loss of output £/farm pa	26,940	“	“	“	“	“
Cost (topping 1year in 5) £/farm	1,500	“	“	“	“	“

[continued]

(b) Alternative costs where arable farming is replaced with beef and sheep (at 1 LSU/ha)

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Initial capital outlay						
Livestock £/farm (net)	60,500	n/a	n/a	n/a	n/a	n/a
Fencing £/farm	43,000	"	"	"	"	"
Hedges £/farm	128,000	"	"	"	"	"
Water £/farm	3,650	"	"	"	"	"
Establish grassland £/farm	29,850	"	"	"	"	"
Total £/farm	265,000					
Livestock£/ha	200	"	"	"	"	"
Fencing £/ha	145	"	"	"	"	"
Hedges £/ha	430	"	"	"	"	"
Water £/ha	12	"	"	"	"	"
Establish grassland £/ha	100	"	"	"	"	"
Total £/ha	890					
Annual costs						
Loss of output £/farm	27,200	n/a	n/a	n/a	n/a	n/a
Fencing £/farm	6,100	"	"	"	"	"
Hedging £/farm	18,200	"	"	"	"	"
Water £/farm	900	"	"	"	"	"
Grassland £/farm	6,000	"	"	"	"	"
Total £/farm	58,400					
Loss of output £/ha	91	"	"	"	"	"
Fencing £/ha	20	"	"	"	"	"
Hedging £/ha	61	"	"	"	"	"
Water £/ha	3	"	"	"	"	"
Grassland £/ha	20	"	"	"	"	"
Total £/ha	195					

Effectiveness:

N: The method is very effective. Conversion to ungrazed grassland reduces nitrate losses by >95%. Annual losses can be about 2 kg N/ha of converted land. If the converted land is used for extensive grazing, losses can be about 20 kg N/ha per year. NB Values for the reductions in nitrate loss for the grazing option in table (b) below differ from those in the Farm Library spreadsheet, in which reductions are shown as being the same as for ungrazed grassland.

P: PE0203 Method 14 ‘Convert arable to beef and sheep’ was used. After adjusting for the expert weighting, this corresponds to an overall 50% reduction in the loss of P in the absence of grazing and a 42% reduction under extensive grazing.

FIOs: Conversion to ungrazed grassland would have no effect on the loss of FIOs but use as extensive grazing might **increase** losses at the farm-scale by 20 relative units on clay loam and by 8 units on sandy loam soil because of introducing a source of viable FIOs to the system. NB These increases are not shown in the Farm Library spreadsheet - conversion to extensive grazing is shown as having no effect on FIO losses.

Estimates of effectiveness at the farm-scale assume that all the farm area is converted to grassland. The tables (below) show the effectiveness of the method separately for the alternatives of (a) leaving the land ungrazed after conversion and (b) using the land for extensive grazing.

[continued]

(a). Conversion to ungrazed grassland

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	49	(51)	45	(47)	0.18	(0.3)	1.16	(2.3)	0	(0)	0	(0)
Arable + manure	55	(57)	49	(51)	0.18	(0.4)	1.24	(2.5)	0	(1)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

(b). Conversion to extensive grazing

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (relative units)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	31	(51)	27	(47)	0.15	(0.3)	0.97	(2.3)	*+8*	(0)	*+20*	(0)
Arable + manure	37	(57)	31	(51)	0.15	(0.4)	1.03	(2.5)	*+8*	(1)	*+20*	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units.*
*This method **increases** the loss of FIOs and the change is shown in relative units, rather than as a % reduction as used for FIOs in the effectiveness tables for all other methods.*

Other benefits or risk of pollution swapping: Nitrous oxide emissions would be reduced as a result of lower fertiliser N inputs. There would also be reductions in energy use and increased carbon sequestration by the accumulation of organic matter that occurs naturally in grassland soil.

2. Establish cover crops in the autumn

Description:

- If land would otherwise 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 will be in place to take up nutrients and provide vegetation cover once the spring crop has been harvested.
- In order to protect the soil surface throughout the period when runoff could occur, do not destroy the cover until the land is due to be prepared for the following crop

Rationale: Cover crops have been shown to reduce nitrate leaching by up to 50% compared with soils that were left bare over the winter. Without a cover crop, nitrate can be lost through leaching by excess winter rainfall and P through sediment transport in surface run-off.

For effectiveness against N leaching, the crop needs to take up N before the onset of winter drainage but thereafter the date of destruction is less critical. For effectiveness against P transfer, the crop does not have to be alive (i.e. straw or even a rough seedbed are equally effective) but the soil must be protected throughout the period when runoff would occur.

Mechanism of action: Cover crops help to reduce the mobilisation of agricultural pollutants by increasing nutrient uptake and reducing surface run-off and soil erosion. A cover crop will take up residual nitrate and other nutrients from the soil after the main crop has been harvested in the summer or early autumn, leaving less nitrate available for leaching over winter. Ensuring that the land is not left exposed helps reduce soil erosion and the mobilisation of associated pollutants. Cover crops can also help to improve soil structure compared with bare soil. This method is unlikely to impact significantly on FIO losses.

Potential for applying the method: This method is applicable to the intensive grassland and arable sectors, particularly on light soils where there are significant areas of spring crops. The area of cropped land in the UK on which a cover crop could be effectively established amounts to around 1.5 million hectares. The effectiveness of cover crops is well proven on arable land under the Nitrate Sensitive Area scheme, where sowing was early in the autumn period. It is also proven on light land following the harvest of fresh peas in June/July. The method is relatively easy to implement and is already used in some grassland systems with the undersowing of maize and spring barley with a grass seed mixture. On light soils, a cover crop can be established using cheap methods (e.g. broadcast seed and tine/roll). The use of cover crops is also compatible with the Environmental Stewardship scheme.

Practicability: For some autumn-sown arable crops, it is difficult to establish a cover crop in the autumn that will take up sufficient N to significantly decrease nitrate leaching losses ahead of sowing the following autumn crop. For undersown spring crops, some farmers prefer to wait until the main crop is established before undersowing the grass seed. However, this may only be practicable on well-drained soils. The cover crop can also be broadcast into the main crop before harvest. However, this can damage the standing crop and lead to yield losses. Except where grass is being established as the following crop, autumn or post-harvest establishment of a mustard type crop would be the most effective cover; however, this would affect crop growth if it were undersown. Where cover crops were established for the Nitrate Sensitive Area scheme, it was found to be preferable for agronomic reasons to destroy the crop in January or February. This could limit the usefulness of this approach in mitigation of P losses.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha cereals etc.	2.5	n/a	n/a	2.5	2.5	n/a
Cost £/ha other crops	17.0	"	"	17.0	17.0	"
Cost £/farm cereals etc.	750	"	"	1,100	180	"
Cost £/farm other crops	5,070	"	"	7,400	1,200	"

[continued]

Effectiveness:

N: Depends on growth of the cover crop and the time of onset of drainage but is typically a 10-45 kg/ha reduction in leaching in the year of establishment. Assume an average reduction of 28 kg N/ha per year for arable without manure and 44 kg N/ha for higher fertility situations where manure is used frequently.

P: PE0203 Method 26 'Establish cover crops' was used, as applied to spring-planted roots and vegetables. After adjusting for the expert weighting, this reduced the soil component of P loss by 25 and 35% on clay loam and sandy loam soil, respectively.

FIOs: Unaffected by the method.

The farm-scale estimates assume that the rotation allows cover crops to be grown 1 year in 4. The method therefore affects 25% of the farm in any single year.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	7	(51)	7	(47)	0.03	(0.3)	0.13	(2.3)	0	(0)	0	(0)
Arable + manure	11	(57)	11	(51)	0.03	(0.4)	0.13	(2.5)	0	(1)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	11	(82)	11	(68)	0.03	(0.4)	0.13	(3.2)	0	(0)	0	(0)
Indoor pigs	11	(89)	11	(74)	0.03	(0.5)	0.13	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Soil structural damage caused by establishing a cover crop late and/or in wet conditions may compromise cover crop establishment and result in soil nitrate being poorly utilised by both the cover crop and subsequent crops. Residual nitrate will be at risk of leaching from soils with a poorly established cover crop and over the following winter drainage period if soil structural damage is not alleviated. Soil structural damage will also increase the risk of soil erosion and the loss of P and sediment.

3. Cultivate land for crop establishment in spring rather than autumn

Description:

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

Mechanism of action: This is a mobilisation method. Cultivation of soils results in mineralisation of organic N and increases the risk of nitrate leaching. The amount of mineralisation is strongly affected by soil temperature, moisture and the N balance under the previous crop. In the case of grassland, mineralisation will be greater following cultivation of grazed swards than cut swards and will also be increased by increasing applications of N fertiliser or manure during the grass ley phase. Autumn cultivation further increases the risk of nitrate loss because the warm and moist soil conditions at this time of year encourage high rates of mineralisation when, in the absence of an actively growing crop, there is little N uptake. Drainage during the following winter period will then transport the accumulated nitrate out of the soil profile. Cultivation in spring is better, because bare soil is not exposed over the 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 is applicable to cultivations prior to the drilling of spring crops (e.g. maize, sugar beet, potatoes) or where there is a switch from winter to spring cereal cropping. It is also applicable to grassland systems where grass leys are ploughed out and re-seeded.

Practicability: Land for spring crops, ploughed in late autumn, has the winter for frost action and wetting and drying cycles to break down soil clods. Ploughing in the autumn also allows early establishment of the following spring crop as only secondary cultivations are required ahead of drilling. On medium to heavy soils, if ploughing is not carried out in late autumn, the delayed cultivations may result in the spring crop being drilled into a drying seedbed. This may impact on establishment and yield. Delaying cultivation until the spring may also have implications for the control of some weeds. There are also soil structural implications associated with cultivating during a wet spring. For grassland, reseeding in spring is less reliable than in autumn.

Cost: See Appendix II for the assumptions used to estimate costs. The method is not applicable to the model dairy and beef farms because the area of autumn-sown grass is assumed to be less than 5%.

Annual costs for farm system at 25% yield loss for all crops	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Spring combinable crop £/ha	11	n/a	n/a	11	11	n/a
Spring combinable crop £/farm	3,190	"	"	4,650	755	"

Effectiveness:

N: Leaving land undisturbed over winter reduces leaching by about 10 kg N/ha. This value was used for arable land without manure and 15 kg N/ha for arable with manure to reflect the higher labile N where manure is applied.

P: There is no equivalent method in PE0203 but Method 28 'Minimum tillage' was used as a basis for estimating the effectiveness. The method was estimated to reduce the soil component of the P loss by 50 and 70% on clay loam and sandy loam soil, respectively.

FIOs: Unaffected by the method.

Estimates of effectiveness at the farm-scale assume that the method can be applied to 10% of the farm area in any single year. Although the method can be applied to areas of re-seeding on grassland farms, the area of autumn-sown grass on the model dairy farm (and beef farm) is assumed to be less than 5% and is ignored.

[continued]

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	1.0	(51)	1.0	(47)	0.02	(0.3)	0.11	(2.3)	0	(0)	0	(0)
Arable + manure	1.5	(57)	1.5	(51)	0.02	(0.4)	0.11	(2.5)	0	(1)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	1.5	(82)	1.5	(68)	0.02	(0.4)	0.11	(3.2)	0	(0)	0	(0)
Indoor pigs	1.5	(89)	1.5	(74)	0.02	(0.5)	0.11	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: If the cultivation causes structural damage, this may compromise crop yields and result in applied mineral fertiliser and organic manure N being poorly utilised by crops and at risk from leaching over the next winter drainage period. There is some possible conflict in this method with the practice of cultivating land in autumn to reduce hydrological connectivity in the soil and cultivating after manure spreading (Methods 5 and 36). For the ploughing out of grass leys, the evidence is that when grass is ploughed in spring, some of the nitrate leaching is deferred to the following autumn.

4. Adopt minimal cultivation systems

Description:

- Use discs or tines to cultivate the surface as a primary cultivation in seedbed preparation.
- Or direct drill into stubbles (no-till).

Rationale: Minimal cultivation (rather than ploughing) may be the best way to maintain organic matter, preserve good soil structure and break up surface crusts. The resulting soil conditions should improve infiltration and retention of water, thereby reducing loss of P and sediment.

Mechanism of action: This is a mobilisation method. Maintaining good structure and promoting infiltration and through-flow reduces soil erosion risk. The reduction in surface run-off is particularly effective when a mulch of crop residues is left on the surface. Good structure also promotes the efficient use of soil nutrients.

Conversion from ploughing to minimum or no cultivation systems in the short-term will decrease total P concentrations in surface run-off but in the long-term can increase dissolved P. Nitrate leaching is generally decreased to a small extent through reduced mineralisation of soil organic matter in the autumn, although there are likely to be small increases in drainage volumes.

Potential for applying the method: This method is already being adopted on a number of arable farms, with around 1.5 million hectares cultivated using discs or tines. It is most commonly applied to medium to heavy soils, although the practice is increasingly being carried out on lighter soils.

Practicability: No-till is unsuitable for light soils that are prone to capping. Minimum cultivation is less applicable in a very wet autumn and is only suitable where soil structural problems have been alleviated. Minimum tillage may increase resistant weed populations and therefore increase reliance on chemical control.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Likely net **savings** £/ha	40	n/a	n/a	40	40	n/a
Range of +/- 25% £/ha	30 – 50	"	"	30 – 50	30 – 50	"
Range of savings £/farm	9,000 – 15,000	"	"	13,110 – 21,850	2,130 – 3,550	"

Effectiveness:

N: Decreases leaching by 0-5 kg N/ha compared with ploughing. A reduction of 2.5 kg N/ha was assumed for soils without manure and 3.5 kg/ha where manure is applied, to reflect the greater content of labile N in the manure system. NB The method is not applicable to all soils.

P: PE0203 Method 28 ‘Minimum tillage’ was used, as applied to break crops and cereals. After including the expert weighting, this corresponds to a 5% reduction in the soil component of P loss from clay loam soils.

FIOs: Unaffected by the method.

Estimates of effectiveness at the farm-scale assume that minimal cultivation is adopted for all fields on the clay loam soil but that the method is not applicable to sandy loam soils.

[continued]

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	n/a (51)	2.5 (47)	n/a (0.3)	0.11 (2.3)	n/a (0)	0 (0)
Arable + manure	n/a (57)	3.5 (51)	n/a (0.4)	0.11 (2.5)	n/a (1)	0 (1)
Dairy	n/a (61)	n/a (34)	n/a (0.2)	n/a (2.8)	n/a (36)	n/a (100)
Beef	n/a (18)	n/a (12)	n/a (0.2)	n/a (1.0)	n/a (15)	n/a (43)
Broilers	n/a (82)	3.5 (68)	n/a (0.4)	0.11 (3.2)	n/a (0)	0 (0)
Indoor pigs	n/a (89)	3.5 (74)	n/a (0.5)	0.11 (3.7)	n/a (4)	0 (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: If minimal cultivation is carried out on soils with poor structure, the method is ineffective at best. Also, the long-term use of minimum cultivations or no-till systems can increase dissolved P losses in run-off. However, in the UK, intermittent ploughing is usually part of farm cultivation systems as means of minimising compaction from discs near the soil surface and for weed control. There is a possibility that incorporation of large volumes of straw into a small volume of soil under a minimum tillage system may immobilise so much N that it restricts crop growth and creates a need for autumn application of N fertiliser (see Method 24).

5. Cultivate compacted tillage soils

Description:

- After harvest, cultivate compacted tillage soils with discs or tines to increase surface roughness and infiltration.
- Carry out the cultivation in dry conditions and well ahead of the start of drainage in late autumn.
- Endeavour to establish a vegetative cover through natural regeneration or from broadcast barley seed.

Rationale: Cultivation disrupts soil surface crusts and increases surface roughness. This enhances opportunities for rain to infiltrate into the soil and reduces the erosive energy of any surface flow that does occur. The method will reduce losses of P and, if manure is spread on compacted tillage soils, will also reduce losses of FIOs.

Mechanism of action: This method reduces surface run-off and soil erosion. When soils are compacted or capped and there is little crop residue or vegetation to intercept rainfall, the land is very susceptible to the generation of surface run-off and the movement of pollutants to a water body. Cultivation of the soil surface during dry conditions will increase surface roughness, which will enhance infiltration of water into the soil and drainage through the soil profile rather than creating surface run-off.

Potential for applying the method: The method is applicable to the arable sector on cereal and maize land where soils are compacted, particularly in high winter rainfall areas.

Practicability: The cultivation itself is straightforward. However, for the method to be effective it should be carried out in the late summer to early autumn (i.e. when soils are dry) when there are many other competing demands for the farmer's time.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	4	n/a	n/a	4	4	n/a
Cost £/farm	1,200	"	"	1,750	285	"

Effectiveness:

N: Effectiveness depends on the size of the compacted area. Nitrogen that is not taken up by the crop because of compaction will not necessarily be leached. The benefit is likely to be minimal and the method is assumed to have nil effect.

P: There is no equivalent method in PE0203 but PE0203 Methods 33 'Increasing surface roughness' and 34 'Subsoiling across the slope' were used as a basis for estimating the effectiveness. After including an expert weighting, it was assumed that the method achieved a 25% reduction of the soil component of the P loss for clay loam and a 35% reduction for sandy loam soils.

FIOs: Unaffected by the method.

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	0	(51)	0	(47)	0.02	(0.3)	0.11	(2.3)	0	(0)	0	(0)
Arable + manure	0	(57)	0	(51)	0.02	(0.4)	0.11	(2.5)	0	(1)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	0	(82)	0	(68)	0.02	(0.4)	0.11	(3.2)	0	(0)	0	(0)
Indoor pigs	0	(89)	0	(74)	0.02	(0.5)	0.11	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Estimates of effectiveness at the farm-scale assume that the method is applied to 20% of the arable farm area.

Other benefits or risk of pollution swapping: Cultivation of compacted soils in the autumn will enhance the mineralisation of soil organic N and water infiltration rates into the topsoil. This will increase the risk of nitrate leaching by a small extent over the winter.

6. Cultivate and drill across the slope

Description: Cultivate and drill land along the contour to reduce the risk of developing surface flow.

Rationale: On fields with simple slope patterns, cultivating and drilling across the slope is thought to reduce the risk of surface run-off being initiated. The ridges created across the slope increase down-slope surface roughness and provide a barrier to surface run-off. Losses of P and FIOs are reduced as a result.

Mechanism of action: This is a mobilisation method. 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 is reduced if they are aligned across the slope. Soils cultivated across the slope will also hold more water in surface depressions, before surface flow is initiated.

Potential for applying the method: Applicable to all cultivated soils on sloping land.

Practicability: The method is more time-consuming and requires greater skill than conventional field operations. Cultivation and drilling should not be carried out across very steep slopes, due to the risk of the machinery overturning. Also, as indicated in the Defra Soil Code, this method is only likely to be effective for crops grown on gently sloping fields with simple slope patterns; these conditions are not present in many fields in England and Wales. For steeper sloping fields with complex slope patterns, it is not practical to follow the contours accurately. In these fields, attempts at cultivations across the slope often lead to channelling of run-off water, particularly in tramlines or wheelings, which can cause severe erosion. 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.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	3	n/a	n/a	3	3	n/a
Cost £/farm	900	"	"	1,310	215	"

Effectiveness:

N: The method has no effect on nitrate leaching.

P: PE0203 Method 29 'Contour cultivation' was used, as applied to the all-arable scenario. After adjusting for the expert weighting, this reduced the soil component of P loss by 35 and 25% for sandy loam and clay loam soils, respectively.

FIOs: Unaffected by the method.

The estimates of effectiveness at the farm-scale assume that the method is applied to 20% of the arable farm area.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	0	(51)	0	(47)	0.02	(0.3)	0.11	(2.3)	0	(0)	0	(0)
Arable + manure	0	(57)	0	(51)	0.02	(0.4)	0.11	(2.5)	0	(0)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	0	(82)	0	(68)	0.02	(0.4)	0.11	(3.2)	0	(0)	0	(0)
Indoor pigs	0	(89)	0	(74)	0.02	(0.5)	0.11	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: As with other methods that combat soil erosion, the reduction in P loss is accompanied by a corresponding reduction in sediment loss.

7. Leave autumn seedbeds rough

Description: Avoid operations that create a fine seedbed that will 'slump' and run together.

Rationale: Leaving the autumn seedbed rough encourages infiltration and reduces the development of surface flow, thereby reducing the loss of P and FIOs.

Mechanism of action: This is a mobilisation and transport method. A more open seedbed is achieved by using a reduced number of cultivations, particularly from powered cultivation equipment, and by avoiding the use of a heavy roller. This helps to reduce the risk of surface flow by preventing soil capping and enhancing infiltration of surface water 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/gully development.

Potential for applying the method: Applicable to the establishment of crops in the arable sector (particularly on sandy and silty soils). It is most applicable to winter cereal crops that can establish well in coarse seedbeds.

Practicability: Herbicide activity is most effective in firm and fine seedbeds. A rough seedbed would reduce this activity. The method is not well suited to crops such as oilseed rape, sugar beet and reseeded grasslands that require fine, clod-free seedbeds. This is particularly the case for sugar beet when a precision drill is used. A rough seedbed may not be appropriate when there is a high risk of slug damage.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	40	n/a	n/a	40	40	n/a
Cost £/farm	2,400	"	"	3,500	570	"

Effectiveness:

N: The method has no effect on nitrate leaching.

P: PE0203 Method 33 'Increasing surface roughness' was used, as applied to the all-arable scenario. After adjusting for the expert weighting, this reduced the soil component of P loss by 35 and 25% for sandy loam and clay loam soils, respectively.

FIOs: Unaffected by the method.

The estimates of effectiveness at the farm-scale assume that the method is applied to 20% of the arable area.

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				Total P (kg P/ha)				FIOs (%)*			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	0	(51)	0	(47)	0.02	(0.3)	0.11	(2.3)	0	(0)	0	(0)
Arable + manure	0	(57)	0	(51)	0.02	(0.4)	0.11	(2.5)	0	(1)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	0	(82)	0	(68)	0.02	(0.4)	0.11	(3.2)	0	(0)	0	(0)
Indoor pigs	0	(89)	0	(74)	0.02	(0.5)	0.11	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: 'Patchy' crop establishment or indeed crop failure would reduce yields and lead to an increased risk of nitrate leaching through the winter, as well as the risks associated with sediment losses from bare soils over winter. Increased infiltration rates may increase nitrate leaching losses to a small extent as the water passes through the soil profile rather than over the surface as run-off.

8. Avoid tramlines over winter

Description: Delay the establishment of tramlines until the spring.

Rationale: Tramlines are generally established for combinable crops at the time of drilling. Compacted tramlines can result in the channelling of surface water and the development of rills and gullies on erosion susceptible soils. Avoiding tramlines over winter therefore helps prevent soil erosion, accelerated run-off and the loss of P.

Mechanism of action: This is a mobilisation method. Avoiding the compaction produced by tramlines over winter helps prevent soil mobilisation and surface run-off. This helps prevent the down-slope transport of sediment-bound and soluble pollutants. Tramlines can act as a flow pathway during periods of increased surface run-off. Avoiding their use in winter will reduce run-off volumes.

Potential for applying the method: This method is applicable to winter cereals in most arable farming systems, particularly on light soils in areas with higher winter rainfall. It is not applicable to most oilseed rape crops, due to the need to apply pesticides during the autumn period.

Practicability: It is not a straightforward method to implement as farmers generally need to access winter cereal fields in the autumn to apply pesticides. To do this while avoiding the compaction associated with tramlines may only be possible by using low ground-pressure vehicles. Such a management practice would probably necessitate a change of herbicide policy on the farm and increase costs. Establishing accurate tramline widths post-drilling may be facilitated by the increasing use of GPS systems. The approach is compatible with the Environmental Stewardship scheme and there is no conflict with other methods.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha	4.5	n/a	n/a	4.5	4.5	n/a
Cost £/farm	1,350	"	"	1,970	320	"

Effectiveness:

N: The method has no effect on nitrate leaching.

P: PE0203 Method 32 ‘Change tramline management’ was used, as applied to the all-arable scenario. After adjusting for the expert weighting, this reduced the soil component of P loss by 35 and 25% for the sandy loam and clay loam soils, respectively.

FIOs: Unaffected by the method.

The estimates of effectiveness at the farm-scale assume that the method is applied to 20% of the arable farm area.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	0	(51)	0	(47)	0.02	(0.3)	0.11	(2.3)	0	(0)	0	(0)
Arable + manure	0	(57)	0	(51)	0.02	(0.4)	0.11	(2.5)	0	(1)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	0	(82)	0	(68)	0.02	(0.4)	0.11	(3.2)	0	(0)	0	(0)
Indoor pigs	0	(89)	0	(74)	0.02	(0.5)	0.11	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: As with other methods that combat soil erosion, the reduction in P loss is accompanied by a corresponding reduction in sediment loss.

9. Establish in-field grass buffer strips

Description: On sloping fields, establish grass buffer strips along the land contour, in valley bottoms or on upper slopes to reduce and slow down surface flow. Cut regularly in the first 12 months to control annual weeds and encourage grasses to tiller.

Rationale: In-field buffer strips can reduce P and, where manures are applied to tillage land, FIO losses by slowing run-off and intercepting the delivery of sediment.

Mechanism of action: An in-field buffer strip is a vegetated strip 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. The Entry Level Environmental Stewardship scheme offers options for strips between 2 and 6 m in width. Also, under the Higher Level Stewardship Scheme, there is the option to establish in-field grass areas to prevent erosion and run-off (with a maximum permissible area of 30% of each field).

The strip acts as a natural buffer to reduce the transfer of diffuse pollutants in surface run-off from agricultural land to water. Buffer strips can act as a sediment-trap, as well as helping to reduce nutrient and pesticide losses in run-off. The strip has no effect on nitrate other than *pro rata* for the area taken out of production (i.e. the buffer strip is similar to unfertilised grass).

Potential for applying the method: In-field buffer strips are applicable to all arable farming systems on sloping land. They are particularly suited to fields with long slopes, where high volumes of surface run-off can be generated.

Practicability: The buffer strips will reduce the length of fields, but increase the time taken for field operations by around 10%. They are reasonably acceptable to farmers who are keen to improve the environmental potential of their farm and are compatible with the Entry Level and Higher Level Environmental Stewardship schemes. They may be more effective when combined with additional riparian buffer strips (Method 43).

Cost: It has been assumed that 10% of the farm area will be put into buffer strips (see Appendix II).

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha of strip	31.6	n/a	n/a	31.6	31.6	440
Cost £/farm	9,480	"	"	13,630	2,240	10,530

Effectiveness:

N: The benefit will be from taking land out of production and will be confined to the area of the buffer strip. The nitrate loss from the strip will be similar to that from ungrazed, zero-N grassland. The buffer strips are assumed to occupy 10% of the farm area; the reduction in leaching at the farm scale will therefore be 10% of the arable reversion value for the particular model farm system and soil type (see Method 1(a)).

P: PE0203 Method 40 ‘Grass buffers’ was used, as applied to the all-arable and grassland scenarios. After adjusting for the expert weighting, this reduced the overall P loss by 40% on both soil types. The benefit was confined to the 10% buffer strip area on the clay loam soil but was effective over 100% of the area on the sandy loam.

FIOs: <10% reduction. Even without the mitigation method, losses of FIOs from arable land are generally small because the storage period for manures is sufficient for most organisms to die-off before spreading and manures are then ploughed in after application.

[continued]

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	4.9 (51)	4.5 (47)	0.14 (0.3)	0.09 (2.3)	0 (0)	0 (0)
Arable + manure	5.5 (57)	4.9 (51)	0.14 (0.4)	0.10 (2.5)	0 (1)	0 (1)
Dairy	n/a (61)	n/a (34)	n/a (0.2)	n/a (2.8)	n/a (36)	n/a (100)
Beef	n/a (18)	n/a (12)	n/a (0.2)	n/a (1.0)	n/a (15)	n/a (43)
Broilers	8.0 (82)	6.6 (68)	0.17 (0.4)	0.13 (3.2)	0 (0)	0 (0)
Indoor pigs	8.7 (89)	7.0 (74)	0.19 (0.5)	0.15 (3.7)	0 (4)	0 (10)
Outdoor pigs	14.0 (108)		4.38 (10.5)		20 (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Buffer strips can also reduce the transfer of BOD and ammonium-N to surface waters by intercepting organic matter in surface run-off. The risk of pollution is increased if fertiliser or manure is spread on the buffer strips and if the buffer strips are used for regular access, turning or storage.

10. Loosen compacted soil layers in grassland fields

Description: Reduce surface run-off from grass fields by shallow spiking or subsoiling to disrupt compacted soil layers. These operations should be carried out in dry conditions.

Rationale: Compacted soil layers reduce the infiltration of rainwater and slurry into the soil and thus increase the frequency of surface run-off. Disrupting these compacted layers by partial cultivation allows more rapid percolation of liquid into the soil and reduces the risk of pollutants being transported to watercourses in surface run-off.

Mechanism of action: Trampling by livestock, particularly cattle, and the passage of heavy farm traffic can compact the upper layers of grassland soils in both grazing and silage fields. Because the soil is cultivated only infrequently, the compaction persists and may build up over a number of years. The reduced porosity impedes the percolation of rainwater and slurry and increases the risk of surface run-off. Shallow spiking, slitting or subsoiling breaks up this compacted layer and allows more rapid infiltration of water, thus reducing run-off from the soil surface. In addition, soil aeration is improved and roots are able to penetrate deeper into the soil, which will increase nutrient uptake from deeper soil layers.

This method will have the greatest benefit in reducing losses of P, as a greater proportion of the loss occurs *via* surface run-off than for nitrate. Also, soil compaction itself need not necessarily increase nitrate leaching. Although compaction reduces N uptake, leaving additional mineral-N in the soil at risk of loss, this N may be taken up by the sward later in the season or it may be denitrified. Furthermore, the physical condition of compacted soils does not favour the percolation of soil water and leaching of solutes.

Potential for applying the method: The method is applicable to grassland farms but most particularly those with high stocking rates of cattle and a high proportion of older swards. Compaction is most likely to occur on medium and fine textured soils.

Practicability: There are few limitations to the adoption of this method although the field operations may be more difficult on stony soils.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	10.8	10.8	n/a	n/a	n/a
Cost £/farm	"	1,620	1,080	"	"	"

Effectiveness:

N: Effectiveness will depend on the size of the affected area. Nitrogen not taken up by the crop because of compaction will not necessarily be leached. Averaged over the farm, the benefit is likely to be minimal and the method is assumed to have no effect.

P: There is no equivalent method in PE0203 but PE0203 Methods 33 'Increasing surface roughness' and 34 'Subsoiling across the slope' were used as a basis for estimating effectiveness, which was then adjusted using an expert weighting. This reduced the soil component of the P loss by 70 and 50% for the sandy loam and clay loam soils, respectively.

FIOs: No change - the method changes the transport pathway from overland flow to macro-pore and matrix flow and will not necessarily reduce losses.

Estimates of effectiveness at the farm-scale assume that the method is applied to 25% of the grassland area.

[continued]

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				Total P (kg P/ha)				FIOs (%)*			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	0	(61)	0	(34)	0.01	(0.2)	0.02	(2.8)	0	(36)	0	(100)
Beef	0	(18)	0	(12)	0.01	(0.2)	0.01	(1.0)	0	(15)	0	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses of FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Reducing surface run-off will also reduce water pollution by ammonium-N and BOD where run-off occurs soon after slurry spreading. Similarly, where slurry has been applied, increased infiltration will reduce gaseous ammonia emissions but FIOs may survive for longer in the soil than if exposed to ultra-violet light and desiccation on the soil surface. Improved infiltration and aeration of the soil will reduce denitrification but may slightly increase nitrate leaching.

11. Maintain or enhance soil organic matter levels

Description: Maintaining and enhancing soil organic matter levels by the regular addition of organic manures and the 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 risk of soil erosion. Maintaining or enhancing the content of soil organic matter helps to reduce the risks of surface run-off and erosion, and enables the efficient use of soil nutrients and added mineral fertiliser. These benefits should be effective in reducing P losses.

Mechanism of action: This is a mobilisation and transport method. 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. Improved soil microbial activity helps increase plant nutrient uptake from soil reserves. Soil aggregate stability improves the soil's ability to resist the erosive forces of rainfall and surface run-off. Well-structured soils are more easily cultivated, resulting in more uniform crop establishment and growth. This will help to avoid areas of poor establishment and low yields with high levels of residual soil nitrate. Additions of organic matter will increase potential N mineralisation in the soil. This will depend on the type of organic matter added and there is therefore a difference between adding FYM and compost (see Defra projects NT1831 and OF0164). To minimise accumulations of P and mineral N in the soil, it is important that the method should be accompanied by a reduction in fertiliser rates to take account of the additional nutrients supplied by the manure and 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. Grasslands tend to be characterised by higher organic matter contents and a more stable structure.

Practicability: Depends on the local availability of organic manures. There is usually ample opportunity for the spreading of organic manure at some point in an arable rotation. However, where the farmland is in a Nitrate Vulnerable Zone (NVZ), the application of manures must comply with the NVZ Action Programme rules on application rate limits and 'closed period' timings on free draining sandy and shallow soils. Composts and biosolids are generally supplied free of charge.

Cost: See Appendix II for the assumptions used to estimate costs.

Transport distance and type of manure	**Arable** Application to 60 ha (£/farm)	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
5 km: cattle FYM	4,200	n/a	n/a	n/a	n/a	n/a
5 km: pig slurry	4,800	"	"	"	"	"
10 km: cattle FYM	9,720	"	"	"	"	"
10 km: pig slurry	11,700	"	"	"	"	"

Effectiveness:

N: The method will build up the soil organic matter pool and may increase the nitrate leaching risk arising from extra mineralisation. There could be an **increase** in nitrate leaching of 1-10 kg N/ha from regular additions of organic matter in each field where organic matter is being built up. An increased loss of 10 kg N/ha has been assumed for the sandy loam and 5 kg/ha for the clay loam soil on farms where manure was not previously applied. The method is assumed to have no effect on those farms already receiving manure.

P: There is no equivalent method in PE0203 but methods that have a similar effect of reducing the loss of sediment from arable fields (e.g. PE0203 Methods 26 'Cover cropping', 28 'Minimum tillage', 30 'Soil stabilisers' and 33 'Increasing surface roughness') typically reduced the soil component of P loss by up to 50%. However, savings from increasing soil organic matter contents would be less than this in the short-term as any comparable reduction in sediment loss might only be achieved by building up organic matter over a period of years. There would also be an increased risk of incidental P losses from the added manures and on the basis of expert opinion, it was assumed that the net short-term effect of the mitigation method would be neutral.

[continued]

FIOs: No change. The addition of manure may slightly increase the risk of FIO losses but any increase is likely to be small because where manure is applied this will usually have been stacked and will have a low FIO load; if slurry is applied, this is usually in autumn when there is a low risk of run-off. Any increase is assumed to be less than one relative unit at the farm-scale.

Estimates of effectiveness at the farm-scale assume that the method is applied to 20% of the arable area. On the basis of these assessments, this method appears to be particularly ineffective in that it achieves no immediate reduction in losses of P or FIOs and potentially increases nitrate losses; however, it may be more beneficial in reducing P losses in the longer term.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	-2.0	(51)	-1.0	(47)	0.00	(0.3)	0.00	(2.3)	0	(0)	0	(0)
Arable + manure	0.0	(57)	0.0	(51)	0.00	(0.4)	0.00	(2.5)	0	(1)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: In the longer term, the method can help to reduce the loss of all pollutants associated with surface run-off. These include FIOs, ammonium, BOD and sediment. The application of organic manures to enhance soil organic matter status will also sequester more carbon in the soil. However, increasing the organic matter content of the soil will potentially increase nutrient and FIO pollution risks, particularly where fresh slurries are applied in the autumn/winter period. In the long term, it will also increase the risk of nitrate leaching in the autumn due to higher rates of mineralisation from the enhanced organic N pool.

12. Allow field drainage systems to deteriorate

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 is a long-term option.
- Other drainage systems may take only a few years to deteriorate.

Rationale: Drainage systems can accelerate the delivery of agricultural 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 transfer of pollutants to the watercourse. Artificial drainage of heavy soils also increases mineralisation of N from soil organic matter and reduces denitrification. Drainage of grazed grassland can typically result in a two to three-fold increase in nitrate leaching, which can be reversed by reducing the effectiveness of the drains. Allowing field drains to deteriorate can therefore be effective in reducing losses of nitrate, P and FIOs.

Mechanism of action: When drains have deteriorated, water is forced to percolate through the soil at a slower rate. This increases the opportunity for the retention or transformation of potential agricultural pollutants through physical filtration and biological activity in the soil. Allowing drains to deteriorate will allow a high water table to be maintained, thereby reducing N mineralisation, increasing denitrification and reducing leaching. During the growing season, a shallow water table increases water availability and thus reduces soil-N contents by promoting crop growth and N uptake. Alternatively, excess water and waterlogging in parts of fields may lead to poor crop establishment and restricted N uptake and thereby increase the content of residual soil nitrate available for leaching. Undrained grassland will wet up earlier in autumn so that stock need to be removed earlier to avoid poaching. However, this will reduce the amount of N excreted in the field and available for leaching.

Potential for applying the method: This method is most applicable to the intensive grassland sector on heavy soils in the centre and west of the country. It is a relatively easy option to implement but is unlikely to be acceptable to farmers, particularly in areas of heavy soils where waterlogging is a problem. There are around 6 million hectares of drained soils in England and Wales. Drainage deterioration is compatible with the Higher Level Environmental Stewardship Scheme, hence farmers may be able to obtain payment by, for example, restoring traditional water meadows.

It is debatable how applicable this method is to arable land, as without an effective drainage system, economically sustainable arable cropping would not be possible on many heavy soils. If the drainage status deteriorated greatly, it is likely that a farmer would revert the arable land to grassland or other alternative land use. Similarly, the method is not applicable for farmers growing potatoes and sugar beet in the east of the country on unstable, silty soils. Ineffective drainage could result in the production of these crops becoming uneconomic.

Practicability: The method is easy to implement as no action is necessary. However, there will be considerable resistance from farmers to adopting the method as a deliberately managed activity without financial incentive. It is probable that with increasing soil wetness, it would also be necessary to reduce stocking rates on livestock farms (see Method 15). The deterioration of field drainage systems is probably occurring in practice, because farmers do not have the funds to replace ageing systems.

Cost: Costs are shown for a progressive reduction in output over ten years as the drainage system deteriorates (see Appendix II).

[continued]

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
£/ha						
Loss of output 0.5% yr 1	2.5	0.5	0.3	2.5	2.5	n/a
Loss of output 1.0% yr 2	5.0	1.0	0.5	5.0	5.0	n/a
Loss of output 1.5% yr 3	7.0	1.5	0.8	7.0	7.0	n/a
Loss of output 2.0% yr 4	10.0	2.0	1.0	10.0	10.0	n/a
Loss of output 2.5% yr 5	12.0	2.5	1.3	12.0	12.0	n/a
Loss of output 4.0% yr 6	20.0	4.0	2.0	20.0	20.0	n/a
Loss of output 5.5% yr 7	27.0	5.5	2.8	27.0	27.0	n/a
Loss of output 7.0% yr 8	34.0	7.0	3.5	34.0	34.0	n/a
Loss of output 8.5% yr 9	42.0	8.5	4.3	42.0	42.0	n/a
Loss of output 10% yr 10	49.0	10.0	5.0	49.0	49.0	n/a
£/farm						
Loss of output 0.5% yr 1	740	75	25	1,070	175	n/a
Loss of output 1.0% yr 2	1,470	150	50	2,150	350	n/a
Loss of output 1.5% yr 3	2,210	225	75	3,220	520	n/a
Loss of output 2.0% yr 4	2,950	300	100	4,290	700	n/a
Loss of output 2.5% yr 5	3,680	375	125	5,360	870	n/a
Loss of output 4.0% yr 6	5,890	600	200	8,580	1,390	n/a
Loss of output 5.5% yr 7	8,100	825	275	11,790	1,920	n/a
Loss of output 7.0% yr 8	10,300	1,050	350	15,000	2,440	n/a
Loss of output 8.5% yr 9	12,510	1,230	425	18,220	2,960	n/a
Loss of output 10% yr 10	14,720	1,500	500	21,440	3,480	n/a

Effectiveness:

N: It is assumed that relatively little of the nitrate will be lost by surface and subsurface flows if drainage deteriorates. Typical reductions in N leaching are 10-20 kg N/ha for arable land and a mid-point value of 15 kg/ha was used for the estimates. Typical reductions for grassland are 15-30 kg N/ha but can be larger in very intensive grassland systems. A lower value of 10 kg N/ha was assumed for affected areas on the dairy farm and 5 kg/ha on the beef farm to take account of the fact that many drainage systems are already deteriorating.

P: There is no equivalent method in PE0203 but other transport/delivery methods, e.g. PE0203 Methods 36 'Move gateways' and 37 'Install hedges and make fields smaller', were used as a basis for estimating the effectiveness of the method. After adjusting by the appropriate expert weighting, the method was assumed to achieve a 5% reduction in the overall P loss.

FIOs: No change. The method has little net effect as it changes the transport pathway from macro-pore and matrix flow to overland flow.

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				Total P (kg P/ha)				FIOs (%)*			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	1.5	(47)	n/a	(0.3)	0.01	(2.3)	n/a	(0)	0	(0)
Arable + manure	n/a	(57)	2.0	(51)	n/a	(0.4)	0.01	(2.5)	n/a	(1)	0	(1)
Dairy	n/a	(61)	1.0	(34)	n/a	(0.2)	0.01	(2.8)	n/a	(36)	0	(100)
Beef	n/a	(18)	0.5	(12)	n/a	(0.2)	0.01	(1.0)	n/a	(15)	0	(43)
Broilers	n/a	(82)	2.0	(68)	n/a	(0.4)	0.02	(3.2)	n/a	(0)	0	(0)
Indoor pigs	n/a	(89)	3.0	(74)	n/a	(0.5)	0.02	(3.7)	n/a	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Estimates of effectiveness at the farm-scale assume that the method is applied to 10% of the farm area. The method is not applicable to sandy loam soils as these soils are not usually drained.

Other benefits or risk of pollution swapping: If soils are wetter for longer, it is likely that more nitrous oxide will be released because of increased denitrification. There is also a risk of increased poaching and surface run-off if drains are allowed to deteriorate (but overall losses of P and FIOs are likely to be smaller than from drained systems). The risk of pollutant transfer in surface run-off is particularly high where organic manures and fertilisers are applied to waterlogged soils. In some circumstances, increased waterlogging may increase the risk of pollution from pesticides in run-off.

13. Reduce overall stocking rates on livestock farms

Description: Reduce the total number of livestock on the farm (rather than redistributing the existing stock within the farm).

Rationale: Reducing the stocking rate reduces the amounts of N, P and FIOs deposited in fields in excreta and handled in manures. It also allows mineral fertiliser inputs to be reduced and reduces poaching of the soil.

Mechanism of action: Livestock excreta deposited in the field and applied in 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. In particular, much of the nitrate leached from grazed pastures originates from the high concentrations of nitrate present in urine patches. With lower stocking rates, there will be fewer urine patches and less nitrate available for leaching. A smaller number of animals will also produce less manure. This will ease pressure on the farm's existing storage capacity and provide greater flexibility in when to apply manure so as to avoid high-risk times. As the farm will need to produce less forage, mineral fertiliser rates will also be reduced. Reducing stocking rates will also reduce the poaching of soils that can exacerbate the transport of pollutants and sediment to watercourses by exposing bare soil and increasing run-off.

Potential for applying the method: The method is applicable to all livestock farms but will have the greatest impact on intensively stocked units that produce large quantities of excreta and where the risk of soil structural damage is greatest. Poaching is generally more severe with cattle grazing than with sheep but is particularly severe with outdoor pigs. The method will also be effective for indoor pig and broiler units because of the reduction in the amounts of manure produced.

Practicability: The method would be relatively simple to implement but would have a serious impact on profitability. The main factor limiting its adoption would be the major reduction in farm income resulting from reduced stock numbers. Some intensive dairy farms may convert to a more extensive beef/sheep system. However, it is more likely that a reduction in livestock would be achieved through a reduction in the number of livestock farms, rather than by reducing the numbers of stock on individual farms. Viable farms may remain or even expand, while less profitable livestock enterprises would either convert or go out of business. Many beef/sheep enterprises are of low to negative profitability and this type of farm may decline in number under the single farm payment system. Some dairy farmers may react to lower stock numbers by providing more feed per dairy cow to maintain income. Feeding more to increase output per cow will tend to reduce the potential effectiveness of the method. Nevertheless, the total N loss from a reduced number of high-yielding cows may still be less than that associated with producing the same volume of milk from a greater number of lower-yielding cows (within limits).

Alternatively, reducing stock numbers might encourage farms to become more reliant on clover-based swards to reduce costs by replacing N fertiliser with biologically fixed N. However, the resulting pollutant losses are likely to be similar to those from fertilised grass swards with a similar (reduced) N input and stocking rate. A moderate reduction in the overall stocking rate can also be achieved on dairy farms by reducing the cow replacement rate, so that fewer young stock need to be kept on the farm.

Cost: Costs assume a 50% reduction in stock numbers on individual farms (see Appendix II). No costs are given for the alternative of halving the number of livestock farms in the catchment as this would be a catchment-based rather than a farm-based approach and cannot be costed in the same way as the other methods.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha	n/a	309	55	261	535	2,700
Cost £/farm	"	46,300	5,410	113,800	38,000	64,400
With additional change to a clover-based system using no fertiliser N						
Cost £/ha	n/a	274	35	n/a	n/a	n/a
Cost £/farm	"	41,000	3,510	"	"	"

[continued]

Effectiveness:

N: The N Cost Curve project modelled the effect of a 20% reduction in livestock numbers. This achieved a reduction of 10-25 kg N/ha for dairy, averaged over the farm; and 3-5 kg N/ha for beef/sheep. A 50% reduction in stock numbers was assumed for the current method but as the baseline leaching losses were less than for N Cost Curve, the range of N reductions was assumed to be the same as in N Cost Curve; using the upper and lower limits of these ranges for sandy loam and clay loam soils, respectively. For broiler and indoor pigs, baseline N losses from manure were assumed to be reduced by 40 and 50% for sandy loam and clay loam soils, respectively. For outdoor pigs, the reduction is 70% of the baseline manure loss.

P: PE0203 Methods 12 ‘Reduce stocking density - intensive dairy’ and 13 ‘Reduce stocking density - sheep’ were used. After applying the expert weighting, this corresponded to a 35% reduction in the soil, manure and fertiliser components of the baseline loss from the dairy and beef farms on clay loam soil. Reductions on the sandy loam were 18% of the soil component and 35% of the manure and fertiliser components. These were applied to 100% of the farm area. On the broiler and indoor pig farms, reducing the stocking rate only affects manure production and the corresponding reductions were only applied to the manure component of the P loss.

FIOs: The reduction is directly proportional to the scale of reduction in livestock numbers; so that a 50% reduction in livestock reduces FIOs by 50%. This achieves no benefit on the broiler farm where losses are already zero because most FIOs will have died off during storage of the litter.

The method is effective over the whole farm area.

	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
Farm type	**Nitrate (kg N/ha)**				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	25	(61)	10	(34)	0.08	(0.2)	0.98	(2.8)	50	(36)	50	(100)
Beef	4	(18)	2	(12)	0.06	(0.2)	0.37	(1.0)	50	(15)	50	(43)
Broilers	13	(82)	11	(68)	0.02	(0.4)	0.28	(3.2)	50	(0)	50	(0)
Indoor pigs	16	(89)	14	(74)	0.04	(0.5)	0.45	(3.7)	50	(4)	50	(10)
Outdoor pigs	60	(108)			3.40	(10.5)			50	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: The method would reduce most forms of diffuse pollution from livestock farms.

14. Reduce the length of the grazing day or grazing season

Description: Reduce the length of time livestock are allowed to graze in the fields, either by keeping stock inside during the night or by shortening the length of the grazing season, particularly in autumn.

Rationale: Urine patches are a major source of leached nitrate. Reducing the time animals spend grazing reduces the amount of urine deposited in fields.

Mechanism of action: Urine patches deposited by grazing livestock contain high concentrations of N and act as 'hotspots' with high losses of leached nitrate. Reducing the time stock spend in the fields reduces the number of urine patches and, hence, the amount of nitrate in the soil and available for loss. Urine deposited later in the season, when there is little opportunity for the sward to utilise the added N, makes the greatest contribution to nitrate leaching. Therefore, implementing this mitigation method in autumn will have the greatest benefit. The method is primarily aimed at reducing nitrate leaching but will provide some reduction in the amounts of P and FIOs lost from fields.

Potential for applying the method: The method is applicable to intensive livestock farms where animals graze outside between spring and autumn and where there is already suitable housing. It will be most effective on free-draining or shallow soils, which are most susceptible to nitrate leaching.

Practicability: Reducing the length of the grazing day is most suited to dairy farms, where cows can be kept indoors between the afternoon milking and morning milking. Shortening the grazing day or grazing season will both increase the time for which animals are housed and increase the amount of manure produced. **The method will only be effective if suitable precautions are taken to minimise losses from this manure when it spread on the fields.**

Increasing the amount of time when animals are housed creates additional work on mixed farms, at a time when labour costs and availability are already serious issues. Reduced grazing is likely to increase the proportion of grass utilised by cutting. The increased labour costs would reduce profitability significantly, particularly on farms with a high dependency on grass forage. Reducing the length of the grazing season goes against the current trend of maximising the use of grazed grass by extending the grazing season.

Cost: Estimated costs are similar for daytime-only grazing and shortening the grazing season and are based on a 20% reduction in grazing time. These costs do not include any extra costs of increased manure storage and handling. See Appendix II for more details.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	30 - 45	25 - 40	n/a	n/a	n/a
Cost £/farm	"	4,500 – 6,750	2,500 - 4,000	"	"	"

Effectiveness:

N: For the Dairy system, changing to grazing in the daytime only or ending grazing early, in August achieved a reduction of 8-16 kg N/ha, averaged over the farm.

P: There is no equivalent method in PE0203 and this is primarily aimed at N. However, the resulting effect for P will be to minimise poaching damage and thus mobilisation of P. The effectiveness is assumed to be the same as for Method 15 in this manual (below).

FIOs: 10% reduction. The direct reduction is proportional to the reduction in time that livestock are grazing but FIOs will still be lost from the extra manure that is generated during the extended housing period.

Estimates of effectiveness assume a 20% reduction in grazing time, with the effect averaged over the whole dairy and beef farm areas.

[continued]

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	12.0	(61)	5.0	(34)	0.00	(0.2)	0.03	(2.8)	10	(36)	10	(100)
Beef	1.5	(18)	0.5	(12)	0.01	(0.2)	0.01	(1.0)	10	(15)	10	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Reducing the amount of urine deposited in fields will also reduce nitrous oxide emissions. Reduced treading will lessen the risk of poaching and loss of sediment but any benefit of reducing P and FIO losses will be dependent on how efficiently the additional manure production is managed. Handling a greater proportion of excreta as manure will increase ammonia emissions.

15. Reduce field stocking rates when soils are wet

Description: When soils are wet, the numbers of livestock per unit area or the time stock spend on the field should be reduced sufficiently to avoid severe poaching and compaction of the soil. Soils are typically considered to be 'wet' when there is significant flow from field drains or, for clay-rich soils, if they smear when pressure is applied.

Rationale: Soils are more easily poached when they are wet. Reducing livestock numbers or the duration of grazing at these times reduces poaching damage, which would otherwise increase the risk of surface run-off and transport of pollutants to watercourses.

Mechanism of action: Poaching reduces the infiltration of rain into the soil and increases the risk of surface run-off. Reducing the amount of treading when soils are wet and most susceptible to structural damage reduces the severity of poaching. Lower stocking rates will also reduce the amount of excreta deposited in these areas and the amounts of pollutants available for loss. Potential benefits are greater for P and FIOs than for nitrate because a greater proportion of the loss of these pollutants occurs *via* surface flow.

Potential for applying the method: The method is applicable to all livestock farms where animals are kept outside but most particularly to those with high stocking rates, where extended grazing is practised or where stock are wintered outdoors. On some farms, it may only be necessary to install temporary fences to exclude stock from temporarily wet areas of particular fields. Poaching is likely to be more severe with cattle grazing than with sheep. Although outdoor pigs are particularly damaging to the soil, the method is of limited applicability to these units as they are usually set-stocked and do not have the option of moving stock to other fields or indoors. Fine-textured, less-permeable soils are most susceptible to poaching and the risk is increased in high-rainfall areas.

Practicability: Implementation will be easier on farms with access to freely-drained, less easily-poached land that can provide alternative grazing during wet periods. Farms where most of the fields are susceptible to poaching may need to house animals earlier in autumn and delay turn-out in the spring. This will increase the amount of manure produced. The method will only be fully effective if methods are adopted to reduce losses from this additional manure when it is spread onto land. Profitability would be seriously reduced on farms that are highly dependant on grass forage and are dominated by fine-textured soils.

Cost: This method gives the livestock more space, but this will reduce overall output of grass, so it is effectively the same as Method 14 in terms of cost.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	30 - 45	25 - 40	n/a	n/a	n/a
Cost £/farm	"	4,500 – 6,750	2,500 - 4,000	"	"	"

Effectiveness:

N: Minimal effect on nitrate loss; 0-1 kg N/ha, averaged over the farm.

P: PE0203 Methods 24 'Restrict livestock access in marginal places/times (dairy)' and Method 25 'Restrict livestock access in marginal places/times (outdoor pigs)' were used. After applying an expert weighting necessary for adjustment to this method and to the defined model farm systems, it was estimated that the method would result in a 10% reduction in the soil and manure components of the baseline loss.

FIOs: 10% reduction. The reduction is proportional to the reduced time that livestock are grazing the fields. However, FIOs will still be lost from the additional manure generated during the extended housing period.

Estimates of effectiveness at the farm-scale assume that the method is applied to 100% of the Dairy and Beef farm areas.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	n/a (51)	n/a (47)	n/a (0.3)	n/a (2.3)	n/a (0)	n/a (0)
Arable + manure	n/a (57)	n/a (51)	n/a (0.4)	n/a (2.5)	n/a (1)	n/a (1)
Dairy	0.0 (61)	0.5 (34)	0.02 (0.2)	0.25 (2.8)	10 (36)	10 (100)
Beef	0.0 (18)	0.2 (12)	0.02 (0.2)	0.09 (1.0)	10 (15)	10 (43)
Broilers	n/a (82)	n/a (68)	n/a (0.4)	n/a (3.2)	n/a (0)	n/a (0)
Indoor pigs	n/a (89)	n/a (74)	n/a (0.5)	n/a (3.7)	n/a (4)	n/a (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: The method would also reduce water pollution from sediment losses, along with ammonium-N and BOD following slurry spreading. If it required stock to be housed for longer, there would be a greater amount of manure produced that would need to be handled and applied to land. This could potentially increase water and air pollution unless precautions were taken to minimise losses.

16. Move feed and water troughs at regular intervals

Description: Feed troughs, feeding racks and water troughs for outdoor stock should be re-positioned at intervals to reduce damage to the soil and improve the distribution of excreta. Troughs and racks should be moved more frequently when the soil is wet and most easily poached. They should not be sited close to water courses.

Rationale: Regular re-positioning of feeding and watering troughs reduces poaching of the soil around these points and reduces the quantity of excreta deposited in any single area, both of which would otherwise exacerbate losses of N, P and FIOs.

Mechanism of action: Animal movements in fields are concentrated around feeding points and water troughs. This results in large inputs of excreta to these areas, which become a source of high levels of N, P and FIOs. Because of frequent treading, soils around these positions also get heavily poached, which increases the risk of run-off and transport of the accumulated pollutants in surface water. The high soil N contents increase nitrate leaching from these areas during the winter. Damage to the sward has a secondary effect of reducing plant uptake that might otherwise reduce concentrations of N and P in the soil. Moving troughs regularly prevents the accumulation of very high levels of N, P and FIOs in localised areas and reduces the severity of poaching.

Potential for applying the method: The method is more applicable to beef/sheep systems than dairy, where feed is usually provided close to or on the farmstead (except for buffer feeds). It is especially relevant to farms where livestock are wintered outside. Indeed, feed troughs and feeding points are already routinely moved on some farms. There is a greater risk of poaching with cattle than with sheep and outdoor pigs are particularly destructive. The potential to reduce poaching will be greatest on imperfectly and poorly drained soils, whereas the benefits of reduced nitrate accumulations will be greatest on freely drained soils.

Practicability: The regular re-positioning of feeding troughs is a simple method with few limitations to its implementation. It is more difficult to vary the position of water troughs. This would probably require use of a bowser or installation of a number of permanent drinking points within the field, as used on dairy farms that employ a strip-grazing system. However, this can only be carried out at considerable cost to the business. Even one day can be enough for serious poaching on wet land in winter. So, the method would only really be effective when applied in combination with Method 15 to reduce field stocking rates when soils are wet. This method may not be applicable to land that is very easily poached, where frequent moving of feeding points may increase the number of poached areas and make the situation worse. Instead, it may be necessary to locate the feeding point on a hard-standing. In all cases, feeders and troughs should be located away from water courses to break the hydrological link between the poached area and surface water.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha	n/a	11.3	10.4	n/a	n/a	33.0
Cost £/farm	"	1,700	1,040	"	"	790

Effectiveness:

N: Minimal effect on nitrate loss; 0-1 kg N/ha, averaged over the farm.

P: There is no equivalent method in PE0203 but PE0203 Method 24 ‘Restrict livestock access in marginal places/times’ as applied to dairy cattle might reduce compaction on grassland and thus be analogous. After applying an expert weighting to the PE0203 figures, it was estimated that baseline losses from the soil and manure components would be reduced by 15%.

FIOs: 10% reduction.

Estimates of effectiveness at the farm-scale assume that the method is applied to 100% of the Dairy and Beef farm areas and 25% of the Outdoor Pig farm area.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	1.0	(61)	0.5	(34)	0.03	(0.2)	0.37	(2.8)	10	(36)	10	(100)
Beef	0.5	(18)	0.2	(12)	0.03	(0.2)	0.14	(1.0)	10	(15)	10	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	2.0	(108)			0.41	(10.5)			10	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: The method would also reduce water pollution from ammonium-N, sediment and elevated levels of BOD. There might also be reductions in gaseous losses of ammonia and nitrous oxide.

17. Reduce dietary N and P intakes

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

- by avoiding diets that contain N and P in excess of the dietary requirement of the animal
- by formulating diets that increase the efficiency of N and P utilisation by the animal.

Rationale: Avoiding excess N and P in the diet and/or making dietary N and P more available allows the concentration of these nutrients in the diet to be reduced without adversely affecting animal performance. Both reduce the amount of N and P excreted, either directly to fields or *via* manure, and thereby minimise additions to the pools of N and P that are 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. In practice, however, surplus N and P is not utilised by the animal and will be excreted. Restricting diets to recommended levels of N and P will limit the amounts excreted, without affecting animal performance. 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. In non-ruminants, N excretion can also be reduced by increasing the digestibility of the ration. In 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 unutilised 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 the rumen microbes produce phytase naturally.

Correctly formulated diets can increase the efficiency of nutrient utilisation without reducing growth rate or milk production. Reducing the N and P contents of excreta and manures will have benefits of reducing nitrate leaching and incidental losses in surface run-off. However, the longer-term benefits of reducing nutrient loadings to land will take longer to be effective for P than for N because of the greater buffering of P reserves in the soil.

Potential for applying the method: Benefits will be greatest on intensive dairy, pig and poultry units and least on those feeding a largely forage diet. Short-term benefits of reducing N and P in run-off will be greatest on less-permeable soils, and for nitrate leaching on sandy and shallow soils. The longer-term benefits of reducing soil nutrient loadings will be effective on all soil types.

Practicability: 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 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. Practical benefits are less-well proven for N than for P. Precise formulation of diets requires accurate analytical data about the chemical composition of the feedstuffs, which may not be readily available for forages. Many protein feeds are rich in P and it may 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 content, optimising 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. Also, matching performance to requirement has cost, labour and housing implications on many farms.

For poultry, considerable steps have already been made through the use of whole wheat feeding and synthetic amino acids in broilers. There is limited scope for further reducing the N content of poultry diets without reducing output. There are concerns that reducing nutrient inputs may also have adverse effects on reproductive performance and carcass quality. The scope to use more digestible materials in broiler diets is also very limited as most diets already employ feed materials of high digestibility. There is an economic incentive to use phytase but this has not been widely adopted by the broiler industry because of problems with increased water consumption and subsequent welfare issues. Once these issues have been addressed, it is likely that dietary P levels will be significantly reduced.

[continued]

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. However, there is very little scope for reducing P inputs. These have already been reduced because of economic pressures and phytase enzymes are universally included in pig diets, further reducing P use.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/head	n/a	42.5	n/a	0.008	17.5	17.5
Cost £/farm	"	6,380	"	7,920	6,130	10,360

Effectiveness:

N: Dairy system (reducing the crude protein content of the diet from 18 to 14%): reduction of 2 kg N/ha. Pigs/poultry: reduction of 2-5 kg N/ha. Both averaged over the farm area.

P: There are a number of methods in PE0203 that can be applied here and all are input control methods. PE0203 Methods 7 ‘Reduce feed P input to dairy’ (15% reduction in P input), 8 ‘Use phytase to reduce feed P input to sows’ and 9 ‘Use phytase to reduce feed P input to fattening pigs’ were all relevant. Using an expert weighting it is estimated that the manure component of the baseline losses will be reduced by about 8%.

FIOs: No change (the method has no impact on the numbers of FIOs voided by livestock).

Estimates of effectiveness at the farm-scale assume that the method is applied to all livestock on the Dairy, Broiler and Pig (Indoor and Outdoor) model farm systems.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	n/a (51)	n/a (47)	n/a (0.3)	n/a (2.3)	n/a (0)	n/a (0)
Arable + manure	n/a (57)	n/a (51)	n/a (0.4)	n/a (2.5)	n/a (1)	n/a (1)
Dairy	3.0 (61)	2.0 (34)	0.01 (0.2)	0.17 (2.8)	0 (36)	0 (100)
Beef	n/a (18)	n/a (12)	n/a (0.2)	n/a (1.0)	n/a (15)	n/a (43)
Broilers	2.0 (82)	2.0 (68)	0.01 (0.4)	0.07 (3.2)	0 (0)	0 (0)
Indoor pigs	2.0 (89)	2.0 (74)	0.01 (0.5)	0.11 (3.7)	0 (4)	0 (10)
Outdoor pigs	0.0 (108)		0.64 (10.5)		0 (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Reducing the amount of N excreted will also reduce the potential for losses of ammonium-N in surface run-off and for gaseous emissions of ammonia and nitrous oxide. For pigs, reducing protein intake also reduces water consumption and ammonia emissions. There may be an increase in methane emissions. Farms that seek to reduce the N content of the diet by replacing grass silage with maize silage may fail to reduce net losses because of the potentially high losses of N, P and FIOs that can occur in surface run-off and drainage from maize fields.

18. Adopt phase feeding of livestock

Description:

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

Rationale: Phase feeding allows more precise matching of the ration to the individual animal's nutritional requirements. Nutrients are utilised more efficiently and less of the dietary N and P is excreted, thereby reducing the N and P content of manures. This reduces the amount of N and P available for loss when these manures are applied to fields and the potential accumulation of N and P in the soil.

Mechanism of action: Livestock at different growth stages or stages of the reproductive or 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 17). 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. There will be less N and P applied in manures and therefore smaller losses in surface run-off and by leaching. The method will also limit the longer-term accumulation of N and P in the soil but will have no effect on losses of FIOs.

Potential for applying the method: The method is applicable to all livestock systems except those based primarily on grazing. It would be effective at reducing losses of P and N in run-off from fine textured soils and in reducing nitrate leaching from free-draining soils.

Practicability: The method is more suited to larger units where there would be greater numbers of animals in the individual feeding groups. It would be most effective if adopted in combination with the actions described in Method 17 to reduce dietary N and P intakes. As with Method 17, it is important that improvements in N and P utilisation are used to reduce total N and P inputs rather than as an opportunity to increase agricultural output from the unit, which would lessen the impact on losses.

In the ruminant sector, this method reflects current practice where cows are grouped according to yield. However, practical application may be difficult on dairy units where cows are fed a single diet across a range of yields. There is limited scope for improvements in the poultry sector, where phase feeding is already widely used. **There is great potential for phase feeding in the pig sector** to reduce N and P excretion. However, this would require financial assistance, as costs would be considerable, without necessarily improving performance.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	16.30	n/a	n/a	24.15	121
Cost £/farm	"	2,440	"	"	1,720	2,900

Effectiveness:

N: Dairy system: reduction of 2 kg N/ha. Pigs/poultry: reduction of 2-5 kg N/ha. Both averaged over the farm area.

P: There is no equivalent method in PE0203 but PE0203 Method 7 'Reduce feed P input to dairy' may have a similar net effect of reducing inputs. Using an expert weighting it is estimated that the manure component of the baseline losses will be reduced by about 8%. This is averaged over the farm area.

FIOs: No change (the method has no impact on the numbers of FIOs voided by livestock).

Estimates of effectiveness at the farm-scale assume that the method is applied to all livestock on the Dairy and Pig (Indoor and Outdoor) Model Farm Systems.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	3.0	(61)	2.0	(34)	0.01	(0.2)	0.17	(2.8)	0	(36)	0	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	2.0	(89)	2.0	(74)	0.01	(0.5)	0.11	(3.7)	0	(4)	0	(10)
Outdoor pigs	0.0	(108)			0.64	(10.5)			0	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Reducing the amount of N excreted will reduce the potential for losses of ammonium-N in surface run-off and for gaseous emissions of ammonia volatilisation and nitrous oxide. For pigs, reducing protein intake also reduces water consumption and ammonia emissions. There may be an increase in methane emissions.

19. Use a fertiliser recommendation system

Description:

- Use a recognised fertiliser recommendation system (e.g. RB209, PLANET and other supplementary guidance) to plan fertiliser applications to all crops.
- Do not exceed optimum recommended rates.
- Time fertiliser applications to minimise the risk of loss of nutrients (e.g. avoid autumn N applications and early spring timings to drained clay soils).
- Take full account of manure inputs when planning mineral fertiliser applications.
- Ensure accurate use of mineral fertilisers by proper maintenance, setting and calibration of spreading machinery and the use of good quality fertilisers.
- Farmers should be FACTS qualified or use a professional FACTS adviser, particularly where fertiliser rates above the RB209 recommendation are being considered.

Rationale: Fertiliser recommendation systems take account of the following factors:-

- soil nutrient supply based on soil analysis or climate, previous cropping and soil type
- crop nutrient requirements for a given soil and climate
- crop requirement for nutrients at the various growth stages
- the amount of nutrients supplied to the crop by added manures and by previous manure applications
- soil pH and the need for lime

Adoption of a fertiliser recommendation system will reduce the risk of applying more fertiliser nutrients than the crop needs and will minimise the risk of causing diffuse water pollution by nitrate and P.

Mechanism of action: A good fertiliser recommendation system ensures that the necessary quantities of the essential crop nutrients are only available when required for uptake by the crop. Nutrients are only applied as mineral fertiliser 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. The system also ensures 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 organic manures. Maintaining an appropriate balance between nutrients is also important to maximise the efficient uptake of all nutrients and reduce losses to a minimum.

Potential for applying the method: Fertiliser recommendation systems can be used in all farming systems, but are particularly effective in intensive grassland, arable and horticultural systems. The method would have less impact in extensive grassland systems, as according to fertiliser practice surveys, most grassland soils receive less N than is recommended by RB209.

Practicability: The method would require investment in education and guidance. At present, farmers in NVZs are permitted to exceed the RB209 recommendations provided that they can demonstrate the reasoning behind the additional fertiliser rates or applications, based on, for example, local trials data or market place needs.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	2	2	2	2	2	n/a
Cost £/farm	600	300	200	875	150	"

Effectiveness:

N: For arable there is a reduction of about 5 kg N/ha leached per year. For grassland, reductions are 1-5 kg/ha per year (dairy) and 2 kg N/ha per year (beef). All averaged over the farm area.

[continued]

P: There is no equivalent method in PE0203 but PE0203 Method 6 ‘Precision farming’ may have a similar net effect in terms of increasing efficiency. After expert weighting, it is estimated that the method reduces the fertiliser component of the baseline loss by 20%.

FIOs: No change (the method does not affect timing of manure applications).

Estimates of effectiveness at the farm-scale assume that the method is applied to the whole farm for all Model Farm Systems, apart from Outdoor Pigs.

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	3.0	(51)	2.0	(47)	0.00	(0.3)	0.03	(2.3)	0	(0)	0	(0)
Arable + manure	2.0	(57)	1.5	(51)	0.00	(0.4)	0.03	(2.5)	0	(1)	0	(1)
Dairy	4.5	(61)	2.0	(34)	0.00	(0.2)	0.06	(2.8)	0	(36)	0	(100)
Beef	0.3	(18)	0.3	(12)	0.00	(0.2)	0.03	(1.0)	0	(15)	0	(43)
Broilers	4.0	(82)	3.0	(68)	0.00	(0.4)	0.03	(3.2)	0	(0)	0	(0)
Indoor pigs	4.0	(89)	4.0	(74)	0.00	(0.5)	0.03	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Fertiliser recommendation systems encourage the efficient use of manure nutrients. They may therefore be effective in reducing ammonia emissions and losses of FIOs, ammonium-N, and BOD if manures are incorporated rather than being left on the surface. Risks associated with the incorporation of manures are dealt with in Method 36.

20. Integrate fertiliser and manure nutrient supply

Description:

- Use a recognised fertiliser recommendation system (e.g. RB209, PLANET and other supplementary guidance) to make full allowance of the nutrients applied in manures and reduce mineral fertiliser inputs accordingly.
- Use manure analysis to gain a better understanding of nutrient applications and supply.
- Keep records of mineral fertiliser and organic manure inputs to individual fields.
- Farmers should be FACTS qualified or use a professional FACTS adviser, particularly where fertiliser rates above the RB209 recommendation are being considered.

Rationale: Robust recommendation systems can be used to provide a good estimate of the amount of nutrients supplied by manure applications. This information can then be used to determine the amount and ideal timing of additional mineral fertiliser required by the crop. The British Survey of Fertiliser Practice shows that farmers do not always allow for the nutrients in applied manure when calculating fertiliser rates. In most cases, making proper allowance for the nutrients in manures will result in a reduction in fertiliser inputs compared with current practice and a concomitant reduction in nitrate and P losses.

Mechanism of action: The amount of nutrient is reduced at source. Mineral fertiliser applications are reduced to no more than is required for optimum economic production levels and to maintain adequate levels in the soil. The amount of nitrate in solution is reduced or optimised throughout the crop cycle. This is particularly important in autumn when the levels of nitrate present in the soil determine how much nitrate is available for leaching over the winter. Where soil P levels are satisfactory (i.e. ADAS Index 2), manure phosphate inputs will generally supply the needs of the next crop but long-term manure applications can lead to a build-up of excessive soil P reserves.

Potential for applying the method: Most applicable to intensive grassland and arable systems, but also relevant to extensive grassland systems where breeding ewes are brought onto more fertile low-lying ground in late autumn to early winter. The method is effective wherever mineral fertilisers are used to top-up the nutrients supplied in organic manures.

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

Cost: The method **achieves a saving**, rather than increasing costs. See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable** 60 ha treated	**Dairy** 33 ha treated	**Beef** 18 ha treated	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Saving £/ha	6	12	6	32	23	n/a
Saving £/farm	1,800	1,800	600	14,000	1,600	"

Effectiveness:

N: For arable there is a reduction of about 5-10 kg N/ha leaching per year, averaged across the rotation. This assumes no change in timing of manure applications. For dairy there is a 5-10 kg/ha per year reduction and for beef, a 2 kg N/ha reduction.

P: There is no equivalent method in PE0203 but PE0203 Method 23 'Reduced rate of application (manure)' was tested for intensive dairy systems and may have a similar net outcome. After an expert weighting it was estimated that on the clay loam soil, the manure and fertiliser component of the baseline losses is reduced by 4%. On the sandy loam soil, the 4% reduction is only applied to the manure component. The method is likely to have a greater long-term effect through avoiding the build-up of unnecessarily high P concentrations in the soil.

FIOs: No change. The method is directed at nutrients and will not affect potential transfers of FIOs.

Estimates of effectiveness at the farm-scale assume that the method is applied to 20% of the Arable (plus manure) system, 85% of the Dairy system, 20% of the Beef system, and 100% of the Broiler and Indoor Pig systems.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	2.0	(57)	1.5	(51)	0.00	(0.4)	0.02	(2.5)	0	(1)	0	(1)
Dairy	4.5	(61)	2.0	(34)	0.01	(0.2)	0.09	(2.8)	0	(36)	0	(100)
Beef	0.3	(18)	0.3	(12)	0.00	(0.2)	0.01	(1.0)	0	(15)	0	(43)
Broilers	4.0	(82)	3.0	(68)	0.00	(0.4)	0.05	(3.2)	0	(0)	0	(0)
Indoor pigs	4.0	(89)	4.0	(74)	0.01	(0.5)	0.07	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: When slurry is spread too soon after the application of N fertilisers, there is a risk of increased nitrous oxide emissions through the process of denitrification. Current advice is to leave at least 5 days between applications of N fertiliser and slurry to the same field.

21. Reduce fertiliser application rates

Description: Reduce the amount of N and P fertiliser applied to crops by a certain percentage below the economic optimum.

Rationale: On most fields, limiting the amount of N fertiliser applied to crops will reduce the quantity of residual nitrate in the soil after harvest. In the short term, limiting P fertiliser rates can reduce the amount of soluble P lost from the system. In the long term, reducing P fertiliser rates can reduce the amount lost as particulate P.

Mechanism of action: The amount of fertiliser applied is reduced at source. There will be a slight reduction in the amount of residual soil nitrate available for leaching in the autumn. However, there will be no effect on the amount of nitrate mineralised from soil organic matter. This mineralised nitrate forms the larger part of the nitrate pool that is available for leaching over the autumn and winter. In the longer term, where soil P reserves are allowed to run down, there will be a reduction in soluble P loss. Limiting P fertiliser applications in any one year will reduce the amount of P that can be lost in surface run-off or in drain-flow. However, where organic manures are applied to the soil, there will be little net effect from reducing mineral fertiliser rates.

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. The impact of reducing fertiliser P would be greatest and immediate for crops that are particularly responsive to the nutrient (e.g. potatoes and some vegetable crops). Reductions in N fertiliser would have an immediate impact on all crops other than legumes. For most crops, any reduction in fertiliser N would cause a small but economically significant reduction in yield. For example, for winter wheat, a 10% reduction in fertiliser N (from the economic optimum) would result in a 1 - 3% reduction in yield. 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 this second nutrient. There would be considerable resistance to the method, due to the impacts on crop yields and the inability to maintain a productive system.

Cost: Nominal losses were used for the arable farms associated with the indoor pigs and the broiler farm types due to the N input from manure (see Appendix II). The negative costs shown for a reduction in P use on dairy and beef farms indicate a financial saving.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
10% Reduction in N £/ha	1.80	31.1	16.8	<1	<1	n/a
20% Reduction in N £/ha	5.30	61.4	34.4	6	6	"
50% Reduction in N £/ha	28.75	166.7	87.2	10	10	"
10% Reduction in N £/farm	550	4,665	1,680	<500	<100	"
20% Reduction in N £/farm	1,585	9,210	3,440	2,620	425	"
50% Reduction in N £/farm	8,625	25,000	8,720	4,370	710	"
10% Reduction in P £/ha	1.20	-1	-1	n/a	n/a	"
20% Reduction in P £/ha	2.30	-2	-2	"	"	"
50% Reduction in P £/ha	5.73	-5	-5	"	"	"
10% Reduction in P £/farm	355	-150	-100	"	"	"
20% Reduction in P £/farm	690	-300	-200	"	"	"
50% Reduction in P £/farm	1,720	-750	-500	"	"	"

Effectiveness:

N: Arable: 5-10 kg N/ha reduction in leaching per year from a 20% reduction in N application below the fertiliser recommendation; 10-15 kg/ha per year reduction for a 50% reduction in rates.

Dairy: 5-10 kg N/ha reduction for a 20% reduction in fertiliser N and 10-15 kg N/ha for a 50% reduction. All effects are averaged over the farm area.

[continued]

P: There is no equivalent method in PE0203 as this project did not differentiate between reduce and 'do not apply' fertiliser (see Method 22 in this Manual, below). The closest analogy is PE0203 Method 5 'Halve P fertiliser input to horticulture land that is index 3'. Using an expert weighting, it is estimated that the method reduces the fertiliser component of the baseline loss by 20%. This is an average over the farm area.

FIOs: Unaffected by the method.

Estimates of effectiveness at the farm-scale assume that the method is applied to the whole farm for all the model farm systems, apart from Outdoor Pigs.

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	6	(51)	6	(47)	0.00	(0.3)	0.03	(2.3)	0	(0)	0	(0)
Arable + manure	7	(57)	7	(51)	0.00	(0.4)	0.03	(2.5)	0	(1)	0	(1)
Dairy	7	(61)	7	(34)	0.00	(0.2)	0.06	(2.8)	0	(36)	0	(100)
Beef	3	(18)	2	(12)	0.00	(0.2)	0.03	(1.0)	0	(15)	0	(43)
Broilers	5	(82)	5	(68)	0.00	(0.4)	0.03	(3.2)	0	(0)	0	(0)
Indoor pigs	8	(89)	6	(74)	0.00	(0.5)	0.03	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: If an attempt was made to make up for the reduction in nutrients by increasing the application of organic manures, there would be an increased risk of pollution from nitrate, P, FIOs, BOD, ammonia and ammonium-N.

22. Do not apply P fertilisers to high P Index soils

Description: Do not apply mineral P fertiliser to soils that have an ADAS Soil P Index of 4 or above.

Rationale: The amount of P lost by erosion or leaching depends on the soil P content. 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.

Mechanism of action: If mineral 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. Soil P is adsorbed on soil particles and is lost when sediment is eroded from fields in surface flow and in drain flow. The higher the soil P reserves, the greater the amount of P lost with the transported soil. The amount of P lost in soil solution is also greater on high P index soils, particularly on P-saturated soils. Balancing P inputs to crop offtakes and not applying P to soil with high P reserves must also take account of the P supplied in manure applications (see Methods 20 and 33). 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).

Potential for applying the method: The method is applicable to all farming systems, but would have greatest effect in intensive grassland and arable systems.

Practicability: The method could be easily implemented *via* advice, education and guidance. Particular guidance is required with soil sampling, analysis and interpretation of Soil P Index levels. There would be resistance to adopting the method for those crops (e.g. potatoes) that can respond to P mineral fertiliser on high P Index soils.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Saving £/ha	1	1	1	n/a	n/a	n/a
Saving £/farm	300	150	100	"	"	"

Effectiveness:

N: Nil effect.

P: PE0203 Method 1 ‘Stop P fertiliser input to all arable above index 4’ and Method 3 ‘Stop P fertiliser input to grassland that is above index 4’ were used. Expert weightings were applied to these to estimate the effect of not applying P fertiliser to soils with a P index of 4 or above. These high P index soils make a disproportionate contribution to the total loss, so that when averaged over the whole-farm area, the reduction was equivalent to 200% of the fertiliser component of the baseline P loss. However, this only applies to 10% of the farm area. The method has little effect on the sandy loam soil because the fertiliser component makes only a small contribution to the baseline P loss. The method will have an additional, longer-term effect because of the gradual reduction in the P content of the soil.

FIOs: Unaffected by the method.

	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)					
Farm type	**Nitrate (kg N/ha)**		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	0 (51)	0 (47)	0.00 (0.3)	0.03 (2.3)	0 (0)	0 (0)
Arable + manure	0 (57)	0 (51)	0.00 (0.4)	0.03 (2.5)	0 (1)	0 (1)
Dairy	0 (61)	0 (34)	0.00 (0.2)	0.06 (2.8)	0 (36)	0 (100)
Beef	0 (18)	0 (12)	0.00 (0.2)	0.03 (1.0)	0 (15)	0 (43)
Broilers	0 (82)	0 (68)	0.00 (0.4)	0.03 (3.2)	0 (0)	0 (0)
Indoor pigs	0 (89)	0 (74)	0.00 (0.5)	0.03 (3.7)	0 (4)	0 (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Estimates of effectiveness at the farm-scale assume that the method is applied to 10% of the farmed area for all the model farm systems, apart from Outdoor Pigs.

Other benefits or risk of pollution swapping: None.

23. Do not apply fertiliser to high-risk areas

Description: Do not apply mineral fertiliser at any time into hedges or ditches or 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. Fields with high P index soils should also be considered as area with a high risk of P loss (see Method 22).

Rationale: The risk of pollution by nitrate and P 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 connected areas helps prevent the mobilisation and transfer of agricultural pollutants from land to water.

Potential for applying the method: This method is potentially applicable to all grassland farming systems, but may be most applicable to the extensive grassland sector, where open drains and waterlogged areas are common. It is also applicable to arable fields with hedges, ditches and areas close to road culverts.

Practicability: It is an easy option to implement, although some farmers may be resistant to not applying fertiliser to grassland that contains areas prone to waterlogging or to grassland areas with a dense network of open drains. Avoiding fertiliser spreading in high-risk areas is compatible with the Environmental Stewardship Scheme and there is no conflict with other methods.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Net loss £/ha	8	7	4	8	8	n/a
Net loss £/farm	2,410	1,065	380	3,510	570	"

Effectiveness:

N: Reduction of 0 -1 kg N/ha when averaged over the farm area but larger in the affected area.

P: There is no equivalent method in PE0203 but Method 18 'Use of placement', as applied to the all-arable scenario, was used as a basis for estimating the effectiveness. These high risk areas make a disproportionate contribution to the total loss and after applying an appropriate weighting, the reduction was estimated as 270% of the whole-farm average P loss originating from fertilisers. However, this only applies to 10% of the farm area. The method has little effect on the sandy loam soil because the fertiliser component makes only a small contribution to the baseline P loss.

FIOs: Unaffected by the method.

Estimates of effectiveness at the farm-scale assume that the method is applied to 10% of the farmed area for all model farm systems, apart from Outdoor Pigs.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	0.3 (51)	0.1 (47)	0.00 (0.3)	0.05 (2.3)	0 (0)	0 (0)
Arable + manure	0.3 (57)	0.1 (51)	0.00 (0.4)	0.05 (2.5)	0 (1)	0 (1)
Dairy	0.3 (61)	0.1 (34)	0.00 (0.2)	0.08 (2.8)	0 (36)	0 (100)
Beef	0.1 (18)	0.1 (12)	0.00 (0.2)	0.04 (1.0)	0 (15)	0 (43)
Broilers	0.3 (82)	0.1 (68)	0.00 (0.4)	0.05 (3.2)	0 (0)	0 (0)
Indoor pigs	0.3 (89)	0.1 (74)	0.00 (0.5)	0.05 (3.7)	0 (4)	0 (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: The method will also be effective in reducing ammonium-N losses and nitrous oxide emissions.

24. Avoid spreading fertiliser to fields at high-risk times

Description:

- Do not spread mineral fertiliser at times when there is a high risk of surface flow or rapid movement to field drains from wet soils.
- Do not spread N fertiliser between September and February when there is a high risk of nitrate leaching loss, unless there is a specific crop requirement during this time.
- Do not apply N fertiliser when there is little or no crop uptake.

Rationale: Fertiliser timing affects the mobilisation of nutrients being released from land to water. Avoiding spreading fertiliser to fields at high-risk times reduces the availability of nitrate for loss through leaching and of P for loss in surface run-off or rapid preferential flow.

Mechanism of action: Surface run-off is most likely to occur when rain falls onto sloping ground with soils that are saturated, frozen or snow covered. Rapid preferential flow of fertiliser nutrients through the soil is most likely to occur from drained soils when they are wet and rainfall follows soon after fertiliser has been applied.The method aims to prevent nutrients being added at times when there is rapid transfer of water from the soil surface to water bodies or rapid leaching to ground water. Avoiding the addition of N fertilisers in the autumn reduces the amount of nitrate available for leaching by over-winter rainfall.

Potential for applying the method: The method is potentially applicable to most farming systems, i.e. all which use mineral fertiliser. Fertiliser timing to avoid high-risk periods is compatible with the Environmental Stewardship Scheme and there is no conflict with other methods.

Practicability: It would be relatively acceptable to the farmer, although the prediction of rainfall and restriction on the timing of mineral N applications may cause practical difficulties for some farmers. The adoption of this method will 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 run-off or drain flow losses may occur) should not be undertaken. Farmers may be particularly reluctant to avoid applying fertiliser to drained clay soils in early spring to promote early season crop growth.

Cost: This is a **zero cost method in most years** but there may be significant costs, as in the table, perhaps one year in ten (see Appendix II).

Occasional costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Net loss £/ha/year	49	7	4	49	49	n/a
Net loss £/farm/year	1,470	106	40	2,140	350	"

Effectiveness:

N: 0-15 kg/ha N reduction in the affected areas depending on circumstances. The reduction, averaged over the farm area, will be smaller depending on the proportion of the farm affected. The average reduction over the farm area is assumed to be 0-2 kg N/ha.

P: PE0203 Method 19 ‘Improved timing windows – fertiliser’ was used, as applied to all arable and grassland. After adjusting for the expert weighting, the fertiliser component of the baseline P loss is estimated to be reduced by 15% on the sandy loam and clay loam soil types. However, the fertiliser component contributes little to the total loss from the sandy loam soil.

FIOs: Unaffected by the method.

Estimates of effectiveness at the farm-scale assume that the method is applied to the whole farm for all model farm systems, apart from Outdoor Pigs.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	0.5 (51)	0.1 (47)	0.00 (0.3)	0.03 (2.3)	0 (0)	0 (0)
Arable + manure	0.5 (57)	0.1 (51)	0.00 (0.4)	0.03 (2.5)	0 (1)	0 (1)
Dairy	0.5 (61)	0.1 (34)	0.00 (0.2)	0.04 (2.8)	0 (36)	0 (100)
Beef	0.1 (18)	0.1 (12)	0.00 (0.2)	0.02 (1.0)	0 (15)	0 (43)
Broilers	0.5 (82)	0.1 (68)	0.00 (0.4)	0.03 (3.2)	0 (0)	0 (0)
Indoor pigs	0.5 (89)	0.1 (74)	0.00 (0.5)	0.03 (3.7)	0 (4)	0 (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: The method will also be effective in reducing ammonium-N losses and nitrous oxide emissions.

25. Increase the capacity of farm manure (slurry) stores

Description: On farms where there is currently limited storage capacity, expand facilities for collection and storage of slurry and dirty water to allow them to be spread at times when there is a low risk of run-off and when there is an actively growing crop to utilise the nutrients supplied in the manure.

Rationale: Collection and storage of slurry and dirty water provides flexibility about when to apply these materials to fields. There will be fewer occasions when a lack of storage capacity forces farmers to apply manures at times when there is a high risk of polluting ground or surface waters.

Mechanism of action: If a farm has little or no storage for slurry and dirty water, the farmer will be obliged to spread these materials as they are produced. This will inevitably result in applications at times when there is a risk of nitrate leaching and of N, P and FIOs from the manure being transported to watercourses in surface run-off or in drainflow. Adequate collection and storage facilities provide greater freedom in choosing when to apply slurry to fields. There will be fewer occasions when lack of capacity forces the farmer to spread manure, particularly slurry, at unsuitable times. Applications can be restricted to periods when nutrients will be used by a growing crop and when there is little risk of surface run-off or rapid transport to field drains.

Potential for applying the method: The method is applicable to livestock farms that have limited manure storage facilities. The provision of adequate storage facilities is most important on farms that handle their manure as slurry and those that produce dirty water. In contrast, solid manure can be stored in field heaps, or sometimes in the animal house, prior to land-spreading at a time of year that presents less risk of pollution. The method would be effective on all types of soil.

Practicability: The method will only be effective if implemented in conjunction with Methods 31 - 36 (where relevant) and particularly where the actions in Methods 26 - 30 have also been adopted.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	21,260	n/a	n/a	12,130	n/a
Annual cost £/ha	"	16	"	"	27	"
Annual cost £/farm	"	2,420	"	"	1,900	"

Effectiveness:

N: On arable farms, 10-20 kg/ha reduction per year if no account is taken of additional manure N in setting fertiliser rates or 15-30 kg N/ha if account is taken of additional manure N. Additional manure N is N that has been saved from leaching by moving application times. Effects in grassland systems are typically 2-5 kg N/ha per year (dairy) or 1 kg N/ha (beef). All values are averaged over the farm area.

P: PE0203 Method 22 ‘Improved timing windows – manure’ was used as the closest analogy because it involved increased storage. After expert weighting, it was estimated that the method would reduce the manure component of the baseline P loss by 25%.

FIOs: 20% reduction.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	n/a (51)	n/a (47)	n/a (0.3)	n/a (2.3)	n/a (0)	n/a (0)
Arable + manure	n/a (57)	n/a (51)	n/a (0.4)	n/a (2.5)	n/a (1)	n/a (1)
Dairy	5 (61)	5 (34)	0.04 (0.2)	0.49 (2.8)	20 (36)	20 (100)
Beef	n/a (18)	n/a (12)	n/a (0.2)	n/a (1.0)	n/a (15)	n/a (43)
Broilers	n/a (82)	n/a (68)	n/a (0.4)	n/a (3.2)	n/a (0)	n/a (0)
Indoor pigs	15 (89)	10 (74)	0.03 (0.5)	0.35 (3.7)	20 (4)	20 (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Estimates of effectiveness at the farm-scale assume that the method affects half of the slurry (autumn and winter applications) on 85% of the farmed area in the Dairy System, and the same proportion of slurry over the whole area of the Indoor Pig System.

Other benefits or risk of pollution swapping: Applying manure at times when there is a lower risk of surface run-off or drainflow following application will reduce the potential for ammonium-N and BOD losses. There are likely to be some increases in ammonia and methane emissions during storage.

26. Minimise the volume of dirty water produced

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 and from roofs, etc.
- roofing over yard areas
- 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 during winter and be forced to spread dirty water or slurry at times when there is a high risk of pollution occurring.

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. Covering dirty water and slurry stores prevents rainfall from adding to the volume to be stored. 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 these yards will avoid additional inputs from rainwater. Poorly designed or badly maintained drains and gutters allow rainwater from non-fouled yards and from roofs to mix with dirty water and further increase the volume. This clean water does not require treatment and 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 storage without needing to increase storage capacity. This helps avoid the need to apply dirty water and slurry when ground conditions are unsuitable, which reduces the likelihood of surface run-off and transport of N, P and FIOs into watercourses and of nitrate leaching to groundwater. The method reduces the volume of liquid to be stored and handled but has no effect on the total amounts of N, P or FIOs.

Potential for applying the method: The method is mainly applicable to farms with cattle, particularly dairy farms, though most livestock farms will produce some dirty water. As part of the Integrated Pollution Prevention and Control (IPPC) regulations, from 2007 all new pig farms (and substantially modified units) will have to cover their slurry stores, although this is directed at reducing ammonia emissions rather than water pollution. The method will be effective in reducing losses from fine textured and capping soils where there is the greatest risk of run-off and on free-draining soils where there is a high risk of nitrate leaching.

Practicability: There are few limitations to the adoption of this method though there may be practical limitations to the roofing of yards and covering of dirty water or slurry stores. The extent to which yard areas can be reduced is limited by the need to avoid overcrowding that might adversely effect herd health and milk quality. Preventing unnecessary inputs of rainwater will be most effective in high rainfall areas. Using a pressure washer to wash down yards uses more water than a non-pressurised supply.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost, fencing etc. £/farm	n/a	1,000	n/a	n/a	n/a	n/a
Capital cost, slurry store cover £/farm	n/a	14,250	n/a	n/a	17,700	n/a
Annual cost, fencing etc. £/ha	"	1.65	"	"	n/a	"
Annual cost, slurry store cover £/ha	"	10.8	"	"	28.3	"
Annual cost, fencing etc £/farm	"	245	"	"	n/a	"
Annual cost, slurry store cover £/farm	"	1,620	"	"	2,010	"

[continued]

Effectiveness:

N: 0-1 kg N/ha reduction in N leaching per year, averaged over the farm area.

P: There is no equivalent method in PE0203 but Method 7 'Reduce feed P input to dairy', was used as a basis for estimating the effectiveness. After expert weighting to allow for differences in methods and model farm systems, it is estimated that on the clay loam soil, the manure component of the baseline P loss is reduced by 5%, as there is very little P in dirty water.

FIOs: 10% reduction.

Estimates of effectiveness at the farm-scale assume that the method affects 10% of the farmed area in the Dairy and Indoor Pig Systems.

	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
Farm type	**Nitrate (kg N/ha)**				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	0.1	(61)	0.1	(34)	0.00	(0.2)	0.01	(2.8)	10	(36)	10	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	0.0	(89)	0.0	(74)	0.00	(0.5)	0.01	(3.7)	10	(4)	10	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: If the volume of dirty water added to the slurry store or of rain falling into the store is reduced, the slurry will have a higher dry matter content, which may slightly increase ammonia emissions when it is spread.

27. Adopt batch storage of slurry

Description:

- Store batches of slurry for at least 90 days before spreading on fields.
- Do not add fresh slurry to the store during this storage period.

Rationale: FIOs die off during storage. There are fewer microorganisms in the material that is spread and therefore less risk of FIOs entering water bodies *via* surface run-off or percolation to field drains.

Mechanism of action: Numbers of FIOs decline during storage and this can be an effective means of reducing bacterial numbers in the slurry. It is less effective for controlling the protozoan parasite, *Cryptosporidium*. If there is run-off or percolation into field drains following slurry application, the transported material will contain many fewer FIOs compared with 'fresh' slurry. The method is primarily directed at reducing pathogen loads and will have little effect on nitrate or P losses.

Potential for applying the method: The method is applicable to livestock farms that produce slurry. Potential benefits would be greatest on sloping ground where the risk of surface run-off is greatest and on soils where drainflow is likely to occur following slurry spreading.

Practicability: The method requires that slurry is stored without any additions of fresh material during the 90-day storage period, otherwise the added slurry would contaminate the stored material with fresh, viable microorganisms. In most cases, this will require more than one store.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Capital cost £/farm	n/a	25,200	n/a	n/a	32,500	n/a
Annual cost £/ha	"	20.30	"	"	11.00/sow	"
Annual cost £/farm	"	3,050	"	"	3,900	"

Effectiveness:

N: Nil effect.

P: There will be no effect on P losses.

FIOs: 40% reduction on the dairy and indoor pig farms but has less impact on the latter because slurry is already stored for 3 months.

Estimates of effectiveness at the farm-scale assume that the method affects 85% of the farmed area in the Dairy system, and 100% of land within the Indoor Pig system.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	0	(61)	0	(34)	0.00	(0.2)	0.00	(2.8)	40	(36)	40	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	0	(89)	0	(74)	0.00	(0.5)	0.00	(3.7)	40	(4)	40	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Unless precautions were taken to reduce volatilisation (e.g. roofing the store), constructing a second store would increase ammonia losses during storage because of the greater surface area contributing to ammonia emissions.

28. Adopt batch storage of solid manure

Description:

- Store solid manure for at least 90 days before spreading on fields.
- No fresh manure should be added to the heap during this storage period.

Rationale: FIOs die off during storage. There are fewer organisms in the material that is spread and therefore less risk of microorganisms from the manure entering water bodies *via* surface run-off or percolation through the soil to field drains. Also, the readily available N and total N content of stored farmyard manure will be lower than in the fresh manure, which will lessen the risk of nitrate leaching losses.

Mechanism of action: Numbers of FIOs decline during storage of the manure. The rate of decline is accelerated if composting occurs and high temperatures develop in the heap. This happens naturally in most FYM and poultry litter heaps. There are thus fewer microorganisms in the manure when it is spread and therefore less risk of FIOs entering water bodies in run-off or where water percolates to underlying drains. Although storage is effective at reducing bacterial numbers, it is less effective in reducing populations of the protozoan parasite, *Cryptosporidium*. There will also be gaseous losses of ammonia and nitrous oxide and immobilisation of N during storage, which will reduce the quantity of mineral-N available for loss by leaching or in surface run-off. Fresh cattle FYM typically contains 25% of ammonium-N, compared with about 10% in FYM that has been stored for more than 3 months. There is also a reduction in the total N content; typically, 30 – 50% of the total N in FYM is lost during storage. For poultry manure, about 15% of the N is lost during storage but the proportion of readily-available N remains similar to that in the fresh material. The method will have no effect on P losses.

Potential for applying the method: The method is applicable to livestock farms that produce solid manure and have only a single store where fresh manure is continuously added to that already present. Potential benefits will be greatest on impermeable soils where the risk of surface run-off is greatest, on drained clay soils with rapid by-pass flow routes to drains and on freely drained soils that are susceptible to nitrate leaching.

Practicability: Storage facilities for solid manures can be constructed relatively simply and cheaply (see Method 32) and there are therefore few limitations to adopting this method. If manure from loose-housed cattle is only removed from the animal house at the end of the winter housing period, a 90-day storage period would restrict its use on some spring-sown crops, e.g. maize.

Cost: Assuming storage on concrete, this involves making a hard-standing with a drain and trap, on which to store the manure, assuming no concrete pad is used at present (see Appendix II).

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	n/a	13,200	15,250	n/a	n/a
Annual cost £/ha	"	"	12.4	3.3	"	"
Annual cost £/farm	"	"	1,240	1,440	"	"

Effectiveness:

N: Estimates of the size of the effect were based on the Beef model farm system in which FYM is stored for three months. Assuming FYM is applied one year in three, the effect would be a reduction of 3 kg N/ha per year on the fields to which the FYM is applied and 1 kg N/ha overall.

P: There will be no effect on P losses.

FIOs: No change. The method is of limited effectiveness because most FYM is already stacked on farms for more than 3 months before spreading.

Estimates of effectiveness at the farm-scale assume that the method affects 20% of the farmed area in the Beef system and all the land within the Broiler system.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	n/a (51)	n/a (47)	n/a (0.3)	n/a (2.3)	n/a (0)	n/a (0)
Arable + manure	n/a (57)	n/a (51)	n/a (0.4)	n/a (2.5)	n/a (1)	n/a (1)
Dairy	n/a (61)	n/a (34)	n/a (0.2)	n/a (2.8)	n/a (36)	n/a (100)
Beef	1.0 (18)	1.0 (12)	0.00 (0.2)	0.00 (1.0)	0 (15)	0 (43)
Broilers	0.0 (82)	0.0 (68)	0.00 (0.4)	0.00 (3.2)	0 (0)	0 (0)
Indoor pigs	n/a (89)	n/a (74)	n/a (0.5)	n/a (3.7)	n/a (4)	n/a (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: There will be increased ammonia and nitrous oxide losses during storage but as the readily-available and total N content of the stored manure will have been reduced, N losses at spreading are likely to be smaller than from fresh manure.

29. Compost solid manure

Description:

- Encourage the breakdown of solid manures by actively composting the manure heap.
- Turn the solid manure heap twice in the first seven days of composting to facilitate aeration and the development of high temperatures within the heap.

Rationale: The aim is to allow naturally occurring microflora to degrade cellulose and other carbon compounds in the manure (or other added material) to produce a more friable, stable, and spreadable product with reduced volume. In the process, the manure is sanitised and the readily available N content is reduced, thereby lowering nitrate and FIO losses when the compost is spread.

Mechanism of action: This is a source method that uses aerobic microbial metabolism to increase temperatures sufficiently to inactivate pathogens and to reduce the readily available N content of manures. The biological and subsequent chemical reactions can involve a rise in temperature up to around 70^{o}C, which serves to inactivate weed seeds and most pathogens. The whole process involves close monitoring to ensure that the pile temperature increases to above 55^{o}C for three days after each turn. The readily available N content of farmyard manure is typically reduced from 25% to 10% of the total N, so N losses following land spreading are likely to be lower. Some N is bound into organic forms and some is lost to the atmosphere as ammonia and nitrous oxide. Turning of the pile allows mixing and the further degradation of material and ensures that all parts of the pile are treated. Composting has no effect on the proportion of readily available N in poultry manure.

Potential for applying the method: Applicable to farms with solid manures, particularly in areas where there is a high risk of pathogen transfer to water systems.

Practicability: Can be easily incorporated into normal farm operations using standard farmyard machinery. A degree of education and guidance is necessary in the first few months of operation.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	n/a	9.00	1.45	n/a	n/a
Cost £/farm	"	"	900	545	"	"

Effectiveness:

N: Estimates of the size of the effect were based on the Beef model farm system in which FYM is stored for three months. Assuming FYM is applied one year in three, the effect would be a reduction of 3 kg N/ha per year on the fields to which the FYM is applied and 1 kg N/ha overall.

P: There will be no effect on P losses.

FIOs: No change. This reflects the small difference between the effects of composting and static piling on FIO viability.

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				Total P (kg P/ha)				FIOs (%)*			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	1.0	(18)	1.0	(12)	0.00	(0.2)	0.00	(1.0)	0	(15)	0	(43)
Broilers	2.0	(82)	2.0	(68)	0.00	(0.4)	0.00	(3.2)	0	(0)	0	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Estimates of effectiveness at the farm-scale assume that the method affects 20% of the farmed area in the Beef system and all the land within the Broiler system.

Other benefits or risk of pollution swapping: It should be noted that many of the benefits of a managed composting process can also be achieved by simply batch storing solid manure (see Method 28). Composting typically results in 30-50% of the total N in farmyard manure being lost to the atmosphere, either as ammonia, nitrous oxide or dinitrogen gas. For poultry manures, losses are more typically 20%. It is possible to reduce ammonia emissions from composting by reducing aeration intensity and by increasing the amount of straw relative to the amount of dung (i.e. providing a higher carbon:nitrogen ratio). However, if the aeration intensity is too low, emissions of nitrous oxide and methane would most likely increase.

30. Change from slurry to a solid manure handling system

Description: Change from a system where the manure from housed animals is collected as a liquid slurry to one where animals are kept on a bed of straw to produce a solid manure.

Rationale: Solid manures are more easily stored than slurries and present less risk of pollutant loss when they are spread. In the period 2001-2004, there were 9.4 times more recorded water pollution incidents caused by slurry than by solid manure.

Mechanism of action: Sufficient bedding is provided in animal houses to soak up the liquid portion of the excreta to produce a solid manure that can be stacked and does not flow under gravity. As a result, there are fewer storage problems than with slurry. Manure in cattle houses is generally allowed to accumulate in the house throughout the winter. Therefore, there is not the same limit on storage capacity that may force farmers to spread slurry at unsuitable times during the winter. Other benefits of solid manure include a more rapid decline in numbers of FIOs than in slurry stores, as composting processes generate heat and increase temperatures within the heap. Because of their low moisture content, solid manures can be spread on fields with much less risk of N, P or FIOs entering field drains or watercourses in surface run-off. Losses will only occur where there is heavy rain in the days following application. Compared with slurries, less of the N is present in a readily-available mineral form. Typically, 50-60% of the N in slurries may be present as ammonium-N, compared with about 25% in fresh cattle FYM and 10% in stored FYM, which results in lower nitrate leaching losses following FYM applications to land.

Potential for applying the method: The method is applicable to those farms with housed stock that currently handle all or part of their manure as a liquid slurry. It is not applicable to sheep or poultry units as these do not produce slurries. It will be most effective on sloping and less permeable soils where the risk of surface run-off is greatest, on free draining sandy or shallow soils that are prone to nitrate leaching and on drained clay soils where rapid losses can occur in drainflow from wet soils.

Practicability: Solid manure requires a source of suitable bedding material and is less-suited to regions where little straw is produced. There will be additional labour requirements associated with spreading straw in the animal house. Solid manure is less easily handled than liquid slurries. It cannot be pumped and cannot be used with umbilical spreading systems.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	70,500	n/a	n/a	442,500	n/a
Annual cost £/ha	"	104	"	"	1,025	"
Annual cost £/farm	"	15,630	"	"	72,800	"
Cost of lost output £/farm in year 1	"	–	"	"	11,100	"

Effectiveness:

N: Dairy and beef: 10-20 kg N/ha reduction in N leaching per year as a result of reducing manure N losses by 40%. Pigs: 15-30 kg N/ha reduction, as a result of reducing manure N losses by 80%.

P: There is no equivalent method in PE0203 but PE0203 Method 21 'Slurry injection' was used as a basis for estimating the effectiveness. After adjusting for the expert weighting, it is estimated that the manure component of the baseline P loss is reduced by 50% for sandy loam soils and 25% for clay loam soils.

FIOs: 40% reduction. As cattle are still out grazing they are still a significant source of FIOs. For this reason, the method may be more effective for indoor pigs. This is not evident for the model pig farm, where the storage period is sufficient to eliminate most of the FIOs in the slurry before spreading.

Estimates of effectiveness at the farm-scale assume that the method affects 85% of the farmed area in the Dairy system, and all the land within the Indoor Pig system.

[continued]

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	7	(61)	5	(34)	0.08	(0.2)	0.39	(2.8)	40	(36)	40	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	32	(89)	23	(74)	0.06	(0.5)	0.28	(3.7)	40	(4)	40	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Ammonia emissions from solid cattle manure systems (i.e. from housing, storage and land spreading) are lower than from slurry systems but there are no clear differences between pig manure systems. Methane emissions are lower from solid manure systems. However, nitrous oxide emissions are higher from solid manure than from slurry systems.

31. Site solid manure heaps away from watercourses and field drains

Description: Where solid manure is stacked in the field or outside of buildings, the heap should not be sited over field drains or close to a watercourse (i.e. at least 10 m separation).

Rationale: Keeping manure heaps away from field drains and watercourses reduces the risk of pollutants from the manure entering surface waters through preferential flow to drains or *via* surface run-off into a watercourse.

Mechanism of action: Siting manure heaps away from drains reduces the risk that preferential flow of effluent though the soil might transport N, P and FIOs to field drains. Similarly, an adequate separation distance between the heap and a watercourse reduces the risk that any effluent from the heap might run over the soil surface directly into the watercourse. There is often an increased risk of run-off from the area immediately surrounding the heap because of damage to the soil structure caused by farm machinery when loading/unloading manure.

Potential for applying the method: The method is applicable to all farms that produce or import solid manure and store it in the field. Benefits are likely to be greatest on heavier soils, where there is a greater risk of surface run-off and where drains are more likely to be present.

Practicability: The method is simple to implement with few limitations to its use. However, it will be difficult to find suitable positions for manure heaps on those farms where most fields have a system of closely-spaced drains. The method will provide little additional benefit where Method 32, to site manure heaps on concrete and collect effluent, has already been adopted and properly implemented.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	2	n/a	2	2	n/a	n/a
Cost £/farm	200	"	200	875	"	"

Effectiveness:

N: The method will only be effective on the clay loam soil, where a reduction of 0-1 kg N/ha per year is estimated on the fields concerned. The calculation assumes that 20% of manure heaps are at risk (i.e. over a drain, etc), and 2% of total N is leached. Averaged over the farm area, this corresponds to a reduction in loss per unit area of 0.2 kg N/ha.

P: There is no direct equivalent in PE0203 but PE0203 Method 22 ‘Improved timing windows – manure’ was used as the basis for estimating effectiveness. It is difficult to translate these losses, expressed on a field area basis, to the loss from a manure heap, which is effectively a point source. However, on the basis of the expert weighting it was estimated that the manure component of the baseline P loss would be reduced by 4%.

FIOs: 10% reduction on the clay loam soil. The effectiveness is assumed to be zero for the broiler farm because the litter is a relatively dry material and the heap would need to receive an appreciable amount of rain before any seepage occurred. By this time, the temperature in the heap would be expected to have risen sufficiently to kill off most of the FIOs that are present.

Estimates of effectiveness at the farm-scale assume that 20% of manure heaps are at risk within the Arable (plus manure), Beef and Broiler systems.

[continued]

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	0.0	(57)	0.2	(51)	0.00	(0.4)	0.01	(2.5)	0	(1)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	0.0	(18)	0.1	(12)	0.01	(0.2)	0.03	(1.0)	0	(15)	10	(43)
Broilers	0.0	(82)	0.2	(68)	0.00	(0.4)	0.04	(3.2)	0	(0)	0	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: The method will also reduce water pollution risks from ammonium-N and elevated levels of BOD. It is unlikely to increase any pollutant losses above those normally arising from manure storage.

32. Site solid manure heaps on concrete and collect the effluent

Description:

- When stored outside, manure heaps should be sited on an impermeable concrete base with facilities for collecting the effluent that drains from the heap.
- The effluent should be spread on the land when there is little risk of it causing pollution.

Rationale: The impermeable base and collection of effluent prevents the transport of pollutants in run-off and in drainage through the soil.

Mechanism of action: If stored directly on the soil surface, liquid from the manure heap will seep into the soil and/or flow over the ground surface. Flows will be increased by rain falling onto the heap. Storing manure on an impermeable base prevents seepage and accumulation of high concentrations of soluble N and P in the soil below the heap, which may subsequently be leached to surface and ground waters or flow directly through cracks to field drains. The concrete surface also reduces the area of soil compaction caused by farm machinery during loading and unloading of manure. Collection of the effluent prevents overland flow from the heap, which could otherwise transport N, P and FIOs to watercourses. The effluent can be spread at a later date when soil conditions are suitable and the nutrient content can be utilised by the crop.

Potential for applying the method: The method is applicable to all livestock farms that produce solid manure (and to arable farms that import manure) and currently do not take these precautions. About 27 million tonnes of straw-based FYM and 4 million tonnes of poultry manure are produced annually in England and Wales. The action will be most effective on heavier soils, where there is a greater risk of surface run-off and where field drains are more likely to be present, and on sandy soils or shallow soils over permeable rocks where the risk of leaching is greatest.

Practicability: The method would be simple to adopt and there are few limitations on where it could be implemented. If the precaution to site manure heaps away from watercourses and drains (Method 31) was already being observed, the additional benefits of this method would be largely confined to reductions in nitrate leaching, as the impact of P and FIO losses in surface run-off would already be minimised.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost/farm	9,800	n/a	6,860	7,630	n/a	n/a
Annual cost £/ha	3.10	"	6.45	1.65	"	"
Annual cost £/farm	920	"	645	720	"	"

Effectiveness:

N: 0-1 kg N/ha per year reduction in leaching on the fields concerned. The calculation assumes that 20% of manure heaps are at risk (i.e. over a drain, etc), and 2% of total N is leached. Averaged over the farm area, this gives rise to a reduction in loss per unit area of 0.1 - 0.5 kg N/ha.

P: There is no direct equivalent in PE0203, but Method 22 'Improved timing windows – manure' was used as a basis for estimating the effectiveness. It is difficult to translate these losses, expressed on a field area basis, to the loss from a manure heap, which is effectively a point source. However, an expert weighting system was used, which estimates that the manure component of the baseline P loss is reduced by 4%.

FIOs: 10% reduction, provided effluent is collected and applied at the correct time and rate.

Estimates of effectiveness at the farm-scale assume that 20% of the farmed area is affected within the Arable (plus manure), Beef and Broiler systems. The effectiveness is assumed to be zero for the broiler farm because the litter is a relatively dry material and the heap would need to receive an appreciable amount of rain before any seepage occurred. By the time, the temperature in the heap would be expected to have risen sufficiently to kill off most of the FIOs that are present.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	0.5	(57)	0.2	(51)	0.00	(0.4)	0.01	(2.5)	0	(1)	0	(1)
Dairy	n/a	(61)	n/a	(34)	n/a	(0.2)	n/a	(2.8)	n/a	(36)	n/a	(100)
Beef	0.1	(18)	0.1	(12)	0.01	(0.2)	0.03	(1.0)	10	(15)	10	(43)
Broilers	0.5	(82)	0.2	(68)	0.00	(0.4)	0.04	(3.2)	0	(0)	0	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: The method will also reduce water pollution risks from ammonium-N and elevated levels of BOD. It is unlikely to increase any pollutant losses above those normally arising from manure storage.

33. Do not apply manure to high-risk areas

Description: Do not apply slurry or solid manure to field areas where there is a high risk of direct flow to watercourses. For example, directly adjacent to a watercourse, borehole or road culvert, to shallow soils over fissured rock or cracked soils over field drains, to areas with a dense network of open (surface) drains, or to wet depressions (flushes) draining to a nearby watercourse. High risk areas also include fields with high P index soils (P Index 4 and above) and manure should not be applied to these areas at any time.

Rationale: These are areas where there is a particularly high risk of rapid transport of solutes or suspended material to watercourses and inputs of potential pollutants to these areas should be avoided wherever possible. Losses of P on eroded soil particles and by leaching are greatest on high P index soils. Applying manures to these areas will further increase the excessive P content of the soil and increase the amounts lost.

Mechanism of action: This 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 slurry contributing to overland flow or draining directly into field drains and transporting pollutants to watercourses. There is a similar risk of losses of soluble and suspended material from solid manures but these will generally only occur where heavy rain follows the application. The method is most effective against losses of P and FIOs, where the primary mechanisms of transport are by preferential flow and in surface run-off. The Water Code advises that manures and slurry 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. The risks associated with high P index soils are less dependent on the degree of hydrological connectivity. Instead, withholding manure from these areas allows the high P content to decline, reducing the quantities lost as adsorbed P on eroding soil particles and by leaching from P saturated soils.

Potential for applying the method: The method is applicable to all farms applying manures and where these ground conditions occur. These will mainly be livestock farms. There are about 6 million hectares of drained soils in England and Wales. Wet depressions are most likely to occur in undulating landscapes over fissured rocks, which produce frequent spring lines. Some upland farms have significant areas of semi-improved grassland with a high density of open drains or gullies within the fields.

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. Wet areas affected by spring lines are difficult to work and may already be excluded from the agricultural area. On some farms, particularly intensive dairy farms, with a history of high P use and of spreading manures on the same fields, a large proportion of the farm may be classified as having high P index soils and be excluded from receiving further applications. In these circumstances, it may be necessary to export surplus manure to other farms (Method 37).

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	2	2	2	2	2	n/a
Cost £/farm	600	300	200	875	140	"

Effectiveness:

N: 0-1 kg N/ha per year reduction in leaching, averaged over the farm area. Effects will be larger in the affected areas, but it has been assumed that these are a relatively small proportion of the farm.

P: There is no direct equivalent in PE0203, but Method 23 ‘Rate of application - manure’ was used as a basis for estimating the effectiveness. An expert weighting was then applied to the figure produced in PE0203. As a result, this method is estimated to reduce the manure component of P baseline losses by 40% over the area to which the method is applied.

FIOs: 10% reduction.

Estimates of effectiveness at the farm-scale assume that 20% of the farmed area is affected within all the model farm systems that use manure.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	0.5	(57)	0.5	(51)	0.00	(0.4)	0.03	(2.5)	0	(1)	0	(1)
Dairy	1.5	(61)	0.5	(34)	0.02	(0.2)	0.19	(2.8)	0	(36)	10	(100)
Beef	0.2	(18)	0.1	(12)	0.01	(0.2)	0.07	(1.0)	0	(15)	0	(43)
Broilers	0.5	(82)	0.5	(68)	0.01	(0.4)	0.09	(3.2)	0	(0)	0	(0)
Indoor pigs	2.0	(89)	2.0	(74)	0.01	(0.5)	0.13	(3.7)	0	(4)	10	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: The method will also reduce water pollution risks from ammonium-N and elevated levels of BOD. It is unlikely to increase any form of pollution.

34. Do not spread farmyard manure to fields at high-risk times

Description: Avoid spreading straw-based FYM to fields at times when there is a high risk of surface run-off or of rainfall causing losses by leaching. There is a high risk of losses in surface run-off when rain falls shortly after applying manure to soils that are either waterlogged or frozen hard.

Rationale: There is a risk of pollution if solid manures are spread under conditions where heavy rain could transport N, P and FIOs in surface run-off.

Mechanism of action: As solid manures have a low moisture content compared with slurries, they do not themselves add sufficient water to the soil to initiate surface run-off or preferential flow to field drains. Pollutants will only be transported to watercourses when there is heavy rainfall following the application. Avoiding spreading solid manures at times when these conditions are likely to occur minimises this risk. Fresh FYM has a higher content of readily-available N and FIOs and generally presents a greater risk of pollution than FYM that has been stored for several months.

Potential for applying the method: The method is applicable to livestock farms producing solid manure and to other farms that import fresh solid manure and spread it directly to fields. The risk of run-off is greatest on impermeable soils and on slopes. High-risk times will be most frequent in winter when soils are wet, particularly in high rainfall areas.

Practicability: Provided the farm has some storage for solid manure or can leave it in the animal house until conditions improve, there are few limitations to adopting this method. However, the method may limit opportunities for applying manure before some spring-sown crops.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha	2	n/a	2	n/a	n/a	n/a
Cost £/farm	600	"	200	"	"	"

Effectiveness:

N: Assume FYM is applied one year in three. Savings are 5 -10 kg N/ha on loamy sand and 1-12 kg N/ha on clay for old and fresh FYM, respectively, averaged over the rotation. However, only old FYM is applied on the Arable + manure and Beef model farm systems.

P: There is no direct equivalent in PE0203 but PE0203 Method 22 'Improved timing windows – manure' was used as a basis for estimating the effectiveness. An expert weighting was then applied to the figure produced in PE0203. As a result, this method is estimated to reduce the manure component of the P baseline losses by 50% on the sandy loam and by 20% on the clay loam soil.

FIOs: No change (because there is a low FIO load after the FYM has been stacked for more than 3 months).

Estimates of effectiveness at the farm-scale assume that the whole farm is affected within those model farm systems using FYM.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	n/a (51)	n/a (47)	n/a (0.3)	n/a (2.3)	n/a (0)	n/a (0)
Arable + manure	1.0 (57)	0.5 (51)	0.01 (0.4)	0.03 (2.5)	0 (1)	0 (1)
Dairy	n/a (61)	n/a (34)	n/a (0.2)	n/a (2.8)	n/a (36)	n/a (100)
Beef	0.3 (18)	0.1 (12)	0.07 (0.2)	0.16 (1.0)	0 (15)	0 (43)
Broilers	n/a (82)	n/a (68)	n/a (0.4)	n/a (3.2)	n/a (0)	n/a (0)
Indoor pigs	n/a (89)	n/a (74)	n/a (0.5)	n/a (3.7)	n/a (4)	n/a (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Other benefits or risk of pollution swapping: The method will also reduce water pollution risks from ammonium-N and elevated levels of BOD. There may be a slightly increased risk of P loss if manure is applied in spring rather than autumn.

35. Do not spread slurry or poultry manure to fields at high-risk times

Description:

- Do not apply slurry or poultry manure to fields at times when there is a high risk of surface run-off; e.g. in winter when soils are saturated 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 or in summer when soils are dry and cracked over drains.
- Do not apply slurry or poultry manure to fields late in the growing season (i.e. autumn/early winter) or when there is no crop to utilise the added N.

Rationale: Slurry and poultry manure have high contents of readily-available N. Avoiding applications of these materials at times when surface run-off or rapid preferential flow to drains is likely to occur reduces the risk of these flows transporting pollutants to watercourses. Avoiding applications in autumn or early winter helps to avoid a build-up of soil nitrate that may be leached over winter.

Mechanism of action: The method reduces the likelihood of recently applied slurry running off the soil surface and transporting N, P and FIOs directly into streams and rivers or indirectly in preferential flow *via* soil cracks into field drains. It lessens the risk of similar losses from poultry manure if heavy rain were to fall after the application.

If slurry or poultry manure is spread late in the growing season, it adds mineral-N to the soil at a time when there is little N uptake by the crop and instead, adds to the nitrate available for leaching over the winter. Therefore, applications in autumn and early winter should be avoided. Applications later in winter present less of a risk, as low temperatures slow the rate of conversion of ammonium to nitrate and there is less opportunity for the nitrate to be leached below the rooting zone by the time growth commences. Nitrate is leached out of the root zone most rapidly on sandy soils and on shallow soils with restricted rooting depth.

Potential for applying the method: The method is limited to those farms producing animal slurry or importing slurry (including liquid sewage sludge) and those using poultry manure. High-risk times will be most frequent in high rainfall areas and on sloping sites with impermeable soils, on shallow or sandy soils and on artificially drained soils where there are preferential loss pathways. There are around 6 million hectares of drained clay soils in England and Wales.

Practicability: For slurry, this method will only be applicable to those farms that have sufficient storage capacity to allow a choice of when to apply slurry. Over 15% of the farms in a recent survey had little or no storage. Even where storage is adequate for normal conditions, exceptional weather or poor planning can create a situation where stores are full during a high-risk period so that land spreading is the only option. It would generally be acceptable to apply slurry to grass later in the season than for other crops, as long as the sward continued to take up N.

Cost: If delaying slurry applications created a need for increased storage on the model dairy and pig systems, there would be additional costs to those in the table, as in Method 25 (see Appendix II).

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	n/a	n/a	n/a	n/a	n/a
Annual cost £/ha	2	2	"	2	2	"
Annual cost £/farm	600	300	"	875	140	"

Effectiveness:

N: Arable: assume slurry is applied one year in three. Savings are 15-25 kg N/ha (on loamy sand) and 15-30 kg N/ha (on clay) for dairy and pig slurry, respectively, averaged over the farm area. Grassland: reductions of 2 kg N/ha per year (dairy) or 1 kg N/ha per year (beef).

[continued]

P: There is no direct equivalent in PE0203, but Method 22 'Improved timing windows – manure' applied to intensive dairy (with slurry) was used as a basis for estimating the effectiveness. An expert weighting was then applied to the figure produced in PE0203. As a result, this method is estimated to reduce the manure component of P baseline losses by 25% on the sandy loam and by 35% on the clay loam soil.

FIOs: 10% reduction.

Estimates of effectiveness at the farm-scale assume that the whole farm is affected within the Arable (plus manure), Broiler and Indoor Pig systems, while 85% of the farmed area is affected in the Dairy system.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	3	(57)	2	(51)	0.00	(0.4)	0.06	(2.5)	0	(1)	0	(1)
Dairy	7	(61)	5	(34)	0.04	(0.2)	0.69	(2.8)	10	(36)	10	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	15	(82)	10	(68)	0.02	(0.4)	0.31	(3.2)	0	(0)	0	(0)
Indoor pigs	15	(89)	10	(74)	0.03	(0.5)	0.49	(3.7)	10	(4)	10	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Moving slurry applications from autumn/winter to spring on drained clay soils will increase the chances of elevated P and ammonium concentrations in drain flow. There are also likely to be greater ammonia emissions from spring slurry applications to arable land and following summer applications to grassland.

36. Incorporate manure into the soil

Description: Incorporate manures into the soil using a plough, discs or tines.

Rationale: The rapid soil incorporation of manures can reduce the loss of P and FIOs in surface run-off.

Mechanism of action: This is a mobilisation and delivery method. Incorporation of manure can reduce the detachment and entrainment of manure particles by increasing surface roughness, promoting infiltration and largely preventing the exposure of manure to the hydrological forces of raindrop impact, surface run-off and drain flow losses. Rapid soil incorporation of manure (i.e. within 6 hours of spreading for slurry and 24 hours for solid manures) also reduces the volatilisation of ammonia by reducing the exposure of manure to the air.

Potential for applying the method: Applicable to the arable sector on all soil types and to maize growing in the dairy sector.

Practicability: In most circumstances this method can be carried out as part of normal field preparations, although not commonly within 24 hours of spreading. Where contractors are carrying out the spreading it would require either additional investment in machinery for the agricultural contractor or a degree of co-ordination between farmers and contractors.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cultivator cost £/ha	0.0	2.2	n/a	0.0	0.0	n/a
Cultivator cost £/farm	0	330	"	0	0	"
Plough cost £/ha	0.0	4.5	"	0.0	0.0	"
Plough cost £/farm	0	675	"	0	0	"

Effectiveness:

N: Effects will be neutral if fertiliser rates take full account of retained N (i.e. N that is not volatilised) and the manure is not applied in the autumn. Manure applied in autumn adds N to the soil and increases the risk of loss because there is very little crop uptake at this time.

P: There is no direct equivalent in PE0203, but Method 20 'Incorporation of manure' applied to fodder crops was used as a basis for estimating the effectiveness. An expert weighting was then applied to the figure produced in PE0203. As a result, this method is estimated to reduce the manure component of P baseline losses by 19% on the sandy loam and by 13% on the clay loam soil.

FIOs: No change, as there is simply a change in the loss pathway.

Estimates of effectiveness at the farm-scale assume that the whole of the farm within the Arable (plus manure), Broiler and Indoor Pig systems is affected, whereas for the Dairy system, the benefit is confined to the 10% of the farm that is reseeded each year.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	-2.0	(57)	-1.0	(51)	0.00	(0.4)	0.02	(2.5)	0	(1)	0	(1)
Dairy	0.0	(61)	0.0	(34)	0.00	(0.2)	0.03	(2.8)	0	(36)	0	(100)
Beef	n/a	(18)	n/a	(12)	n/a	(0.2)	n/a	(1.0)	n/a	(15)	n/a	(43)
Broilers	-2.0	(82)	-1.0	(68)	0.01	(0.4)	0.11	(3.2)	0	(0)	0	(0)
Indoor pigs	-2.0	(89)	-1.0	(74)	0.02	(0.5)	0.18	(3.7)	0	(4)	0	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Other benefits or risk of pollution swapping: Rapidly incorporating manures into the soil will reduce ammonia losses and will increase the soil mineral N pool that may be lost to water systems by nitrate leaching or to the air as nitrous oxide. If the rapid cultivation policy damages soil structure, this may compromise crop yields and result in applied mineral fertiliser and organic manure N being poorly utilised by crops and at risk of leaching over the next winter drainage period. When manures are incorporated, FIOs are protected from ultra-violet radiation and can survive for longer than if exposed on the surface. However, as they are mixed throughout the soil matrix, they are less likely to be lost in surface run-off or *via* drain-flow.

37. Transport manure to neighbouring farms

Description: For farms within the 2002 designated Nitrate Vulnerable Zones (NVZs) where organic manure N loadings averaged over the tillage area exceed 210 kg/ha of total N each year or where they exceed 250 kg/ha over the grassland area, organic manures in excess of this loading must be transported to other farms (or stocking rates must be reduced – see Method 13).

NB From 19 December 2006, the organic manure N limit for tillage land within these NVZs will be reduced to 170 kg total N/ha.

Rationale: Where there is a surplus of nutrients, farm manures can be exported to neighbouring farmland. As a result, farms are able to balance the input of nutrients with the capacity of land to absorb those nutrients. Current regulations concentrate on N, but it is possible to introduce limits on P loading as well.

Mechanism of action: Nutrients are removed and exported to neighbouring farmland. This reduces the nutrient load on the farm that has an excess of organic manure, thereby reducing the risk of diffuse pollution. The export of manure also enables the remaining manure to be managed in a more integrated way. There is less pressure to spread manures during high risk periods and in some cases it may also be possible to delay spreading until crops require the nutrients (e.g. pig slurry application on winter wheat and oilseed rape in spring or farmyard manure ahead of maize).

Potential for applying the method: The method is applicable to the intensive grassland, indoor pig and poultry sectors. In 1996, an estimated 40% of poultry manures, 15% of pig manures and 2% of cattle manures were exported from the unit of production.

Practicability: The method is reasonably easy to implement and enforce since it is based on livestock numbers and recordable vehicle movements. The method is most easily applied where receiving farm holdings are in close proximity (e.g. within 5-20 km) The receiving farms must have the land capacity to absorb the transported organic N (and P) load, and if transport takes place during NVZ Action Programme 'closed periods' they must have sufficient storage.

Cost: .See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Transport 5 km £/ha	n/a	87.0	14.0	14.8	77.5	n/a
Transport 5 km £/farm	"	13,050	1,400	6,470	5,500	"
Transport 20 km £/ha	"	180.5	29.0	30.7	160.7	"
Transport 20 km £/farm	"	27,070	2,900	13,420	11,410	"

Effectiveness:

N: Arable (indoor pigs and poultry): reduction of 15-25 kg/ha on clay or 35 kg N/ha saving on sand, averaged over the farm area. Grassland: reduction of 5 kg N/ha per year.

P: There is no direct equivalent in PE0203 but PE0203 Method 23 'Rate of application - manure' was used as a basis for estimating the effectiveness. An expert weighting was then applied to the figure produced in PE0203. As a result, this method is estimated to reduce the manure component of P baseline losses by 50% on both sandy loam and clay loam soil types.

FIOs: The rating reflects that some manure may still remain on the farm and outdoor livestock remain as a source of FIOs in fields.

Estimates of effectiveness at the farm-scale assume that 50% of manure/slurry will be exported to a distance of 5 km or 20 km and that the whole farm is affected for those model farm systems that produce manure.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	n/a (51)	n/a (47)	n/a (0.3)	n/a (2.3)	n/a (0)	n/a (0)
Arable + manure	n/a (57)	n/a (51)	n/a (0.4)	n/a (2.5)	n/a (1)	n/a (1)
Dairy	6 (61)	3 (34)	0.10 (0.2)	1.16 (2.8)	20 (36)	20 (100)
Beef	2 (18)	1 (12)	0.07 (0.2)	0.41 (1.0)	0 (15)	0 (43)
Broilers	16 (82)	11 (68)	0.04 (0.4)	0.45 (3.2)	0 (0)	0 (0)
Indoor pigs	20 (89)	14 (74)	0.06 (0.5)	0.71 (3.7)	50 (4)	50 (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: There is some potential for odour emissions associated with the transport of manure and increased concerns about biosecurity.

38. Incinerate poultry litter

Description: Transport poultry litter to an incinerator where it is burnt.

Rationale: The manure and the N, P and FIOs it contains are removed from the farm and eliminated as a source of diffuse pollution.

Mechanism of action: Removing the manure from the farm removes the source of pollution. The manure is reduced to a much smaller quantity of ash, which is generally returned to other farmland as a P and K fertiliser where there is a requirement for these nutrients. Although FIOs are destroyed by incineration, these organisms are not normally of concern where poultry manure is applied to farmland as the usual practice is to stack the manure in the field for several months before spreading. This allows sufficient time for most FIOs to die off during the storage period.

Potential for applying the method: The method is only applicable to poultry litter and some dry layer manures. The moisture content of straw-based farmyard manures is too high for incineration.

Practicability: Applicability of the method will be limited by the availability of suitable incineration facilities within an acceptable distance of broiler and turkey farms.

Cost: See Appendix II for the assumptions used to estimate costs.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha	n/a	n/a	n/a	0	n/a	n/a
Cost £/farm	"	"	"	0	"	"

Effectiveness:

N: Most of the poultry litter on the model broiler farm is applied in autumn and early winter. Elimination of this N input is responsible for most of the reduction in N losses.

P: There is no equivalent method in PE0203. The effectiveness of the method was estimated by assuming that removing all broiler manure from the farm reduced the manure component of the baseline P loss by 90%. There will be additional savings in the longer term as the method will gradually reduce soil P contents, which will reduce losses of P attached to soil particles and by leaching.

FIOs: Unaffected by the method – because most FIOs will have already died off before spreading.

Estimates of effectiveness at the farm-scale assume that almost all poultry manure is removed from the Broiler system and that the whole of the farm area is affected.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	n/a (51)	n/a (47)	n/a (0.3)	n/a (2.3)	n/a (0)	n/a (0)
Arable + manure	n/a (57)	n/a (51)	n/a (0.4)	n/a (2.5)	n/a (1)	n/a (1)
Dairy	n/a (61)	n/a (34)	n/a (0.2)	n/a (2.8)	n/a (36)	n/a (100)
Beef	n/a (18)	n/a (12)	n/a (0.2)	n/a (1.0)	n/a (15)	n/a (43)
Broilers	32 (82)	22 (68)	0.08 (0.4)	0.89 (3.2)	0 (0)	0 (0)
Indoor pigs	n/a (89)	n/a (74)	n/a (0.5)	n/a (3.7)	n/a (4)	n/a (10)
Outdoor pigs	n/a (108)		n/a (10.5)		n/a (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: When incinerated, the N content of the manure is lost to the atmosphere but mostly as harmless dinitrogen gas. Compared with land spreading, there are reductions in emissions of ammonia and nitrous oxide but a small increase in carbon dioxide emissions.

39. Fence off rivers and streams from livestock

Description: Erect stock-proof fences in grazing fields and on trackways adjoining stream and rivers.

Rationale: Trampling by livestock can erode banks and increase inputs of sediment 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 stream and river 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 P into the watercourse. Livestock also add N, P and FIOs by defecating and urinating directly into the water. Fencing to prevent access to the banks eliminates this source of pollution. Because of the importance of surface flows in transporting P and FIOs, this method has a greater impact on losses of these pollutants than for nitrate.

Potential for applying the method: The method is applicable to farms with grazing livestock and to all soil types. Benefits will be greatest on intensively stocked farms, particularly those with cattle. The method is not applicable to outdoor pigs as these are more securely fenced and do not have access to streams or rivers.

Practicability: The method may be less feasible on some upland beef/sheep farms with extensive areas of rough grazing and considerable lengths of unfenced stream banks. Fortunately, pollutant inputs to these streams are likely to be smaller than on more intensively stocked farms. There may also be a need to provide an alternative source of drinking water.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	11,520	7,680	n/a	n/a	n/a
Annual cost £/ha	"	11	11	"	"	"
Annual cost £/farm	"	1,650	1,100	"	"	"

Effectiveness:

N: 0-1 kg N/ha reduction, averaged over the farm area. The estimate of effectiveness assumes that 5% of the N excreted by the animals is deposited in the water.

P: There is no directly equivalent method in PE0203 but Method 24 'Restrict livestock access in marginal places/times' as applied to dairy cattle was used as a basis for estimating the effectiveness. After applying an expert weighting, the method is estimated to reduce the soil and manure components of the baseline P loss from the dairy and beef systems by 50%. However, it is assumed that stream bank erosion affects only 5% of the farm area.

FIOs: 10% reduction.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	0.5	(61)	0.5	(34)	0.01	(0.2)	0.06	(2.8)	10	(36)	10	(100)
Beef	0.2	(18)	0.2	(12)	0.00	(0.2)	0.02	(1.0)	10	(15)	10	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Other benefits or risk of pollution swapping: The method will also reduce water pollution risks from ammonium-N, suspended sediment and enhanced levels of BOD.

40. Construct bridges for livestock crossings of rivers and streams

Description: Construct bridges to allow livestock 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 the watercourse. 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 poaching on either side of the fording position and stir up sediment on the stream/river bed. This will increase the transport of sediment and attached P downstream. This will be less of a problem where there is a coarse, stony river bed but even here, livestock may defecate and urinate directly into the watercourse, providing a direct input of N, P 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: The method is applicable to livestock farms where there are stream crossings without bridges. It is particularly applicable to dairy farms where cows are typically moved between the fields and dairy twice a day. This method will only be effective when combined with Method 39, to fence off other areas of river and stream bank from livestock.

Practicability: There are few circumstances that would limit the adoption of this method. It may be impractical on some upland farms with extensive areas of rough grazing and many streams and crossing points.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	6,800	6,800	n/a	n/a	n/a
Annual cost £/ha	"	6.5	9.7	"	"	"
Annual cost £/farm	"	970	970	"	"	"

Effectiveness:

N: 0-1 kg N/ha reduction, averaged over the farm area. The estimate of effectiveness assumes that 2.5% of N excreted by the animals is deposited in the water.

P: There is no directly equivalent method but PE0203 Method 24 ‘Restrict livestock access in marginal places/times’ as applied to dairy cattle was used as a basis for estimating effectiveness. After applying an expert weighting, the current method was estimated to reduce the soil component of the P baseline loss by 50% and the manure component by 1%. However, it is assumed that only 1% of the dairy farm area and a negligible proportion of the beef farm are affected.

FIOs: 10% reduction.

Farm type	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				Total P (kg P/ha)				FIOs (%)*			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	n/a	(47)	n/a	(0.3)	n/a	(2.3)	n/a	(0)	n/a	(0)
Arable + manure	n/a	(57)	n/a	(51)	n/a	(0.4)	n/a	(2.5)	n/a	(1)	n/a	(1)
Dairy	0.5	(61)	1.0	(34)	0.00	(0.2)	0.00	(2.8)	0	(36)	0	(100)
Beef	0.2	(18)	0.2	(12)	0.00	(0.2)	0.00	(1.0)	0	(15)	0	(43)
Broilers	n/a	(82)	n/a	(68)	n/a	(0.4)	n/a	(3.2)	n/a	(0)	n/a	(0)
Indoor pigs	n/a	(89)	n/a	(74)	n/a	(0.5)	n/a	(3.7)	n/a	(4)	n/a	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Other benefits or risk of pollution swapping: The method will also reduce water pollution risks from ammonium-N, suspended sediment and enhanced levels of BOD.

41. Re-site gateways away from high-risk areas

Description: Move gateways located in high-risk 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 loss of P associated with sediment losses and of FIOs from grass fields, by reducing hydrological connectivity. There would be minimal effect on nitrate losses.

Mechanism of action: A gateway at the bottom of a slope provides a break in the hedge bank, which might otherwise retain surface run-off within the field. In addition to the poaching and compaction that occurs around gateways, ruts from tractor wheelings and animal pathways tend to converge on these points and can channel surface water to these positions. Re-siting gateways away from the lower boundary of fields lessens the risk of surface water transporting sediment, associated P and FIOs out of sloping fields. Similarly, moving gateways away from watercourses lessens the risk of pollutants being transported directly from these disturbed areas into the water. This could also greatly reduce sediment and nutrient losses from sloping fields onto adjacent roads.

Potential for applying the method: This method is potentially applicable to all farming systems in sloping 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 could improve opportunities for access then it may be seen as being advantageous, particularly in wet years. Practicability will be reduced where new tracks have to be constructed in addition to the new gateways. Re-siting gateways is compatible with the Environmental Stewardship Scheme and there are no conflicts with other methods.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	2,850	1,425	950	4,275	2,140	715
Annual cost £/ha	1.35	1.35	1.35	1.40	4.30	4.20
Annual cost £/farm	405	200	135	607	304	100

Effectiveness:

N: Nil effect.

P: PE0203 Method 36 ‘Move gateways’ was used, as applied to the all-arable and grassland scenarios. From this, it was estimated that all components of the baseline P loss would be reduced by 7.5%.

FIOs: The method may possibly reduce losses in circumstances where livestock congregate around gateways but in the absence of any quantitative data, it has been assumed that the effect is negligible.

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	0 (51)	0 (47)	0.01 (0.3)	0.06 (2.3)	0 (0)	0 (0)
Arable + manure	0 (57)	0 (51)	0.01 (0.4)	0.06 (2.5)	0 (1)	0 (1)
Dairy	0 (61)	0 (34)	0.01 (0.2)	0.07 (2.8)	0 (36)	0 (100)
Beef	0 (18)	0 (12)	0.00 (0.2)	0.03 (1.0)	0 (15)	0 (43)
Broilers	0 (82)	0 (68)	0.01 (0.4)	0.08 (3.2)	0 (0)	0 (0)
Indoor pigs	0 (89)	0 (74)	0.01 (0.5)	0.09 (3.7)	0 (4)	0 (10)
Outdoor pigs	0 (108)		0.82 (10.5)		0 (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

The method is applicable to all of the model farm systems. Estimates of effectiveness at the farm-scale assume that one third of the fields on the farm are affected.

Other benefits or risk of pollution swapping: The method would decrease sediment losses, and to a small extent ammonium-N and BOD losses in surface run-off.

42. Establish new hedges

Description: Lay new hedges along fence lines and use them to re-create old field patterns that serve to break the hydrological connectivity of the landscape into its constituent parts.

Rationale: The expansion of farming after World War 2 up to the late 1980s led to larger field sizes and a loss of many established hedgerows as field boundaries in the UK. Increasing the number of hedgerows can help to reduce P and FIO losses by trapping sediments and lowering run-off volumes (breaking up slopes). Hedges can also help to protect soils from wind erosion.

Mechanism of action: Installing hedges reduces the slope length and can help prevent delivery of agricultural pollutants in surface water by reducing the force of surface flow. Hedges also act as 'natural' buffer strips and sediment traps. Smaller fields also enable separate parts of the landscape to be managed in different ways.

Potential for applying the method: This method is most applicable to the arable sectors where hedgerows have been removed but is potentially applicable to all farming systems. There is great potential for this method in areas with complex soil or landscape patterns, particularly on erosion susceptible sandy and silty soils.

Practicability: Planting hedges and making fields smaller will increase the time required for field operations and would be resisted by many larger arable farms. On grassland farms it may help with stock management and provide useful shelter in summer but considerable investment and time is involved in establishing the hedgerows. On most farms the laying of hedges would have to be carried out over a number of years to fit in with current farming operations. It is compatible with the Environmental Stewardship Scheme and there would be no conflicts with other methods.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Capital cost £/farm	30,000	15,000	n/a	45,000	22,500	7,500
Annual cost £/ha	25.0	25.0	"	25.0	77.5	76.3
Annual cost £/farm	7,320	3,360	"	10,980	5,490	1,830

Effectiveness:

N: Nil effect.

P: PE0203 Method 37 'Install hedges and make fields smaller' was used, as applied to the all-arable and grassland scenarios. After adjusting for the expert weighting, it was estimated that the baseline P loss would be reduced by 50% on the sandy loam soil and by 10% on the clay loam.

FIOs: No change.

The method is applicable to all but the Beef model farm system, which is assumed to already have a high proportion of fields with hedges. Estimates of effectiveness at the farm-scale assume that about one third of the farm is affected.

	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)					
Farm type	**Nitrate (kg N/ha)**		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	0 (51)	0 (47)	0.06 (0.3)	0.08 (2.3)	0 (0)	0 (0)
Arable + manure	0 (57)	0 (51)	0.06 (0.4)	0.08 (2.5)	0 (1)	0 (1)
Dairy	0 (61)	0 (34)	0.04 (0.2)	0.09 (2.8)	0 (36)	0 (100)
Beef	n/a (18)	n/a (12)	n/a (0.2)	n/a (1.0)	n/a (15)	n/a (43)
Broilers	0 (82)	0 (68)	0.07 (0.4)	0.11 (3.2)	0 (0)	0 (0)
Indoor pigs	0 (89)	0 (74)	0.08 (0.5)	0.12 (3.7)	0 (4)	0 (10)
Outdoor pigs	0 (108)		1.81 (10.5)		0 (190)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

[continued]

Other benefits or risk of pollution swapping: The method will also reduce water pollution risks from ammonium-N, suspended sediment and enhanced levels of BOD. Establishing new hedges can benefit wildlife and improve the landscape.

43. Establish riparian buffer strips

Description: Establish a vegetated and unfertilised grass/woodland buffer strip alongside watercourses.

Rationale: The grass/woodland strip will act as a 'natural' buffer feature to reduce the transfer of P and FIOs from agricultural land to water.

Mechanism of action: Riparian buffer strips can reduce pollution delivery in two ways. They distance agricultural activity from the riparian area and therefore reduce direct pollution from inorganic fertiliser and organic manure additions. They are also used to intercept overland flow from agricultural land just before it reaches the watercourse. Buffer strips can therefore act as a sediment trap, as well as helping to reduce nutrient transfers.

To control sediment pollution, riparian strips should ideally be free-draining and have a good surface porosity to intercept surface run-off. For reducing nitrate pollution, riparian strips should have wet anaerobic conditions to encourage denitrification losses of N. However, work has shown that they are largely ineffective at preventing nitrate leaching. They are also ineffective at reducing P losses from clay soils with drains as water flow *via* the drains effectively by-passes the buffer strip. Strips should be as wide as possible. The Entry Level Environmental Stewardship scheme offers options for buffer strips between 2 and 6 m in width and for 10-m borders 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, therefore they are particularly suited to low-lying and gently undulating landscapes where the topography does not concentrate the flow into channels. They are potentially applicable to all farming systems.

Practicability: Riparian strips require a certain amount of investment to establish but once established require little maintenance. Farmers may have issues related to controlling weeds from the strips but the impact is less than from in-field grass buffer strips as it is usually the less productive land that is lost. They are compatible with the Environmental Stewardship Scheme and there is no conflict with other methods.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	15,520	9,600	7,680	26,200	3,880	1,920
Annual cost £/ha	15.8	16.3	19.5	18.2	16.6	102.7
Annual cost £/farm	4,720	2,440	1,950	7,960	1,180	2,460

Effectiveness:

N: Benefit on free-draining soils will be from taking land out of production (i.e. similar to zero-N grass). Assume, as a rule of thumb, that nitrate leaching reduction is 1 kg N for each ha of field with a buffer strip (6 m wide). On soils where there is lateral water movement there may be additional N reduction by denitrification. The reduction is estimated as 1 - 5 kg N for each ha of field with a riparian strip.

P: PE0203 Method 39 'Riparian zones', as applied to all-arable and grassland, was used as a basis for estimating effectiveness. An expert weighting was then applied to the figure produced in PE0203. As a result, this method is estimated to reduce all components of the baseline P loss by 30% on the sandy loam soil. This is effective over the whole farm area. The baseline P loss is reduced by 90% on the clay loam but the benefit is restricted to the 3% of the farm area within the strip.

FIOs: 10% reduction (assuming that riparian strips on livestock farms are fenced off, otherwise they are relatively ineffective i.e. no change).

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	1.5	(51)	1.0	(47)	0.10	(0.3)	0.05	(2.3)	0	(0)	0	(0)
Arable + manure	1.5	(57)	1.0	(51)	0.11	(0.4)	0.06	(2.5)	0	(1)	0	(1)
Dairy	1.5	(61)	1.0	(34)	0.07	(0.2)	0.06	(2.8)	10	(36)	10	(100)
Beef	0.5	(18)	0.2	(12)	0.06	(0.2)	0.02	(1.0)	10	(15)	10	(43)
Broilers	2.0	(82)	1.5	(68)	0.13	(0.4)	0.07	(3.2)	0	(0)	0	(0)
Indoor pigs	2.0	(89)	2.0	(74)	0.14	(0.5)	0.08	(3.7)	10	(4)	10	(10)
Outdoor pigs	4.0	(108)			3.29	(10.5)			10	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: There may be a small risk of increased nitrous oxide losses if the buffer strip is ’wet‘, thereby encouraging denitrification of nitrate.

44. Establish and maintain artificial (constructed) wetlands

Description: Construct or establish wetlands with fences and channels that will be sufficient to capture run-off and sediment from a field or group of fields or farm hard-standings that regularly discharge run-off water and sediment.

Rationale: Constructed wetlands are used for the 'treatment' of wastewater generated from farm hard-standing areas and to intercept run-off water from a field or group of fields. They can trap sediment and through the retention of run-off, reduce N, P (soluble and particulate) and FIO loads in water exiting the wetland.

Mechanism of action: Wetlands act by intercepting pollutant delivery, 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 flowing, fresh or brackish. Constructed flow wetlands can be either surface (overland) flow or subsurface (percolation) flow systems. The subsurface flow wetland is generally a highly engineered, confined system of graded gravels and reeds, while surface flow wetlands are more similar to a natural wetland such as a marsh. The wetland may be in the form of a reed bed, bog, wet grassland, wet woodland, sedimentation pond or lake. A range of biological, physical and chemical processes occur in the wetland environment, which can reduce the nutrient and FIO concentrations in the water as it passes through the wetland.

Potential for applying the method: Wetlands can potentially be applied to all farming systems on soils with moderate to poor drainage, but are particularly applicable in the intensive livestock and arable sectors. They are not effective on free-draining soils, where drainage water moves to the groundwater. Their construction is compatible with the Environmental Stewardship Scheme and there is no conflict with other methods.

Practicability: Artificial wetlands are difficult and expensive to implement as a pollution control method. Their construction will inevitably involve the loss of some agricultural land. However, where they can be used to address a potential pollution problem they are reasonably acceptable to farmers. The outflow of water from artificial wetlands into a watercourse may require a discharge consent from the Environment Agency. There will also be a need to obtain Environment Agency approval if the wetland is being used to treat farm hard-standings run-off. Constructed, subsurface flow systems require maintenance due to deposition of sediment and organic matter that can result in some sections becoming impermeable. Current experience from wastewater treatment suggests that action is required every 5-7 years.

Cost: See Appendix II for the assumptions used to estimate costs.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	36,100	18,040	12,030	52,560	8,540	n/a
Annual cost £/ha	13.3	12.8	12.8	13.3	13.3	"
Annual cost £/farm	3,980	1,930	1,280	5,780	940	"

Effectiveness:

N: The method is not appropriate on sands. It will not stop nitrate leaving individual fields as it is a catchment-based approach. These are still experimental systems; their effectiveness may be in the range 5 - 15 kg N/ha but there is still much research to be done. See the N Cost Curve review and Fogg *et al*. (ES0132)

P: PE0203 Method 35 'Constructed wetlands/sedimentation ponds', as applied to the all-arable scenario, was used as a basis for estimating effectiveness. As a result, this method is estimated to reduce all components of the P baseline loss by 40% on clay loam soils.

FIOs: 20% reduction on clay loam soils.

The method is applicable to all model farm systems on the clay loam soil (hence it is not applicable to outdoor pigs). Estimates of effectiveness at the farm-scale assume that all fields drain to the wetland so that the reduction is achieved over the whole farm area.

[continued]

Farm type	**Reduction in pollutant loss at the farm scale** (baseline loss for the farm type is shown in parentheses)											
	Nitrate (kg N/ha)				**Total P (kg P/ha)**				**FIOs (%)***			
	sandy loam		clay loam		sandy loam		clay loam		sandy loam		clay loam	
Arable	n/a	(51)	10	(47)	n/a	(0.3)	0.92	(2.3)	n/a	(0)	0	(0)
Arable + manure	n/a	(57)	12	(51)	n/a	(0.4)	0.98	(2.5)	n/a	(1)	0	(1)
Dairy	n/a	(61)	12	(34)	n/a	(0.2)	1.12	(2.8)	n/a	(36)	20	(100)
Beef	n/a	(18)	10	(12)	n/a	(0.2)	0.42	(1.0)	n/a	(15)	20	(43)
Broilers	n/a	(82)	12	(68)	n/a	(0.4)	1.28	(3.2)	n/a	(0)	0	(0)
Indoor pigs	n/a	(89)	12	(74)	n/a	(0.5)	1.48	(3.7)	n/a	(4)	20	(10)
Outdoor pigs	n/a	(108)			n/a	(10.5)			n/a	(190)		

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentage reductions of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Wetlands can also be effective at reducing BOD, ammonium-N and sediment losses. There is likely to be a small increase in nitrous oxide emissions due to denitrification of nitrate in the wetland system. Wetlands may add to the wildlife and amenity value of the area.

APPENDIX I. DESCRIPTION OF THE MODEL FARM SYSTEMS

Farm-scale estimates of the cost and effectiveness of the mitigation methods refer to the following seven farm systems, as previously used for the Cost DP project. Effectiveness was assessed for each farm type on a sandy loam and on a clay loam soil, assuming these were located in a medium rainfall (850 mm) region. For farms on clay loam soils, some or all of the fields are assumed to have artificial drainage. Sandy loam soils are assumed to be at risk of capping, with the result that surface run-off may be greater than from corresponding farms on clay loam soil. However, where this occurs, there is less transport of suspended soil particles.

Arable System

The model arable system is defined as having an area of 300 ha of mixed combinable crops. The average field size is 8 ha. The crops receive an average ammonium nitrate fertiliser application of 165 kg N/ha and an average phosphate fertiliser application rate of 60 kg P_2O_5/ha (British Survey of Fertiliser Practice, 2003). One quarter of the farm area is under combinable spring crops, so in each field there is the opportunity to establish a cover crop in the autumn once in every four years. There is no grassland and no imported manure. For the arable farm on the clay loam soil, all fields are assumed to have artificial drainage.

Arable with manure

The arable farm with manure is 300 ha in size with the same cropping as for the arable farm without manure. It receives solid manure (FYM) which is stacked in field heaps for >3 months prior to spreading. The FYM is spread at 40 t/ha to 30 ha of land. The farm also receives pig slurry which is applied at 50 m^3/ha to 30 ha of land (there is no storage of slurry on this arable farm). FYM and slurry are both applied in the autumn. Nitrate fertiliser is applied at the RB209 (Anon, 2000) rate of 165 kg N/ha to the 240 ha of land that does not receive manure and at 140 kg/ha N on the 60 ha of land that receives manure. Phosphate fertiliser is applied at a rate of 60 kg P_2O_5/ha to the 240 ha of land that does not receive manure and at 48 kg P_2O_5/ha on the 60 ha of land that receives manure. On the clay loam soil type all the fields are assumed to be drained. Because all the manure is stored before being spread (as is common practice), it contains relatively few FIOs, which are killed off during storage. The effectiveness of methods to reduce FIO losses is therefore less on the model farm than it would be on farms that applied fresh manures.

Dairy System

The model dairy system is defined as having 150 adult dairy cows with a forage grassland area of 75 ha (2 cows per hectare). There are 120 followers on an additional forage area of 75 ha. It is an all-grass farm and does not grow any maize. Ten percent of the grassland area is re-seeded each year. The average field size is 8 ha. The animals are housed for 180 days each year, with 60% of the excreta deposited in the housing or parlour and the rest at grazing. In this farm, the cows use dairy collecting yards, feeding yards and (in winter) self-feed silage yards. Excreta deposited in the animal house, collecting yards and parlour is managed as slurry and is stored for 3 months. Slurry is stored in a circular tank 5 m tall, with a 25 m diameter (2450 m^3 capacity). All the managed slurry is spread across the grassland area.

The managed slurry is diluted in storage, so that the dry matter content is reduced from 10 to 6%. Hence, the total volume of slurry is 5,040 tonnes. The total available N content of the managed slurry at the time of application (after accounting for volatilisation losses) is 4,760 kg N and of the directly voided applications at grazing, 4,740 kg N. Dirty water is collected in a separate store and is spread on 10% of the farm area. No significant amounts of solid manure are produced.

The total N content of all the excreta is 25,200 kg N annually. Given a maximum across-farm NVZ application rate for grassland of 250 kg total N/ha, this N can all be accommodated within the given farm area. Manure applications to individual fields within NVZs are permitted to supply up to 250 kg total N/ha. Approximately 85% of fields receive one application of 30 t/ha stored slurry and 25% of fields receive a second application at 30 t/ha. This accounts for all of the slurry produced on the farm. Around 85% of the slurry is applied in the winter-spring period (40% in autumn, 20% in winter and 25% in spring) and 15% is applied in the summer to silage aftermaths. The grassland area also receives an average ammonium nitrate fertiliser application of 190 kg N/ha and an average phosphate fertiliser application of 35 kg P_2O_5/ha (British Survey of Fertiliser Practice, 2003). On the clay loam soil type, two-thirds of the fields are drained.

Suckler Beef System

The beef system is defined as having a farm size of 100 ha, located in Durham/Cumbria. The average field size is 8 ha. The herd size is 80 cows, plus 140 progeny (70 calves and 70 yearlings). Of the farm area, 50 ha is assumed to be for silage making (at first cut) and 50 ha for grazing, with an overall average N fertiliser application rate of 80 kg N/ha and an average phosphate fertiliser rate of 30 kg P_2O_5/ha (British Survey of Fertiliser Practice, 2003). On the clay loam soil type one-third of the fields are drained.

The stocking rate equates to 0.8 cows/ha and 0.7 calves/ha. Cows are fed 280 kg concentrate per cow. Calving is assumed to take place in spring, with youngstock taken through two winters before being sold at 18 - 24 months. Total FYM production is 900 tonnes per year. The weight reduces during storage so that around 550 tonnes are available for spreading. This is applied at a rate of 25 t/ha on 22 ha of land. All the FYM is stored for 3 months prior to spreading in field heaps and is surface spread to grassland. Around 40% of the FYM is applied in autumn (August-October), 25% in winter (November-January), 25% in spring (February-April) and 10% in summer (May-July). On this farm, the adult cows and yearlings have access to concrete yards for feeding in winter. It is assumed that all excreta are produced as straw-based manure and no significant quantities of slurry are generated. Because all the manure is stored before being spread, it contains relatively few FIOs (which are killed off during storage) and the effectiveness of methods to reduce FIO losses is therefore less on the model beef farm than it would be on farms that applied fresh manures.

Broiler System

The model broiler system is defined as having 150,000 bird places. The total litter-based manure production is 2,550 tonnes (Smith *et al*., 2000). The excreta are managed as solid manure (litter), which is spread to arable land adjoining the unit. This land is considered to be part of the system. The total N content of all the litter is 74,250 kg N annually. Given the maximum across-farm NVZ loading rate of 170 kg N/ha, the required arable field area is 437 ha. Around 75% of the broiler litter is applied in autumn (August-October), 5% in winter (November-January) and 20% in spring/summer. The total available N content of the litter at the time of application (after accounting for volatilisation losses) is 19,305 kg N.

The arable land is assumed to be in conventional production, and receives an average ammonium nitrate fertiliser application of 145 kg N/ha (British Survey of Fertiliser Practice, 2003). This rate includes a reduction to take account of the nutrients supplied in the manure. The average phosphate application rate is 48 kg P_2O_5/ha, which does not take full account of the P supplied in the manure (British Survey of Fertiliser Practice, 2003). All of the litter is stored for an average of 3 months in field heaps before land application. The litter is spread at an equivalent rate of 5.7 t/ha across the whole farm. It is surface applied and incorporated into the soil after one week. Because all the manure is stored before being spread (as is common practice), it contains few FIOs, which are killed off during storage. The effectiveness of methods to reduce FIO losses is therefore less on the model broiler farm than it would be on farms that applied fresh manures. On the clay loam soil type all the fields are drained.

Breeding Pig (Indoor) System

The model breeding pig (indoor) system is defined as having 290 dry sows (120 kg liveweight), 60 farrowing sows (200 kg liveweight), 585 first stage weaners (10 kg liveweight) and 565 second stage weaners (10 kg liveweight) places. The total undiluted excreta production is 2,125 tonnes annually (Smith et al., 2000). The excreta are managed as slurry, with slatted floors in the pig houses. Slurry is stored in a circular tank, 5 m deep by 15 m diameter (880 m^3), providing 3 months storage capacity. During storage the excreta is diluted with rain and wash water from the buildings, resulting in a slurry volume of 3000 m^3 and a dry matter content of 4%.

The total N content of slurry at land spreading is 11,986 kg N annually. The slurry is spread to arable land adjoining the unit, which is considered to be part of the unit. Slurry is surface applied at the rate of 42 m^3/ha in autumn/spring, supplying 170 kg/ha total N. Given the maximum across-farm NVZ loading rate of 170 kg N/ha, the arable field area required is 70.5 ha. Around 50% of the slurry is applied in autumn (August-October), 15% in winter (November-January) and 35% in spring/summer. The arable land is assumed to be in conventional production and receives an average ammonium nitrate fertiliser application of 145 kg N/ha, including a reduction to take account of the manure contribution (British Survey of Fertiliser Practice, 2003). The average phosphate application rate is 48 kg P_2O_5/ha, as not all of the P in the pig slurry is taken into account (British Survey of Fertiliser Practice, 2003). It is assumed that 100% of the slurry is stored for an average of 3 months. No significant quantities of FYM are generated. On the clay loam soil type all the fields are drained.

The total available N content of the slurry at the time of application (after accounting for volatilisation losses) is 5,322 kg N. Cropping is the same as for the arable farm. Because all the manure is stored before being spread, it contains relatively few FIOs (which are killed off during storage) and the effectiveness of methods to reduce FIO losses is therefore less on the model pig farm than it would be on farms that applied fresh manures.

Breeding Pig (Outdoor) System

The model breeding pig (outdoor) farm is defined according to Defra project NT2010 (Appendix 10). The farm has places for 500 dry sows, 92 farrowing sows, and 1,944 first stage weaners. The annual excreta production is 3,568 tonnes with a total N content of 20,090 kg N (Smith *et al*., 2000).

The sows occupy an area of 24 ha and are assumed to deposit excreta across the whole of the free range dunging area (25 sows per ha). The weaners occupy an area of 0.1 ha (40 weaners per kennel plot of 23 m^2). The quantity of excreta cleared from the kennels is negligible overall. There is no collection or storage of manure. The total available N, allowing for volatilisation, is 11,330 kg N annually. There are no harvested crops on the unit and no fertiliser is applied. The main input of nutrients is in the feed given to the pigs.

APPENDIX II. ASSUMPTIONS USED IN DERIVING ESTIMATES OF COSTS

The calculations of costs below are based on the typical farm types described in Appendix I. The typical arable farm has only combinable crops, so any effects on root crops are not costed, but are referred to where necessary. Costs per hectare are for the whole farm, not the area affected by the method. For example, cultivating compacted tillage soils will affect 20% of the farm at a cost per hectare treated of £20/ha, but the cost over the whole farm will be £4/ha. Where capital costs are shown, the annual costs will have this amount included as an amortised cost.

Land use

1. Convert arable land to extensive grassland

This method applies to the typical arable farm and would mean a complete change of farming style. Some farmers may choose to use the grassland for livestock production, but many would, if given the option through an annual payment, choose to manage the grassland in an environmentally appropriate manner, such as cutting once every five years to allow indigenous wild flowers to seed, for example.

Two options have been costed, the first is where land is left to regenerate following harvest with no cultivation and no grass seeding, which is topped one year in five. The second is where a ‘Countryside Stewardship’ type of mixture of grass seed is broadcast after harvest to establish an open sward and extensively grazed at one livestock unit per hectare.

The first is the simplest option, since it will only require an annual payment for loss of income. The farm machinery may be sold if this were a permanent change, leaving only a light tractor and topper for grassland management. Alternatively, the machinery could be used for contracting work. For this reason, the capital value of the machinery has not been taken into account in this option.

For farms where livestock production would be taken up, many other factors apply. Most arable farms have general purpose buildings which can be used to store machinery or to house livestock. It has been assumed that this is the case here. The farmer will be changing from cropping to livestock, which need daily, year-round care, sometimes at unsocial hours, e.g. calving cows and lambing sheep. This will produce a fall in gross margin of £140/ha net of rent changes.

The proceeds from any farm machinery sales would be used for part funding of livestock purchasing. On this size of farm, with a stocking rate of 1 Livestock Unit/hectare (LSU/ha), 120 beef cows and two bulls along with 800 ewes and rams would require capital input. Livestock depreciation has been included at 25%. This would equate to an additional cost of £15,125 per annum or £50/ha/year. Fencing and gates, including some for the buildings will be required, since many arable farms are not stockproof. The calculation assumes 36 equal sized fields of approximately 8.3 ha, this would cost some £42,360 for new fencing. Assuming a wire fence, a rounded figure of £43,000 has been used, giving an annual amortised cost of £6,100/year. If hedges were preferred, this would cost an additional £9/m or an annual amortised cost of £18,200/year. Assuming water will be required, this will be at an additional cost of £3,650, giving an annual amortised cost of £630/year.

There may also be issues of redundancy and accommodation if any farm workers were involved and landlord’s income for let farms from the lower rental value of an extensive grassland farm. There are also problems with the viability of this method in terms of the demand for beef and sheep meat and how this additional production could disrupt the home and export markets. Clearly, if this method were taken up over a large area, there may be issues for fencing supplies, for example. However, as an economic exercise and assuming rents at current levels, there would be a major cost in terms of lost output of a beef and sheep system, compared with arable, together with additional depreciation.

(a) No livestock purchased

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital outlay	0	n/a	n/a	n/a	n/a	n/a
Loss of net output £/ha pa	90	“	“	“	“	“
Cost (topping 1year in 5) £/ha	5	“	“	“	“	“
Loss of output £/farm pa	26,940	“	“	“	“	“
Cost (topping 1year in 5) £/farm	1,500	“	“	“	“	“

(b) Replace arable with livestock – beef & sheep (at 1 LSU/ha)

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Initial capital outlay						
Livestock £/farm (net)	60,500	n/a	n/a	n/a	n/a	n/a
Fencing £/farm	43,000	"	"	"	"	"
Hedges £/farm	128,000	"	"	"	"	"
Water £/farm	3,650	"	"	"	"	"
Establish grassland £/farm	29,850	"	"	"	"	"
Total	265,000					
Livestock£/ha	200	"	"	"	"	"
Fencing £/ha	145	"	"	"	"	"
Hedges £/ha	430	"	"	"	"	"
Water £/ha	12	"	"	"	"	"
Establish grassland £/ha	100	"	"	"	"	"
Total	890					
Annual costs						
Loss of output £/farm	27,240	n/a	n/a	n/a	n/a	n/a
Fencing £/farm	6,100	"	"	"	"	"
Hedging £/farm	18,175	"	"	"	"	"
Water £/farm	890	"	"	"	"	"
Grassland £/farm	5,970	"	"	"	"	"
Total £/farm	58,375					
Loss of output £/ha	91	n/a	n/a	n/a	n/a	n/a
Fencing £/ha	20	"	"	"	"	"
Hedging £/ha	61	"	"	"	"	"
Water £/ha	3	"	"	"	"	"
Grassland £/ha	20	"	"	"	"	"
Total £/ha	195					

Soil management

2. Establish cover crops in the autumn

In most combinable crop fields, there will be good ground cover of volunteer plants and weeds following harvest if left uncultivated. In this case, the root balls of the harvested crop plants will hold the soil together well. In these cases, a light spring tine harrowing may be all that is necessary to assist re-growth and ground cover at a cost of £10/ha/year, perhaps over 25% of the (300 ha) farm, at a cost of £750/farm/year.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha cereals etc.	2.5	n/a	n/a	2.5	2.5	n/a
Cost £/ha other crops	17.0	"	"	17.0	17.0	"
Cost £/farm cereals etc	750	"	"	1,100	180	"
Cost £/farm other crops	5,070	"	"	7,400	1,200	"

In other crops, ground cover may be poor due to the lack of re-growth and the time of year of the harvest operation. Cultivation costs would be applicable after the main cultivation of the field. These would be some £17.50/ha plus £50/ha average cost for the seed, a total of £67.50/ha, perhaps for 25% of the (300 ha) farm, hence £5,070/farm/year.

3. Cultivate land for crop establishment in spring rather than autumn

Sugar beet and potatoes are less likely to suffer from changes to cultivation times since they are planted later in the spring to avoid bolting in sugar beet and ‘little potato’ and ‘coiled sprout’ disease in potatoes due to cold conditions. These crops are not part of the rotation of the defined arable farm system but here there may be soil damage from carrying out deep cultivations in spring if conditions are cold and wet, which may result in poorer than average yields.

For spring cereals and combinable breaks, losses will vary with soil type and the weather, where a 25% yield penalty may be quite common. The costs shown below represent the effect on the typical arable farms. Changing the cultivation time to spring will miss the benefit of frost action breaking down soil clods, hence requiring an additional cultivation at a cost of £25/ha. The following assumes that 10% (30 ha) of the arable farm will be planted with spring combinable crops.

The method could potentially be applied to the 10% of grassland on the typical dairy farm that is ploughed and re-sown annually However, only part of this area is likely to be reseeded in autumn and this has been ignored in these assessments. The beef farm is mainly extensive grassland, which is not reseeded at regular intervals.

Annual costs for farm system at 25% yield loss for all crops	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Spring combinable crop £/ha	11	n/a	n/a	11	11	n/a
Spring combinable crop £/farm	3,190	"	"	4,650	755	"

4. Adopt minimal cultivation systems
Many farmers currently use a plough system for crop establishment, costing around £100/ha. Most would not be able to carry the costs of two cultivation systems and in switching to a minimal cultivation system, a contractor would be the only option. This would be at a cost of £50/ha, saving £50/ha. However, many would keep the option of ploughing, incurring an annual cost of some £10/ha, thus the total saving of adopting minimal cultivation systems would be £40/ha.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Likely net **savings** £/ha	40	n/a	n/a	40	40	n/a
Range of +/- 25% £/ha	30 – 50	"	"	30 – 50	30 – 50	"
Range of savings £/farm	9,000 – 15,000	"	"	13,110 – 21,850	2,130 – 3,550	"

5. Cultivate compacted tillage soils
Light surface cultivation to avoid soil erosion costs £20/ha over 20% of the farm, that is 60 ha for the arable system, a total of £1,200 per year.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha	4	n/a	n/a	4	4	n/a
Cost £/farm	1,200	"	"	1,750	285	"

6. Cultivate and drill across the slope
The additional time required will depend on the size and configuration of the field, adding to the time taken, but if more sophisticated techniques, such as a hillside combine, were to be used, the cost would be higher. The cost of the method is estimated as £10/ha to be applied to 30% of the farm.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha	3	n/a	n/a	3	3	n/a
Cost £/farm	900	"	"	1,310	215	"

7. Leave autumn seedbeds rough
The cost may be zero, but could possibly be up to £80/ha if yield losses and increased costs from slug and weed control occurred, so an average of £40/ha would be appropriate. Note that this figure is for 20% of the farm. Some areas of fields may be severely affected but others may be unaffected, since slugs and weeds (especially black-grass) tend to be in greatest numbers on headlands. In this way, whilst there may be high losses on headlands, they will average out at a far lower level across the whole farm.

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha	40	n/a	n/a	40	40	n/a
Cost £/farm	2,400	"	"	3,500	570	"

8. Avoid tramlines over winter
Spraying out tramlines in spring would require marking out and adjustments to the sprayer to treat only selected rows. This would be more time consuming and costly than conventional spraying. Assuming 20% of the farm is affected, the total cost to the typical arable farm would be £1,350 per annum.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	4.5	n/a	n/a	4.5	4.5	n/a
Cost £/farm	1,350	"	"	1,970	320	"

9. Establish in-field grass buffer strips
It has been assumed that 10% of the farm area will be put into buffer strips. Establishment will follow that of buffer strips in the Entry Level Stewardship scheme. This involves establishment if possible using natural regeneration and a light cultivation. The buffer strip will be topped once in five years to control woody growth. Spot treatment of scheduled weeds may be required. On the outdoor pig enterprise, there will need to be a pig-proof fence on each side of the strip, bringing additional costs.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha strip	31.6	n/a	n/a	31.6	31.6	440
Cost £/farm	9,480	"	"	13,630	2,240	10,530

10. Loosen compacted soil layers in grassland fields
For the typical dairy farm, costs are for subsoiling or flatlifting to avoid damage to grass, at £43/ha over 25% of the farm.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	10.8	10.8	n/a	n/a	n/a
Cost £/farm	"	1,620	1,080	"	"	"

11. Maintain or enhance soil organic matter levels
The cost of manure will be partly offset by the value of the nutrients applied. A further area of cost may be in surface compaction, which may be relevant depending on the timing and field conditions of the application. Amounts applied are as specified in the farm description in Appendix I – NB these will include both types of manure shown below at two distances. It is assumed that composts and biosolids are generally supplied free of charge.

Transport distance	Transport cost £/t	Stock class	Value of manure £/t	Net cost £/t	Tonnes applied/ha	Tonnes applied/yr	Net cost £ pa
5km	5.2	Cattle FYM	1.7	3.5	40	1,200	4,200
"	"	Pig slurry	2.0	3.2	50	1,500	4,800
10km	9.8	Cattle FYM	1.7	8.1	40	1,200	9,720
"	"	Pig slurry	2.0	7.8	50	1,500	11,700

Distance transported & class of stock	Arable Application to 60 ha Cost (£/farm)	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
5 km: cattle FYM	4,200	n/a	n/a	n/a	n/a	n/a
5 km: pig slurry	4,800	"	"	"	"	"
10 km: cattle FYM	9,720	"	"	"	"	"
10 km: pig slurry	11,700	"	"	"	"	"

12. Allow field drainage systems to deteriorate
Yield losses may be little or none on some soils. On other soils, the output will gradually deteriorate over the years to the point at which arable cropping is not economic because timely field operations are no longer possible. This time scale will vary from perhaps ten years to decades. In grassland, any loss of crop would be made up by purchasing sufficient bulk feed to replace lost grass production, which for beef has been taken as half the loss in dairy.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
£/ha						
Loss of output 0.5% yr 1	2.5	0.5	0.3	2.5	2.5	n/a
Loss of output 1.0% yr 2	5.0	1.0	0.5	5.0	5.0	n/a
Loss of output 1.5% yr 3	7.0	1.5	0.8	7.0	7.0	n/a
Loss of output 2.0% yr 4	10.0	2.0	1.0	10.0	10.0	n/a
Loss of output 2.5% yr 5	12.0	2.5	1.3	12.0	12.0	n/a
Loss of output 4.0% yr 6	20.0	4.0	2.0	20.0	20.0	n/a
Loss of output 5.5% yr 7	27.0	5.5	2.8	27.0	27.0	n/a
Loss of output 7.0% yr 8	34.0	7.0	3.5	34.0	34.0	n/a
Loss of output 8.5% yr 9	42.0	8.5	4.3	42.0	42.0	n/a
Loss of output 10% yr 10	49.0	10.0	5.0	49.0	49.0	n/a
£/farm						
Loss of output 0.5% yr 1	740	75	25	1,070	175	n/a
Loss of output 1.0% yr 2	1,470	150	50	2,150	350	n/a
Loss of output 1.5% yr 3	2,210	225	75	3,220	520	n/a
Loss of output 2.0% yr 4	2,950	300	100	4,290	700	n/a
Loss of output 2.5% yr 5	3,680	375	125	5,360	870	n/a
Loss of output 4.0% yr 6	5,890	600	200	8,580	1,390	n/a
Loss of output 5.5% yr 7	8,100	825	275	11,790	1,920	n/a
Loss of output 7.0% yr 8	10,300	1,050	350	15,000	2,440	n/a
Loss of output 8.5% yr 9	12,510	1,230	425	18,220	2,960	n/a
Loss of output 10% yr 10	14,720	1,500	500	21,440	3,480	n/a

Livestock management

13. Reduce overall stocking rates on livestock farms

The cost of a 50% reduction in livestock numbers on individual farms has been assumed to be a halving of gross margin on dairy, beef and outdoor pig farms. The figures are net of N fertiliser costs, which with clover are reduced to zero. No costs are given for the alternative of halving the number of livestock farms in the catchment as this would be a catchment-based rather than a farm-based approach and cannot be costed in the same way as the other methods.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	309	55	261	535	2,700
Cost £/farm	"	46,300	5,410	113,800	38,000	64,400
Addition of change to clover-based system using no fertiliser N						
Cost £/ha	n/a	274	35	n/a	n/a	n/a
Cost £/farm	"	41,000	3,510	"	"	"

14. Reduce the length of the grazing day or grazing season

For this method, it has been assumed that livestock will be fed additional forage to make up for being kept off the pasture for a total of 4 - 6 weeks, either by ending grazing early or by restricting cows to daytime grazing for the final 2 - 3 months of the grazing season. On the typical dairy farm, ending grazing early would apply to both cows and followers. It is assumed that silage will be substituted for grazed grass with no change in concentrate levels, and no effect on output of milk or growth rates in heifers. On the typical beef farm, it has been assumed that silage consumption by the suckler cows would be for maintenance, so the same amount has been used as for dairy cows. The estimated costs of daytime-only grazing and shortening the grazing season are similar but daytime-only grazing may be a cheaper option where suitable equipment is available for harvesting fresh grass to feed to the cattle when they are indoors during the growing season.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	30 - 45	25 - 40	n/a	n/a	n/a
Cost £/farm	"	4,500 - 6,750	2,500 - 4,000	"	"	"

15. Reduce field stocking rates when soils are wet
This method is effectively the same as Method 14 in terms of cost.

16. Move feed and water troughs at regular intervals
This method allows for physical movement of round feeders for cattle, a job easily carried out by turning them on to their sides and rolling along the ground. This can be done across slopes by hand or by pulling them up the slope by a tractor and chain. Disconnecting large water troughs is not easy, so one additional trough per field has been allowed for plus 25 m additional pipework and fittings to tap into the main pipe. Moving feed troughs 6 times and alternating water troughs 12 times in the grazing season has been allowed for in dairy and beef. This is applied to 80% of the farm area for dairy and beef farms, as not all fields will be grazed.

For outdoor pigs, this method allows for small feeders to be moved by hand and for two additional small troughs per field and for moving 26 times, that is twice a month, since the pigs are out all year. In dry conditions on light land, this may not be necessary. This method is based on the farmer carrying out the work himself, there would be additional costs if contractors carried out the work.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	11.3	10.4	n/a	n/a	33.0
Cost £/farm	"	1,700	1,040	"	"	790

17. Reduce dietary N and P intakes
(a) Reducing dietary N - An average dairy cow consumes one tonne of compound over the winter feeding period plus silage, etc. A farmer would aim to reduce low quality N feed and replace it with high quality protein. This would maintain milk yield and quality whilst reducing N losses in dung and urine. This would involve switching from a standard dairy cake to a lower protein one and supplementing with soya, which would be fed at a rate of 2 kg/day for 180 days. Alternatively, where cows are being fed a diet providing more than the recommended N intake, the protein content of the diet could be reduced without a loss in production and with a possible saving in feed costs. The method is less applicable to beef systems, which are managed less-intensively.

For sows, protein levels can be reduced from birth to finishing with less than 10% fall in production, say 7.5%, provided the correct balance of amino acids is provided at little or no additional cost.

For broilers, there appears to be less scope to reduce protein intake and output reductions are greater, e.g. a 4% reduction in crude protein resulted in a fall in output of 8.73%. Gross margins per broiler are very small but numbers of birds are large. However, greater reductions in protein in rations are likely to produce larger falls in output and because of the high numbers of birds, this would multiply up to a high figure.

(b) Reducing dietary P - For dairy cows, relatively high phosphate levels have been seen as attractive to avoid reproductive or other health problems and there would be no cost to reducing additions, provided the cows were fed sufficient P; the method has therefore a zero cost.

For non-ruminants, phytase addition to rations has been an increasing option in recent years. The rate of inclusion varies depending on the manufacturer of the phytase and feed and the ingredients used. A common product is Natuphos, produced by BASF. The inclusion rate of Natuphos by BOCM Paul's is 100 g/tonne of feed for pig rations and broilers (table fowls) and 80 g/tonne for layers at a cost of £1 to £0.80/tonne. This cost is offset by lowering the dichlorophosphate use by 1.15 kg/tonne of feed produced. This small cost is insignificant compared with the variation in the bulk ingredients in the ration and most products are re-formulated approximately monthly as market conditions change. Therefore, a zero cost has been applied to the use of phytase.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/head	n/a	42.5	n/a	0.008	17.5	17.5
Cost £/farm	"	6,380	"	7,920	6,130	10,360

18. Adopt phase feeding of livestock
This can be a difficult move when farm buildings do not allow separate rations to be provided, such as in auger feeding systems where a row of pens or buildings is fed by one pipe. For dairy cows, it is easy to solve this by using transponders and in-parlour feeders. This has been costed for 150 cows.

Youngstock will be reared in separate groups requiring no change. For indoor sows, the same method as dairy cows can be used (costed for 350 sows). Clearly, there will be some savings in feed costs, say 5%. Costs are given for outdoor sows but in practice this system has been tried and abandoned.

In deriving the costs for dairy cows and indoor breeding sows, the equipment has been amortised at a rate of 7% over 5 years and the feed savings have been taken into account. The result is a small net cost per ha in both cases, provided feed savings were made, but at the cost of a large capital outlay.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	16.30	n/a	n/a	24.15	121
Cost £/farm	"	2,440	"	"	1,720	2,900

Fertiliser management

19. Use a fertiliser recommendation system
In terms of cost, this method will be a management issue, costed at £2/ha, but there may be savings in fertiliser, which would produce a net benefit.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	2	2	2	2	2	n/a
Cost £/farm	600	300	200	875	150	"

NB The Environment Agency booklet, *Best Farming Practices: Profiting from a Good Environment*, provides a more favourable assessment than do our costs. It assumes much greater savings in P and K fertiliser. British Survey of Fertiliser Practice statistics show that P and K use has declined in recent years and our assumption is that savings in fertiliser have largely been made in our baseline farms. Also, the Environment Agency example is one particular case, whereas the aim of this manual is to represent the ‘typical’ case.

20. Integrate fertiliser and manure nutrient supply
This method will save money in artificial fertiliser nutrients not applied. The table shows the savings associated with slurry/manure from winter storage, which can be spread evenly, but savings from dung and urine deposited during grazing have not been included.

Annual costs for farm system	Arable 60 ha treated	Dairy 33 ha treated	Beef 18 ha treated	Broilers	Pigs (indoor)	Pigs (outdoor)
Saving £/ha	6	12	6	32	23	n/a
Saving £/farm	1,800	1,800	600	14,000	1,600	"

21. Reduce fertiliser application rates
The reductions refer to rotational reductions of 10%, 20% and 50% of N use and 2%, 5% and 15% of gross output, respectively. Reductions in P fertiliser were not expected to reduce grass yields so the method achieved a cost saving on the dairy and beef farms. Nominal losses were assumed for the arable farms associated with the Breeding pigs (indoor) and the Broiler farm types due to the N input from manure.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Reduction in N 10% £/ha	1.80	31.1	16.8	<1	<1	n/a
Reduction in N 20% £/ha	5.30	61.4	34.4	6	6	"
Reduction in N 50% £/ha	28.75	166.7	87.2	10	10	"
Reduction in N 10% £/farm	550	4,665	1,680	<500	<100	"
Reduction in N 20% £/farm	1,585	9,210	3,440	2,620	425	"
Reduction in N 50% £/farm	8,625	25,000	8,720	4,370	710	"
Reduction in P 10% £/ha	1.2	-1	-1	n/a	n/a	"
Reduction in P 20% £/ha	2.30	-2	-2	"	"	"
Reduction in P 50% £/ha	5.73	-5	-5	"	"	"
Reduction in P 10% £/farm	355	-150	-100	"	"	"
Reduction in P 20% £/farm	690	-300	-200	"	"	"
Reduction in P 50% £/farm	1,720	-750	-500	"	"	"

22. Do not apply P fertilisers to high P index soils
Assuming 10% of the farm area has high P index soils, which misses a maintenance dressing of P.fertiliser, the method will bring cost savings to farmers in terms of P not applied (net of soil testing costs). There may be savings from possible field operations not carried out in applying it (if planned as a separate operation).

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Saving £/ha	1	1	1	n/a	n/a	n/a
Saving £/farm	300	150	100	"	"	"

23. Do not apply fertiliser to high-risk areas
Some extensive grassland systems do not have fertiliser applied and still produce good levels of grass. The cost would be in terms of avoiding a drop in production proportional to the lost grass. However, not applying fertiliser, especially N fertiliser, to areas within arable fields will result in patchy crops with unfertilised areas ripening first, often with reduced yield and poor quality grain. If it were essential to avoid fertilising these areas, they would be better sown with grass. This may have major consequences for the farm viability.

Assume that 2% of the farm is affected (i.e. 6 hectares on the arable farm). This would be left to natural regeneration, which on the arable farm would require topping every year.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Net loss £/ha	8	7	4	8	8	n/a
Net loss £/farm	2,410	1,065	380	3,510	570	"

24. Avoid spreading fertiliser to fields at high-risk times
This is a zero cost method because in most cases, the fertiliser should not be required at high risk times, since the crop will not be growing. However, there may be indirect opportunity costs if the high risk times coincide with crop development in spring. These may be zero or a higher figure; for example, if the timing of spring top dressing on arable crops or grass is not optimal and caused a 10% reduction in farm gross output. For dairy and beef farms, it has been assumed that the costs will be the same as for a 10% yield reduction in Method 12. Therefore, assume this method generally has a zero cost, but that there may be significant costs, perhaps one year in ten. This is shown in the table as an annual cost.

Occasional costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Net loss £/ha/year	49	7	4	49	49	n/a
Net loss £/farm/year	1,470	106	40	2,140	350	"

Manure management

25. Increase the capacity of farm manure stores
Typical dairy farms will require 6 months storage and it has been assumed that at present, the farm has 3 months storage for just cows. An additional 3 months (90 days) storage will require long term investment. The youngstock will generally be on straw, with the resulting manure being left in the buildings or stored in heaps in the field. For the typical beef farm, it will be straw-based, so manure will be stored in the field at no extra cost. Pig slurry is exported to an arable farm and may need a further 90 days storage. For slurry, where further storage is required, the amortised cost is £3.99/tonne slurry pa for 20 years.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	21,260	n/a	n/a	12,130	n/a
Annual cost £/ha	"	16	"	"	27	"
Annual cost £/farm	"	2,420	"	"	1,900	"

26. Minimise the volume of dirty water produced
This method would require additional fencing and gates to keep dairy cows away from some of the concrete areas. It also includes covering the slurry store. For indoor breeding pigs, there is only a

capital cost of covering the slurry store. The annual costs in the table include the amortised capital cost of the fencing and the slurry tank cover, where appropriate.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost, fencing etc. £/farm	n/a	1,000	n/a	n/a	n/a	n/a
Capital cost, slurry store cover £/farm	"	14,250	"	"	17,700	"
Annual cost, fencing etc. £/ha	"	1.65	"	"	n/a	"
Annual cost, slurry store cover £/ha	"	10.8	"	"	28.3	"
Annual cost, fencing etc. £/farm	"	245	"	"	n/a	"
Annual cost, slurry store cover £/farm	"	1,620	"	"	2,010	"

27. Adopt batch storage of slurry
For additional slurry storage, where no storage currently exists, the amortised cost is £3.99/tonne slurry pa for 20 years plus a reception pit at £1,800 capital cost. The figure for cows excludes youngstock, since they will be on straw. The figure for sows includes slurry from weaners. The annual costs in the table include the amortised capital cost.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	25,200	n/a	n/a	32,500	n/a
Annual cost £/ha	"	20.30	"	"	11.00/sow	"
Annual cost £/farm	"	3,050	"	"	3,900	"

28. Adopt batch storage of solid manure
A typical beef system, would involve leaving the solid manure in the cattle accommodation, over the summer period. (approx. 150 days). This method assumes that this is not possible, and therefore involves making a hard-standing with a drain and trap, on which to store the manure, assuming no concrete pad is used at present. For broilers, there will be two pads used twice a year for 90 days each time and it has been assumed that the manure will be spread on to 437 ha arable land. It has been assumed that the manure will be stacked 2 m deep. The annual costs in the table include the amortised capital cost.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	n/a	13,200	15,250	n/a	n/a
Annual cost £/ha	"	"	12.4	3.3	"	"
Annual cost £/farm	"	"	1,240	1,440	"	"

29. Compost solid manure
Operational costs of turning manure are £2.56/tonne. This is assuming that the manure is already being stored on a concrete pad.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	n/a	9.00	1.45	n/a	n/a
Cost £/farm	"	"	900	545	"	"

30. Change from slurry to a solid manure handling system
This is likely to be a capital intensive method, since it will require more space per animal and not all buildings lend themselves to being extended, nor farm steadings to allow additional buildings if that is the alternative. Costs have been calculated for dairy cows and indoor sows.

For dairy cows, most are housed in cubicles, which will need to be removed and the building extended, to allow for the greater area required for loose housing. Assuming this is the case, there will be a capital cost of £470/cow (Ryan, 2003) or £70,500/farm. It has been assumed that slurry handling will be by contractor and this operation will remain so when the farm transfers to a solid manure system. In addition to amortised capital costs, there are annual costs of straw at £30/tonne delivered.

For pigs, the whole of the indoor farrowing system is slurry based, which may comprise a large range of building types, some that might be altered, but most of which would not be amenable to alteration. The alternative chosen for this farm type would be to de-stock, demolish and re-build, subject to any planning issues. This would involve selling all stock including breeding stock and buying in new stock on completion of the buildings, a loss of at least six months output and a loss on selling and re-purchasing breeding stock and the purchase of a manure spreader. The annual cost £/farm shown is for the loss of one year's gross margin spread over five years. The annual costs in the table include the amortised capital cost.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	70,500	n/a	n/a	442,500	n/a
Annual cost £/ha	"	104	"	"	1,025	"
Annual cost £/farm	"	15,630	"	"	72,800	"
Cost of lost output £/farm in year 1	"	–	"	"	11,100	"

31. Site solid manure heaps away from watercourses and field drains
For the arable farm, there is assumed to be a £2/ha over 100 ha nominal management cost of changing the location of the manure heap. For the beef and broiler farm, this cost is applied over the whole farm area.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	2	n/a	2	2	n/a	n/a
Cost £/farm	200	"	200	875	"	"

32. Site solid manure heaps on concrete and collect the effluent
It has been assumed that manure will be stacked to 2 m depth and amounts have been taken from RB209. Costs are for a 150 mm concrete pad with drains and a runoff trap. The arable farm has been costed as accepting manure from livestock farms. The annual costs in the table include the amortised capital cost.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost/farm	9,800	n/a	6,860	7,630	n/a	n/a
Annual cost £/ha	3.10	"	6.45	1.65	"	"
Annual cost £/farm	920	"	645	720	"	"

33. Do not apply manure to high-risk areas
This is possibly a zero cost method if ground is available elsewhere on the farm, incurring only a £2/ha management charge. If there was a need for increased slurry storage in the dairy and pig systems, there would be additional costs, as in Method 25.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	2	2	2	2	2	n/a
Cost £/farm	600	300	200	875	140	"

34. Do not spread farmyard manure to fields at high-risk times
There is a £2/ha nominal management cost of delaying spreading. Where it becomes impossible to spread on spring crops, it can be replaced by bagged fertiliser and nutrient status can be taken into account at the next opportunity to spread.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	2	n/a	2	n/a	n/a	n/a
Cost £/farm	600	"	200	"	"	"

35. Do not spread slurry or poultry manure to fields at high-risk times
As for Method 34, this assumes a £2/ha nominal cost of delaying spreading. If there was a need for increased slurry storage in the dairy and pig systems, there would be additional costs, as in Method 25.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	2	2	n/a	2	2	n/a
Cost £/farm	600	300	"	875	140	"

36. Incorporate manure into the soil
This method is intended for the re-seeded grass area, i.e. 15 ha of the typical dairy farm. For the dairy farm, it has been assumed that the cultivation or ploughing would be an additional operation closely following application of the slurry. For the arable farms, it is assumed that manure is applied shortly before the routine cultivation and there is, therefore, no additional cultivation required. Cultivation with tines or discs would cost around £22/ha and ploughing would cost around £45/ha.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cultivator cost £/ha	0.0	2.2	n/a	0.0	0.0	n/a
Cultivator cost £/farm	0	330	"	0	0	"
Plough cost £/ha	0.0	4.5	"	0.0	0.0	"
Plough cost £/farm	0	675	"	0	0	"

37. Transport manure to neighbouring farms
The costings assume that 50% of manure/slurry will be exported to a distance of 5 km or 20 km.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Transport 5km £/ha	n/a	87.0	14.0	14.8	77.5	n/a
Transport 5km £/farm		13,050	1,400	6,470	5,500	
Transport 20 km £/ha		180.5	29.0	30.7	160.7	
Transport 20 km £/farm		27,070	2,900	13,420	11,410	

38. Incinerate poultry litter
Energy Power Resources Limited (EPRL) currently carries out this service, producing energy for the national grid. The plants are located at Thetford in Norfolk and Eye in Suffolk and account for some 420,000 tonnes and 160,000 tonnes respectively, a total of 580,000 tonnes of poultry manure/year. Currently no charge is made for collecting the litter from the farms and the ash is sold as Fibrophos, an organic fertiliser. Where poultry litter is not incinerated, it does have a commercial value. It therefore pays the poultry producer to export it and the accepting arable farmer to import it at around this level. Transport costs at 20 km make it a break-even operation, so buyers and sellers will agree prices up to this level. However, in some cases, poultry manure is transported over 70 km, which will be at a cost to the producer.

Annual costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Cost £/ha	n/a	n/a	n/a	0	n/a	n/a
Cost £/farm	"	"	"	0	"	"

Farm infrastructure

39. Fence off rivers and streams from livestock
This method has been costed for the dairy and beef farms. Assuming fields on the farms are 8 ha with sides of 250 m x 320 m and assuming the stream side is 320 m, fencing at £3/m will cost £960 for one field. If the dairy farm has 19 fields with 12 adjacent to water, the costs will be as in the table. Similarly, the beef farm is assumed to have 12 fields of which 8 are adjacent to water. The annual costs in the table include the amortised capital cost.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	11,520	7,680	n/a	n/a	n/a
Annual cost £/ha	"	11	11	"	"	"
Annual cost £/farm	"	1,650	1,100	"	"	"

40. Construct bridges for livestock crossings on rivers and streams
This method has been costed for dairy and beef farms. It has been assumed that two bridges will be needed in each case. The annual costs in the table include the amortised capital cost.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	n/a	6,800	6,800	n/a	n/a	n/a
Annual cost £/ha	"	6.5	9.7	"	"	"
Annual cost £/farm	"	970	970	"	"	"

41. Re-site gateways away from high-risk areas
Assuming a new gate will be required, the total cost plus other materials will be £237.50 per field. This applies to 6 fields on the dairy farm, 4 fields on the beef farm and the pig area has three fields. The annual costs in the table include the amortised capital cost. This method is based on the farmer carrying out the work himself - there would be additional costs if contractors were to carry out the work. Costs would be lower than those shown for the arable, broiler and indoor pig farms if the fields did not need to be stockproof and no gates were required.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	2,850	1,425	950	4,275	2,140	715
Annual cost £/ha	1.35	1.35	1.35	1.40	4.30	4.20
Annual cost £/farm	405	200	135	607	304	100

42. Establish new hedges
The costing assumes that the method will apply to dairy and arable farms, which have 8 ha fields. This has been applied to 6 out of 20 fields on the dairy farm, 12 out of 38 fields on the arable farm and to all the fields on the pig farms. Each new hedge will require fencing to prevent damage to the young hedge plants and a new gateway at an additional cost of £2500. The annual costs in the table include the amortised capital cost.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	30,000	15,000	n/a	45,000	22,500	7,500
Annual cost £/ha	25.0	25.0	"	25.0	77.5	76.3
Annual cost £/farm	7,320	3,360	"	10,980	5,490	1,830

43. Establish riparian buffer strips
This method has been costed for dairy, beef, arable and outdoor pig farms. On arable farms, it has been assumed that the crop loss will be for the average rotation and on the dairy and beef farms, it has been assumed that the crop is silage. The figures include the loss of the arable crops and silage as well as the very high figure for lost pig production. Not all fields will require riparian strips, but in many cases, there will be one each side of a watercourse on the same farm. It has been assumed that on the arable farm, there will be 16 fields with a riparian strip, 10 fields on the dairy farm, 8 on the beef farm and 2 on the outdoor pig unit. The annual costs in the table include the amortised capital cost.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	15,520	9,600	7,680	26,200	3,880	1,920
Annual cost £/ha	15.8	16.3	19.5	18.2	16.6	102.7
Annual cost £/farm	4,720	2,440	1,950	7,960	1,180	2,460

44. Establish and maintain artificial (constructed) wetlands
This method has been costed for arable, dairy, beef, indoor pigs and broiler on a *pro rata* basis per ha of the total farm area. The method has been costed for a contractor to carry out the work and includes

the cost of building the wetland, fencing and loss of output due to the area taken. The annual costs in the table include the amortised capital cost.

Costs for farm system	Arable	Dairy	Beef	Broilers	Pigs (indoor)	Pigs (outdoor)
Capital cost £/farm	36,100	18,040	12,030	52,560	8,540	n/a
Annual cost £/ha	13.3	12.8	12.8	13.3	13.3	"
Annual cost £/farm	3,980	1,930	1,280	5,780	940	"

GLOSSARY

Definitions followed by [R] are taken from Pain, B. & Menzi, H. (2003) *Glossary of terms on livestock manure management.* Recycling Agricultural, Municipal and Industrial Residues in Agriculture Network (RAMIRAN), European System of Cooperative Research Networks in Agriculture (ESCORENA), 59 pp.

AGGREGATE STABILITY	The cohesive strength of the forces binding together the 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] Volatilised from urine patches in the field, from animal houses and yards and from some N fertilisers.
AMMONIUM	NH_4^+. Positively charged ionic form of mineral N, present in soil and manures. It is not readily leached from soils because it is attracted to soil particles but can be lost in RUN-OFF 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 five. Interest rates used are based on current rates and their likely future value.
ANAEROBIC	Condition of soils, manures, etc, where there is an absence of free oxygen (usually because of waterlogging). 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	In this context, refers to the 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 dinitrogen 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.
BOD	Biochemical Oxygen Demand. A measure of the pollution potential in water bodies and organic wastes. 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^{o}C for a given number of days. [R] Surface waters with a high BOD contain high concentrations of potentially oxidisable organic matter. The natural decomposition of this organic matter utilises the dissolved oxygen in the water, leaving it without free oxygen and unable to support most forms of animal life.
BOLTING	Early flowering of a plant (e.g. cabbages, lettuce) before it develops its 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.
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 run-off 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 bare soil. This prevents infiltration of rainwater and increases RUN-OFF.
CARBON SEQUESTRATION	Processes that remove carbon dioxide from the atmosphere to mitigate global warming. In the present context, this refers to an increase in the amount of carbon in soils by increasing the organic matter content of the soil. Grassland soils naturally contain more organic matter than arable soils and converting arable to grassland therefore increases the amount of carbon captured and stored.
CLOSED PERIOD	The rules for Nitrate Vulnerable Zones define closed periods for arable land and for grassland, during which applications of N fertiliser are not permitted (on any soil type); and similarly for applications of manures with high available N on sandy and shallow soils.
COARSE-TEXTURED SOILS	Soils with a high proportion of sand and coarse silt particles. These soils are free draining and are easily worked.
COMBINABLE CROPS	Crops that produce a hard seed that is suitable for harvesting with a combine harvester (e.g. cereals, beans, oilseed rape).
COMPACTION	An increase in bulk density and a decrease in soil porosity resulting from treading by livestock or the pressure of heavy vehicles. Soil compaction decreases the water holding capacity of the soil and the soil air content. It can impede root growth and increases the risk of run-off and erosion.
COMPOSTING	This normally refers to the breakdown of SOLID MANURES in the presence of free oxygen, i.e. under aerobic conditions. This can be achieved by mechanical turning or mixing a heap or pile to incorporate air. The potential benefits of composting are: reduction in the mass of manure, improved friability and handling characteristics, kill of weed seeds and decrease in pathogens through generation of heat, reduction in odour, concentration of plant nutrients. [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. They have potential for the treatment (e.g. removal of BOD and plant nutrients) from dilute farm effluents such as parlour washings. [R]
COVER CROP	A rapidly growing crop sown in autumn for the purpose of taking up soil nitrate, which would be at risk of leaching if the soil was left bare over winter, e.g. where a spring cereal follows an autumn-harvested crop. The cover crop either dies naturally over winter or is cultivated into the soil to release the N to the next crop in the following spring.
CROP OFFTAKE	Amount of nutrient removed from a field in the harvested crop.
CROP RESIDUES	The unharvested part of a crop that is left in the field. In common usage, this often refers to above-ground residues, e.g. straw, leaf material and stubble but more accurately should also include roots.
CUBICLE (house)	The building is 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. Passageways are cleaned at least once per day and the manure is removed as SLURRY. [R]

DAIRY CAKE	A general term for processed feedstuff 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]
DENITRIFICATION	The transformation, most commonly by bacteria, of nitrate to nitrous oxide and nitrogen gas. An anaerobic process that occurs in soils and in manure stores and in some treatment methods, after a nitrification period. [R]
DINITROGEN	N_2. The (harmless) form of nitrogen gas that constitutes 78% of the atmosphere.
DIRTY WATER	Water derived from washing of equipment and floors in milking parlours, rainfall run-off from concrete area or hard-standings 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 negligible fertiliser value. [R]
EROSION	Wearing away and loss of topsoil, principally by wind and running water. Important pathway of P loss from land to surface water. [R] Erosion by water in particular is an important contributor to diffuse pollution by transporting P adsorbed on the surface of soil particles into surface waters. The soil particles themselves also contribute to increased river sediment loads. Sandy and silty soils are the most susceptible to erosion.
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 losses of nutrients to the wider environment. Recommendations take account of crop requirements, soil type, existing levels of nutrients in the soil and the nutrients supplied in organic manures. This information can be supplied in book form (e.g. RB209) or as a computer-based package (e.g. PLANET).
FINE-TEXTURED SOILS	Soils with a high proportion of clay and fine silt particles. They usually have poor natural drainage and are more difficult to work.
FINISHING	Growth stage of pigs, between 60 kg and slaughter. [R]
FIO	Faecal Indicator Organism. Microorganisms excreted by and present in the dung of livestock and in manures. Their presence in water indicates contamination by dung or manure.
FIXED N	See BIOLOGICALLY FIXED N
FLATLIFTING	Method of soil treatment using a specialised SUBSOILER designed for breaking compacted soil pans, 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 the 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 the 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.

HARD-STANDING	A general term for any outdoor, normally unroofed, area with a hard surface, usually of concrete (includes dairy cow collecting yards, feeding yards, farmyard manure storage areas). [R]
HEAVY SOILS	See FINE-TEXTURED SOILS
HILLSIDE COMBINE	Combine harvester designed to operate efficiently when travelling across a slope.
HYDROLOGICAL CONNECTIVITY	The water-mediated transfer of matter, energy and/or organisms within or between elements of the hydrologic cycle. Waters or flow paths that run into one another (e.g. a culvert running directly into a stream) will have a high degree of connectivity.
INCIDENTAL LOSSES	Losses of pollutant that occur when rainfall creates run-off shortly after application of fertiliser, manure and excreta to the soil surface, even when 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 help plants bush out to form a thick, stock-proof hedge.
LEACHING	The loss of soluble elements and compounds from soil in drainage water to the aqueous environment including ground water. This applies especially to nitrate leaching. [R] Leaching of dissolved P may also be important, particularly in P SATURATED 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). For example for the EU, one 600 kg dairy cow producing 3000 litres of milk per year equals 1 LU, a sow equals 0.45 LU and a ewe equals 0.18 LU. [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 larger diameter soil pores, earthworm burrows, cracks and old root channels. Because the flow by-passes the soil aggregates, it is less effective at leaching solutes from the soil matrix.
MAINTENANCE APPLICATION (of fertiliser)	Fertiliser application rate that when applied to soils with an optimum nutrient content will maintain this content over the longer term. It is sufficient to replace 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]
MANURE	A general term to denote any organic material that supplies organic matter to soils together with plant nutrients, usually in lower concentrations compared to inorganic 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 for the intended purpose. Crop yields and financial returns are likely to be lower than from land more suited to the purpose.

MATRIX FLOW	Predominantly vertical, relatively uniform flow of water through the bulk soil, as opposed to the more rapid MACRO-PORE FLOW that is confined to the larger diameter soil pores. Because of the greater contact with soil surfaces and finer pores, matrix flow is more effective at leaching solutes from the soil matrix.
METHANE	CH_4. A greenhouse gas produced during anaerobic fermentation of organic matter, especially from enteric fermentation in ruminants and storage of liquid manure. A constituent of biogas. [R]
MINERAL FERTILISER	Fertiliser manufactured by a chemical process or mined, as opposed to organic material that contains carbon. [R]
MINERALISATION	The transformation by microorganisms of organic compounds to organic compounds e.g. in soils and in stored manures. [R]
MINIMAL CULTIVATION	Method of shallow cultivation for arable soils using discs and tines without ploughing and inverting the soil. Because there is less disturbance of the soil, there is less mineralisation of soil organic matter and production of nitrate 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. 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]
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 RUN-OFF
P	Phosphorus
P INDEX	ADAS Soil P Index; a method of expressing the results of laboratory determinations of the concentration of plant-available P in soils on a scale of 0 (low) to 9 (very high). The target for agricultural crops is Index 2 or 3. There is an increased risk of P loss from soils that are at Index 4 or above.
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 grains and thereby makes the P more available to animals.
POACHING	The puddling of soil as a result of trampling by livestock under wet conditions. This compacts the soil and further reduces infiltration of water, thus intensifying the problem and encouraging surface run-off.

POLLUTION SWAPPING	Refers to pollution control methods, where the method is effective at reducing losses of the target pollutant but in doing so, increases the loss of some other form of pollutant, e.g. where a reduction in nitrate leaching is accompanied by increased emissions of nitrous oxide or ammonia.
PREFERENTIAL FLOW	Broadly equivalent to MACRO-PORE FLOW.
RB209	Reference Book 209. Fertiliser Recommendations for Agricultural and Horticultural Crops. 7th Edition (2000) MAFF, London: The Stationery Office
REPLACEMENT RATE	The percentage of milk cows in the herd that are culled and replaced each year by younger animals. This is determined by the number of lactations for which each cow is kept in the herd. A high replacement rate requires a greater number of young stock to be kept on the farm to provide the necessary replacements.
RESPONSE CURVE	The shape of the graph describing the relationship between crop yield and the amount of fertiliser applied. Typically, this shows an initial, linear increase in yield with increasing fertiliser rate, which gradually levels off and remains constant or declines at high rates of fertiliser use. Increasing fertiliser rates beyond the point at which the graph begins to level off is wasteful because it produces little additional yield and little of the added nutrient is taken up by the crop.
RILL EROSION	Soil erosion caused by surface run-off water collecting and concentrating into channels, e.g. along depressions or tractor wheelings. 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 the diet of ruminants that is broken down in the rumen to liberate ammonia. This is utilised by other microorganisms in the rumen to synthesise microbial protein, which 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]
RUN-OFF	The flow of rainfall, irrigation water, liquid manure, etc. over the land surface. Run-off can cause pollution by transporting pollutants, e.g. from manures, to surface waters. [R]
SEDIMENT	In this context, refers to soil particles washed into surface waters from agricultural land. These particles will settle onto the stream bed when the flow rate of the water is insufficient to keep them in suspension. In addition to the direct effect of increased sediment loadings, eroded soil particles are also an important contributor to diffuse P pollution because of the 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. The rock limits rooting depth, so that soluble nutrients are rapidly leached out of the zone where they can be utilised by growing plants.
SHEET EROSION	Removal of a uniform thin layer of topsoil by raindrop splash and water run-off. Less perceptible than RILL or GULLY EROSION.
SHEET FLOW	Water accumulating on a slope and flowing as a thin sheet of water over the ground surface. May cause SHEET EROSION.

SHEET WASH	See SHEET FLOW
SLITTING	A mechanical soil treatment to penetrate shallow impermeable layers in grassland soils to improve water infiltration and root penetration. Achieved by drawing an implement across the ground to produce regular, shallow slits in the upper soil layer.
SLUMPING	Process that can occur in sandy and silty soils when cultivation to create a fine seedbed is followed by heavy rain. Raindrop impact and wetting causes a collapse of the structure of the immediate soil surface and creates a thin crust that prevents infiltration and increases RUN-OFF. See CAPPING.
SLURRY	Mixture of faeces and urine produced by housed livestock that flows under gravity and can be pumped. There are several different types of liquid manure arising from different types of livestock housing, manure storage and treatment. [R]
SOAK-AWAY	Pit where unpolluted or only slightly contaminated water is collected and allowed to soak into the surrounding ground.
SOIL AERATION	Process of increasing the porosity and permeability of the 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 the more fully decomposed, relatively stable humus.
SOIL STRUCTURE	The way in which the individual particles comprising a soil (sand, silt, clay, organic matter) are organised into aggregates, crumbs and soil blocks 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. There are several different types of solid manure arising from different types of livestock housing, manure storage and treatment. [R] Usually includes bedding (e.g. straw).
SOM	SOIL ORGANIC MATTER
SPIKING	A mechanical soil treatment to penetrate shallow impermeable layers in grassland soils to improve water infiltration and root penetration. Achieved by drawing a spiked roller across the ground to produce many closely-spaced, vertical holes in the upper soil layer.
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 up to twice daily by means of a moveable fence. Grazed strips are 'back-fenced' (i.e. behind the cattle) to allow for regrowth of the grass. [R]
STRUCTURAL DAMAGE (of soil)	Physical damage to the SOIL STRUCTURE, caused by trampling by livestock or passage of farm machinery, particularly under wet conditions. Soil aggregates are broken down with a resulting increase in soil bulk density and reduced porosity, water infiltration, aeration and root penetration. See COMPACTION and POACHING.

SUBSOILING	A mechanical soil treatment to break up impermeable (usually deep) layers in soils 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 RUN-OFF	See RUN-OFF
SURFACE WATER	Water that flows in streams and rivers and in natural lakes, in wetlands, and in reservoirs constructed by humans. [R]
TILLAGE	General term for the process of cultivating soil.
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. spraying, fertiliser application. [R]
TRANSPONDER	A wireless communications, monitoring or control 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 the feed allocated to it.
ULTRA-VIOLET LIGHT	A component of the spectrum of sunlight, which is harmful to organisms and accelerates the death of microorganisms 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 developing crop. The undersown crop develops as an understorey, which grows on after the main crop has been harvested. This avoids an interval of bare soil between crops and ensures there is a continued uptake of plant nutrients from the soil.
URINE PATCH	Localised area of grazed pasture that has received urine from (generally) a single urination. These patches of soil contain very high concentrations of urea, which breaks down to form ammonia and ammonium-N. The ammonium-N is then converted to nitrate.
VOLATILISATION	The process by which AMMONIA gas is released from solution. [R] Refers to the loss of AMMONIA from urine and from MANURES during storage and when spread on fields.
VOLUNTEER (plants)	Plants that have resulted from natural propagation, as opposed to having been planted by humans; including crop plants that re-occur in subsequent seasons following their harvest e.g. through germination of shed seed.
WATER MEADOWS	Traditional management of low-lying grassland adjoining water courses. The stream or river is allowed to naturally flood the fields during winter and the land is grazed during the drier summer period. Alternatively, water levels may be managed by a system of dams and sluices.
WATER TABLE	In its simplest sense, this is the level in the soil below which the ground is completely saturated with water.
WATERLOGGED SOIL	A soil that is saturated with water so that 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.